INVENTORY OF
SHARED WATER RESOURCES
IN WESTERN ASIA

german cooperation
DEUTSCHE ZUSAMMENARBEIT

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

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United Nations Economic and Social Commission for Western Asia

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The groundwater-fed Hamidan Lake in the Rub' Al Khali Desert in Saudi Arabia, January 2011.
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Foreword

Prof. Dr. Hans-Joachim Kümpel
PRESIDENT, FEDERAL INSTITUTE FOR GEOSCIENCES AND NATURAL RESOURCES

Water knows no political borders. Across the world, there are 263 transboundary river basins and at least 300 transboundary aquifers and aquifer systems. The shared nature of these resources represents an opportunity for cooperation, but also creates challenges in the form of rising abstraction, pollution and uncoordinated use by riparian states. Optimal use and effective protection of transboundary waters are only possible if riparian states apply the principles of Integrated Water Resources Management (IWRM) in a cooperative spirit. This is especially important in the arid Arab region, where water scarcity has always been a harsh reality and a recurring source of conflict. Sound management of shared water resources is therefore a core component of water security and sustainable development in Arab countries.

In this light, the German government seeks to promote the protection and sustainable use of shared water resources and supports partner governments worldwide in the following areas within the transboundary water cooperation sector: harmonizing national water policies, developing cooperation agreements, promoting South-South exchange, and supporting investment in the implementation of joint protection and management plans.

The Federal Institute for Geosciences and Natural Resources (BGR) is directly mandated by the Federal Ministry for Economic Cooperation and Development (BMZ) to implement technical cooperation projects in developing countries in the field of geo-sciences. As geo-scientists, we work with our partners to remove stumbling blocks on the path to development. We harness our internationally recognized geo-scientific competencies to realize the development goals of the German government.

Cooperation between ESCWA and BGR started in 1992 with special emphasis on groundwater resources assessment and management. Already in the late 1990s, the issue of shared water resources became a core pillar in this regional project, and it has remained an area of focus ever since. Over the years, the ESCWA-BGR Cooperation addressed technical, institutional and legal issues related to various aspects of shared water resources including assessment, management, negotiation and cooperation. This has been realized through numerous activities, including local hydrogeological studies, technical advisory services, regional expert group meetings and workshops on an array of topics.

The comprehensive Inventory of Shared Water Resources in Western Asia is a logical continuation of these efforts and, in certain aspects, represents the culmination of this long cooperation on shared water management. It provides a comprehensive knowledge base that can inform national and regional debates on shared water resources.
It targets a wide expert audience of decision-makers, government officials, researchers, donors and multi-lateral agencies.
More importantly, we hope that this Inventory will stimulate future cooperation and joint projects between riparian countries.

Dr. Rima Khalaf
UNDER-SECRETARY-GENERAL
EXECUTIVE SECRETARY, UNITED NATIONS ECONOMIC AND SOCIAL COMMISSION FOR WESTERN ASIA

The Arab region is one of the most arid regions in the world. The member countries of the United Nations Economic and Social Commission for Western Asia (ESCWA) have deployed intensive efforts to ensure water security, a core element of any sustainable development agenda. This goal is particularly challenging in a region where over two-thirds of available freshwater resources are shared, crossing one or more geopolitical borders.

Intergovernmental mechanisms, including the ESCWA Committee on Water Resources established in May 1997 and the Arab Ministerial Water Council, which held its first session in June 2009, were mandated to support regional dialogue and cooperation on the integrated management of water resources. They have contributed to dealing with this challenge within institutional processes that demonstrate the commitment of Arab Governments to work collectively and regionally to address common concerns about water scarcity. Support for regional water cooperation is also manifested in the adoption, by the Arab Ministerial Water Council in 2011, of the Arab Strategy for Water Security in the Arab Region to Meet the Challenges and Future Needs for Sustainable Development (2010-2030). This Strategy primarily aims to strengthen the shared management of water resources between Arab States, as well as between Arab and non-Arab States.

The interest of ESCWA in water issues derives from its mandate in economic and social development, and regional integration. Its subsidiary Committee on Water Resources works in close collaboration with the Arab Ministerial Water Council to fulfill the needs of the region through providing continued technical assistance on the management of shared water resources. The Inventory of Shared Water Resources in Western Asia was prepared in collaboration with the Federal Institute for Geosciences and Natural Resources (BGR) as part of this collective effort. This Inventory provides a comprehensive catalogue of shared surface water basins and groundwater aquifer systems in Western Asia grounded in sound scientific assessments.

It is hoped that the Inventory can inform dialogue between Arab States and between Arab and non-Arab States on the most pressing socioeconomic development challenges that currently face the region, including food security, adaptation to climate change, energy security, migration and conflict. Resolving these issues largely depends upon the ability of the region to effectively manage its scarce water resources. However, Israeli occupation will continue to hamper the ability of the Palestinian people to exercise full sovereignty over their water resources.

The Inventory is the culmination of long and fruitful cooperation between ESCWA and BGR. For over two decades this cooperation has been a valuable source of technical assistance to strengthen the capacity of member countries in the integrated management of water resources according to regional circumstances and needs. By informing discussions, the Inventory offers a basis for enhancing regional cooperation, identifying integrated solutions and advancing sustainable development efforts in the Arab region. The ESCWA Secretariat expresses its deep appreciation of the support provided by the Federal Ministry for Economic Cooperation and Development of Germany (BMZ) to this constructive partnership and to our commitment towards strengthening regional processes in this critical area for development. We hope that the release of this Inventory will foster new research in the management of shared water resources and provides a platform for incorporating these related issues in regional debates.

Preface

It is our pleasure to present the "Inventory of Shared Water Resources in Western Asia", a joint publication by the United Nations Economic and Social Commission for Western Asia (ESCWA) and the German Federal Institute for Geosciences and Natural Resources (BGR). The Inventory is the first UN-led effort to make a comprehensive assessment of the state of transboundary surface and groundwater resources in the Middle East. It contains a wealth of up-to-date information on shared river basins and aquifer systems in the region and represents the outcome of a process of collaborative scientific research spanning several years, involving representatives of member countries, academics and other water experts and practitioners in the Arab region and beyond.

Traditionally, the discourse on shared water resources in the Arab region has been highly politicized and the subject of high-level negotiations between governments, while also being very personalized, evoking concerns about justice and security among the general public. Attention has largely been focused on long-standing disputes arising from Arab dependence on surface water resources originating from (or controlled by) non-Arab countries. The academic and international community has dominated this discourse by propelling the management of shared water resources into the wider sphere of international relations and by dedicating extensive research projects, political theories and resources to examining cases like the Jordan River Basin, which may be the most studied river in the Middle East.

The dominant outward-looking narrative in the region attaches great importance to securing Arab water rights. Perhaps this also explains the early and relatively widespread support of Arab countries for global instruments of international water law. Of the 29 countries who are today party to the 1997 United Nations Convention on the Law of the Non-Navigational Uses of International Watercourses, eight are from the Arab region; Syria, Jordan and Lebanon were among the first to sign, ratify or accede to this important legal instrument. By contrast, none of the non-Arab riparian countries have signed or become party to the convention. In recent years, a more inward-looking perspective has emerged in the regional discourse on shared water resources within the Arab region. Since its founding in 2008, the Arab Ministerial Water Council has provided a forum for the debate of regional water issues at the highest political level. The Arab Strategy for Water Security in the Arab Region, which was adopted by the Council in 2011, identifies the use and management of shared water resources as a core challenge to sustainable development in the region. The strategy's core objectives include not only the protection of Arab water rights in waters shared with non-Arab states and in occupied territories; it also calls for enhanced cooperation between Arab states to manage water resources shared within the region. As this Inventory shows, these resources are plentiful but poorly understood, especially when it comes to groundwater. Furthermore, at its second ministerial session in 2010, the Council mandated the preparation of a legal framework for shared waters in the Arab region. After several rounds of technical negotiations the draft is now being discussed at the political level within member states.

While this publication is not formally related to the aforementioned regional processes, its release comes at an opportune time as it provides context and substance for many of these discussions. In fact, the findings of this Inventory have already been presented to actors engaged in these processes and have generally been met with interest and sometimes even with surprise. Many of the aquifer systems described in this Inventory have never been identified, let alone discussed, as shared resources by riparian countries. In better-known basins, the Inventory also presents recent and comprehensive data sets which had not been made publicly available until now. The new maps generated for the Inventory also help to update the discourse by offering a modern set of reference materials on shared water resources in Western Asia based on the content elaborated in each chapter, all of which is presented in a user-friendly, accessible and contemporary design. This does not mean, however, that findings and interpretations in the Inventory are to be considered complete or absolute. While the Inventory is a static reference document, it aims to inform a dynamic, multi-stakeholder process of continued analysis and assessment of shared water resources and governance structures. Preliminary feedback from governments and experts in the region shows that such a debate is ongoing and that the Inventory has the potential to provide such input and to help move the conversation forward.

The preparation of this Inventory involved the collaborative effort and the active participation of officials from ESCWA member countries, whether as nominated focal points or as members of the ESCWA Committee on Water Resources, and we would like to express our gratitude for their interest and support. We are equally grateful to the German Federal Ministry for Economic Cooperation and Development (BMZ), which has provided continued funding for the ESCWA-BGR Cooperation and allowed us to embark on this and other long-term initiatives to promote integrated approaches to water resources management and to foster cooperation on shared waters in the ESCWA region. We would also like to thank all the experts from the region and beyond who contributed with texts, expertise, information and feedback throughout the process.

Our sincere thanks is also extended to the committed core team of ESCWA and BGR staff members in the Water Resources Section of the Sustainable Development and Productivity Division at ESCWA, who showed the utmost dedication and discipline at every stage of the lengthy and challenging process of developing the Inventory. Without each and every one of you, from chief of section, water expert, lead author, author, coordinator, researcher and assistant to GIS expert, editor, graphic designer and web-designer, this Inventory would never have materialized in its current form. The finalization of the Inventory would also not have been possible without the able editorial support provided by the ESCWA Conference Services Section. Finally, we would like to commemorate our dear colleague and friend John Redwine, who died in a tragic accident in December 2011. John worked with the ESCWA-BGR Cooperation team and provided valuable editorial input to the Inventory.

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Acronyms & Units of Measurement

UNITS OF MEASUREMENT	
c/100 ml	colonies per hundred millilitres
BCM	billion cubic metres
Bq/L	becquerel per litre
g/L	gram(s) per litre
GWh	gigawatt hour(s)
GWh/yr	gigawatt hour(s) per year
ha	hectare(s)
inhab./km^2	inhabitant(s) per square kilometre
km	kilometre(s)
km^2	square kilometre(s)
km^3	cubic kilometre(s)
kW/m^3	kilowatt(s) per cubic metre
L	litre
L/cap./d	litre(s) per capita per day
L/s	litre(s) per second
l/s/km^2	litre(s) per second per square kilometre
m	metre(s)
m/d	metre(s) per day
m/yr	metre(s) per year
m/km	metre(s) per kilometre
m^2	square metre(s)
m^2/d	square metre(s) per day
m^2/s	square metre(s) per second
m^2/hr	square metre(s) per hour
m^3	cubic metre(s)
m^3/cap./yr	cubic metre(s) per capita per year
m^3/s	cubic metre(s) per second
m^3/d	cubic metre(s) per day
m asl	metre(s) above sea level
m bgl	metre(s) below ground level
m bsl	metre(s) below sea level
MCM	million cubic metres
MCM/yr	million cubic metres per year
mg/L	milligram(s) per litre
mm	millimetre(s)
mm/yr	millimetre(s) per year
MW	megawatt(s)
µS/cm	microSiemens per centimetre
pCi/L	picocurie(s) per litre
ppm	part(s) per million
ppt	part(s) per trillion
s	second
ton/yr	ton(s) per year
TU	Tritium Units

SYMBOLS	
°C	degree(s) Celsius
%	percent
‰	per mille
~	approximately
—	indicates that the amount is nil or negligible
-	indicates that the item is not applicable
..	indicates that data is not available or is not reported separately

ABBREVIATIONS	
^{18}O	oxygen 18
approx.	approximately
Ar	arsenic
AVG	average
B	boron
BOD	Biochemical Oxygen Demand
Ca	calcium
CE	Common Era
Cd	cadmium
Cl	chloride
Co	cobalt
CO_2	carbon dioxide
Cr	chromium
Cu	copper
CV	Coefficient of Variation
DO	Dissolved Oxygen
EC	Electrical Conductivity

F	fluoride
Fe	iron
Fm	Formation
GMWL	Global Meteoric Water Line(s)
Gp	Group (lithological)
H_2S	hydrogen sulfide
HCO_3	bicarbonate
L.	Lower (Formation)
M.	Middle (Formation)
max	maximum
min	minimum
Mb	Member
Mg	magnesium
Mn	manganese
MoU	Memorandom of Understanding
Mt.	Mount
N	nitrogen
Na	sodium
Ni	nickel
NO_2	nitrite
NO_3	nitrate
P	phosphorus
PO_4	phosphate
Ra	radium
Rn	radon
S	Storativity
SI	Saturation Index
STQ	Secondary-Tertiary-Quaternary (Aquifer Complex)
(N)	Neogene
(Q)	Quaternary
Sst	Sandstone
Se	selenium
SO_4	sulphate
T	Transmissivity
TD	Total depth
TDS	Total Dissolved Solids
TN	Total Nitrogen
TP	Total Phosphorus
U.	Upper (Formation)
U	uranium

ACRONYMS	
ACSAD	Arab Center for the Studies of Arid Lands and Dry Zones
AWSA	Amman Water Sewerage Authority
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe
DAWSSA	Damascus Water Supply and Sewerage Authority
DCA	Department of Civil Administration
DSI	Devlet Su Isleri (General Directorate of State Hydraulic Works in Turkey)
ESCWA	Economic and Social Commission for Western Asia
ETIC	Euphrates-Tigris Initiative for Cooperation
FAO	Food and Agriculture Organization of the United Nations
GCC	Gulf Cooperation Council
GTZ	Gesellschaft für Technische Zusammenarbeit (German Technical Cooperation)
GAP	Güneydoğu Anadolu Projesi (Southeastern Anatolia Project)
IPCC	Intergovernmental Panel on Climate Change
ISARM	Internationally Shared Aquifer Resources Management Initiative
JRDP	Jordan Red Dead Sea Project
JRSP	Jordan Red Sea Project
JTC	Joint Technical Committee
JTLAS	Jezira Tertiary Limestone Aquifer System
JTSC	Joint Technical Sub-Committee
JWC	Joint Water Committee
KAC	King Abdullah Canal
LAS	League of Arab States
NWC	National Water Carrier
PDO	Petroleum Development of Oman
PLO	Palestine Liberation Organization
SDC	Salinity Diversion Channel
SHADCO	Al Sharqiyah Agricultural Development Company
UAE	United Arab Emirates
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNESC0	United Nations Educational, Scientific and Cultural Organization
UNESCO-IHP	United Nations Educational, Scientific and Cultural Organization International Hydrological Programme
UNRWA	United Nations Relief and Works Agency
USD	United States Dollars
WGA	Western Gravel Aquifer
WHYMAP	World-wide Hydrogeological Mapping and Assessment Programme
WWAP	World Water Assessment Programme
WWDR	World Water Development Report

OVERVIEW

- INTRODUCTION TO THE INVENTORY
- SHARED WATER RESOURCES IN WESTERN ASIA
- KEY FINDINGS

OVERVIEW

INTRODUCTION TO THE INVENTORY

Over 40% of the world's population resides in shared water basins.[1] Human settlements, agriculture and industry have proliferated along shared surface waters that have been the cradles of civilizations, while increased capacity for groundwater abstraction has created new opportunities for development and expansion around transboundary aquifers. There is a general consensus in the international community that there are 263 shared river basins and over 300 transboundary aquifers and aquifer systems in the world.

Shared water resources provide an essential source of freshwater, especially in water-scarce regions. Water scarcity is a fundamental challenge to sustainable development in arid and semi-arid regions where renewable freshwater resources at the national level are insufficient to satisfy growing needs. As water scarcity intensifies due to increasing socio-economic demands and environmental pressures, so does the dependency of states on shared water resources needed to complement domestic supplies. This situation increases interdependencies between riparian states whereby changes in the management of a transboundary water resource in one country can have significant implications for water quantity or quality in a neighbouring country situated downstream. Decision-making regarding the management of these resources can thus have important implications for regional stability, socio-economic development, environmental protection, as well as peace and security. Cooperation across borders is thus necessary to support the integrated management of shared water resources within a regional context.[2] This requires accurate, up-to-date information on shared surface and groundwater systems to inform regional dialogue and debate regarding the management of these precious resources.

There is a prevailing perception that shared water resources in Western Asia have been extensively studied. Water scarcity and water security challenges are regularly evoked by political theorists, analysts and members of the international community engaged in the geopolitical discourse that has contextualized the management of shared water resources and inter-state relations in the region for decades. However, while there is an extensive literature on a few surface water basins, very little has been written on shared water resources in Western Asia as a whole.

Shepherd near Afrin, Syria, 2009. Source: Andreas Renck.

Furthermore, no publication has sought to study all the shared surface and groundwater resources in the region in an integrated and comprehensive manner. The research that has been conducted has been limited in scope or drawn from dated documentation, assessments and maps that do not adequately represent the state of knowledge regarding these shared resources today.

This Inventory of Shared Water Resources in Western Asia is the first systematic effort to catalogue and characterize shared surface water and groundwater systems throughout the region. Its main purpose is to provide a sound scientific basis for informing discussion and fostering dialogue on these precious resources that have become increasingly important to sustain development in an era of growing demand and dwindling supply. To do so, the Inventory identifies all shared water resource systems within the region and provides a comprehensive, descriptive analysis of each basin based on the following guiding questions:

- Where are the shared water resources?
- What is the status of these resources, at present and in a historical context?
- How is the water being used?
- What cooperative arrangements and structures are in place?

Conceptually, the Inventory is situated at the science-policy interface, with two sets of objectives. The scientific objectives aimed at assessing shared water resources in the region are:

- To identify shared surface and groundwater resources.
- To document the state of shared water resources and their use.
- To improve the knowledge base and facilitate access to information on shared water resources.

The policy and development objectives aimed at enhancing cross-border cooperation on shared water resources are:

- To raise awareness among decision-makers, experts and the general public.
- To stimulate an informed discussion within and between riparian countries.
- To support regional processes towards improved dialogue and cooperation over shared water resources.

The result is a comprehensive reference document of shared surface and groundwater resources in Western Asia that encompasses water resources that are shared between Arab states and between Arab and non-Arab states situated in the Western Asia study area.

The Inventory targets a wide audience of experts from water, environment and other sectors, including decision-makers, government representatives, academia, donors, specialized agencies, international and non-governmental or civil society organizations.

BOX 1

Shared vs. Transboundary – A Question of Terminology

Water bodies that cross political borders are most commonly described as "international" or "transboundary".[a] The 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Helsinki Convention) adopted by the United Nations Economic Commission for Europe (UNECE) defines "transboundary waters" as "any surface or ground waters which mark, cross or are located on the boundaries between two or more States".[b] The term "international" has been used to characterize the specialized focus on water in the international law community, and also tends to encompass marine water systems.

The term "shared" has been widely used in the context of efforts by the international community to foster cooperation over natural resources that cross political borders. The adoption of United Nations General Assembly Resolution 3129 (XXVIII) on 13 December 1973 entitled "Co-operation in the field of the environment concerning natural resources shared by two or more States" led to the development of guiding principles to support the formulation of bilateral and multilateral agreements regarding natural resources shared by two or more States.[c] In 2002 the United Nations International Law Commission initiated the Shared Natural Resources of States programme, which issued the Draft Articles on the law of transboundary aquifers in 2008.

In the Arab region, the term "shared" is regularly used in inter-governmental forums that seek to promote cooperation and integration between Arab States. While the League of Arab States has adopted no official decision stipulating the adoption of this term, the Arab Ministerial Water Council established in 2008, commonly uses "shared" in its resolutions. Moreover, the "Arab Strategy for Water Security in Arab Region to Meet the Challenges and Future Needs for Sustainable Development 2010-2030" approved in 2011 also adopted the term "shared" for both surface and groundwater resources; however, this does not imply an allocation for the sharing of the resource by the riparian countries.[d] The Arabic term for "transboundary" is not commonly used in the context of water resources. The Inventory therefore consistently refers to "shared" water resources, which may here be considered synonymous with "transboundary" in its English-language context.

(a) UNECE, 1992 , UNILC, 2008, United Nations General Assembly, 1997.
(b) UNECE, 1992.
(c) United Nations General Assembly Resolution 34/186 of 18 December 1979 (United Nations General Assembly, 1979).
(d) LAS, 2010; LAS, 2011a; LAS, 2011b, LAS, 2012. In December 2011, Saudi Arabia formally suggested the use of the term "transboundary" as an alternative to "shared" in the "Legal Framework of Shared Water Resources in the Arab Region"

Methodology & Information Sources

The Inventory started as a desk study by the German Federal Institute for Geosciences and Natural Resources (BGR) and the United Nations Economic and Social Commission for Western Asia (ESCWA) in 2009 following a request by the ESCWA Committee on Water Resources to build national capacity for the integrated management of shared water resources in ESCWA member countries.[3] An integrated and iterative process of development, review, consolidation and consultation with regional and international experts and country representatives enhanced the study to result in a comprehensive reference on shared water resources in the Western Asia region.

However, while the preparation of the Inventory was initiated and conducted in consultation with the ESCWA Committee on Water Resources, it is not formally tied to a binding inter-governmental agreement or monitoring mechanisms, such as a regional convention on shared water resources with associated reporting requirements. Preparation of the Inventory under such a framework would have provided an umbrella for the official exchange and submission of information on the shared basins.[4] Rather, country participation in the process of preparing the Inventory was voluntary and based on the spirit of cooperation. Country submissions thus varied significantly in terms of scope and level of detail and the outcome is not necessarily based on consensus.

In line with its intended character as a technical reference document, the Inventory is primarily descriptive in its nature and writing style. The Inventory is the outcome of an unbiased scientific process and all information and data in the chapters are duly referenced to allow for independent verification. However, the authors of the Inventory cannot be held responsible for the accuracy or correctness of data taken from published sources or provided by countries. Similarly, the involvement of country representatives in the compilation of the Inventory does not imply their official endorsement of the report or the information presented therein, except where explicitly stated. Unresolved issues are dealt with by presenting the different points of view, by including apparently contradictory information or by offering multiple, differing values for certain parameters.

The different research and production phases of the Inventory can be subdivided into three stages outlined below. As the chapters were not produced simultaneously or by the same author, the Inventory team adopted an iterative approach, which allowed for adjustments and modifications in different chapters throughout the process. For example, findings generated during later stages were often used to refine the initial chapters and templates or to modify the delineation and description of shared surface or groundwater resources.

Agriculture in the area of Azraq, Jordan, 2008. Source: David L. Kennedy, Aerial Photographic Archive for Archaeology in the Middle East.

BOX 2

Involvement of ESCWA Member Countries

ESCWA member countries have been involved in all stages of preparation of the Inventory. This consultative process mainly took place through the ESCWA Committee on Water Resources, which is an inter-governmental committee composed of senior technical and managerial staff of sector ministries in ESCWA member countries responsible for water resources management. The Committee meets biannually and approves ESCWA's biannual work programme in the water sector. The recommendations of the Committee are subsequently reviewed and approved by the ESCWA Technical Committee and the ESCWA ministerial session, which is the Commission's highest political body.The Committee's involvement in the consultation process for the Inventory consisted of the following phases:

ESCWA Committee on Water Resources – Eighth session (December 2008)
The Committee requested ESCWA to continue to provide technical support to its member countries to build national capacity in the domain of integrated water resources management, especially in the area of shared surface and groundwater resources, and to update an assessment of legal and institutional tools for shared water resources management by itself or in coordination with BGR and other regional and international organizations.[a]

ESCWA Committee on Water Resources – Ninth session (March 2011)
Following a presentation of the scope, status and preliminary findings of the Inventory by the ESCWA-BGR Cooperation at the ninth session of the Committee on Water Resources, the Committee called for the nomination of focal points in ESCWA member countries to support the further preparation and finalization of the Inventory and encouraged governments to consider its outcomes.[b]

Nomination of Inventory focal points (April-September 2011)
After ESCWA sent a note verbale to Committee members calling for the nomination of focal points, nominations were received between April and September 2011. Many of the nominated focal points were also members of the ESCWA Committee on Water Resources, and were thus already familiar with the Inventory process.

Regional Consultation Meeting with member countries (October-December 2011)
Focal points gathered in Beirut from 29 November to 1 December 2011 for a briefing on progress achieved thus far on the preparation of the Inventory and to encourage an open and transparent discussion among riparian countries on the preliminary findings. In preparation for the consultative meeting, an information note on the preliminary overall findings of the Inventory was sent to the countries in early November 2011 together with dedicated questionnaires. Focal points and experts from 8 of the 13 countries that had nominated focal points attended the meeting. Participants reiterated their support for the Inventory and agreed to submit the requested data.

Follow-up and informal consultations (starting December 2011)
Countries that did not participate in the meeting were informed of its outcomes in early December 2011. The Inventory team went on a number of missions to member countries to follow up on data submission and for further clarifications and discussions of the preliminary findings, the methodology applied and next steps in the consultation process. Conferences at ESCWA and in the region as well as other missions allowed for further informal meetings with focal points and experts. Upon request of member countries, the deadline for submission of information was extended twice.

Chapter comments (May 2012-December 2012)
Focal points received the completed draft basin chapters for comment. Draft chapters were released only to the riparian countries of a shared basin. Countries were asked to submit their comments on each basin chapter within a month of receipt of the chapter. Focal points were encouraged to consult other experts and authorities in their country in order to allow for a comprehensive review.

Final Consultation on the Inventory (February-March 2013)
All nominated focal points as well as all members of the ninth session of the ESCWA Committee on Water Resources received the complete Inventory in layout form for final comments. The Inventory was presented to the members of the ESCWA Committee on Water Resources during its tenth session in March 2013 and invited to provide their final comments prior to its publication.

(a) UN-ESCWA, 2008.
(b) UN-ESCWA, 2011.

Mukalla, Yemen, 2000. Source: Kebnekaise.

PREPARATORY PHASE – TRANSLATING CONCEPT INTO STRUCTURE

The core themes, content, structure and overall design were developed based on the overall concept for the Inventory aimed at providing a comprehensive reference document on shared water resources in the study area. Core themes were selected to allow for a comprehensive characterization of the shared water resources (hydrology and hydrogeology), prevailing water uses (water resources management and use) and riparian agreements and cooperation over these water resources (agreements, cooperation and outlook).

Water resources were identified and described following the basin approach, with each identified shared basin generally included in a separate chapter in the Inventory. A river "basin" hydrologically consists of an area of land in which all surface water drained by the river system is conveyed to the same outlet; topography is the key element affecting the boundary of the basin. Similarly, a groundwater basin is a physiographic unit made up of one large aquifer or several connected aquifers delimited by a groundwater divide, in which groundwater flows to a common outlet.

In practice, however, the "basin" terminology and approach was not applicable to many shared groundwater resources covered in this Inventory due to the specific hydrogeological context, scale issues or the lack of available information to determine groundwater basin boundaries. In these cases, the scope of chapters on shared aquifer systems was adapted accordingly, as explained in the 'Overview & Methodology: Groundwater' chapter, which introduces Part II.

In other cases, the chapter structure was adapted in order to emphasize certain aspects that would otherwise be overlooked, for example the tributaries to the larger transboundary Euphrates and Tigris Rivers (see 'Overview & Methodology: Surface Water' chapter, which introduces Part I).

For simplicity's sake, a shared water body is referred to as a "basin" and a chapter in the Inventory on a shared water body is referred to as a "basin chapter", regardless of whether they represent basins in the narrow hydrological or hydrogeological sense.

Each basin chapter contains significant amounts of technical information needed to identify, delineate and characterize the basin. This is particularly the case for groundwater chapters (Part II).

The basin chapters have a unified structure and table of contents based on the core themes of the Inventory, with separate templates for surface and groundwater. The chapter templates facilitate direct thematic access to the content, underlining the descriptive character of the Inventory as a reference work. In practice, however, numerous interactions exist between surface and groundwater resources in their natural environment, between consumptive and non-consumptive water uses and other water development projects implemented in the basins. The chosen structure of the Inventory may not always fully reflect the complexity of these interdependencies and readers may need to consult several sub-sections of a basin chapter to review these linkages. Cross-references and box texts with additional information help readers in this navigation.

Other studies have used more advanced analytical tools and methodologies for structuring assessments of shared water resources, such as the DPSIR framework,[5] but data availability for this first assessment was largely insufficient for such analysis. A more causal, analytical assessment of water issues in the identified shared basins may take place as part of future updates of the Inventory.

RESEARCH AND IDENTIFICATION OF BASINS

Information on shared surface and groundwater resources was initially collected and summarized from ESCWA reports, regional literature, scientific publications, country papers, national and regional maps and data sets, satellite imagery, media reports and other grey literature. The research process was markedly different for the surface water and groundwater sections of the Inventory.

Generally speaking, the shared rivers in the study region were already known and a wealth of information was already publicly available for many of the shared basins albeit often outdated or limited to specific issues. For each basin, information packages were compiled according to the core themes and chapter templates, which were later used, where necessary, as a basis for consultation with countries (Box 2).

On the other hand, groundwater resources in the study region had not previously been catalogued across borders, nor was there a common methodology adapted to this purpose and the specific conditions of the region. Research for "Part II: Groundwater" therefore started with the screening of all available geological and hydrogeological information and its interpretation in view of identifying potentially shared aquifers and aquifer systems (see 'Overview & Methodology: Groundwater' chapter). The findings were discussed internally and with a panel of regional and international experts, most notably during a regional expert

consultation meeting held in Beirut in May 2011. The experts were also involved in a peer review of data sets and, later on, of chapter drafts with a focus on overall coherence and integrity, and possible shortcomings and gaps. Where relevant, they contributed references and technical information.[6] Modified information packages were then compiled and used in the consultation with countries (Box 2).

Riparian countries received the modified information packages for the surface and groundwater chapters with overview maps, consolidated fact sheets and bibliographies,[7] as well as specific requests regarding missing data and other information needed to complete the chapters. Any relevant information subsequently received from the countries was incorporated into the chapter drafts.

DRAFTING AND REVIEW

Based on the revised information packages, full basin chapters were drafted, together with all supporting figures, tables and maps. Where no information was received from countries, information from the literature was used. In some cases additional proxy data was included to compensate for the lack of information on some of the core themes, such as surface and groundwater abstraction and use. For example, in some cases national agricultural statistics on production and irrigated areas were included to characterize water use trends in predominantly agricultural basins.

All draft chapters were made available to ESCWA member countries for comment and the Inventory team thoroughly reviewed all substantive comments from countries.

Comments and additions received before the deadline were usually directly incorporated and countries received feedback or clarification where necessary or requested. Where differing or contradictory information was obtained from different sources, the different data sets and arguments were all included to reflect a range of findings and viewpoints.

Chapter drafts were also distributed for review to selected experts, many of whom had already been consulted in earlier stages of the research process. The final drafts were formally edited and proofed according to UN standards.

BOX 3

Spelling of Names

In general, the spelling of all place names, as well as names of rivers, lakes, seas, mountains and other geographical features, is based on the United Nations Multilingual Terminology Database (UNTERM) and the ESCWA Internet Terminology and Reference System (ESCWATerm).[a] However, as geographical features are often not included in these two databases, many Arabic names were transliterated and cross-checked with references in the literature.

Two geographical names are subject to regular controversy in the region: "Persian Gulf" and "State of Palestine".

In accordance with the two editorial directives issued by the United Nations Secretariat in 1994 and 1999, the Inventory consistently uses the term "Persian Gulf" instead of "Arabian Gulf".

The text also consistently refers to "Palestine" instead of "Palestinian territories" or "occupied Palestinian territories" as Palestine is a member country of ESCWA.[b] This is also in accordance with the 29 November 2012 vote by the United Nations General Assembly that recognizes Palestine as a non-member observer state of the United Nations. Following this vote it was decided that the United Nations Secretariat will use the designation "State of Palestine" in all official United Nations documents.[b] However, in doing so, "State of Palestine" would be used only in instances where the full name of the country is applied; otherwise, the term "Palestine" would be used,[b] as is the case when referring to "Jordan" rather than "Hashemite Kingdom of Jordan".

It is also important to clarify the use of the geographical name "Gulf of Oman". The Government of the Sultanate of Oman decided to officially designate it as the "Sea of Oman" in 2010,[c] and has designated it as such in its national documents and newly issued maps.[d] However, the term "Gulf of Oman" was used throughout the Inventory in accordance with the terminology used in all maps issued to date by the United Nations Cartographic Section.[e]

(a) UNTERM, 2012; UNOV, 2012.
(b) UN-DGACM, 2012.
(c) Embassy of the Sultanate of Oman in Beirut, 2010.
(d) Ministry of Regional Municipalities and Water Resources in Oman, 2011.
(e) United Nations Cartographic Section, 2012.

Readers' Guide

This introduction is followed by an overview of shared water resources in Western Asia, which details the scope of the region under study, as well as a list of key findings of the Inventory. The core report is then divided in two parts: Surface Water (Part I) and Groundwater (Part II). Each part opens with an overview and methodology chapter, which is followed by descriptive chapters on each of the shared water basins (basin chapters). The Inventory features 9 surface water basin chapters and 17 groundwater basin chapters. They are designed to be read as stand-alone chapters as they are available in this form on the Inventory website.

All basin chapters open with an overview map, an overview table highlighting main facts and figures, and a summary of the most relevant issues, especially regarding water use, trends and management. More detailed information is then found in the main text, which varies in length depending on the availability of information. Each basin chapter concludes with a bibliography.

Many parts of the basin descriptions, especially the sections on 'Geography', 'Water Resources Management', and 'Agreements, Cooperation and Outlook', are generally written in a non-technical language to be accessible to a wide audience of interested readers.

The basin chapters also contain specialized technical information, especially in the 'Hydrology/Hydrogeology' sub-sections, which are aimed at a more specialized technical audiences and experts. An icon coding scheme allows readers to identify and navigate between different chapter sections.

BOX 4

The Map Production Process

The production of 60 maps for the Inventory was GIS based using ArcGIS 9.3 software. The following sources of information were used in map production:

- Administrative boundaries and coastlines come from UNGIWG, 2012.
- Capitals and selected cities are taken from ESRI, 2002 and, wherever necessary, added based on Google Earth coordinates. The selection of cities and other geographical landmarks was mainly based on geographical references used in the chapter texts.
- Stream network and drainage basins for the Western Asia region were taken from different sources. As a starting point, the FAO data set 'Rivers of the Near East' was used, which is derived from the HydroSHEDS data set.[a] Further stream network data was added, removed and/or modified manually based on the original 15-second HydroSHEDS data set, regional and national maps, and Google Earth.
- Lake polygons were taken from a 2007 data set by GRDC, 2011 and were modified by BGR during the same year. Smaller reservoir lakes were digitized using Google Earth.
- The location of dams and canals was digitized from Google Earth and crossed-checked with entries in reports or other documents.
- Monitoring and climate stations were included based on their coordinates published in the respective literature.
- Areas marked as "zone of agricultural development" are taken either from FAO, 2009 or were approximated using green cover areas in Google Earth.
- Wetlands and sabkhas were taken from basin studies and maps, from UN-ESCWA and BGR, 1999b or were digitized from Google Earth.
- Mean annual precipitation was taken from WorldClim, 2011, an interpolated global climate data set at 1 km^2 spatial resolution that combines meteorological data (1960-2000) and the global SRTM elevation data set.
- Population density data was taken from CIESIN, 2010 data set with a native grid cell resolution of 2.5-5 km, produced by the Center of International Earth Science Information Network, based on its 2004 statistics.
- Outcrops and subsurface extent of geological formations as well as major structural features were taken from various regional and national maps, including the Water Atlas of Saudi Arabia,[b] the Geological Map of the Middle East,[c] the International Geological Map of the Middle East[d] and the maps on Paleogene Aquifers of the Arabian Peninsula.[e]
- The Middle East Geologic Map Series (MEG maps)[f] were used extensively for subsurface considerations of certain aquifer formations and particularly the calculation of depth to top of the aquifer as part of the exploitability assessment.[g]
- Smaller-scale structural geological features, wells, groundwater basin boundaries and other relevant features were taken from the literature as available. Examples include UN-ESCWA et al., 1996, Jassim and Goff, 2006, ACSAD, 1983, and other national reports.
- A map relief (hillshade) background layer was prepared and used at two different resolutions depending on map scale. The low resolution relief was derived from the European Digital Elevation Model "eu-DEM-15hill". The high resolution relief was prepared based on SRTM data processed by the CGIAR-Consortium for Spatial Information.[h]

(a) HydroSHEDS stands for "Hydrological data and maps based on SHuttle Elevation Derivates at multiple Scales". It has been developed by the Conservation Science Program of World Wildlife Fund (WWF), in partnership with the U.S. Geological Survey (USGS), the International Centre for Tropical Agriculture (CIAT), The Nature Conservancy (TNC), and the Center for Environmental Systems Research (CESR) of the University of Kassel, Germany (USGS, 2010).
(b) Ministry of Agriculture and Water in Saudi Arabia, 1984.
(c) Aghanabati, 1993.
(d) CGMW, 2009.
(e) UN-ESCWA and BGR, 1999a.
(f) Christian, 2000.
(g) See 'Overview & Methodology: Groundwater' chapter for further information on the process and criteria used in the exploitability assessment.
(h) CGIAR-CSI, 2008.

Notes

1. UN-ESCWA, 2009.
2. Ibid., 2012.
3. Ibid., 2008.
4. Such as the UNECE Assessment of Transboundary Waters in Europe (UNECE, 2007; UNECE, 2011), which was implemented by the Working Group on Monitoring & Assessment under the secretariat to the Helsinki Convention of 1992.
5. DPSIR is a causal framework for describing the interaction between society and the environment, built on the following components: Driving forces, Pressures, States, Impacts and Responses. This framework has been adopted by the European Environment Agency and has also been applied by UNECE in both assessments of transboundary waters in Europe.
6. All experts and contributors are listed in the contributors section.
7. Relevant countries are all countries that were identified to share the watercourse, the surface water basin or the aquifer or aquifer system.

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OVERVIEW

SHARED WATER RESOURCES IN WESTERN ASIA

The sharing of water resources has been an influential feature affecting life, society and development in the Arabian Peninsula, the Mashrek and Mesopotamia for millennia. Historically, communities living in these arid and semi-arid regions always shared the water of rivers, springs and wadis, although this was more out of necessity than idealism. Water resources were traditionally managed at the local level, with tensions emerging between Bedouins, shepherds, pastoralists and growing urban centres. Water management and irrigation schemes – such as the underground aqueducts or falaj networks found in Bahrain, Oman, Saudi Arabia and Yemen – sustained different communal needs for dozens of centuries, while the marshes of Mesopotamia, the Tigris floodplain and the Jordan River

Shoyoukh Tahtani, Lake Tishreen, Syria, 2009. Source: Adel Samara.

Valley were cultivated and sustained successive civilizations since earliest of times. Hillside terraces from Lebanon to Yemen meanwhile demonstrated the early integration between water and land resources management schemes and local efforts to safeguard water for productive purposes. With the expansion of empires and the changing patterns of commerce between east and west, tradesmen tried to tame the waters of the Euphrates and Tigris Rivers for navigation purposes prior to the opening of the Suez Canal in 1869, albeit with limited success. Following the creation of modern nation states in Western Asia starting in the first half of the 20th century, most of the region's major rivers and many aquifer systems were found to cross political borders. However, their management did not emerge as a major problem until increasing freshwater scarcity exposed dependencies on internationally shared water resources.

During the second half of the 20th century, technological transformations, demographic changes, natural resource extraction, ethno-sectarian conflicts and development needs fundamentally altered the way that water resources were managed internally and addressed in international relations. Large-scale irrigation projects boosted investments in and socio-economic dependencies on the water and agricultural sectors. The damming of major rivers for hydropower generation and the expansion of irrigation networks created new economic opportunities upstream, while causing negative impacts on downstream water users and ecosystems in neighbouring countries, especially during the filling of reservoirs. Small-scale dams on tributaries and in catchment areas also impacted downstream flows, and affected the availability and seasonality of water in intermittent streams. Political conflicts and the occupation of Arab lands also prevented access to surface and groundwater resources, which had traditionally sustained the livelihoods of rural communities. Meanwhile, changing development paradigms and political uncertainties prompted the adoption of national policies to pursue food security through food self-sufficiency in many Western Asian countries, which led to the further extraction of surface and groundwater resources through the subsidization and centralization of large- and small-scale agricultural production. Considerable quantities of surface water were thus abstracted and increasingly diverted out-of-basin, while return flows from water-intensive agricultural projects polluted rivers and groundwater reserves. Water quality deteriorated, most notably through increased salinity, further affecting domestic and agricultural users downstream. In addition, exponential population growth rates throughout the region caused a sharp rise in demand.

Concurrently, agricultural production flourished with the introduction of groundwater pumps in the 1960s and 1970s, which resulted in the intensive development of groundwater resources. However, the arid climate and low rainfall levels meant that groundwater abstraction quickly exceeded recharge, which in turn led to the drying up of springs, streams and shallow groundwater bodies, some of which had flowed across national borders. Further advances in drilling and pumping technology allowed for the exploitation of deep groundwater reserves in the Arabian Peninsula, which were created thousands of years ago and are non-renewable under current climatic conditions. These deep fossil aquifers are often highly productive and constitute a unique kind of shared water resource in the region.

Today, water scarcity levels regionally are well below the water poverty level of 1,000 m^3 per capita. However, population growth rates and rural-to-urban migration patterns continue to fuel the expansion of the industrial and service sectors and to increase demand for freshwater resources, as well as water supply and sanitation services. Political unrest and the Arab-Israeli conflict also impede opportunities for constructive dialogue on shared water resources. Meanwhile, the agricultural sector remains the largest consumer of freshwater resources and shared water resources in the region. Climate variability and climate change evidenced by droughts and flash floods, in addition to the unsustainable abstraction of groundwater resources have affected agricultural productivity and further fuelled social unrest.

Some states in the Western Asia region have been able to adapt to this condition by increasing investments in desalination, dams, diversions and non-conventional water resources to enhance supply in the face of increasing demand. However, these supply side interventions have often been pursued unilaterally with limited consultation or coordination with downstream users within a shared basin. Water use efficiency improvements have also been pursued, but only to a moderate extent, despite the shared benefits that could be generated by reducing freshwater consumption. As such, dependency on shared surface and groundwater resources persists in the face of growing water scarcity and will continue to be a dominant influence on development policy and inter-state relations in Western Asia.

State of Knowledge on Shared Water Resources

GLOBAL AND REGIONAL EFFORTS TO ASSESS SHARED WATER RESOURCES

Several regional and global studies to assess transboundary water resources have been published in recent decades. The United Nations Educational, Scientific and Cultural Organization International Hydrological Programme (UNESCO-IHP) has collected a wealth of aggregate information on global water resources as part of its World Water Assessment Programme (WWAP), which has been regularly included in the World Water Development Report (WWDR). The Internationally Shared Aquifer Resources Management Initiative (ISARM), a multi-agency effort led by UNESCO and the International Association of Hydrogeologists, has also launched a number of global and regional initiatives to delineate and analyse transboundary aquifer systems and encourage riparian cooperation. However, to date, none of these initiatives have centred on the Middle East.

The World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP), another multi-agency consortium with BGR as executing institution, has produced several maps on river and groundwater basins around the world. This includes a map of river and groundwater basins of the world at a 1:50,000,000 scale.[1]

Several regional, political and economic organizations have also undertaken detailed assessments of transboundary water resources at the regional level which are often tied to multilateral agreements which regulate the management and use of transboundary waters, or the monitoring of environmental targets. The European Union Water Framework Directive is perhaps the most far-reaching agreement of this type, built on the river basin management approach and not limited to transboundary waters. The 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes is

The Tigris River in Baghdad, Iraq, 2007. Source: James Gordon.

an international environmental agreement negotiated by members of the United Nations Economic Commission for Europe (UNECE). Its Working Group on Monitoring and Assessment, a subsidiary body to the Convention's Meeting of the Parties, has conducted two comprehensive assessments of transboundary waters in Europe, which also inspired the preparation of this Inventory.

The global and regional initiatives outlined above all have a similar aim: to encourage and foster cooperation over shared water management and to protect and manage the resource in a sustainable manner for the benefit of all riparians. Many of these initiatives have used the assessment of shared surface and groundwater resources as a baseline and reference for bilateral and multilateral dialogue. The development of this Inventory is closely connected to the global and regional efforts outlined above, though it is a formally independent initiative of ESCWA and BGR in partnership with ESCWA member countries.

ASSESSMENT OF SHARED WATER RESOURCES IN WESTERN ASIA

The state of knowledge on shared surface and groundwater resources in the region is largely drawn from the literature available at the global level and reflects the historical context outlined above. Research on surface water resources has tended to dominate the literature. However, information on shared surface water is limited given the political context and national security concerns that are evoked regarding data sharing and exchange. Even less is known about groundwater resources hidden deep underground.

The region's few shared surface water basins are generally well known. Most basins have been subject to discussion and negotiations between riparian states, and some, most notably the Jordan River Basin, have been overshadowed by sustained political conflict. A wealth of literature exists on these disputed basins, although not necessarily on all relevant aspects. For example, the literature on the Jordan River Basin and, to a lesser extent, on the Euphrates and Tigris River Basins, is dominated by a focus on political relations, occupation and power asymmetry. However, the underlying scientific base is often limited and data is not publicly available, resulting in the republication of outdated maps, incomplete hydrological records and unreliable water use estimates.

At the same time, the focus on disputed rivers has diverted attention from smaller shared rivers and tributaries, which often play an important role on a local level and which may already have been affected by upstream water development projects.

Governments, scholars and international organizations have generally focused much less on shared groundwater resources in the region, and literature on the topic is limited and rarely publicly available. The Arab Centre for the Studies of Arid Lands and Dry Zones (ACSAD) published a comprehensive Hydrogeological Map of the Arab Region and Adjacent Areas in 1988.[2] ACSAD has also carried out a number of detailed groundwater studies in border areas on behalf of line ministries in ACSAD member countries. In addition, ESCWA has over the years worked on a range of projects with BGR, other partners and national governments to assess the state of shared water resources, such as the RJGC study,[3] the Basalt Study[4] and the study of Paleogene Aquifers,[5] all of which were released to experts.

However, the overwhelming majority of groundwater studies is undertaken by or on behalf of national governments, and rarely transcends political borders. Most groundwater maps delineate aquifers only up to the national borders and disregard the transboundary extent of the resource. The same goes for academic studies, which in this region can often only be implemented in close coordination with competent national authorities, who determine which information is released to the general public. Data from such studies is sometimes transferred into scholarly articles or sector assessments. The aquifers shared between Israel and Palestine form an exception. Here the political context, international interest and the continuous presence of local and foreign experts has allowed for the implementation and publication of technical and political studies, some of which were carried out on a basin-wide scale.

By contrast, little information is available on the deep fossil aquifers in the Arabian Peninsula. Over the last three decades, the exploitation of these extensive groundwater bodies has grown exponentially. In many cases, dealing with these aquifers and aquifer systems from a transboundary "basin" perspective raises complex conceptual questions (see 'Overview & Methodology: Groundwater' chapter).

The Western Asia Region: Study Area

The Western Asia region has no clearly agreed-upon boundaries and various international institutions and agencies define the region differently (Box 1). The geographical coverage of this Inventory was first determined by the membership of ESCWA, which includes all Arab countries in Western Asia as well as some Arab countries situated in North Africa. This coverage was then modified according to the following four criteria:

- Focus was placed exclusively on shared surface and groundwater resources included in the Western Asia geographic sub-region covered by ESCWA, given that there exists no comprehensive study of shared drainage basins and aquifer systems in this sub-region and there was a clear mandate to examine water resources management within a regional, transboundary context.
- Surface and groundwater resources located on the African continent were excluded from the Inventory. These resources are covered extensively in other studies and are better addressed in an intra-African context.
- As the Inventory is intended to focus on shared water resources, parts of drainage basins or aquifer systems originating in or shared with non-ESCWA member countries are necessarily included in the Inventory. However, as the relevant countries – Iran, Israel and Turkey – are not members of ESCWA, they were not included in the consultative process undertaken with country representatives.[6]
- The study area excludes a number of shared basins in the northern part of Western Asia situated outside the ESCWA region, but these are covered to a large extent in a similar initiative undertaken by UNECE.[7]

Zagros Mountains, Iraq, 2010. Source: Stefan Jürgensen.

This Inventory therefore closes a geographical gap between similar assessments implemented in Africa and European-Central Asia.

The Western Asia region as defined in this Inventory thus extends from the Red Sea in the west to the Gulf coast in the east, and from the north-eastern shore of the Mediterranean Sea to the Gulf of Aden in the south to comprise 12 ESCWA member countries and Israel, Iran and Turkey (Table 1). From a geological perspective, the study region lies entirely within the Arabian Plate and is characterized by common geo-tectonic systems, which have contributed to the development of shared surface and groundwater systems. Furthermore, as will be explained in more detail below, the region can be divided into three sub-regions: the Mashrek, Mesopotamia and the Arabian Peninsula.

BOX 1

Defining the Western Asia Region

The Western Asia region is geographically not clearly defined and various institutions use the term to designate different geographical areas, depending on the scope of their operations. In its broadest geographic sense, the Western Asia region can comprise countries located from the eastern shores of the Red Sea and the Mediterranean Sea to the Gulf coast in the east, up to the Caucasus Mountains in the north. The United Nations Statistics Division defines Western Asia as a geographic sub-region of Asia that encompasses Armenia, Azerbaijan, Bahrain, Cyprus, Georgia, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, Syria, Turkey, United Arab Emirates and Yemen.[8]

However, some organizations, even within the UN system, refer only to a sub-section of this wider geographic definition, based on regional, cultural or political identities. For instance, the membership of the United Nations Economic and Social Commission of Western Asia (ESCWA) comprises only the Arab countries of Western Asia, sometimes also referred to as Arab Western Asia or the Arab Mashrek, plus most Arab countries situated in North Africa (Egypt,[9] Libya, Morocco, Tunisia and Sudan); as such, it excludes Cyprus, Iran, Israel, Turkey and other countries located further north towards the Caspian Sea.

Within the UN and other international organizations, Western Asia has also often come to replace the narrower terms "Middle East" and "Near East", which are regarded as Eurocentric as they designate the region in relation to Europe. Other institutions use Middle East in combination with "North Africa", resulting in the term "MENA region", which also includes non-Arab countries.

Table 1. General features of countries in the study area

SUB-REGION	COUNTRY	SURFACE AREA[a] (km^2)	POPULATION[b]	MEAN ANNUAL PRECIPITATION (mm/yr)[c]
Mashrek[d]	Egypt (Sinai Peninsula)	60,174	546,799	<100
	Israel	22,070	7,625,000	435
	Jordan	89,324	6,113,000	111
	Lebanon	10,452	4,227,597	661
	Palestine	6,020	4,048,403	402
	Syria[e]	185,180	20,619,000	252
Mesopotamia	Iraq	438,317	32,438,000	216
Arabian Peninsula	Bahrain	694	1,234,571	83
	Kuwait	17,818	2,672,926	121
	Oman	309,500	2,773,479	125
	Qatar	11,493	1,699,435	74
	Saudi Arabia	2,149,690	27,563,432	59
	United Arab Emirates	83,600	8,264,070	78
	Yemen	527,970	23,154,000	167
Other	Iran	1,745,150	74,339,576	228
	Turkey	783,560	72,698,000	593
TOTAL		6,441,012	290,017,288	-
TOTAL (Arab countries)		3,890,772	135,354,712	-

Source: Compiled by ESCWA-BGR.
(a) Figures based on UN-ESCWA, 2009a, except for Egypt (from CAPMAS, 2012) and Israel, Iran and Turkey (from World Bank, 2011).
(b) Figures referring to 2010 (census data or estimates), based on UN-ESCWA, 2011b except for Egypt (from CAPMAS, 2012) and Israel, Iran and Turkey (from UN-DESA, 2012).
(c) Figures referring to 2009, based on World Bank, 2011 except for Egypt (from CAPMAS, 2012).
(d) The Mashrek refers to the region located on the eastern Mediterranean coast between Anatolia in the north and the Sinai Desert in the south (Harris, 2003).
(e) North-eastern Syria is considered part of Mesopotamia (Encyclopédie Larousse, 2012).

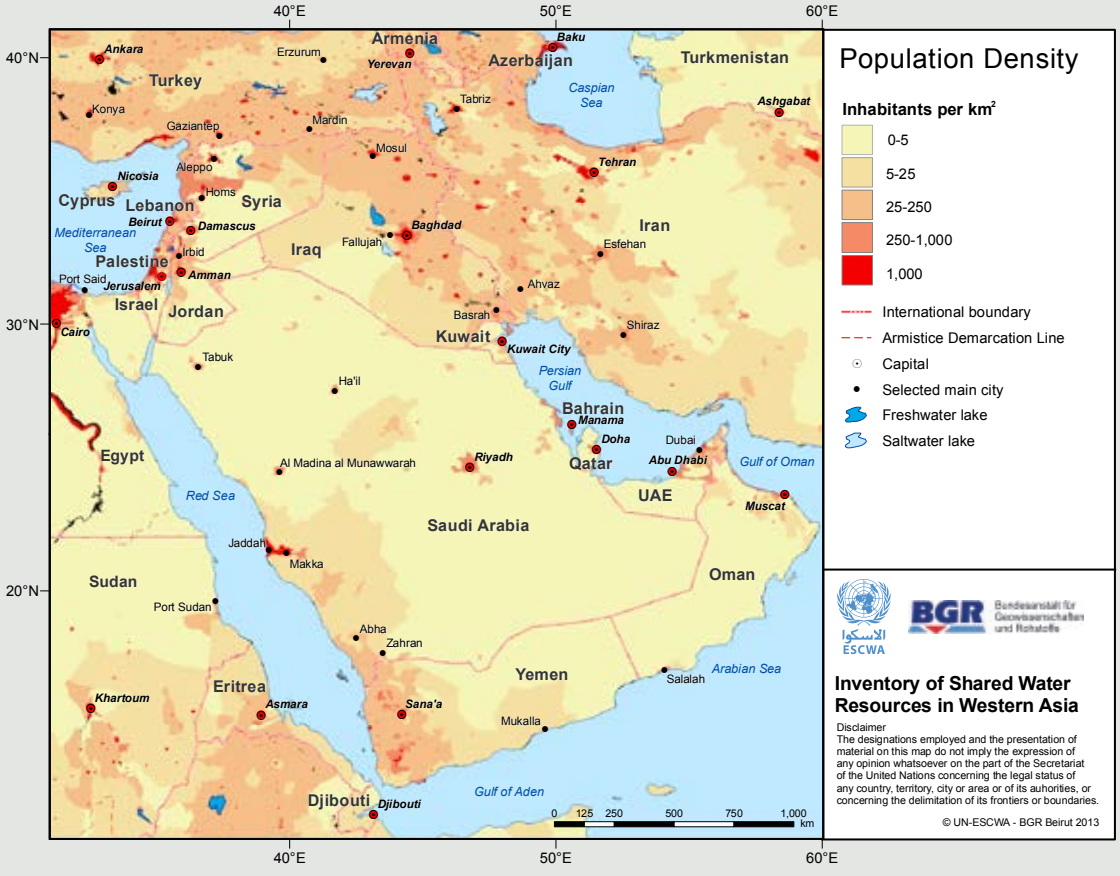
Population

The Western Asia region as defined in this Inventory covers an area of approximately 4 million km^2 or about 2.6% of the world's surface area.[10] The region's total population of around 135 million inhabitants[11] has more than tripled since 1970, and the populations of Iraq, Palestine and Yemen are expected to double between 2010 and 2050.[12]

Population increase in the region has in some cases contributed to very high population densities. The average population density in the region was estimated at 325 inh./km^2 in 2010, with the highest density found in Bahrain (1,818 inh./km^2) and the lowest in Oman (9 inh./km^2). Figure 1 shows that the region's population is unevenly distributed within and between countries, and is in general concentrated along major rivers on the coast or in mountain ranges near the coast. These relatively water-rich areas have fertile soils and are strategically located along major trade routes.

While population growth rates in the region have declined in recent years, the average growth rate (3.28%) still remains well above the world average.[13] Urban growth is an important challenge facing the region; the urban population is growing at a faster rate than the total population, indicating a continued urbanization trend.[14] Approximately three quarters of the region's population live in cities today,[15] with the highest urban population percentages found in the countries of the Gulf Cooperation Council (GCC).[16] Urban expansion in the region is a result of demographic growth, internal rural-to-urban migration, and the influx of displaced people fleeing conflicts in the region. Another important factor is the influx of expatriates attracted by the region's employment opportunities, particularly in the Gulf and in oil-producing countries.[17] This has led to the creation of new settlements in urban peripheries, especially along the coast, but also in reclaimed deserts.[18] Urban growth is placing increasing pressure on the region's already limited water resources, and spurring investment in non-conventional water resources such as desalination, particularly in the wealthier GCC countries.

Figure 1. Population density in the Western Asia region



Source: Compiled by ESCWA-BGR based on CIESIN, 2010.

Topographical Features

The Western Asia region is characterized by large mountainous zones and vast deserts that cover most of the Arabian Peninsula (Figure 2).The Taurus-Zagros Mountain range, which extends from southern Turkey to the Iraq-Iran border, bounds the Western Asia study region to the north. Two other mountain chains run along the Mediterranean shore. The Lebanon Western Mountain range extends along the eastern Mediterranean coast in Lebanon, with Qurnat as Sawda as its highest peak (3,090 m).[19] The Eastern Mountain Range (Anti-Lebanon) runs parallel to the western range and stretches to the Golan Heights Plateau in the south, where Mount Hermon (2,814 m) on the Lebanese-Syrian border forms the highest peak. Towards the east, the Zagros Mountain range in northern Iraq reaches into western and southern Iran. Zard Kuh in Iran (4,548 m) is the highest peak here.[20]

In the Arabian Peninsula, the Hijaz and Asir Mountain ranges extend along the length of the Red Sea coast with elevations of approximately 2,000 m.[21] Situated along the southern stretch of the Red Sea coast, the Yemen Mountain range rises up to 3,666 m (the highest elevation in the Arab countries included in the study area) and then runs parallel to the Gulf of Aden as the Hadhramaut Mountain range.[22] The Hadhramaut Plateau is situated in the same area, covering a total area of 158,000 km^2.[23] The fertile Najd Plateau in the centre of the Arabian Peninsula slopes from west to east with elevations of up to 1,500 m.[24] There are also many wadis (Box 2) and large salt marshes or sabkhas (Box 3) scattered

BOX 2

Wadis

A common feature in the Arabian Peninsula, wadis (singular: wadi) are seasonal streams with lengths that can vary from a few tens of kilometres to hundreds of kilometres. For example, Wadi al Batin covers 970 km and crosses Iraq, Kuwait and Saudi Arabia (see Chap. 26, Box 1). Despite their seasonal nature, some wadis have been crucial in supplying populations with water for domestic and irrigation purposes in Oman, Saudi Arabia and Yemen.

Source: Compiled by ESCWA-BGR based on Shahin, 2007; Edgell, 2006.

Afrin dam, Syria, 2009. Source: Andreas Renck.

through the peninsula. In the south-east, the Oman Mountain range borders the Gulf of Oman with a peak elevation of more than 3,000 m at Jebel Shams.[25] In addition to mountain ranges and highlands, the region also features areas well below sea level, such as the Dead Sea which is considered the lowest point on earth at 422 m bsl.[26]

One of the region's most distinctive topographical features is its extensive desert areas. The Syrian Desert (500,000 km^2) in the north covers more than half of Syria, as well as parts of western Iraq, Jordan and Saudi Arabia.[27] In the Arabian Peninsula, the An Nafud Desert (65,000 km^2) spans north-western Saudi Arabia to the Dahna Desert. It is connected to the Rub' al Khali Desert (the Empty Quarter), one of the world's largest sand deserts which extends over 650,000 km^2 in the southern third of the Arabian Peninsula. The Rub' al Khali is mainly situated in Saudi Arabia, but also covers parts of Oman, the United Arab Emirates and Yemen.[28] Smaller deserts also exist in the region, such as the Negev Desert (Al Naqab in Arabic), which borders the Sinai Peninsula Desert in Egypt and has a surface area of 13,000 km^2.[29]

Other important topographical bearings in the region are plains, such as the coastal Tihama Plain along the Red Sea in western Saudi Arabia and Yemen, the Batinah Plain in northern Oman and the Hasa Plain along the eastern shores of the Arabian Peninsula . In addition, alluvial plains formed by river sedimentation exist along the Euphrates and Tigris Rivers and on the banks of other rivers situated in Lebanon and Syria.[30]

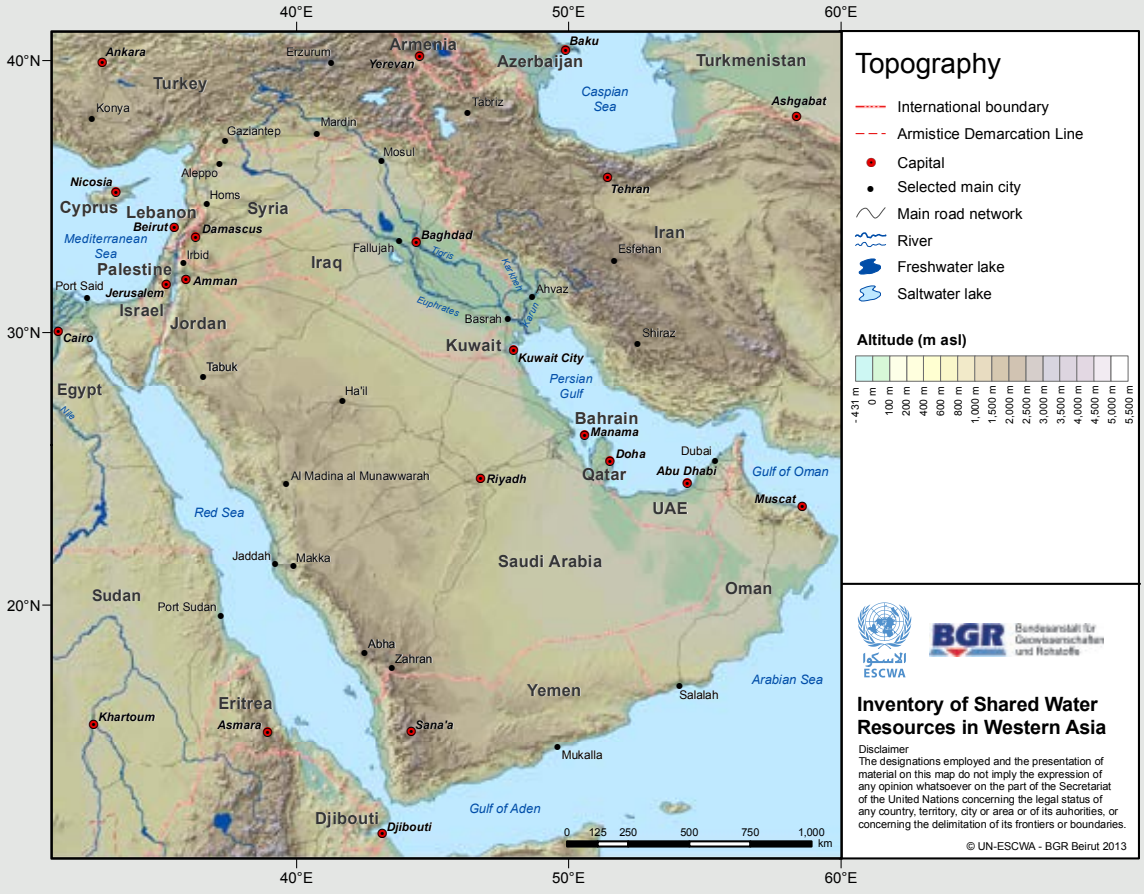
BOX 3

Sabkhas

A very common physiographic feature in the Arab region, sabkhas (singular: sabkha) are salt flats or salt-crusted depressions lying just above the water table. These sandy or silty areas have impermeable floors where salt brine has accumulated due to episodic flooding and evaporation. Sabkhas are commonly found in the eastern Arabian Peninsula and in parts of Iraq and Syria. With an elevation of 100 m, the Umm es Sammim Sabkha in the east of the Rub' al-Khali Desert is probably one of the highest salt formations in the region.

Source: Compiled by ESCWA-BGR based on West, 2012; Ghazanfar, 2006; Jabbul Consultative Committee, 2008.

Figure 2. Topography of the Western Asia Region



Source: Compiled by ESCWA-BGR based on SRTM, 2000.

Climate

The Western Asia region is dominated by a dry, arid or semi-arid climate with limited rainfall and high evaporation rates. The mountain ranges along the Mediterranean and Red Sea coasts and winds from the Atlantic and Indian Oceans play an important role in determining precipitation patterns. While certain mountainous areas receive more than 1,000 mm/yr of precipitation, the largest part of the study area receives less than 100 mm/yr (Figure 3). Most countries experience a critical combination of low rainfall and high spatial and temporal rainfall variability, which impacts water availability.

The western areas of Jordan, Lebanon, Palestine and Syria have a Mediterranean climate with warm, dry summers and rainy, cold winters. In the east, the vast deserts of Iraq, Jordan and Syria are arid with excessively hot, dry summers. In winter, daytime temperatures here are mild, while nights can be very cold. Temperatures in the highlands of north-eastern Iraq, Lebanon and northern Syria are below 10˚C in January, rising to 20˚C to the south and the east. July and August are generally the warmest months on the Mediterranean and Red Sea coasts and temperatures can reach 50˚C or more in parts of Iraq and Saudi Arabia.[31]

A hot desert climate[32] characterizes most of the Arabian Peninsula, including the narrow coastal strip along the Red Sea and the vast desert plain along the Gulf coast. In the elongated plateau parallel to the Dead Sea and on the Oman Plateau along the western coast of the Gulf of Oman, a hot steppe climate[33] prevails. Finally, the south-western corner of the Arabian Peninsula has a warm temperate rainy climate,[34] with temperatures reaching around 25˚C in January along the Red Sea coast. Temperatures in northern coastal zones of the peninsula are slightly lower and much lower in inland areas (13˚C-14˚C).[35]

Precipitation is one of the most influential climatic features, and in the northern mountainous areas[36] it is a result of cold fronts coming in from Siberia and the Atlantic Ocean between November and February. These fronts become saturated with moisture as they reach the Mediterranean and generate precipitation until April or early May, and especially from December to February. In Mount Lebanon and western Syria, precipitation can reach 1,500 mm/yr, gradually diminishing to the east as fronts cross the coastal mountain ranges and reach Jordan, northern Saudi Arabia and western Iraq.

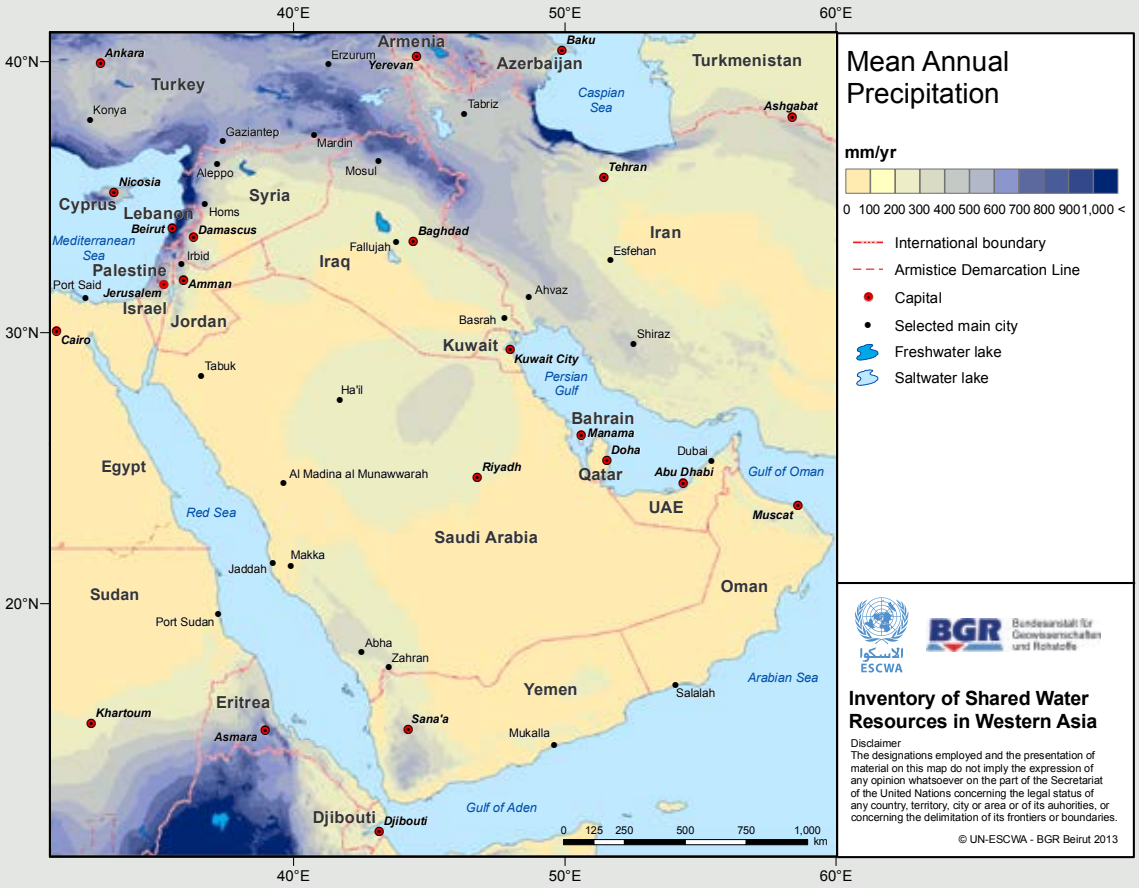
Precipitation in the Arabian Peninsula is affected by seasonal (monsoon) winds, which bring moist air masses from the Indian Ocean with them, causing rainfall in the coastal zones of eastern Oman, Saudi Arabia (Hijaz region) and Yemen.[37] Most of the precipitation occurs in May and continues until August in the uplands, but often appears as early as March. In this area, precipitation mainly occurs in the form of heavy showers followed by flash floods. Precipitation levels can reach up to 1,500 mm/yr on the south-western mountain slopes in Yemen.[38] Some moderate seasonal shifts in rainfall patterns and intensities have also been observed in the region in recent years.

Over the past decade, climate change has become increasingly prominent within the regional debate surrounding sustainable water resources management. According to the IPCC Fourth Assessment Report,[39] the Arab region is highly vulnerable to the potential impacts of climate change, which include higher average temperatures, less and more erratic precipitation and sea-level rise.

Despite this, the issue of climate change does not feature prominently in this Inventory, which was conceived as a desk study to compile and consolidate past and current data on hydrology, water use, and agreements and cooperation in shared water basins in the region. As such, the Inventory aims to take stock of the recent development and current state of shared water basins, without making projections into the future. In most cases the literature on the basins covered in this Inventory has not yet

Agriculture in the Disi-Mudawwara area, Jordan, 2009. Source: Andreas Renck.

Figure 3. Mean annual precipitation distribution across the Western Asia region



Source: Compiled by ESCWA-BGR based on WorldClim, 2011.

reached a clear conclusion as to the impact of climate change. In most cases, too few studies have been undertaken and insufficient data is available. More fundamentally, the intensive development of all available water resources in this arid region makes it difficult to identify the underlying causes of hydrological changes.

There are currently a number of initiatives underway to improve data availability and projections for the study region, such as the Regional Initiative for the Assessment of the Impact of Climate Change on Water Resources and Socio-Economic Vulnerability in the Arab Region which is led by ESCWA, the League of Arab States and other specialized organizations. This initiative aims to assess the impact of climate change on freshwater resources and its associated implications for socio-economic vulnerability in the region. It draws on the findings and basin chapters of the Inventory to inform its integrated assessment methodology comprised of regional climate modelling, regional hydrological modelling, and vulnerability assessment tools.[40]

BOX 4

Availability of Water Resources in the Region

The prevailing semi-arid to arid climate in the Western Asia region governs the occurrence of freshwater. Although the region's aridity is mainly a result of low precipitation, high evaporation rates also severely reduce the amount of water that remains as surface runoff or groundwater recharge.

In the north, the Taurus-Zagros Mountain range captures significant precipitation from moist westerly winds, which feeds the Euphrates and Tigris Rivers. Similarly, precipitation from the eastern Mediterranean mountain ranges feed the headwaters of the Jordan and Orontes Rivers, the Nahr el Kabir and smaller Lebanese and Syrian rivers. Perennial rivers are thus confined to the Mashrek region where humid conditions prevail and where water resources are renewable.

In the Arabian Peninsula, scarce rainfall and very high evaporation rates limit the occurrence of surface water and groundwater recharge. Nevertheless, the irregular but heavy rainfall that occurs in the mountainous areas of the Arabian Peninsula accumulates and infiltrates along the extensive network of wadi channels (Box 2), often constituting important local sources of freshwater. The climate in this area cannot sustain perennial river systems. Groundwater occurrence is also affected by the arid climate and by the region's geology and geo-tectonics (e.g. tectonic faults and structure, types of rock formation/aquifer, lithological and structural features, etc.).

Many aquifer systems in the region occur in large geological formations that cover tens or even hundreds of kilometres. Significant volumes of groundwater are stored in these sedimentary formations, which stem mainly from past pluvial periods. Recharge under current conditions is very limited. Smaller aquifer systems also exist: for example in wadi discharge areas where several channels join together and enhance the accumulation of thick alluvial deposits to form wadi aquifers.

Notes

1. WHYMAP, 2012.
2. ACSAD-UNESCO, 1988.
3. RJGC, 1995.
4. UN-ESCWA et al., 1996.
5. UN-ESCWA and BGR, 1999.
6. ESCWA member countries have been involved at all stages of the preparation of this Inventory through a consultation process aimed at improving and enriching basin chapter content through visits, regional workshops and tailored basin questionnaires. For further information, see 'Introduction to the Inventory'. Libya, Morocco and Tunisia joined ESCWA in August 2012 and, as they are not geographically situated in Western Asia, they were not included in the consultative process with countries.
7. UNECE, 2011, 'Drainage basins draining to the Caspian Sea', features the riparian countries Armenia, Azerbaijan, Georgia and Iran, among others.
8. UNStats, 2011.
9. The Sinai Peninsula is the only part of Egypt that is located in Western Asia.
10. UN-DESA, 2011. Excluding Iran, Israel and Turkey.
11. 2010 estimates.
12. Mirkin, 2010.
13. UN-DESA, 2011.
14. UN-HABITAT, 2012.
15. With the exception of Yemen (32%), urban population shares in the region make up between 55% (Syria) and 98% (Kuwait) of the total population (UN-ESCWA, 2009b).
16. Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates.
17. UN-HABITAT, 2012. Moreover, most of the countries in the region are characterized by relatively high levels of foreign migration, such as Qatar and Kuwait where 75% of the population are migrants, and Jordan, where nearly 50% are migrants (UN-ESCWA, 2011b).
18. UNESCO, 2012.
19. Ministry of Tourism in Lebanon, 2012.
20. Encyclopaedia Britannica, 2012b.
21. Teach Middle East, 2010.
22. OWNO, 2012.
23. Edgell, 2006, p. 431.
24. Hussein et al., 1992.
25. Ministry of Tourism in Oman, 2012.
26. Khlaifat et al., 2010.
27. Graphic Maps, 2011.
28. Central Department of Statistics and Information in Saudi Arabia, 2011.
29. Metz, 1988.
30. Encyclopaedia Britannica, 2012a; Al-Jassar, 2005.
31. Shahin, 2007; Treehugger, 2010.
32. Characterized by sparse vegetation, negligible annual rainfall and some seasonal variation in temperature (National Geographic Society, 2008).
33. The hot steppe climate is milder than the hot desert climate with some rain in spring and winter (Benders-Hyde, 2010).
34. Characterized by rainfall throughout the year with maxima in spring and summer, and a dry winter season (Ibid).
35. Shahin, 2007.
36. Referring to Lebanon, the West Bank in Palestine and the northern parts of Iraq, Jordan and Syria.
37. Encyclopaedia Britannica, 2012a.
38. UN-ESCWA, 2007.
39. IPCC, 2007.
40. UN-ESCWA, 2011a.

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OVERVIEW

KEY FINDINGS

Wadi Rum, Jordan, 2009. Source: Maarten Schäfer.

This Inventory of Shared Water Resources in Western Asia is the first systematic effort to catalogue and characterize shared surface and groundwater resources across the Middle East. It provides detailed information on 7 shared river basins including numerous shared tributaries, and it identifies 22 shared aquifer systems in the region. For each of the described shared freshwater bodies, the Inventory addresses key aspects of hydrology, hydrogeology and water resources development and use, and examines the status of international water agreements and cross-border management efforts. As a descriptive reference document on shared waters in the region, the Inventory's main purpose is to provide a sound scientific basis for informing further discussion and analysis at the basin level. The main finding of this work is the identification of all the major shared surface water basins and aquifer systems in Western Asia, as listed in Tables 1 and 2 below.

In addition to identifying the number of shared water basins that are found in Western Asia, the 10 key findings below highlight important general and region-specific observations related to the state and assessment of shared water resources. These key findings synthesize and consolidate some of the main issues regarding the identification, state, use and management of shared water resources. In doing so, they offer ideas for further research into shared water resources and provide insights into how the Inventory can inform complementary research in the other important areas of concern for the region, such as climate change, food security, the water and energy nexus, and efforts to achieve sustainable development.

Table 1. **List of shared surface water basins in Western Asia**

	SHARED RIVER		RIPARIAN COUNTRIES	MAIN SHARED TRIBUTARIES[b]
MESOPOTAMIA	Euphrates-Tigris-Shatt al Arab Basin	Euphrates River	Iraq, Jordan,[a] Saudi Arabia,[a] Syria, Turkey	Sajur River Jallab/Balikh River Khabour River
		Tigris River	Iran, Iraq, Syria, Turkey	Feesh Khabour River Greater Zab River Lesser Zab River Diyala River
		Shatt al Arab River	Iran,[c] Iraq[c]	Karkheh River Karun River[d]
MASHREK	Jordan River		Israel, Jordan, Lebanon, Palestine, Syria	Hasbani River Banias River ---------- Yarmouk River
	Orontes River		Lebanon, Syria, Turkey	Afrin River Karasu River
	Nahr el Kabir		Lebanon, Syria	-
	Qweik River		Syria, Turkey	-

(a) Riparians that contribute surface water only under extreme climatic conditions.
(b) Not all shared tributaries listed are shared by all the displayed countries.
(c) Iran and Iraq are only riparians to the river, however all riparians to the Euphrates and Tigris Rivers are riparians to the Euphrates-Tigris-Shatt al Arab basin. See 'Overview and Methodology: Surface Water' chapter for more information.
(d) The Iranian Karun River does not cross any political boundary, but provides a significant freshwater contribution to the Shatt al Arab and forms an important part of the transboundary river system; it is thus included in the Inventory as part of the shared basin covered in the chapter related to the Shatt al Arab.

The Afrin River, Syria, 2009. Source: Andreas Renck.

Table 2. List of shared aquifer systems in Western Asia

	SHARED AQUIFER SYSTEM	RIPARIAN COUNTRIES
ARABIAN PENINSULA	Saq-Ram Aquifer System (West)	Jordan, Saudi Arabia
	Wajid Aquifer System	Saudi Arabia, Yemen
	Wasia-Biyadh-Aruma Aquifer System (South): Tawila-Mahra/Cretaceous Sands	Saudi Arabia, Yemen
	Wasia-Biyadh-Aruma Aquifer System (North): Sakaka-Rutba	Iraq, Saudi Arabia
	Umm er Radhuma-Dammam Aquifer System (South): Rub' al Khali	Oman, Saudi Arabia, United Arab Emirates, Yemen
	Umm er Radhuma-Dammam Aquifer System (Centre): Gulf	Bahrain, Qatar, Saudi Arabia
	Umm er Radhuma-Dammam Aquifer System (North): Widyan-Salman	Iraq, Kuwait, Saudi Arabia
	Tawil-Quaternary Aquifer System: Wadi Sirhan Basin	Jordan, Saudi Arabia
MASHREK	Ga'ara Aquifer System[a]	Iraq, Jordan, Saudi Arabia, Syria
	Anti-Lebanon[b]	Lebanon, Syria
	Western Aquifer Basin	Egypt, Israel, Palestine
	Central Hammad Basin[a]	Jordan, Syria
	Eastern Aquifer Basin[a]	Israel, Palestine
	Coastal Aquifer Basin	Egypt, Israel, Palestine
	North-Eastern Aquifer Basin[a]	Israel, Palestine
	Basalt Aquifer System (West): Yarmouk Basin	Jordan, Syria
	Basalt Aquifer System (South): Azraq-Dhuleil Basin	Jordan, Syria
	Western Galilee Basin[a]	Israel, Lebanon
MESOPOTAMIA	Taurus-Zagros[b]	Iran, Iraq, Turkey
	Jezira Tertiary Limestone Aquifer System	Syria, Turkey
	Neogene Aquifer System (North-West), Upper and Lower Fars: Jezira Basin	Iraq, Syria
	Neogene Aquifer System (South-East), Dibdibba-Kuwait Group: Dibdibba Delta Basin	Iraq, Kuwait, Saudi Arabia

(a) These aquifer systems are not covered in stand-alone chapters. See 'Table of Contents' and 'Overview and Methodology: Groundwater' chapter for more information.
(b) Aquifers in faulted and folded tectonic areas have been classified as one group. However, in practice they may represent more than one aquifer system.

1. There are more shared water resources in Western Asia than generally assumed.

More than 70% of the study area is part of a shared surface or groundwater basin. A quick look at a map of the region shows that most surface water is shared and originates from outside the region. However, the Inventory also identifies a number of transboundary aquifer systems, most of which are shared between Arab countries. Many of these had not been previously delineated or recognized as shared. The groundwater reserves in these large aquifer systems far exceed the discharged volume of all rivers combined.

2. Water quantity and allocation dominate the discourse on shared water resources in this water-scarce region.

As in other arid and semi-arid regions, water scarcity in Western Asia has led to a supply management approach that seeks to harness all available water resources and that prioritizes quantitative water allocation. Riparian countries are more intent on dividing the region's water resources than on sharing them. Both on the level of discourse and agreements, the focus lies on the quantity of available water, not on the potential benefits derived from its shared use.

3. Water quality is rapidly deteriorating, a fact that is largely neglected.

The problem of deteriorating water quality across the region is eclipsed by concerns over quantity. However, increasing levels of pollution and salinity of both surface and groundwater resources is increasingly affecting the ability to use the scarce water resources available in the region, and is heightening tensions between riparian countries. In addition, while environmental ministries consider the need for minimal environmental flows to maintain ecosystems, this issue is rarely incorporated in national water management planning in the region.

4. The lack of accurate data hampers joint water resources management.

Water remains a sensitive topic in the Arab region and data sharing between riparian countries is limited. As a result, there is no common understanding of the state and development of water availability, use and trends. On a national level, data is often lacking, incomplete or inaccessible, particularly when it comes to water use, which is rarely measured. Regionally, data from different countries can be contradictory, often because there are no unified standards for measuring hydrological changes. The fact that cooperation between riparian countries is limited further impedes the development of a common vision on shared water resources management.

Facts & Figures

More than 70% of the study region forms part of shared basins.

Aquifer with the most riparians: Umm er Radhuma.

Saudi Arabia shares all identified aquifer systems in the Arabian Peninsula.

Country that shares the most rivers: Syria.

River shared by most riparians: Jordan River.

About 40 BCM of surface water originate from outside the study region. 75% of the mean annual flow volume of surface water originates from outside the region.

Five largest transboundary rivers in terms of discharge: Tigris, Euphrates, Greater Zab, Lesser Zab, Diyala, Orontes.

Five longest rivers: Euphrates, Tigris, Diyala, Greater Zab, Khabour.

Basins with the most dams: Euphrates, Jordan, Tigris.

Number of agreements on water in Western Asia: 8.

5. Cooperation over shared water exists, but is never basin-wide.

Long-standing political instability in the region has hampered successful basin-wide cooperation. There is not a single basin-wide agreement on shared water resources in the Middle East. Existing bilateral agreements centre on water allocation, with an emphasis on infrastructure development and use. Water quality is not addressed in these agreements. While there are no river basin associations in place, bilateral cooperation over surface water does take place through technical committees and local projects.

6. There is not a single agreement on shared groundwater resources in the region.

There are no specific agreements on shared groundwater resources, though in a few cases bilateral agreements include groundwater-related provisions. Cooperation over shared groundwater is rare as resources are often not clearly delineated and may therefore not be recognized as shared by riparian countries.

7. The region's groundwater is largely non-renewable and aquifers are rapidly being depleted.

Most aquifer systems in the Arabian Peninsula are non-renewable. Their massive development over the past 30 years has led to aquifer depletion and unprecedented hydrogeological changes, which threaten the sustainability of groundwater use. In addition, the cross-border implications of high abstraction are generally neglected. In some cases, shared aquifer systems are developed so rapidly that they may be exhausted before being recognized as a shared resource.

8. Groundwater plays an important role in surface water basins, a link which is often overlooked.

The link between surface and groundwater is rarely explored. Groundwater forms the base flow of many rivers in this arid region, including the Jordan, Orontes and Nahr el Kabir. Similarly, groundwater over-abstraction has lowered water tables and led to the disappearance of freshwater springs, which has in turn affected surface water flows. Groundwater abstraction and the development of large-scale irrigation schemes also produces return flows, which contribute to the discharge of rivers. The understanding and management of shared basins may change if surface and groundwater are considered together.

9. A new thinking is required to deal with large regional aquifer systems from a shared perspective.

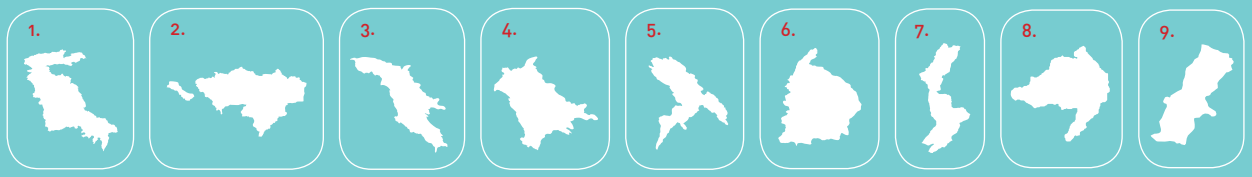
Regional aquifer systems in the Arabian Peninsula are among the most extensive and productive in the world, with some stretching into eight countries. Closer cooperation over these resources will require the delineation of more manageable units where cross-border impacts can occur. This regional Inventory can stimulate this discussion among riparian countries, but cannot replace more detailed hydrogeological studies needed for this process.

10. It is already too late to save some shared waters.

Man-made diversions of upstream surface waters the over-exploitation of some groundwater resources and intensive irrigated agriculture have already led to the disappearance of intermittent streams, the drying up of wadis, and rendered some groundwater resources too polluted or saline to use. This has fuelled tensions along international borders, affected health and livelihoods in rural communities, and increased costs to industry. More cooperative action and constructive dialogue is needed to sustain the shared water resources that remain.

PART I

SURFACE WATER



OVERVIEW & METHODOLOGY:

SURFACE WATER

Part I of the Inventory provides a comprehensive overview of shared (transboundary)[1] surface water basins in Western Asia. This chapter presents the methodology and approaches used to identify, delineate, characterize and describe these shared water resources in the Inventory. After defining the terminology used in the surface water chapters, all shared surface water resources in the region are listed together with the list of chapters for Part I of the Inventory. The section also explains why certain shared tributaries were covered in a single chapter and why some river basins were dealt with in separate chapters. The second part of the chapter outlines the Inventory's approach to basin delineation, describes the structure of the surface water basin chapters and explains how the content of basin chapters was prepared and collated in a structured and unified way.

Definition of terminology

Water resources that cross national borders are most commonly referred to as international, transboundary or shared waters or watercourses. The terms are often used interchangeably although the terms transboundary waters and international watercourse are most commonly used. For instance, the latter is used in the United Nations Convention on the Law of Non-Navigational Uses of International Watercourses where it is defined as "a watercourse, parts of which are situated in different States".[2]

For reasons outlined in 'Overview: Introduction to the Inventory', the Inventory uses the term shared water, but generally follows the methodology and definitions put forward by the Transboundary Freshwater Dispute Database at Oregon State University. The Database defines a river basin as the area which contributes hydrologically (including both surface and groundwater) to a first order stream, which, in turn, is defined by its outlet to the ocean or to a terminal (closed) lake or inland sea. A river basin is defined as international if any perennial tributary crosses or represents the political boundaries of two or more nations.[3] A similar integrated understanding is put forward in the aforementioned United Nations Convention, which, however, refers only to the (system of) watercourses and not to the river basin as a whole.[4]

The Inventory deviates from the Database approach in two points. First, a strict differentiation between perennial, seasonal and intermittent streams (or tributaries) as a qualifying criterion for inclusion was not appropriate within the context of this Inventory. Rainfall and stream discharge in this predominantly arid region are highly variable, with pronounced seasonal and inter-annual cycles. In addition, hydrological information in the literature is scarce and often not comparable. Moreover, growing water use has had a tremendous impact on water resources in recent decades, leading to the drying up of springs and rivers on one side, but also to increasing flows downstream of urban and agricultural centers where once had been only dry wadis.

Second, the Inventory dedicates several chapters to the complex hydrology of the Euphrates-Tigris-Shatt al Arab basin, whereas the Database registers it as one basin based on its single outlet to the sea, the Shatt Al Arab. This is important to remember, particularly when findings of this Inventory are presented in an abbreviated or simplified way. For instance, the number of chapters in this Inventory does not necessarily match the number of shared basins identified in the study region, which, in turn, depends largely on the approach followed in the classification of river basins as well as the scale of study. At the same time, there may be a plethora of political, legal, administrative or management reasons why certain basins or sub-basins are dealt with as separate entities or vice versa. The added value of this Inventory lies in the identification, delineation and systematic description of shared basins and conditions – the number count of basins in itself is not its primary objective.[5]

Overview of Shared Surface Water Basins & Chapters

Shared surface water resources are only found in the Mashrek and Mesopotamia regions of Western Asia where humid conditions prevail in the northern, north-eastern and Mediterranean parts and where water resources are renewable. In the north, mountain ranges capture significant precipitation that feeds the Euphrates and Tigris Rivers; in the north-east, the Mediterranean mountain ranges feed the headwaters of the Jordan River, the Orontes River and the Nahr el Kabir (see Map 1).

The shared perennial rivers that flow through Western Asia have generally been recorded and therefore do not need to be identified in the same way as shared groundwater resources. The challenge for the Inventory was to apply a unified approach in delineating shared surface basins, as their boundaries differ from one publication and/or map to another. Furthermore, the Inventory offers complete coverage of shared water resources in Western Asia,[6] featuring key shared basins such as the Euphrates, Tigris and Jordan Basins, but also less prominent basins such as the Nahr el Kabir and Qweik Basins.

LIST OF SHARED WATER RESOURCES

The list of shared surface basins presented in Table 1 comprises all perennial watercourses in Western Asia that are shared between two or more countries. In addition, the right-hand column features shared tributaries for each basin. The table distinguishes between shared basins in the Mashrek and Mesopotamia.

Table 2 lists the countries in the region and shows which surface water basins they share. As several basins are shared with other countries, the table also includes Iran, Israel and Turkey.

Identifying riparian countries in these basins is not always a straightforward affair. The Euphrates River Basin, for example, is commonly regarded to have three riparians, Iraq, Syria and Turkey, which also share the watercourse. Its topographic catchment as delineated in this Inventory, however, also stretches slightly into Jordan and Saudi Arabia. Given the aridity of these areas and their distance to the watercourse, an active hydrological contribution originating from these areas is highly theoretical or might occur only under extreme climatic conditions, through ephemeral wadis. These countries are therefore marked in red in Table 2.

The Tigris River, in turn, flows through Iraq, Syria and Turkey, while its basin also extends into Iran, which provides significant contributions to river discharge through a number of perennial and seasonal tributaries. Iran is also a riparian of the Shatt al Arab

Table 1. List of shared surface water basins in Western Asia

REGION	BASIN	RIVER	MAIN SHARED TRIBUTARIES
MESOPOTAMIA	Euphrates-Tigris-Shatt al Arab	Euphrates River	Sajur River Jallab/Balikh River Khabour River
		Tigris River	Feesh Khabour River Greater Zab River Lesser Zab River Diyala River
		Shatt al Arab River	Karun River[a] Karkheh River
MASHREK	Jordan River		Hasbani River Banias River ------ Yarmouk River
	Orontes River		Afrin River Karasu River
	Nahr el Kabir		-
	Qweik River		-

Source: Compiled by ESCWA-BGR.
(a) The Iranian Karun River does not cross any political boundary, but provides a significant freshwater contribution to the Shatt al Arab and forms an important part of the transboundary river system; it is thus included in the Inventory as part of the shared basin covered in the chapter related to the Shatt al Arab.

Fish farms on the Orontes River, Lebanon, 2008. Source: Andreas Renck.

Table 2. Shared surface water basins and riparian countries

		ESCWA MEMBER COUNTRIES													OTHER		
	Basin/ Country	Bahrain	Egypt	Iraq	Jordan	Kuwait	Lebanon	Oman	Palestine	Qatar	Saudi Arabia	Syria	UAE	Yemen	Iran	Israel	Turkey
MESOPOTAMIA	Euphrates			•	•						•	•					•
	Tigris			•								•			•		•
	Shatt al Arab[a]			•											•		
MASHREK	Jordan				•		•		•			•					
	Orontes						•					•					•
	Nahr el Kabir						•					•					
	Qweik											•					•

• Riparians that contribute surface water only under extreme climatic conditions.

Source: Compiled by ESCWA-BGR.
(a) Iran and Iraq are only riparians to the river, however all riparians to the Euphrates and Tigris Rivers are riparians to the Euphrates-Tigris-Shatt al Arab basin.

River, which forms the border between Iran and Iraq in its lower part, and hosts most or all of the Karkheh and Karun river basins, which provide important freshwater inputs to the Mesopotamian marshlands and the estuary.

The Jordan Basin is shared between Israel, Jordan, Lebanon, Palestine and Syria.

LIST OF CHAPTERS

Table 3 features a complete list of the nine chapters on shared surface water resources in the Inventory. Four chapters cover the four shared basins in the Mashrek region.

The Euphrates-Tigris-Shatt al Arab river system constitutes by far the largest surface water resource in the study area. Given its importance and in order to adequately reflect the specific conditions as well as its complex hydrology, the Inventory dedicates five chapters to this river system.

The Euphrates River Basin and Tigris River Basin each have a different dynamic and set of characteristics, particularly with regard to their riparian countries, tributaries and contribution to discharge, as well as water use patterns and water quality. The shared tributaries of the Euphrates River and the major shared tributaries of the Tigris River

Table 3. List of chapters

	CHAPTER	SHARED RIVER BASIN
MESOPOTAMIA	1	Euphrates River Basin
	2	Shared Tributaries of the Euphrates River
	3	Tigris River Basin
	4	Shared Tributaries of the Tigris River
	5	Shatt al Arab, Karkheh and Karun Rivers
MASHREK	6	Jordan River Basin
	7	Orontes River Basin
	8	Nahr el Kabir Basin
	9	Qweik River Basin

Source: Compiled by ESCWA-BGR.

are covered in more detail in two separate chapters in order to highlight the role of these rivers and draw attention to local water issues and transboundary impacts. Finally, the Shatt al Arab River is discussed together with two additional major tributaries, the Karkheh and the Karun Rivers, which discharge directly into the Mesopotamian Marshes or the Shatt al Arab itself, and are hence neither part of the Euphrates or Tigris River basins. The Karun is not a shared river, but as it discharges into the Shatt al Arab, it is considered part of the Shatt al Arab basin and is therefore included in the Inventory.

Structure & Content of Surface Water Basin Chapters

Each chapter follows a set structure, introducing the basin through a list of facts and figures, a summary of key basin features and an overview map. Information presented in the main text is organized in four main sections:

1. Geography
2. Hydrological Characteristics
3. Water Resources Management
4. Agreements, Cooperation & Outlook

The two chapters on shared tributaries and the chapter on the Shatt al Arab, Karkheh and Karun are organized slightly differently. After a short introduction, these chapters discuss each river/tributary separately with respect to its hydrological characteristics and water resources management. Information on water quality and environmental issues, groundwater linkages and the section on agreements, cooperation and outlook is presented for all rivers/tributaries together.

Before presenting the four sections, it is important to clarify the approach applied to the delineation of surface water basins, which helped refine and standardize basin information.

GEOGRAPHY

The objective of this section is to present the main features of a river as it flows through the riparian countries. This includes information on the basin area according to own calculations and its distribution among the riparian countries as well as a short description of the river course. Furthermore, the section features a climate diagram, a table on the estimated basin population and, in most chapters, a precipitation map of the basin (see 'Introduction to the Inventory', Box 4). The climate diagram displays monthly precipitation and air temperature averages over the period of a year for representative cities in the basin. Data is provided by WorldClim, 2011, Climate Diagrams, 2009 and the Phytosociological Research Center, 2009.

The inclusion of basin population estimates is a distinguishing feature of the Inventory. Most literature cites total country population figures rather than the population living in the basin in each riparian country. The population estimates in the Inventory are based on basin delineations and country borders. They were compiled using the latest available (national) statistics on population within administrative divisions such as provinces or governorates. Whenever an administrative division does not fall entirely in the basin, only the population of larger cities and smaller administrative areas is included.

The population figures presented in the Inventory should therefore be considered as estimates.

In addition, it is important to note that basin population estimates do not necessarily reflect the number of people that make use of the respective water resources. Often water resources are transferred out of the basin as is the case with Israel's National Water Carrier (see Chap. 6) that supplies populations outside the basin boundaries with water for domestic and agricultural purposes.

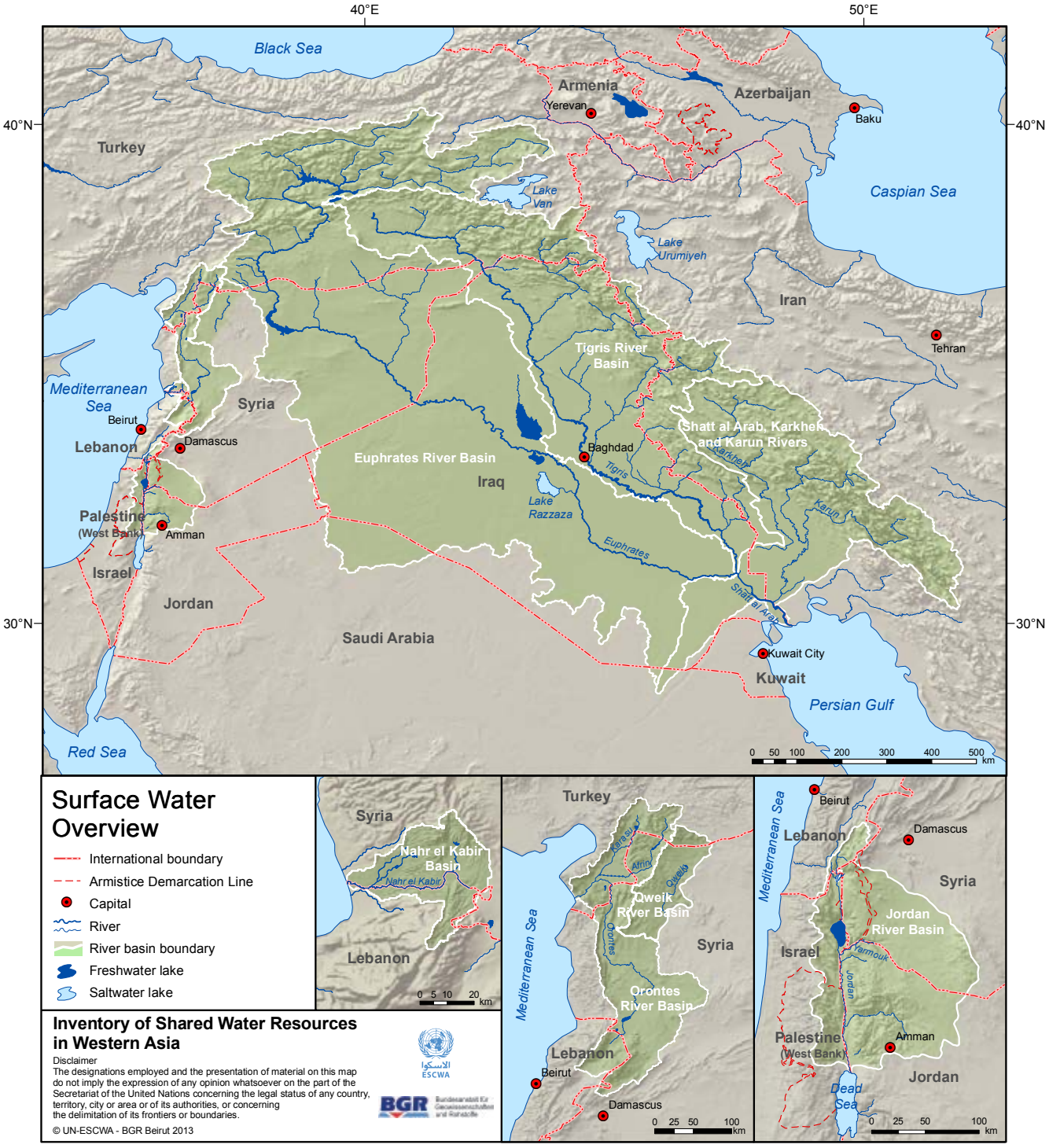
Basin delineation

The following procedure was applied to delineate the surface water basins using the topographical database HydroSHEDS[a]: the regional digital elevation model (DEM) with a grid resolution of 30x30 m was converted into contours representing lines of equal altitude similar to common topographic maps using standard Geographical Information System (GIS) software (ESRI ArcMap 9.3). The contour lines reflect topographical features such as valleys, ridges and plateaus and therefore allowed to manually delineate the surface boundary of a watershed from which theoretically all water drains towards a defined point or outlet. GIS software MapInfo 9 was used for this task.

For this analysis, manual basin delineation was preferred over automatic algorithms due to the relatively coarse spatial resolution of the regional DEM and large floodplain areas with little or no topographical features. In those cases, a manual approach was considered to provide greater consistency. This also explains the discrepancies between basin area estimates of different literature references. Furthermore, topographical and hydrogeological (below ground) watersheds are not necessarily similar. Also, depressions (or sinks) occurring in nature represent endorheic (or inland) basins, which have no visible topographic outlet to the ocean, but may be geologically connected to the basin (e.g. Lake Van in Turkey). Additionally, the delineation of a drainage basin over large, flat areas challenges the definition of drainage directions and may lead to unrealistic boundaries.

(a) See 'Overview: Introduction to the Inventory', Box 4 for more information on HydroSHEDS.

Map 1. **Overview Map of shared surface water basins in Western Asia**



Source: Compiled by ESCWA-BGR.

HYDROLOGICAL CHARACTERISTICS

The section on hydrology contains more complex scientific information, targeting a specialized audience of academics and technical experts. Therefore it is technical in language and analytical in the sense that it attempts to give a hydrological description of the respective water resources. The following section briefly explains some of the common methods and concepts applied in hydrology. Readers are referred to textbooks and literature for more in-depth information.

The characteristics of the basins were analysed and presented in three sub-sections according to data availability:

1. Annual discharge variability and long-term trends
2. Flow regime
3. Groundwater linkages

Generally, all analysis is geared towards facilitating comparison between rivers and basins. In larger and/or more complex basins and wherever discharge data was available, a

comparison between time periods and data from monitoring stations along the river's course was included.

The hydrological data is mainly drawn from public databases that provide monthly and/or yearly time series of discharge data (e.g. Global Runoff Data Centre). In addition, ESCWA member countries provided discharge data through the Inventory's Country Consultation process (see 'Introduction to the Inventory' for further information).

The section on Hydrological Characteristics outlines the riparian country contribution to the annual discharge of the river using data from the literature. As measured water balance data is not available in all cases and the literature often presents widely varying data, riparian contributions are sometimes expressed in ranges.

Annual discharge variability

The annual flow volume dynamics is summarized in a table, which shows the mean, maximum, minimum and the coefficient of variation (CV). The CV is a statistical measure to describe the variability inherent in a time series with respect to the mean and standard deviation. This can be applied to any time series, but here it is used to express the variability of annual discharge data. The annual discharge variability figures present both the discharge and the specific discharge, which allows for a comparison of the water yield across different river basins regardless of their size. The specific discharge is expressed as a unit volume per time and area, while discharge is expressed as a unit volume per time. In addition, a Mann-Kendall trend and student T-test were performed on the annual discharge series to assess whether a statistically significant long-term trend could be observed. The trend line is only included when the trend is statistically significant; otherwise no trend line is displayed. Furthermore, the discharge anomaly is shown as a deviation from the long-term mean to assess periods of water surplus or deficit, reflecting wet or dry conditions.

Flow regime

In the following section on stream-flow regimes, the mean monthly discharge is illustrated over the available period of record. This allows to distinguish periods of low- and high-flow and seasonality. Flow regimes also allow for an interpretation of some of the dominant hydrological processes generating runoff, for example when snow-melt causes a period of high flow. Different rivers and their basins can be compared if their flow regimes are normalized using a discharge coefficient, for example over the mean annual discharge. In the case of unregulated or natural river systems, the term natural flow regime is frequently used.

Groundwater linkages

The interaction between surface water and groundwater can occur both ways and may vary over the course of the river or with the seasons. Groundwater can feed a river through discharge at springs or discharge through the riverbed (gaining conditions) supporting the base flow of the river. Alternatively, a river or lake can recharge the groundwater through leakage in the riverbed (loosing conditions). Especially in cases where the connectivity is high, the separation between the two is not straightforward, creating a risk of counting and allocating the same water twice.

Groundwater linkages addressed in the Inventory are based on available information and on the relative importance and size of the respective resource. Wherever this information is available, the surface water chapter elaborates on connectivity to groundwater, including a brief description of the relevant aquifer system and formation(s) and a list of important springs in the area including discharge data. Groundwater chapters also address the issue of discharge to surface water wherever applicable and when information is available.

WATER RESOURCES MANAGEMENT

Information on water development and use is presented for each riparian country and tackles two main issues: water infrastructure projects and irrigated agriculture. Details of water use by other sectors in the basin are also mentioned whenever available.

Information for this section was collected from a wide range of sources. One set of references are national and official sources such as data provided during the Country Consultation process, content from national yearbooks and statistical reports, water resources and irrigation master plans, publications from national research centres, etc. Data was also compiled from reports of international organizations or research centres, as well as scientific articles published in peer-reviewed journals.

As irrigated agriculture infrastructure development and river flow characteristics are strongly interlinked, this section systematically analyses the connection between water regulation projects, irrigation schemes, changes

in hydrological characteristics and water use. Wherever possible, trends are displayed or estimated. The water quality and environmental issues sub-section further examines the link between infrastructural developments and environmental conditions in the basin.

Water infrastructure

The first part of the Water Resources Management section provides information on water regulation structures in the basin, such as dams, storage reservoirs, barrages, channels and diversion structures.[7] Each chapter includes an overview table of dams, which lists the completed and planned structures of each country, with basic information such as completion year, capacity and purpose[8] as well as some relevant background information. In heavily developed basins, generally only the main dams with a storage capacity of 5 MCM or more are listed.

In addition, information boxes focus on larger or more controversial infrastructure projects which may have a social, political or environmental impact in the region, such as the Southeastern Anatolia Project (See Chap. 1, Box 2) or the Mesopotamian Marshes (See Chap. 3, Box 2).

Irrigated agriculture

Agriculture is the main water consumer in all the surface water basins featured in the Inventory and thus one of the most important factors to be taken into consideration in water resources planning and management. This is why the Water Resources Management section largely focuses on this sector, providing information on established and projected irrigated areas in the basin for each riparian country. In cases where no data is available on irrigated areas in the basin, existing irrigated area is estimated using agricultural data from the administrative division(s). Details of annual agricultural water withdrawal in the basin are also included, specifying the share of groundwater and surface water wherever possible.

This sub-section also deals with existing and planned irrigation schemes in the basin, highlighting main characteristics, progress made, and impacts on the basin in terms of additional irrigated surface area, irrigation return flows, hydrological characteristics, etc. Based on the above, total projected irrigated area in the basin is estimated from data on established and planned irrigated surface for each riparian country.

Agriculture near Raqqah, Syria, 2009. Source: Adel Samara.

In addition to agriculture, data on annual water withdrawal for other sectors is also included when available, i.e. for domestic, municipal and industrial use.

Water quality & environmental issues

The aim of the sub-section is to provide an overview of the basin's environmental conditions, with a focus on river water quality. Other notable environmental threats and issues of particular concern within the basin are also mentioned where relevant. The following describes the methodology used for the assessment of river water quality and provides definitions for related terms commonly used in the basin chapters.

For each basin chapter, water quality information was gathered from extensive research in the available literature such as scientific publications and reports, as well as data provided by member countries through the Country Consultation process. Generally, the core of the compiled information comprises results of water quality monitoring, including analysis of different water quality parameters from river samples.

Relevant data is presented in tables, graphs or figures and is then used to analyse whether the water is suitable for designated uses and meets international standards. The analysis mainly evaluates the suitability of water for agricultural use, which is generally the major consumer of water in the region, as well as its environmental status with respect to the aquatic ecosystem. For these purposes, the main water quality parameters taken into consideration are: salinity, nutrient concentrations, dissolved oxygen and oxygen demand levels. Other selected parameters such as bacteriological indicators and heavy metal concentrations are also mentioned when available.

A substantial part of the section is dedicated to identifying the causes of observed environmental conditions by systematically linking the presence of pollution indicators to potential sources in the basin, whether natural or anthropogenic. In addition, whenever long-term information was available, the data was used to determine trends over time and thus relate variations in water quality to other physical factors in the basin, such as changes in river flow, infrastructure development, etc.

Table 4. **Water quality parameters used in the Inventory**

INDICATOR/PARAMETER	DESCRIPTION	GUIDELINE
Salinity indicators		
Total Dissolved Solids (TDS) in mg/L or ppm	The total concentration of soluble salts or ions in a given volume of water.	The guideline[a] set by FAO, 1994 limits salinity at <700 µS/cm (as EC) or <450 mg/L (as TDS) for agricultural use. This level indicates that a full yield potential should be obtainable for nearly all crops (in particular salt-sensitive crops). Water with salinities higher than 3,000 µS/cm (or 2,000 mg/L) would have severe restrictions on use for irrigation.
Electrical Conductivity (EC)[b] in µS/cm		
Chloride (Cl^-) in mg/L	One of the major constituents of saltwater. It originates from natural minerals, saltwater intrusion into estuaries, irrigation return flows, and industrial pollution.[c]	The guideline for irrigation differs according to crop tolerance (range: 106-109 mg/L).[d] The guideline for drinking water (<250 mg/L) is only taste-based and no health-based guideline is proposed.[e]
Nutrients		
Total Nitrogen (TN) in mg/L	The sum of total organic and reduced nitrogen, ammonia and nitrate-nitrite.	An acceptable range in water bodies is 2-6 mg/L, while higher levels cause eutrophic conditions.[f]
Ammonia (NH_3 or NH_4^+) in mg/L	High concentrations of ammonia could indicate organic pollution from domestic sewage, industrial waste and fertilizer run-off. This results in toxicity to aquatic life at certain pH levels.[g]	There is no clearly defined guideline, but total ammonia concentrations measured in surface waters are typically less than 0.2 mg/L as nitrogen.[g]
Nitrate (NO_3^-) in mg/L	Essential nutrient for aquatic plants, but high concentrations tend to stimulate algal growth and stimulate the onset of eutrophication.	Natural nitrate-nitrogen (NO_3-N) concentrations are typically less than 0.1 mg/L, but may be enhanced by municipal and industrial wastewaters, leachates from waste disposal, animal wastes, sanitary landfills and fertilizers. Concentrations in excess of 0.2 mg/L create possible eutrophic conditions and human activities can increase nitrate concentrations to 1-5 mg/L.[g]

Nitrite (NO_2^-) in mg/L	When present in elevated concentrations, it is highly toxic to vertebrates including fish.[h] High concentrations generally indicate the presence of industrial effluents and are associated with unsatisfactory microbiological water quality.[g]	Nitrite-nitrogen (NO_2-N) levels are usually in the order of 0.001 mg/L in freshwaters, and rarely higher than 1 mg/L.
Total Phosphorus (TP) in mg/L	Phosphorus is a nutrient required by all organisms for the basic processes of life and is naturally found in rocks, soils and organic material. It is rarely found in high levels in freshwaters as it is actively taken up by plants. However, domestic wastewater, industrial effluents and fertilizer runoff contribute to elevated levels. Phosphate itself does not have notable adverse human health effects but high concentrations are largely responsible for eutrophic conditions as it is generally the limiting nutrient for algal growth.[i]	In most surface water that is not contaminated by algal blooms, levels range between 0.01 and 0.03 mg/L. When levels exceed 0.075 mg/L the river is considered eutrophic.[j]
Phosphate (PO_4^{3-}) in mg/L		The maximum acceptable phosphate-phosphorus (PO_4-P) level to avoid accelerated eutrophication is 0.1 mg/L.[k]
Other parameters		
Biochemical Oxygen Demand (BOD)[l] in mg/L	An indicator of the amount of biochemically degradable organic matter present in a water sample, originating from natural sources as well as anthropogenic sources such as domestic sewage, fertilizer runoff, etc.	The acceptable BOD limit for fisheries and aquatic life is set at 3-6 mg/L and usually ranges between 20 and 100 mg/L in treated sewage waters, depending on the treatment type.[g]
Dissolved Oxygen (DO) in mg/L	Concentration of oxygen in a given volume of water. It is a measure of the degree of pollution by organic matter, the destruction of organic substances and the level of self-purification of the water. Waste discharges high in organic matter and nutrients can cause decreases in DO concentrations as a result of the increased microbial activity occurring during the degradation of the organic matter. Very low DO levels threaten aquatic life.[m]	Concentrations below 5 mg/L may adversely affect the functioning and survival of biological communities and levels below 2 mg/L lead to the death of most fish.[n]
Coliform bacteria[o] in cfu/100 ml	Sanitary indicators of water and food quality. High levels in a water sample indicate either an inefficient water treatment or the presence of other disease-causing organisms, including pathogenic bacteria, viruses or parasites.[p]	The guidelines for drinking, irrigation and bathing waters are respectively 0 cfu/100ml, 1,000 cfu/100ml and 10,000 cfu/100 ml.[q]
Heavy metals	Can originate from natural or anthropogenic sources and some, when present in trace concentrations, are important for the physiological functions of living organisms. When discharged into natural waters in increased concentrations (in sewage, industrial effluents or from mining operations) they can have severe toxicological effects on humans and on the aquatic ecosystem.[g]	International guidelines for specific heavy metals are mentioned in the chapters where relevant.

Source: Compiled by ESCWA-BGR.
(a) Guidelines differ between countries.
(b) A high EC means a high salt concentration (more ions in solution conduct more current). Havlin et al., 2004; FAO, 1999.
(c) Rice University, 2006; FoEME, 2010.
(d) FAO, 1994.
(e) WHO, 2003.
(f) US-EPA, 2011b; NCSU, 2006.
(g) Chapman, 1996.
(h) Eddy and Williams, 1987.
(i) Chapman, 1996; NCSU, 2006.
(j) Varol et al., 2011; NCSU, 2006.
(k) Pütz, 2009; Oram, 2009.
(l) Measure of the amount of oxygen used by microorganisms (e.g. aerobic bacteria) in the oxidation of organic matter present in a given water sample at certain temperature over a specific time period.
(m) Chapman, 1996; US-EPA, 2011a.
(n) Chapman, 1996; Varol et al., 2011.
(o) Colony forming units (cfu) per 100 ml of water.
(p) Faecal coliform bacteria appear in great quantities in the intestines and faeces of people and animals, and their presence in water samples often indicates recent faecal contamination. Washington State Department Of Health, 2011.
(q) Woerden and Berkel, 2004 in World Bank, 2006.

Water salinity is a prominent water quality indicator throughout the chapters (Table 4). Crop tolerance to salinity depends on climate, soil conditions, cultural practices, etc. National guidelines in basin countries are often less strict than international guidelines.[9] The region is prone to water and soil salinization due to several factors such as seawater intrusion into coastal aquifers and the upward flow of brackish and saline water supplies from lower aquifers. Accordingly, agriculture in these areas is mostly restricted to highly salt-tolerant crops such as date palms, which allows for the application of irrigation guidelines that are less stringent than the international standards.

Irrigation return flows and eutrophication are also frequently referred to in the surface water chapters. Irrigation or drainage return flow represents the part of applied water that is not consumed by plants or evaporation, and that eventually flows into a surface water body or seeps into an aquifer. It usually contains high levels of salts, agricultural chemical residues and nutrients. Eutrophication refers to the enrichment of a body of water with high concentrations of nutrients, typically compounds containing nitrogen, phosphorus or both. It may occur naturally but can be accelerated by human activity in the form of fertilizer runoff and sewage discharge. This can cause excessive growth of algae, whose decomposition depletes the oxygen supply in the water, leading to the death of aquatic organisms and the loss of biodiversity.[10] Table 4 briefly describes specific water quality parameters mentioned in the chapters along with their respective recommended guidelines.

AGREEMENTS, COOPERATION & OUTLOOK

This section focuses on water agreements among riparian countries, interstate cooperation on rivers as well as future developments and key concerns in the basin.

Water treaties and agreements are listed in a table, specifying year, signatories and significance. Only agreements that refer explicitly to the respective rivers are listed. Key water treaties are described in more detail and in chronological order in the text.

The section on cooperation touches on interstate relations in general and then elaborates on institutions and committees responsible for cooperation if applicable. The Inventory does not attempt to assess or analyse the status of water cooperation in any specific or scientific way; the main aim is to present institutions and mechanisms that were established to foster interstate water cooperation.

The Shatt al Arab at Basrah, Iraq, 2003. Source: Christian Briggs.

Notes

1. The terms "transboundary" and "shared" are used interchangeably in the Inventory. See 'Overview: Introduction to the Inventory', Box 3 for more information.
2. United Nations General Assembly, 1997.
3. Wolf et al., 1999. The term river basin is therefore synonymous with the terms watershed and catchment. Perennial streams flow year-round, as opposed to intermittent streams, which have periods of no flow.
4. The 1997 UN Convention on Non-Navigational Uses of International Watercourses defines a watercourse as a system of surface and underground waters constituting by virtue of their physical relationship a unitary whole and flowing into a common terminus. An international watercourse is a watercourse, parts of which are situated in different States.
5. See Wolf et al., 1999. Due to the grouping of complex basins by outlet and first-order river, the number of international basins in the Transboundary Freshwater Dispute Database is lower than in other assessments, which were, for instance, based on management aspects or had a more local focus.
6. See 'Overview: Shared Water Resources in Western Asia' for scope and regional extent.
7. A key difference between a barrage and a dam is that the latter is built to store water in a reservoir which raises the water level significantly. A barrage, on the other hand, diverts water, and is generally built on flat terrain across wide meandering rivers whereby the water level is raised only a few metres.
8. Such as: irrigation, flood management, power generation or water supply; or a combination in the case of multi-purpose dams.
9. For instance, the Jordanian guideline for salt-sensitive crops is set at <1,700 µS/cm and can even exceed 7,500 µS/cm for highly salt-tolerant crops (JVA and GTZ, 2006); while FAO, 1994 considers that a salinity of 6,000 µS/cm is generally the limit for highly salt-tolerant crops.
10. Chapman, 1996.

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Chapter 1

Euphrates River Basin

Euphrates River Basin

The Euphrates at the Syrian-Turkish border, Syria, 2009. Source: Adel Samara.

EXECUTIVE SUMMARY

The Euphrates River is the longest river in Western Asia. The river has three riparian countries, Iraq, Syria and Turkey, and its basin is distributed among five countries with a total estimated population of 23 million.

Most of the Euphrates stream-flow originates from precipitation in the Armenian Highlands; contributions by the remaining riparian countries are generally small. In addition to some intermittent streams, the Sajur, Balikh and Khabour are the main contributors to Euphrates flow in Syria.

Historically, the natural annual flow of the Euphrates at the Syrian-Turkish border was around 30 BCM. However, data records over the last 70 years show a negative trend, indicating a decrease in mean annual flow to about 25 BCM. The regulation of the Euphrates River is an extreme example of how human intervention can impact a river regime. With the construction of large water engineering structures in upstream Turkey and Syria, the Euphrates flow regime has shifted towards less pronounced seasonal variation.

Water use in the Euphrates Basin in Iraq, Syria and Turkey focuses on irrigation, hydropower and drinking water supply, with agriculture consuming the largest share of water (more than 70%).

As a result, water quality has become a serious issue on the Euphrates River: return flows from agricultural drainage cause salinity problems

that are exacerbated along the river course. In addition, dumping of untreated sewage into the Euphrates and its tributaries contributes to other forms of water pollution.

The Euphrates is subject to two bilateral accords: an agreement between Syria and Turkey specifies the minimum average flow at the Syrian-Turkish border; and an agreement between Iraq and Syria determines the allocation of Euphrates water between those two countries. Riparian countries hold conflicting positions on international water law and terminology that have prevented a basin-wide agreement, with the exception of a Protocol for Technical and Economic Cooperation that was signed in 1980.

This resulted in the creation of the Joint Technical Committee, which is no longer functional.

BASIN FACTS

RIPARIAN COUNTRIES	Iraq, Syria, Turkey
BASIN AREA SHARES	Iraq 47%, Jordan 0.03%, Saudi Arabia 2.97%, Syria 22%, Turkey 28%
BASIN AREA	440,000 km^2
RIVER LENGTH	2,786 km
MEAN ANNUAL FLOW VOLUME	Before damming (1930-1973): ~30 BCM After damming (1974-2010): ~25 BCM
MAIN DAMS	>60 (max. storage capacity 144 BCM)
PROJECTED IRRIGATED AREA	~2.3 million ha
BASIN POPULATION	23 million

MAIN AGREEMENTS

SYRIA - TURKEY	1987 – The Protocol on Economic Cooperation is an interim agreement on water quantity which states that an annual 16 BCM (500 m^3/s) is to be released at the Syrian-Turkish border. 2009 – The Turkish-Syrian Strategic Cooperation Council Agreement addresses joint activities in the field of water such as the improvement of water quality, the construction of water pumping stations and joint dams as well as the development of joint water policies.
IRAQ - SYRIA	1990 – The Syrian-Iraqi Water Accord allocates the water of the Euphrates River according to a fixed ratio of 42% to Syria and 58% to Iraq.
IRAQ - TURKEY	2009 – The Memorandum of Understanding (MoU) on Water is one of 48 MoUs signed between the two countries. Both sides agreed to share hydrological and meteorological information and exchange expertise in these areas.

KEY CONCERNS

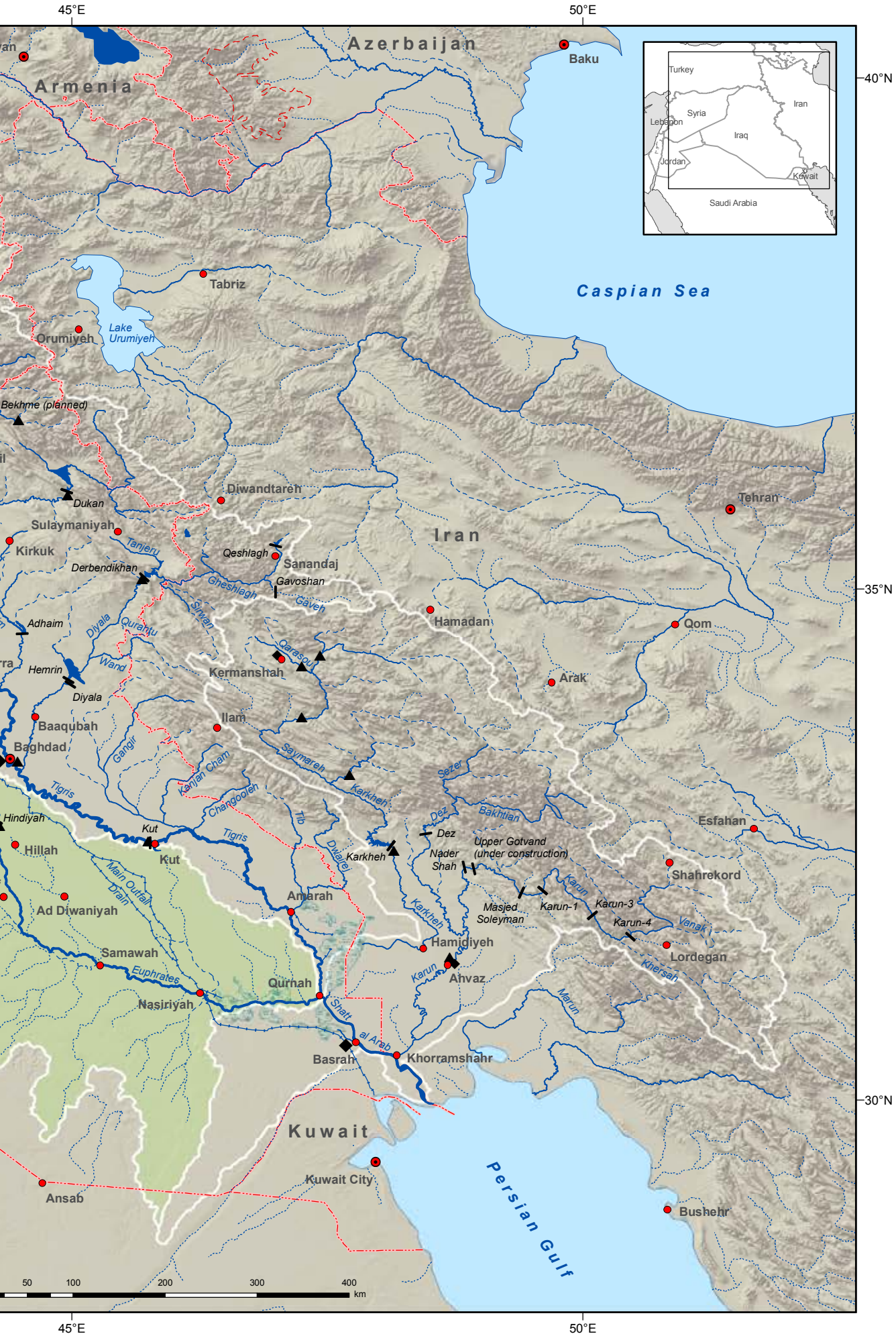
WATER QUANTITY

There is no basin-wide agreement and no common approach or consensus on how to regard the Euphrates and Tigris Rivers (i.e whether the two rivers should be considered part of a single watercourse system or as separate basins). In the past, the three riparians have disagreed on the division of water quantities and embarked upon individual water sector projects. Water use for human purposes (mainly irrigation and hydropower) increased sharply in the second half of the 20th century, resulting in a significant reduction in stream-flows and changes to the natural hydrological regime of the river.
The highly variable climate results in variable water availability. Under the current water management regime, droughts form a major natural hazard that affect water supplies in the basin, as witnessed in recent decades in Syria and Iraq.

WATER QUALITY

Pollution from agricultural and domestic sources seriously affects water quality. In Iraq, the Euphrates suffers from severe salinity that increases along the course of the river.

OVERVIEW MAP


45°E
50°E
40°N
35°N
30°N
Azerbaijan
Armenia
Baku
Caspian Sea
Tabriz
Lake Urumiyeh
Orumiyeh
Bekhme (planned)
Dukan
Diwandtareh
Sulaymaniyah
Kirkuk
Tanjeru
Qeshlagh
Sanandaj
Derbendikhan
Gheshlagh
Gavoshan
Gaveh
Siwan
Iran
Tehran
Hamadan
Qom
Adhaim
Diyala
Qurahtu
Wand
Qarasou
Kermanshah
Arak
Hemrin
Diyala
Ilam
Baaqubah
Baghdad
Gangir
Kanjan Cham
Saymareh
Sezer
Kalkheh
Changoolen
Tib
Dez
Bakhtiari
Esfahan
Tigris
Hindiyah
Kut
Hillah
Tigris
Kut
Dujeiel
Karkheh
Dez
Nader Shah
Upper Gotvand (under construction)
Shahrekord
Main Outfall Drain
Amarah
Karkheh
Karun
Masjed Soleyman
Karun-1
Karun-3
Karun-4
Vanak
Ad Diwaniyah
Hamidiyeh
Lordegan
Samawah
Euphrates
Ahvaz
Karun
Khersan
Qurnah
Marun
Nasiriyah
Shatt al Arab
Basrah
Khorramshahr
Kuwait
Persian Gulf
Kuwait City
Ansab
Bushehr
Turkey
Syria
Iran
Lebanon
Iraq
Jordan
Kuwait
Saudi Arabia
50
100
200
300
400
km

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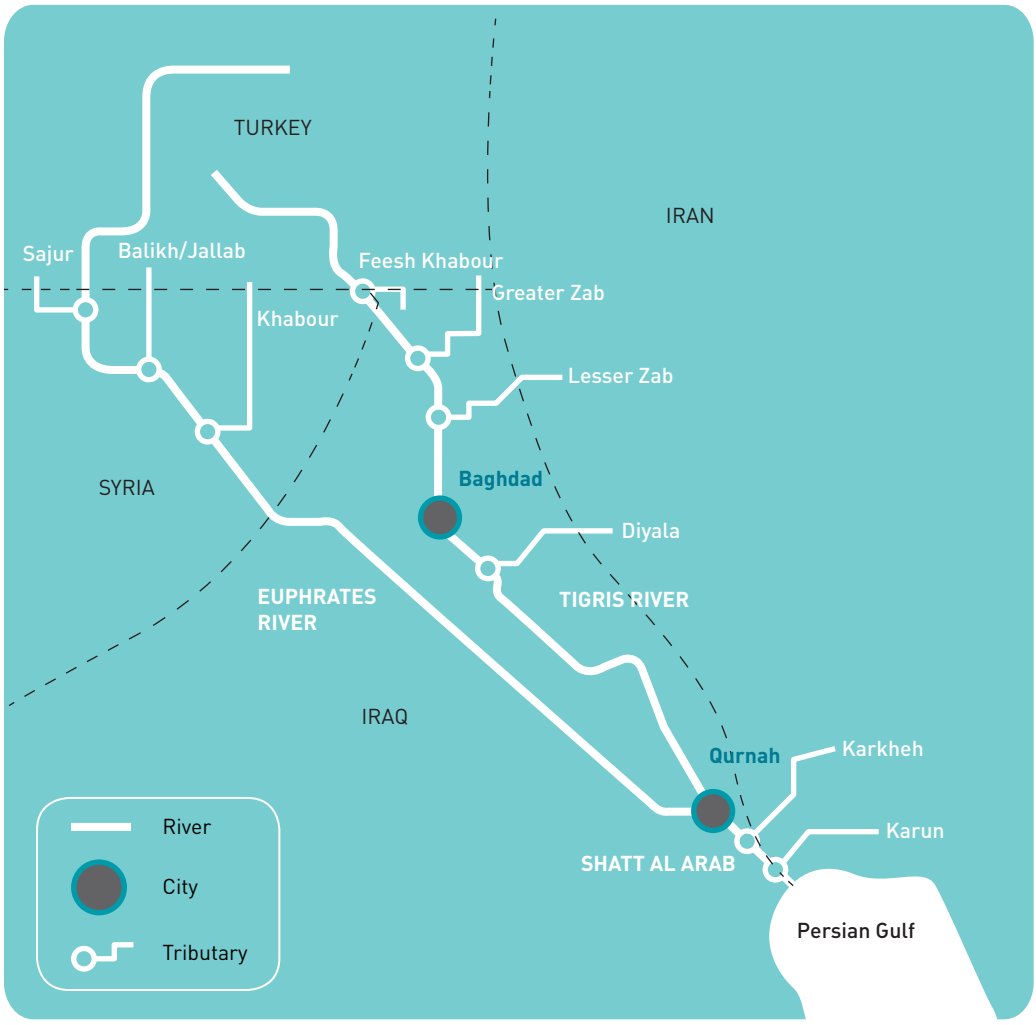
Defining the Euphrates-Tigris-Shatt al Arab Basins

The Euphrates-Tigris-Shatt Al Arab river system constitutes by far the largest surface water resource in the study area. Its combined topographic catchment covers more than 900,000 km^2 from the headwaters in the Taurus-Zagros Mountain Range to the Mesopotamian lowlands and the only outlet to the Persian Gulf, the Shatt Al Arab (Fig. 1). The overall basin is also home to around 54 million people in Iran, Iraq, Syria and Turkey. Given its importance and in order to adequately reflect the specific conditions as well as its complex hydrology, the Inventory dedicates five chapters to this river system.

The Euphrates River Basin (Chap. 1) and Tigris River Basin (Chap. 3) each have a different dynamic and set of characteristics, particularly with regard to their riparian countries, tributaries and contribution to discharge, as well as water use patterns and water quality. The shared tributaries of the Euphrates River (Chap.2) and the major shared tributaries of the Tigris River (Chap. 4) are covered in more detail in two separate chapters in order to highlight the role of these rivers and draw attention to local water issues and transboundary impacts. Chapter 4 also provides information on water use in Iran, which does not share the watercourse of the Tigris River itself but hosts important tributaries within the Tigris Basin. Finally, the Shatt al Arab River is discussed together with two additional major tributaries, the Karkheh and the Karun Rivers, which discharge directly into the Mesopotamian Marshes or the Shatt al Arab itself, and are hence neither part of the Euphrates or Tigris River basins (Chap. 5).

Figure 1. Sketch of the Mesopotamian river system

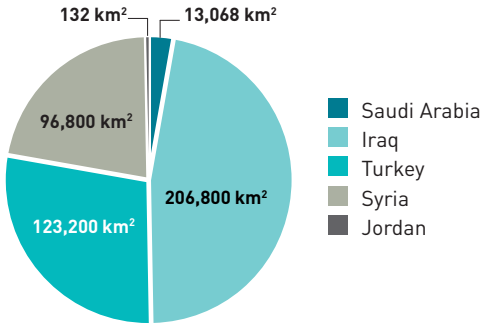


Source: Compiled by ESCWA-BGR.

Geography

The Euphrates River originates in Turkey, flows through Syria and joins the Tigris in Iraq to form the Shatt al Arab, which discharges into the Persian Gulf (see Overview Map and Fig. 1). The river has three riparians, but its basin is distributed among five countries: Iraq, Jordan, Saudi Arabia, Syria and Turkey. The Euphrates Basin covers about 440,000 km^2 of which 47% is located in Iraq; 22% in Syria, and 28% in Turkey (Figure 2).[1] Jordan (0.03%) and Saudi Arabia (2.97%) are considered basin riparians, but they contribute surface water only under very rare and extreme climatic conditions (see 'Overview and Methodology: Surface Water' for further information).

Figure 2. Distribution of the Euphrates Basin area



Source: Compiled by ESCWA-BGR.

RIVER COURSE

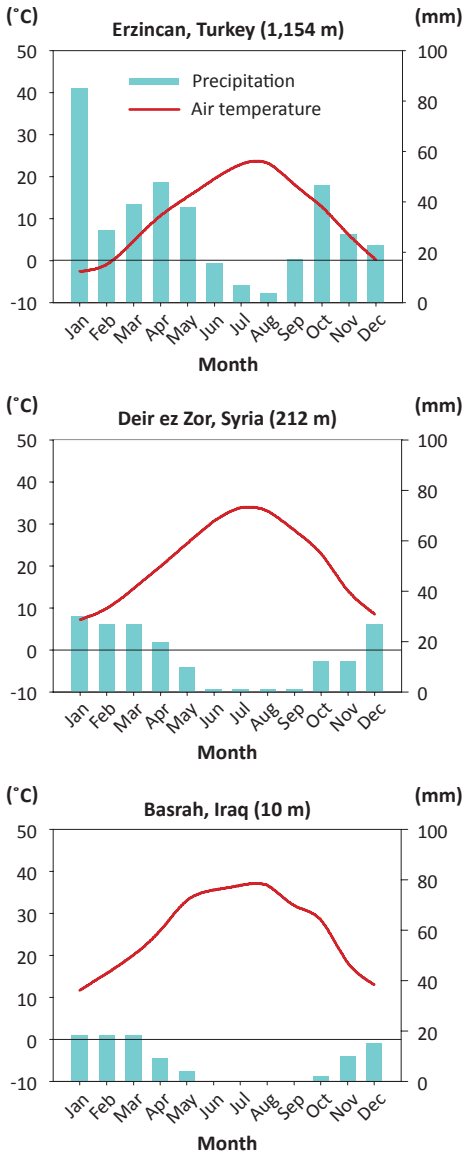
The Euphrates is the longest river in Western Asia with a total length of 2,786 km.[2] It originates in the mountains of eastern Turkey, not far from the city of Erzurum in the Armenian Highlands. Its headwaters, the eastern and western tributaries Karasu[3] and Murat,[4] originate at an altitude of nearly 3,000 m asl and join to form the Euphrates at the city of Keban. The Keban Dam is located 10 km downstream in a narrow gorge. From here the Euphrates flows south, and is fed by small tributaries and wadis before it crosses into Syria at the towns of Karkamis, Turkey, and Jarablus, Syria. The river covers 455 km from the confluence of the Karasu and the Murat to the Syrian-Turkish border.

Three tributaries flow into the Euphrates in Syria. The Sajur, the Balikh and the Khabour Rivers are all fed by tributaries or groundwater from Turkey.[5] These three sub-basins are therefore shared between Syria and Turkey.

South of the Khabour, the Euphrates has no other tributaries in Syria or Iraq. However, a number of dry riverbeds suggest that seasonal tributaries in the Syrian Desert flow into the Euphrates.[6] The river leaves Syria at Al Bukamal and enters Iraq at an elevation of 165 m asl. The Syrian stretch of the Euphrates covers 661 km.

Lake Assad, Syria, 2010. Source: Andreas Renck.

Figure 3. **Climate diagrams for Erzincan in Turkey, Deir ez Zor in Syria, and Basrah in Iraq**



Source: Compiled by ESCWA-BGR based on data provided by WorldClim, 2011; Climate Diagrams, 2009; Phytosociological Research Center, 2009.

Along its course to the Mesopotamian Plains in Iraq, the Euphrates continues in south-easterly direction, crossing desert uplands and narrow wadis until Ramadi. Near Hit, the river enters the alluvial lowlands of Mesopotamia, where it briefly splits into various channels. Further downstream, the river loses water to a number of desert depressions and canals, some natural and others man-made. Near the town of Fallujah, the river course veers to the north-east towards the Tigris, but then turns southward again. Here, parts of the river are diverted into canals, some of which drain into the shallow Lake Hammar, while others discharge into the Tigris. The Tigris joins the Euphrates from the east close to the city of Qurnah to form the Shatt al Arab River, which discharges into the Persian Gulf.

CLIMATE

From its origin in Turkey until its confluence with the Tigris, the Euphrates crosses several climatic zones. Mean annual precipitation in the Euphrates Basin ranges from approximately 1,000 mm in the Turkish headwaters in the north to 150 mm in Syria and just 75 mm in southern Iraq. The climate diagrams (Figure 3) for selected stations (see Overview Map for location) clearly illustrate this shift from a cooler Mediterranean climate to an increasingly hot and dry (arid) climate as the river progresses to the sea.

The Euphrates originates in a mountainous Mediterranean climatic zone, which is characterized by hot, dry summers and cold, wet winters. In the mountainous headwater areas, precipitation predominates in autumn, winter and spring with a mixture of rain- and snowfall in winter.[7]

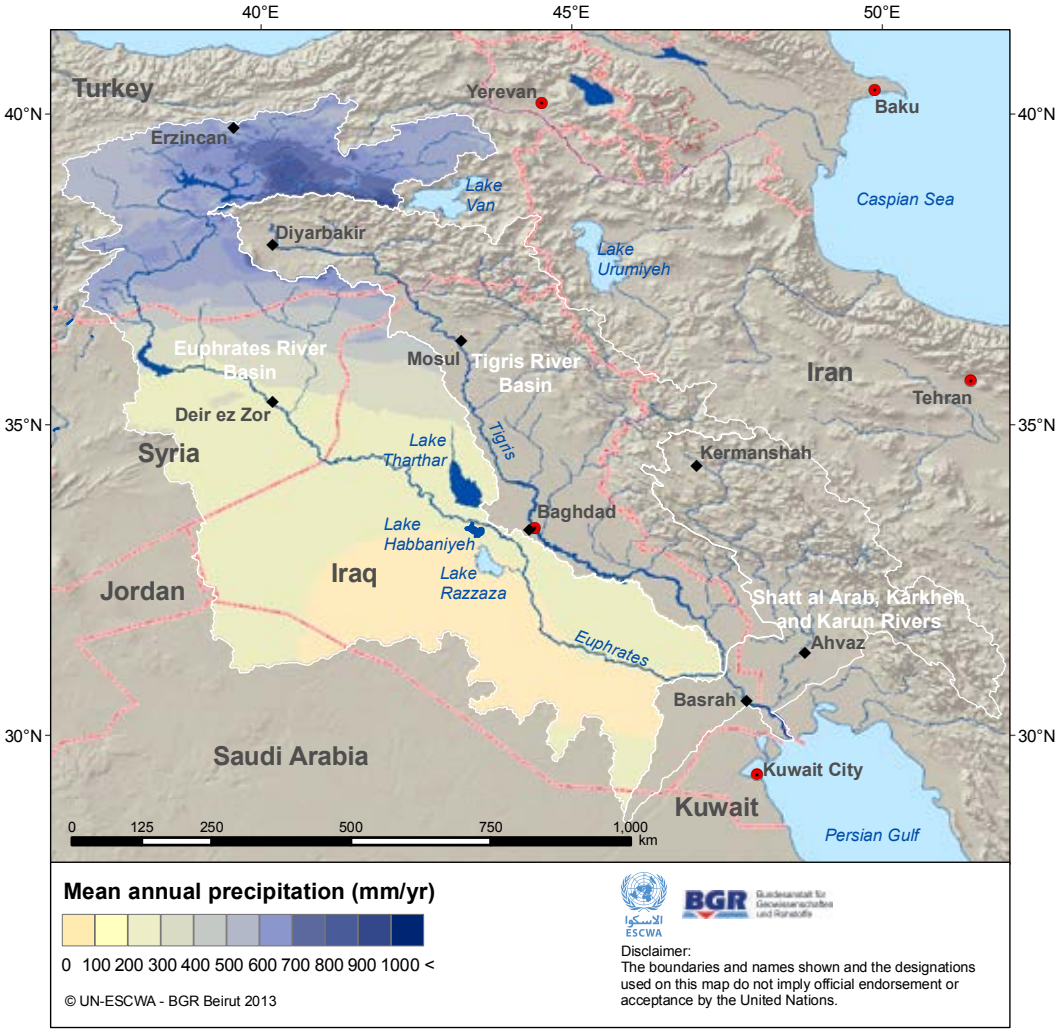
Figure 4 illustrates that mean annual precipitation gradually decreases to the south-west to about 300 mm near the Syrian-Turkish border. The mild influence of the Mediterranean Sea further decreases inland and to the south. Rainfall is sparse in the arid climate of the Iraqi Lowlands (Mesopotamian Plain), with an annual average of 150-200 mm falling mainly in the winter months. Summers are dry and hot with daytime temperatures of up to 50°C.

POPULATION

The Euphrates Basin has an estimated population of about 23 million, of which 44% lives in Iraq, 25% in Syria and 31% in Turkey (Table 1).

The Euphrates at the Syrian-Turkish border, Syria, 2009. Source: Andreas Renck.

Figure 4. **Mean annual precipitation in the Euphrates Basin**



Source: Compiled by ESCWA-BGR based on data provided by WorldClim, 2011.

Table 1. **Estimated basin population**

RIPARIAN COUNTRY	COUNTRY POPULATION (MILLIONS)	ESTIMATED POPULATION IN THE BASIN		SOURCE
		MILLIONS	AS PERCENTAGE OF TOTAL BASIN POPULATION	
Turkey	73.7	7.15	31	Turkstat, 2010.[a]
Syria	20.9	5.69	25	Central Bureau of Statistics in the Syrian Arab Republic, 2005.[b]
Iraq	32	10.2	44	Central Organization for Statistics in Iraq, 2010.[c]
Total		23.04		

Source: Compiled by ESCWA-BGR.
(a) The population estimate for the area of the basin situated in Turkey is based on a 2010 census and includes populations living in the Turkish provinces of Adiyaman, Agri, Bingol, Elazig, Erzincan, Erzurum, Gaziantep, Malatya, Mardin, Mus, Sanliurfa, Sivas and Tunceli.
(b) The population estimate for the area of the basin located in Syria is based on a 2010 assessment and includes populations living in the Syrian governorates of Aleppo, Deir ez Zor, Hama, Hasakah, Homs and Raqqah.
(c) The population estimate for the area of the basin situated in Iraq is based on a 2009 assessment and includes populations living in the Iraqi provinces of Anbar, Babil, Karbala, Najaf, Ninewa, Qadisiyah and Muthanna.

Hydrological Characteristics

Turkey provides about 89% of the total Euphrates flow generated from 28% of the basin area. By contrast, Syria contributes only 11% of total river flow generated from 22% of the drainage area due to comparatively less rainfall.[8] Contributions by the remaining riparians are generally very small.[9]

Most of the Euphrates stream-flow originates from precipitation in the Armenian Highlands, and in particular the Keban Hills (Figure 4).[10] In Syria, the Sajur, Balikh and Khabour Rivers and some intermittent streams contribute water to the Euphrates. Their contributions depend on the intensity and volume of precipitation and, increasingly, on water use and drainage in upstream irrigation areas. In Iraq, there are no major surface water contributions to the Euphrates except for rare runoff events generated by heavy storms.[11]

ANNUAL DISCHARGE VARIABILITY

The discharge of the Euphrates varies annually corresponding to climate variability. The stations at Jarablus in Syria (1938-2010), Hussaybah (1981-2011), Hit (1932-1998) and Hindiyah (1930-1999) in Iraq (see Overview Map for location) have the longest available data records, covering the period from 1930 to 2011. They were therefore used to illustrate the discharge dynamics and trends of the Euphrates (Figure 5). In order to allow for comparison of the flow along the main stream of the Euphrates, common periods have been selected (Table 2) for all stations. The period 1938-1974 was selected because it represents the near-natural flow of the river. Measured flow characteristics changed with the filling of the Keban Dam reservoir in Turkey and Lake Assad in Syria in the winter of 1973-74. This is reflected in the downstream discharge.[12] Hence the period between 1974 and 1998 was selected as it covers the first phase of infrastructure development in the basin.[13] In early 1990, construction on the Atatürk Dam in Turkey began. Hence, the last matching period covers the years between 1990 and 2010.

The mean annual flow for the entire period of record is 26.6 BCM at Jarablus and 27.1 BCM at Hit (Table 2). Maximum flow levels were recorded in 1969 with 40 BCM at Hindiyah, 56.8 BCM at Jarablus, and 63 BCM at Hit. This contrasts with the lowest annual flow of 3.1 BCM at Hindiyah in 1974, 12.7 BCM at Jarablus in 1976, and 9 BCM at Hit in 1990.

Table 2. **Summary of annual flow volume statistics for the Euphrates River (1930-2011)**

STATION (DRAINAGE AREA, km²)	PERIOD	MEAN (BCM)	MINIMUM (BCM)	MAXIMUM (BCM)	CV[a] (-)
Jarablus, Syria (120,000)	1938-2010	26.6	12.7	56.8	0.33
	1938-1973	**30.0**	**15.0**	**56.8**	**0.29**
	1974-1987	24.9	12.7	34.1	0.27
	1988-1998	25.5	14.4	50.1	0.42
	1974-1998	**25.1**	**12.7**	**50.1**	**0.34**
	1990-2010	**22.8**	**14.4**	**32.6**	**0.34**
Hussaybah, Iraq (221,000)	1981-2011	20.0	8.9	47.6	0.44
	1988-1998	22.8	8.9	47.6	0.54
	1999-2010	15.5	9.3	20.7	0.27
	1990-2010	**16.8**	**8.9**	**30.7**	**0.39**
Hit, Iraq (264,000)	1932-1998	27.1	9.0	63.0	0.36
	1938-1973	**30.6**	**15.1**	**63.0**	**0.30**
	1974-1987	23.1	9.3	31.2	0.32
	1988-1998	22.4	9.0	46.6	0.51
	1974-1998	**22.8**	**9.0**	**46.6**	**0.40**
Hindiyah, Iraq (274,100)	1930-1999	17.6	3.1	40.0	0.4
	1938-1973	**19.8**	**6.6**	**40.0**	**0.35**
	1974-1987	15.3	3.1	24.1	0.45
	1988-1998	13.8	7.7	27.9	0.48
	1974-1998	**14.7**	**3.1**	**27.9**	**0.46**

Source: Compiled by ESCWA-BGR based on Ministry of Irrigation in the Syrian Arab Republic in ACSAD and UNEP-ROWA, 2001; USGS, 2012; Ministry of Irrigation in the Syrian Arab Republic, 2012.
(a) Coefficient of Variation. For information on the definition and calculation of the CV see 'Overview & Methodology: Surface Water' chapter.

Negative trend

Figure 5 shows a statistically significant negative trend for the period of record (1937-2010) on the Euphrates at Jarablus indicating a decrease in mean annual discharge. Before 1973, the mean annual flow of the Euphrates at the Syrian-Turkish border (Jarablus) was around 30 BCM, but this figure dropped to 25.1 BCM after 1974 and fell to 22.8 BCM after 1990 (Table 2). This is most likely due to climate variability and more frequent drought periods, and the construction of large dams in Turkey as part of the Southeastern Anatolia Project (GAP).

The construction of a series of dams in Syria and downstream Iraq since the 1960s has further impacted flow volumes due to regulation and increased evaporation losses.[14] Even though a significant long-term trend could only be detected at Jarablus, all stations show lower mean annual flow volumes after 1973, most likely due to stream regulation through water abstractions and storage (Table 2).

Recent data on mean annual flow volumes of the Euphrates in Syria, as well as Euphrates annual inflow rates into Iraq measured at Hussaybah for the years 1990-2010 indicate a decline in flow volume compared to previous decades (Table 2).[15] According to the Iraqi Ministry of Water Resources, the inflow of water at the Iraqi-Syrian border is constantly decreasing. In March 2009, Iraq registered a record low discharge of 250 m^3/s on the Euphrates.[16]

Figure 5b illustrates the mean annual specific discharge time series for the period from 1937 to 2010 at Jarablus, Hussaybah, Hit and Hindiyah. Since all time series are normalized by their respective drainage area, a lower discharge yield can be observed further downstream at Hit compared to the upstream station Jarablus. This is a typical hydrological feature of arid regions where no or few tributary rivers discharge within the area.

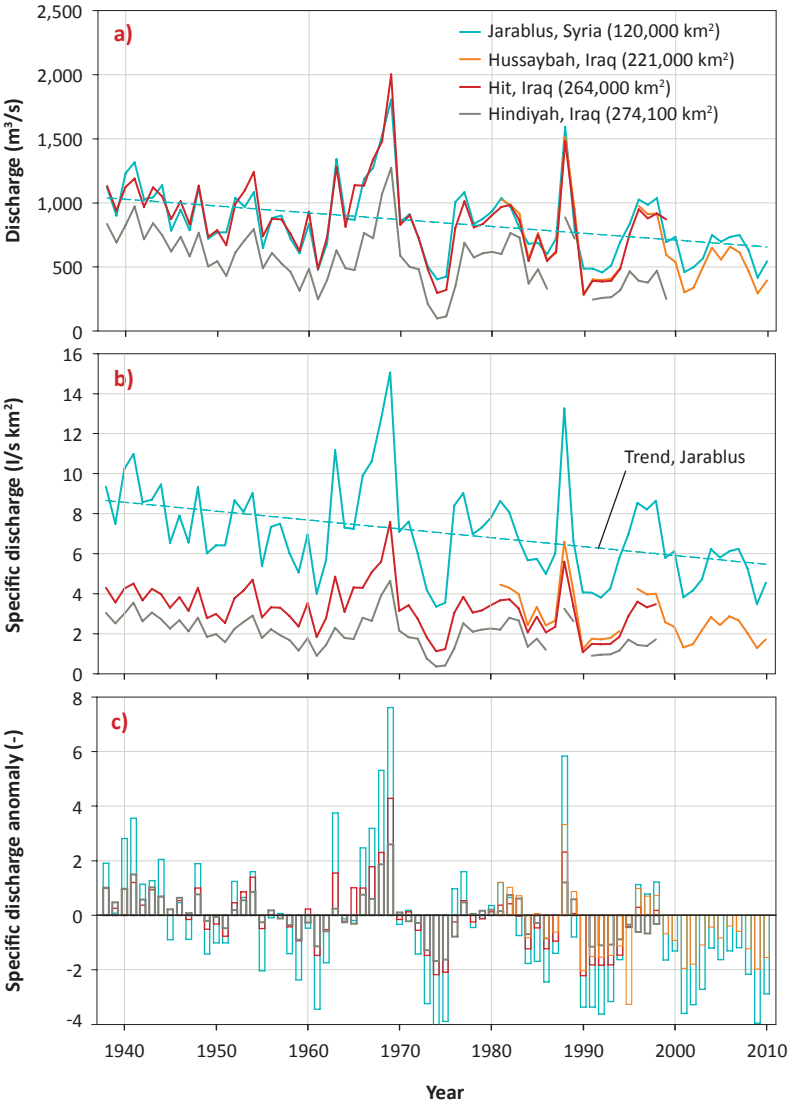
Droughts

Figure 5c shows the mean annual discharge anomaly in terms of water surplus (positive) and deficit (negative) compared to the long-term mean discharge over the period of record from 1937 to 2010. It shows wet and dry periods and reflects the impacts of stream regulation. The period of record exhibits four prolonged drought cycles (1958-1962; 1972-1976; 1983-1995; 1999-2011). The 1983-1995 drought was interrupted by a very wet year in 1989. Since 1999, the Euphrates shows below-average discharge at Jarablus and Hussaybah, possibly reflecting a combination of drier weather conditions and the effects of extensive dam building.

Comparison

For the common period 1938-1973 (Table 2), the comparison of the flow along the main stream of the Euphrates for the stations Jarablus and Hit shows no differences in mean annual flow volume. This period is often referred to as representing the near-natural flow of the river.[17] However, for the same period, differences in mean annual flow volume can be observed between the stations Hit and Hindiyah. This is most likely due to the fact that water is being diverted to a secondary branch that begins at the Ramadi Barrage (Table 3) from where it goes

Figure 5. a) Mean annual discharge, b) specific mean annual discharge and c) discharge anomaly time series of the Euphrates (1937-2010)



Source: Compiled by ESCWA-BGR based on data provided by the Ministry of Irrigation in the Syrian Arab Republic in ACSAD and UNEP-ROWA, 2001; USGS, 2012; Ministry of Irrigation in the Syrian Arab Republic, 2012.

to Lake Habbaniyeh and Lake Razzaza in flood seasons. In addition, river water is used for various purposes.[18]

For the common period 1974-1998, the comparison between the stations shows an obvious reduction in the mean annual flow volume from 25.1 BCM at Jarablus to 22.8 BCM at Hit and 14.7 BCM at Hindiyah. Droughts and the construction of dams account for the diminishing flow volumes along the main stream.

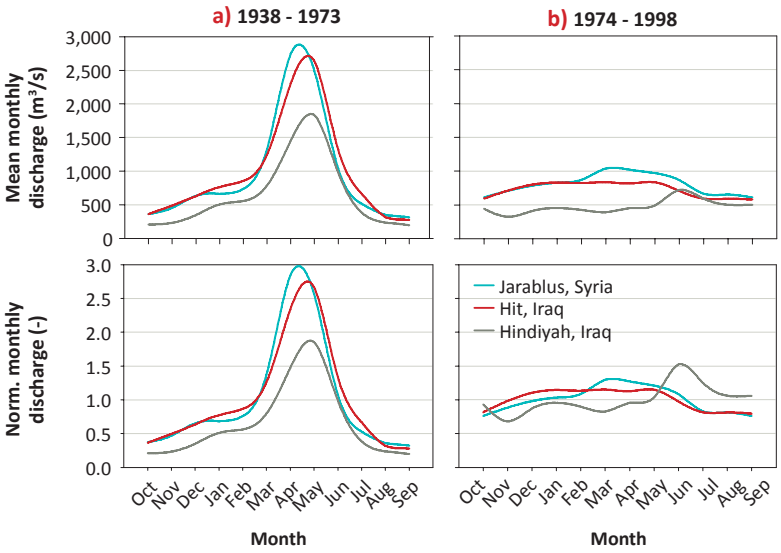
For the period 1990-2010 mean annual flow volume at Hussaybah is lower than at Jarablus, which suggests a water consumption of about 6 BCM between the two stations. The flow is also reduced between Hussaybah and Hindiyah but a complete data record was not available for the most downstream station Hindiyah.

FLOW REGIME

The Euphrates river flow regime before 1973 can be considered near natural as there was limited water regulation in the runoff-generating area in Turkey. This natural flow regime is shown in Figure 6a, with a high-flow season from March to July and a low-flow season from August to February. The increased discharge during the high-flow period was generated by snow-melt from the Highlands. Such a snow-melt regime was typical for the period of record from 1937 until the 1970s.

The construction and operation of the Keban Dam in Turkey in 1974 and the Tabqa Dam in Syria in 1975 led to a shift in the Euphrates flow regime. Figure 6b shows that increased regulation of the naturally snow-melt-driven flow regime of the Euphrates resulted in less pronounced seasonal flow variation (1973 to 1998). The water discharged during the high-flow period from March to July was mainly stored to fill the reservoirs and released later

Figure 6. **Mean monthly flow regime of the Euphrates River at different gauging stations for different time periods**



Source: Compiled by ESCWA-BGR based on data provided by the Ministry of Irrigation in the Syrian Arab Republic in ACSAD and UNEP-ROWA, 2001; USGS, 2012; Ministry of Irrigation in the Syrian Arab Republic, 2012.

The Tabqa Dam, Syria, 1992. Source: Ed Kashi/VII.

BOX 1

Regulating Seasonal Variability

The seasonal variability of the Euphrates is not suitable to meet crop needs. Water for winter crops is most needed during the low-flow season in September and October. The flood season with frequent inundations in spring puts the harvest at risk. Engineering works have therefore prioritized Euphrates stream-flow regulation in order to provide irrigation water in the low-flow season.

in the year for irrigation purposes (Box 1), thus artificially increasing the discharge during the low-flow season. The river was further regulated with the operation of the Atatürk Dam in Turkey in 1992 and the development of related irrigation projects.

GROUNDWATER

Along its course in Syria, the Euphrates River receives groundwater from aquifers in the western part of the river catchment. These include Eocene chalky limestones east of Aleppo and a multi-aquifer system of Cretaceous to Neogene Aquifers in the eastern steppe in Syria. The discharge quantities are, however, insignificant in comparison to the total river flow.

In the eastern part of the catchment in Syria, the Euphrates River receives important inflows from spring discharges, which feed the tributaries Balikh and Khabour. Syria and Turkey share the Jezira Tertiary Limestone Aquifer System, a productive limestone and dolomite aquifer of Middle Eocene to Oligocene age, which lies in the area between these tributaries on the northern edge of the Syrian Jezira (see Chap. 24). The aquifer system's annual recharge is estimated at 1,600 MCM; the recharge areas are located mainly on Turkish territory, while discharge occurs via two major springs in Syria.[19]

Small-scale irrigation from river water in Iraq may produce minor quantities of recharge from irrigation return flow in shallow aquifers. In the west and south-west of the Iraqi Jezira, groundwater movement in the Miocene Fatha Formation is directed toward the Euphrates. In most parts of the Iraqi Jezira and the adjoining south-eastern Jezira in Syria, groundwater moves to internal drainage discharge zones such as Wadi Tharthar, Lake Tharthar and the Tawila Salt Flat.[20]

Groundwater flow in Paleogene to Neogene carbonate aquifers in the western and southern deserts of Iraq (Umm er Radhuma-Dammam [North]) is directed toward the Euphrates river plain. The groundwater from these aquifers discharges mainly in mudflats, sabkhas and through a series of springs that run parallel to the river course over a length of about 450 km[21] on the edge of the Mesopotamian Plain.[22] The main recharge areas of the aquifers are located in Iraq; minor subsurface inflows occur from outcrop areas of the Paleogene aquifers in Saudi Arabia.

Alluvial deposits in the marshlands in the lower Mesopotamian Plain in Iraq create a shallow aquifer. Recharge mainly occurs during winter and through infiltration of Euphrates and Tigris river water. Generally, water flows into the groundwater during high flows when the water level of the rivers exceeds the groundwater table. Conversely, groundwater is discharged into the river during low-flow periods in summer. In the past, several springs discharged south of the Euphrates River and along the base of the western plateau in the marshlands. Groundwater from these springs most likely emanated from the Neogene Aquifer System (North-West) (see Chap. 25).

Water Resources Management

Water management in the Euphrates Basin dates back 6,000 years when the Mesopotamian landscape was transformed by the introduction of irrigation networks to improve agricultural yield. More recently in the 20th century, the basin witnessed the implementation of extensive water resources development schemes, with the construction of dams, reservoirs and hydro-electric power plants (Table 3). Today, water management in Iraq, Syria and Turkey focuses on hydropower, irrigation and drinking water supply. More than 70% of water in the Euphrates Basin is used for agricultural production.[23] The Southeastern Anatolia Project (GAP)[24] in the upper Euphrates Basin in Turkey has drastically impacted the natural flow regime of the river in recent decades (Box 2). The maximum storage capacity of the major dams and reservoirs (>144 BCM) on the Euphrates exceeds the natural annual flow volume of the river (30 BCM) by four to five times.

DEVELOPMENT & USE: TURKEY

Since the 1970s, the upstream riparian Turkey has become a strategic protagonist in water resources management in the Euphrates Basin. Its water infrastructure projects and programmes, particularly GAP, have greatly impacted water resources throughout the basin, modifying the natural flow regime of the Euphrates and affecting other riparians' water use patterns.

The first large project on the Euphrates in Turkey was the Keban Dam, which was built in the 1960s and completed in 1974. It is the farthest upstream of a series of Turkish dams on the Euphrates, serving the dual purpose of hydropower generation and flow regulation.[25] The Karakaya Dam, which was completed in 1987, was the first dam built as part of GAP. It was followed five years later by the project's centrepiece, the Atatürk Dam.

An aerial view of farmlands near the Atatürk Dam, Turkey, 1992. Source: Ed Kashi/VII.

Since then, the State Hydraulics Works (DSI) in Turkey constructed two more dams on the Euphrates River: the Birecik and Karakamis. Ultimately, a total of 14 dams and 11 hydroelectric power plants are to be built on the Euphrates and its tributaries, making the upper Euphrates the largest component of GAP.[26]

Besides hydropower generation, Turkey plans to expand irrigated agriculture as part of its long-term development strategy, particularly in south-eastern Anatolia. Ultimately, GAP aims to use water from both the Euphrates and Tigris to irrigate a total area of about 1.8 million ha, of which 270,000 ha is currently operational. Most of this land (230,000 ha) lies in the Euphrates Basin.[27] The Atatürk Dam provides water to two major irrigation projects through the Urfa tunnels. These projects have an impact on the Balikh catchment (see Chap. 2).[28]

Table 3. **Main dams and barrages on the Euphrates River in chronological order of construction**

COUNTRY	NAME	COMPLETION YEAR	CAPACITY (MCM)	PURPOSE[a]	BACKGROUND INFORMATION
Iraq	Hindiyah	1914	—	I, HP	This regulator was the first modern water diversion structure in the Euphrates Basin and was built when Iraq was still part of the Ottoman Empire. In the 1980s the old structure was replaced by a new barrage. This project also included the production of hydroelectricity.
Iraq	Ramadi	1948	3,300 (Lake Habbaniyeh)	FC, I	The Ramadi Barrage regulates the Euphrates flow regime by discharging excess flood water into Lake Habbaniyeh through the Warrar Regulator. After temporary storage in the lake, the water is either released back into the Euphrates or diverted to Lake Razzaza (2,000 km^2) through the Mujarra Regulator which was built in 1957.
Turkey	Keban	1974	31,000	HP, FC	Reservoir area: 675 km^2
Syria	Tabqa	1975	14,000	HP, I	Also called the Euphrates Dam or the Revolution Dam, it is considered the largest earth-fill dam in the world. The dam was built with the aim of producing hydropower and providing irrigation water.
Iraq	Fallujah	1985	..	FD, I	The Fallujah Dam was constructed next to the riverbed. The Euphrates River was rerouted to the dam after construction was completed.
Iraq	Haditha (Al Qadisiyah)	1987	8,280	FC, I, HP	The Haditha Dam was jointly constructed with the former Soviet Union. The nearly 10 km-long earth-fill dam created Lake Qadisiyah, which covers an area of 500 km^2.
Syria	Baath	1987	90	HP, FC	The Baath Dam generates electricity and regulates water flow from the Tabqa Dam.
Turkey	Karakaya	1987	9,580	HP	The dam is part of GAP and has a reservoir surface area of about 268 km^2.
Turkey	Atatürk (originally Karababa)	1992	48,700	HP, I	The Atatürk Dam is the centrepiece of GAP and one of the largest dams in the world. It is located about 80 km from the Syrian border. The dam's reservoir, Lake Atatürk, is the third-largest lake in Turkey. Turkey began filling the reservoir in 1990, and guaranteed a 500 m^3/s flow from the dam. With a maximum capacity of 48,700 MCM, the dam's reservoir is large enough to store the entire annual discharge of the Euphrates.
Syria	Tishreen	1999	1,900	HP	-
Turkey	Karkamis	1999	160	HP, FC	The dam is part of GAP and is located 4.5 km from the Syrian-Turkish border.
Turkey	Birecik	2000	1,220	HP, I	The dam's hydroelectric power plant has an annual average capacity of 2,500 GWh.

Source: Compiled by ESCWA-BGR based on Jones et al., 2008, p. 62; FAO, 2009; Beaumont, 1998; General Directorate of State Hydraulic Works in Turkey, 2009; Altinbilek, 2004, p. 21; Kaya, 1998; ACSAD and UNEP-ROWA, 2001; Ministry of Environment in Iraq et al., 2006; Ministry of Irrigation in the Syrian Arab Republic, 2012; Ministry of Water Resources in Iraq, 2012.
(a) Irrigation (I), Hydropower (HP), Flood Control (FC) and Flow Diversion (FD).

BOX 2

The Southeastern Anatolia Project

Launched in 1977, the Southeastern Anatolia Project (GAP) is an ambitious Turkish project to harness the water of the Tigris and the Euphrates for energy and agricultural production, and provide an economic stimulus to south-eastern Anatolia, the majority Kurdish region in Turkey. The project covers an area of 74,000 km^2 between the lower reaches of the Turkish part of the Euphrates, the tributaries of the Euphrates and the Tigris River. The area is home to approximately 7 million people.[a]
Once completed, the project will comprise 22 dams and 19 hydroelectric power plants on the Euphrates and Tigris Rivers. In addition, numerous smaller dams and canal systems will channel reservoir water to newly irrigated land.[b]

The overall objective of the mega-development project is to produce 27,367 GWh of hydroelectric energy annually and to double irrigable farmland in Turkey to 1.8 million ha.[c] The project is currently still in its first phase, in which 1 million ha of irrigable land is to be created. To date, 27% of the project's first phase has been made operational (270,000 ha), 10% (100,000 ha) is under construction and 63% (630,000 ha) is in planning.[d]

The project originally started as a 'hydraulic mission'-type scheme.[e] In 1989, it was transformed into an integrated, multisectoral development programme that focuses on economic prosperity and sociocultural improvement in south-eastern Anatolia, with greater emphasis on agricultural development and energy production.[f] The project forms an integral part of the Turkish national development strategy and aims to create four million new jobs in impoverished south-eastern Anatolia.

Project completion was scheduled for 2010, but has been delayed until 2047 due to financial constraints.[g] Today almost half of GAP has been implemented with an estimated USD 21 billion of investment, which means a further USD 15 billion is needed to complete the project.[h]

The downstream riparians Iraq and Syria have objections to the project as they fear a decrease in water quantity and quality in the basin.[i] International experts share their concerns and expect GAP, once completed, to consume more than 50% of the Euphrates and about 14% of the Tigris.[j] The natural flow regime of the Euphrates has changed entirely over the last 40 years, mostly due to human interventions, as exemplified by the water development programmes along the upper Euphrates. However, not all changes are negative as regulation of the Euphrates can protect downstream countries from destructive floods and droughts, provided that reservoir water is released.

In addition to sparking regional tensions among riparians, GAP has also caused national discord and protests from NGOs and activists worldwide due to its potential harm to the region's natural environment[k] and social fabric; the flooding of archaeological sites; and the involuntary displacement of local populations.[l] Projects and programmes implemented as part of GAP have led to increased salinity of irrigated soils and changes to the ecosystem and river flow regimes. The current construction of the Ilisu Dam and Hydraulic Power Plant on the Tigris River has elicited strong worldwide condemnation (see Chap. 3, Box 1).

(a) This represents almost 10% of the total population of Turkey.
(b) For more information and discussion of GAP, see Kolars and Mitchell, 1991; Kibaroglu, 2002a; Unver, 1997.
(c) Ministry of Environment and Forestry in Turkey, 2009, p. 60; Unver, 1997, p. 466. The 1.8 million ha correspond to nearly 10% of the total surface area of Turkey.
(d) Daoudy, 2009, p. 369 states that a total of 272,972 ha are under irrigation in the entire project, of which roughly 240,000 ha lie in the Euphrates Basin and 32,000 ha in the Tigris Basin. A further 111,500 ha are under preparation.
(e) Warner, 2008, p. 279 also notes that GAP was based on the Tennessee Valley Authority (TVA) model.
(f) General Directorate of State Hydraulic Works in Turkey, 2009.
(g) Daoudy, 2009, p. 369.
(h) General Directorate of State Hydraulic Works in Turkey, 2009, p. 60.
(i) In particular, huge hydraulic infrastructure projects like the Atatürk Dam created severe tensions between the riparians.
(j) With reference to Kolars and Mitchell, 1991 and Kliot, 1994, Daoudy, 2009, p. 370 states that GAP will withdraw up to 70% of the natural flow of the Euphrates, 40-50% of the observed flow and 50% of the natural flow of the Tigris River. For further estimates see Tomanbay, 2000.
(k) For instance, Jones et al. underline that "upon completion of the GAP project (with projected reductions in AFV [annual flow volume] exceeding 5.3x10^9 m^3/yr, the sustainable marshes in Central and Al-Hammar area will be reduced by at least an additional 550 km^2" (Jones et al., 2008).
(l) For information see Sahan et al., 2001, p. 7.

DEVELOPMENT & USE: SYRIA

Like Turkey, Syria did not start exploiting the Euphrates until the 1960s. Upon completion of the Tabqa Dam in the 1970s, the country developed ambitious plans for major irrigation projects along the Euphrates River.[29] The Tabqa Dam, also known as the Euphrates Dam, was designed to meet Syria's primary irrigation and energy needs. Its construction led to the creation of Lake Assad, the country's largest water reservoir[30] with a projected capacity to irrigate 640,000 ha of land.[31] The third-largest dam on the Euphrates in Syria, the Baath Dam, was built in 1987, mainly to regulate flow from the upstream Tabqa Dam. The Tishreen Dam, located upstream of Lake Assad, was built in 1999 to generate hydropower.

Water resources in the basin are mainly used for a series of large irrigation projects.[32] Syria has vastly expanded its irrigated area in recent decades: total irrigated area has increased from 652,000 ha in 1985 to 1.4 million ha in 2005, remaining constant since then. Overall, the Euphrates Basin comprises the largest share of cultivated area in the country.[33]

One of the main water development projects in the Syrian part of the Euphrates Basin is the Great Khabour Irrigation Project, as part of which three dams were built on the Khabour River to produce hydropower and store water for irrigation. In 2010, about 59,550 ha of land were

The Euphrates at Jarablus, Syria, 2009. Source: Adel Samara.

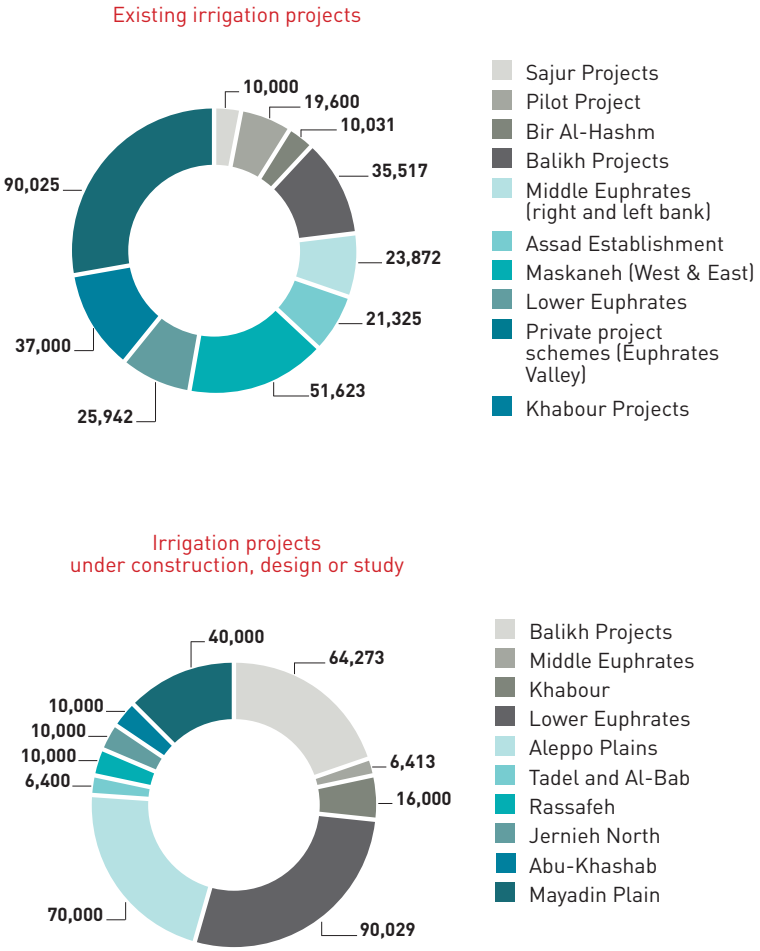
irrigated by the Khabour and Jagh Jagh Rivers[34] (see Chap. 2). In addition, two development projects in the Balikh/Jallab sub-basins use water imported from Lake Assad, while water from the Sajur River is also used for irrigation.

In the Syrian part of the Euphrates Basin, an estimated total of 325,000 ha of land were irrigated in 2000, with a further 325,000 ha of land earmarked for future irrigation projects (Figure 7).[35] The annual volume of water required for the proposed projects is assumed to be about 5,180 MCM. This volume should be added to the 3,586 MCM used in operational irrigation projects.[36] Official data states that 206,987 ha were irrigated by the Euphrates River in 2010 (Figure 8) in addition to 59,550 ha from the Khabour and Jagh Jagh Rivers, amounting to almost 270,000 ha.[37] Applying a commonly accepted rate for irrigation requirements,[38] this suggests an irrigation water use of about 2,700 MCM from the Euphrates, Khabour and Jagh Jagh Rivers.

Lack of information on the current state of irrigated land in the Euphrates Basin in Syria makes it difficult to explain the difference between the 2000 and 2010 figures. However, it is likely that irrigated agriculture has declined in some areas. The disparity could also be the result of different methods of assessing and defining irrigated land.

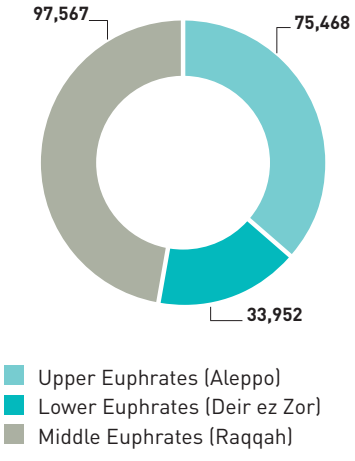
Either way, the figures show that the scale of Syrian irrigation projects is comparable to that of GAP in the Euphrates Basin in Turkey in terms of irrigated area. However, it must be noted that in Turkey as well as in northern Syria (unlike arid south-eastern Syria or Iraq), agriculture is partly rain-fed with seasonal supplementary irrigation. Nevertheless, Syria depends largely on the Euphrates as more than 50% of the blue water used in the country is abstracted from the basin.[39] While most of this is used for irrigation, the Euphrates also supplies drinking water to the cities of Deir ez Zor and Raqqah. Since 2006, Aleppo also draws its water from the Euphrates, with a pipeline running west from Lake Assad and supplying cities and villages along its route.

Figure 7. **Irrigation projects in the Euphrates Basin in Syria in 2000 (ha)**



Source: Compiled by ESCWA-BGR based on data provided by Ministry of Irrigation in the Syrian Arab Republic, 2000 in ACSAD and UNEP-ROWA, 2001; Varelo-Ortega and Sagardoy, 2003.

Figure 8. **Total area irrigated by the Euphrates River in Syria in 2010 (ha)**



Source: Compiled by ESCWA-BGR based on data provided by Ministry of Irrigation in the Syrian Arab Republic, 2012.

BOX 3

The Euphrates Valley Project

The Tabqa Dam was Syria's main development focus in the Euphrates Basin. Initiated in the 1960s, the project had multiple objectives including the expansion of the region's irrigated area to 640,000 ha, the generation of energy, and the prevention of seasonal flooding. The project comprised six irrigation districts which were all centrally supervised by the General Authority for the Development of the Euphrates Basin. However, after the initial plan failed, the government reduced the irrigated area objectives to 370,000 ha. The problems encountered included high gypsum levels in the soil and salinization caused by intensive irrigation.

DEVELOPMENT & USE: IRAQ

Before Turkey and Syria developed an interest in the Euphrates, Iraq was the main user of river water.[40] It was the first riparian to develop engineering projects along the river, irrigating more than five times as much land as Syria and nearly 10 times as much as Turkey in the Euphrates Basin.[41] However, by the late 1960s Syrian and Turkish irrigation projects had outgrown Iraqi projects.

Built in the first half of the 20th century, the Hindiyah Dam and the Ramadi-Razzaza Regulator were constructed to prevent flooding and ensure year-round irrigation of crops via canal systems.[42] The Haditha Dam is the largest dam along the Iraqi stretch of the Euphrates River with a maximum capacity of 8.2 BCM. It is located about 120 km from the Syrian border and regulates flow in addition to generating electricity.[43] Iraq also constructed a complex network of canals on the Euphrates, diverting Euphrates water to reservoirs such as Lake Habbaniyeh and Lake Tharthar which store excess flood water.

Iraq irrigates a greater surface area along its part of the Euphrates River than Syria and Turkey. In the 1960s, Iraq extracted about 16 BCM between Hit and Hindiyah to irrigate around 1.2 million ha.[44] While no recent statistics on irrigated area in Iraq are available, figures from 2000 suggest irrigated areas along the Euphrates River in Iraq added up to about 1.5 million ha.[45] Other sources suggest that an area of 1 to 1.3 million ha were irrigated by Euphrates water.[46] These estimates do not support the assumption that irrigated agriculture in Iraq had declined since the 1980s as a result of the Iraq-Iran war, economic sanctions and the two Gulf wars.

Total potential irrigable land in Iraq within the Euphrates Basin is estimated at 1.8 million ha.[47] Another study states that 4 million ha of land are suitable for agriculture in the Euphrates Basin in Iraq.[48]

BOX 4 The Third River or Main Outfall Drain

Also known as the Saddam River, the Third River flows from Baghdad to the Persian Gulf via the Khor Zubair Canal. Construction on the 565 km canal system was completed in 1992 after 30 years of work. As a main outfall, it collects drainage water from more than 1.5 million ha of land between the Euphrates and Tigris Rivers. The canals discharge into the extensive southern Hammar Marshes that are fed by the Euphrates and Tigris. The project was also set up to resolve the chronic salinity problem affecting farmland between the two rivers, by collecting saline drainage water and preventing it from flowing into the Euphrates. In 1995, around 17 million tons of salt reportedly flowed into the Gulf through the Third River.

The Haditha Dam on the Euphrates in Iraq, 2008. Source: Tyler W. Hill.

WATER QUALITY & ENVIRONMENTAL ISSUES

Irrigated agriculture is prevalent throughout the Euphrates Basin, resulting in a considerable return flow of drainage water, which in turn causes water pollution.[49] Salts are the main pollutants in drainage waters: as they are not naturally removed from the water, they tend to accumulate along the course of the river. The Euphrates is particularly prone to salinization as almost all of its discharge is generated in its headwaters in Turkey. The river then flows through semi-arid to arid areas for over 1,500 km, with high evaporation rates and no further dilution. In Syria, the Euphrates flows through areas with gypsiferous soils,[50] which have a high potential for salt mobilization and thus contribute to further salinization.[51] These characteristics, in addition to issues such as direct sewage disposal into the river, have resulted in a rapid decline in water quality along the Euphrates.[52] This increasingly affects potential downstream users of Euphrates river water.

The area south of the Tigris and Euphrates confluence has also been severely affected by upstream developments and the Mesopotamian Marshes have been largely destroyed as a result of large damming and drainage projects pursued in the second half of the 20th century. It has also led to the salinization of the Shatt al Arab River (see Chap. 5). The regulation of the Euphrates in particular led to heavy losses in river runoff.[53]

Spatial variation

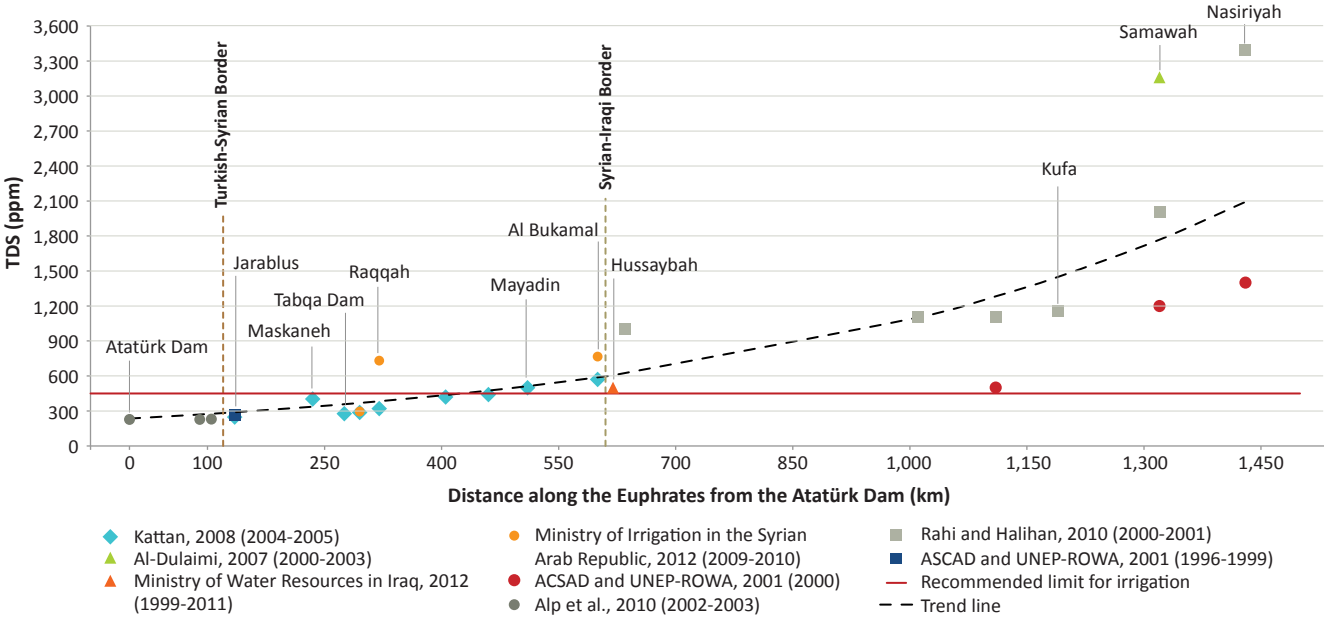
Figure 9 shows available data on Total Dissolved Solids (TDS) at different stations on the Euphrates from 1996 (after most of the dams were constructed). The spatial variations in salinity levels generally indicate an increasing trend of dissolved solids downstream.

In Turkey, analysis of water quality along the river for the years 2002-2003 showed an average salinity of around 237 ppm, a value that does not constitute a salinity hazard for crop productivity.[54] The Euphrates waters at Jarablus near the Syrian-Turkish border are of similar quality with a TDS value of 248 ppm.[55]

Further downstream, however, a progressive increase in salinity can be observed. This is probably the result of upstream pollution from Turkish irrigation projects, and Syrian agricultural activities in the floodplains of the Euphrates River as well as in the Balikh and Khabour sub-basins.[56] These sub-basins drain saline irrigation return waters into the Euphrates River itself (Box 5).[57]

This is reflected in the salinity values registered at Maskaneh (the site of the Maskaneh irrigation scheme located near the southern part of Lake Assad),[58] the city of Raqqah (at the confluence with the Balikh) and the city of Mayadin (after the confluence with the Khabour). Overall, the salinity level of the river at least doubles between the Syrian-Turkish border and the point where the Euphrates enters Iraq.[59]

Figure 9. **Salinity variations along the Euphrates River since 1996**



Source: Compiled by ESCWA-BGR based on the sources mentioned above.
Notes:
- This graph aims only to provide a general overview of salinity variations along the Euphrates River and should not be considered fully accurate: data was extracted from a number of literature sources and official data provided by riparian countries; for some stations only individual measurements were available. The margin of error may be significant as readings could differ depending on the methodology used, location and date of measurement, rounding of means, etc. Interpretation of the salinity data is further hampered by the fact that values cannot be compared with river flow data due to information gaps.
- The years in brackets refer to the sampling years. TDS values in Syria were converted from initial EC values. Cities/stations locations and distances along the river were estimated using Google Earth.

Intensive irrigation along the course of the Euphrates, Syria, 2009. Source: Adel Samara.

The same pattern is observed in Iraq, where salinity increases downstream as a consequence of a decrease in flow, which can in turn be ascribed to the presence of several dams, the inflow of saline water from Lake Tharthar,[60] and drainage originating from upstream and local irrigation projects.[61] In particular, the Euphrates absorbs irrigation return flows from at least four agricultural drains in the stretch extending from Kufa to Samawah.[62] In the lower reaches of the river, water quality deteriorates to a point where it is no longer safe for domestic or agricultural use. Current levels may lie well above the relatively conservative trend line in Figure 9.[63]

Temporal variation

Temporal variations of TDS concentrations also reflect the various water-related developments in the basin over the years.

In Turkey, a study using data from 1971 to 2002 concluded that there was no apparent change in salinity over this time period, except for some tributaries where an increase was observed (Murat and Tacik Rivers).[64] No information is available on water quality downstream of the Urfa-Harran agricultural area, where most of the Turkish use of Euphrates water takes place (see Box 5 and Chap. 2). Limited historic information was available for the quality of the Euphrates River in Syria (Table 4), and statistical trend analysis could not be performed. However, the most recent data for the Raqqah and Al Bukamal[65] stations suggests that salinity levels have increased over the last decade or so (Table 4 and Figure 9).

Table 4. **Mean Total Dissolved Solids (TDS) values of the Euphrates at different stations in Syria for different periods**

PERIOD	STATIONS				SOURCE
	TABQA DAM	RAQQAH	DEIR EZ ZOR	AL BUKAMAL	
pre-1971	333	..	413	..	Raslan and Fardawi, 1971 in Kolars and Mitchell, 1991.
2004-2005	..	320	..	571	Kattan, 2008.
2009-2010	277	732	441	766	Ministry of Irrigation in the Syrian Arab Republic, 2012.

Source: Compiled by ESCWA-BGR.

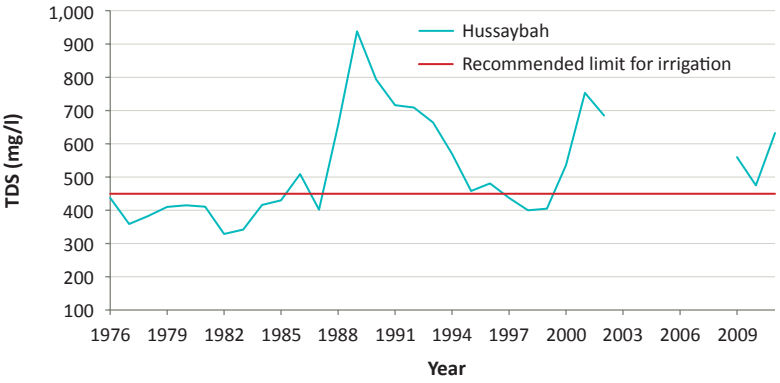
In Iraq, the salinity time series for the stations of Hussaybah (Iraqi-Syrian border) and Samawah (Figure 10 and 11) show variability over the data period. However, the data period included gaps or was too short to perform a solid trend analysis. While changes in salinity often result directly from agricultural activities, the levels of discharge and hence dilution are also important factors in determining salt concentrations over time. The large peak in TDS values observed at Hussaybah in the period 1989-1993 coincides

with reduced flow of the Euphrates entering Iraq, possibly due to the filling of upstream reservoirs, such as the Baath Dam (1987) and the much larger Atatürk Dam (1990).[66] Further increase in salinity can be observed after 2000, as additional reservoirs in Turkey and Syria were filled around this time.[67] This also applies to the station at Samawah, where salinity peaks also correspond to periods of dam filling in Iraq.[68] Data for Samawah over the years 1984-2003 might suggest an increasing trend, and the literature also indicates that salinity values were much lower before this period, with an average TDS value of 525 ppm in 1955.[69] This is also the case at the southernmost station Nasiriyah, where the mean annual TDS value has increased from 1,080 mg/L in 1979 to 5,000 mg/L in 2002.[70]

Overall, one can conclude that current salinity levels are in the range of 300 ppm at the Syrian-Turkish border, 600-800 ppm at the Iraqi-Syrian border, and 2,000-3,500 ppm in southern Iraq near the confluence with the Tigris River.

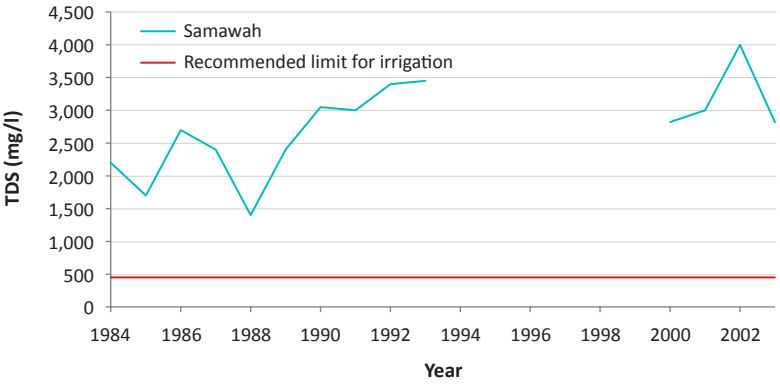
In addition to increasing salinity, intense agricultural activities and the dumping of untreated sewage in the Euphrates and its tributaries have contributed to other forms of pollution in all three riparian countries. These include increasing nutrient levels and coliform bacteria counts in the river.[71] Euphrates characteristics such as the high rate of evaporation, sharp climatic variations, the accumulation of salts and sediments, poor drainage and low soil quality in the lower reaches of the river[72] exacerbate the damaging effects of pollution from human activities.

Figure 10. **Mean Total Dissolved Solids (TDS) values of the Euphrates at Hussaybah in Iraq (1976-2011)**



Source: Compiled by ESCWA-BGR based on ACSAD and UNEP-ROWA, 2001; Ministry of Water Resources in Iraq, 2012.

Figure 11. **Mean Total Dissolved Solids (TDS) values of the Euphrates at Samawah in Iraq (1984-2003)**



Source: Compiled by ESCWA-BGR based on Al-Dulaimi, 2007.

BOX 5

Water Diversion in the Euphrates Basin Affects Water Quality

Agricultural development has a significant effect on water quality in the Euphrates Basin and is by far the largest source of pollution. It is worth noting, however, that these impacts are not necessarily felt at or near the point of abstraction of river water for irrigation. In Turkey, large quantities of good-quality water are diverted from the main course of the Euphrates at Lake Atatürk and taken through the Urfa tunnel and canal system to the extensive Urfa-Harran agricultural area in the upper Jallab/Balikh sub-basins (see Chap. 2). Return flows from this irrigation development are significant, entering Syria through the Jallab River and other streams near the town of Tell Abyad, around 90 km east of the point of inflow of the Euphrates River. These waters carry a considerable salt load and other pollution, which is ultimately discharged into the Euphrates River through the Balikh River near Raqqah, around 200 km from the Syrian-Turkish border. Water is also carried from Lake Atatürk through the Urfa tunnels to the Urfa-Harran project in the upper Khabour basin. This may be one of the reasons why Euphrates water quality at the Syrian-Turkish border has remained relatively unaffected by upstream Turkish development. Either way, assessing the dynamics of the various tributaries along the Syrian-Turkish border is of paramount importance when trying to understand the overall hydrological status of the upper part of the basin, and especially the downstream impacts of Turkish agricultural development. Water quality would therefore be an important topic to address in future discussions between Euphrates Basin riparians.

Agreements, Cooperation & Outlook

While no basin-wide agreement exists, some bilateral accords on water issues are in place, and there have been a number of attempts to find common ground.[73] In 1920, the first treaty entirely focused on the Euphrates and Tigris Rivers was put in place between France, as the mandatory power for Syria, and Great Britain, the mandatory power for Iraq. Protocols and treaties on basic water use rights for the Euphrates River followed, together with commitments for coordinated use (Table 5). In the wake of a protocol annexed to the 1946 Treaty of Friendship and Good Neighbourly Relations between Turkey and Iraq, both countries agreed to share related data and launch consultations.[74]

AGREEMENTS

Two bilateral agreements concluded since the 1980s play a vital role in the allocation of water quantities in the Euphrates Basin. In 1987, Syria and Turkey signed the Protocol on Economic Cooperation, in which Turkey agreed to release a minimum average flow of 500 m³/s across the Syrian border.[75] In the second agreement in 1990, Syria and Iraq agreed to allocate 42% of the Euphrates water measured at the Syrian-Turkish border to Syria and the remaining 58% to Iraq.

COOPERATION

After all attempts at joint projects in the Euphrates Basin failed in the 1960s,[77] the riparians embarked on unilateral development plans and dam projects, which sparked disputes in the 1970s.[78] In particular, the filling of the Keban and Tabqa Dams, and later the Atatürk Dam caused tension as downstream riparians feared a long-term decrease in flow.[79] However the tensions over planned or implemented water infrastructure projects also promoted cooperation and exchange between the riparians, such as the establishment of joint technical committees and even bilateral agreements on water allocation.

The idea of forming a Joint Technical Committee (JTC) between the three major riparians dates back to 1964 when Iraqi and Turkish experts met to discuss flow guarantees on the Euphrates.

BOX 6 Positions on International Water Law

Turkey regards the term "sharing waters" as inadequate and argues it is not possible to share a commodity that constantly changes in quantity and quality, and in time and space due to the variable conditions of the hydrological cycle. For Turkey, the Euphrates is a transboundary river that falls under Turkish sovereignty as long as it is within its territory. Iraq and Syria, on the other hand, view the Euphrates as an "international river" that should be treated as a shared entity by all riparians.[a]

Another point of contention revolves around whether the Euphrates and Tigris form a single water basin, as favoured by Turkey, or whether they should be regarded as two separate basins as favoured by Iraq and Syria.[b] Furthermore, Turkey claims that in order to reach an efficient allocation among the riparians, negotiations should include the total available water resources of each riparian. However, Syria does not want to include the Orontes River in the negotiations, while Iraq wants to exclude the waters flowing from Iran to Iraq.

Source: Aydin and Ereker, 2009; Ünal et al., 2009, p. 48; Akanda et al., 2007.
(a) Turkey is the only Euphrates Basin country that voted against the 1997 UN Convention on the Law of Non-navigational Use of International Watercourses. If Turkey signed the law, it could give lower riparians a veto right over development plans in Turkey, such as GAP.
(b) For Turkey, the Euphrates and Tigris Rivers form one river system because they merge into the Shatt al Arab water course. This view is reinforced by the existence of the Iraqi-built Tharthar Canal, which diverts water from the Tigris to the Euphrates. Syria and Iraq do not share this view.

The first trilateral meeting took place in 1965 in Baghdad, where riparians exchanged information on dam projects and negotiated a draft agreement for the establishment of a permanent JTC. However, Turkey refused the Iraqi proposition that JTC should have supervisory power over a water-sharing agreement. Although no agreement was reached, riparians continued to hold technical meetings.[80]

A decade later, JTC was formally established at the first meeting of the Joint Economic Commission between Turkey and Iraq in 1980. Syria joined the committee three years later, whereupon the three riparian countries participated in 16 meetings until 1993.

The committee worked under a mandate to "determine the methods and procedures which would lead to a definition of the reasonable and appropriate amount of water that each country would need from both rivers".[81] The agenda of JTC mainly focused on the exchange of hydrological data, sharing information on dam construction, irrigation schemes and plans for the filling of large dams.[82] After 1993, deadlock led to the group's dissolution.[83]

Riparian rapprochement

Although the riparians have not had a trilateral meeting that focuses exclusively on the Euphrates waters, their relationship has changed distinctly over the past 10 years.

While riparian relations were tense during the Cold War, with countries either following a strategy of unilateral water resources management (Turkey) and/or veto strategies to prevent a riparian from achieving its development plans (Syria, Iraq),[84] political relations between the riparian countries started to improve in the early 2000s. In 2001, the Turkish GAP and Syrian General Organization for Land Development agreed to hold joint trainings. Bilateral visits and a free-trade agreement between Turkey and Syria followed. In 2005, a group of scholars and professionals created the Track II Euphrates-Tigris Initiative for Cooperation (ETIC)[85] which seeks to promote cooperation on the technical level among the three riparian countries. In 2007 the three countries agreed to revitalize periodic JTC meetings.[86]

Table 5. **Water agreements on the Euphrates River**

YEAR	NAME	SIGNIFICANCE	SIGNATORIES
1920	Franco-British Convention	Mandatory powers agreed to establish a committee to examine and coordinate use of the Euphrates and Tigris Rivers.	France (Syria), Great Britain (Iraq)
1920	On Koveik River[a]	Includes mention of possible use of the Euphrates River.	France (Syria), Turkey
1921	Ankara Treaty	Reference is made to the obligation of riparian states to share the waters of a transboundary river and to satisfy the two parties. Article 12 states that the city of Aleppo should be able to use Euphrates water from Turkey to satisfy water demand in the city.	France (Syria), Turkey
1923	Lausanne Treaty	Article 109 confirms that issues related to transboundary water should be dealt with separately and with mutual respect. It also includes a provision that Turkey must consult Iraq before undertaking any hydraulic works.	Allied powers, Turkey
1926	Convention of Friendship and Good Neighbourly Relations	Commitment by both parties to coordinate their plans for use of the Euphrates River.	France (Syria), Turkey
1946	Treaty of Friendship and Good Neighbourly Relations	This was the first legal instrument of cooperation. Both parties agreed that Turkey shall install and operate permanent flow measurement facilities and inform Iraq periodically about recorded data (article 3) and water infrastructure projects.[b]	Iraq, Turkey
1980	Protocol for Technical and Economic Cooperation	The protocol mandates establishment of a joint technical committee to study the issue of regional waters – particularly the Euphrates and Tigris Rivers.	Iraq, Turkey (Syria signed in 1983)
1987	Protocol on Economic Cooperation	First bilateral agreement dealing with water sharing since World War II. It guarantees a yearly average release of 16 BCM (at a minimum annual average of 500 m^3/s) from the Euphrates at the Syrian-Turkish border.[c]	Syria, Turkey
1990	Water-Sharing Agreement	Agreement on water allocation between Iraq and Syria, which divides the flow of the Euphrates at the Syrian-Turkish border according to a 42% to 58% ratio.	Iraq, Syria
2001	Joint Communiqué	Under this agreement, the Regional Development Administration of the Southeastern Anatolia Project (GAP RDA) in Turkey and the General Organization for Land Development at the Syrian Ministry of Irrigation are to conduct joint projects and programmes.[76]	Syria, Turkey
2008	Declaration on the Establishment of the High-Level Strategic Cooperation Council	The mechanism of joint meetings between the Iraqi and Turkish cabinets also includes communication over the issue of shared water.	Iraq, Turkey
2009	Syrian-Turkish Strategic Cooperation Council Agreement	The agreement states that water is a focus point for cooperation between the two countries with specific emphasis on improvements to water quality, the construction of water pumping stations and joint dams, as well as the development of joint water policies.	Syria, Turkey
2009	Protocol on Water	The Memorandum of Understanding (MoU) on Water is one of a total of 48 MoUs signed between the two countries. The parties agreed to share hydrological and meteorological information, and exchange expertise in these areas.	Iraq, Syria

Source: Compiled by ESCWA-BGR based on data provided by Aydin and Ereker, 2009; Scheumann, 1998a; Scheumann, 1998b; Oregon State University's International Freshwater Treaties Database, ORSAM, 2009; Kibaroglu et al., 2008; Kibaroglu et al., 2011.
(a) More commonly spelled Qweik River.
(b) Hager states that while the treaty has demonstrated the two countries' best intentions, it has not been applied by either Turkey or Iraq (Hager in Elhance, 1999, p. 141).
(c) Article 7 states Syria and Turkey should work with Iraq to allocate Euphrates (and Tigris) water within the shortest possible time. Article 9 asserts the intention of the two states to construct and jointly operate irrigation and hydropower projects (Syrian Arab Republic and Turkey, 1993).

In 2009, Turkey and Syria signed 52 agreements in a Strategic Cooperation Council meeting on energy cooperation, transportation, trade and security. The two countries planned to jointly develop shared water resources under the umbrella of the Syrian-Turkish Strategic Cooperation Council.[87]

The regime change in Iraq created new opportunities for cooperation in the field of shared water. Negotiating mechanisms between Iraq and Turkey were created or revived and in 2009 a new water protocol was signed along with many other protocols on trade and security. Economic and strategic interests drive political cooperation between Iraq and Turkey. However, the question of shared water resources, water security and energy could become an obstacle in continuing good relations.[88] The dispute over the construction of the Ilisu Dam and the consecutive years of drought strained relations between the two countries.

OUTLOOK

With the Syrian crisis erupting in March 2011, relations between Turkey and Syria has severely deteriorated, with Turkey imposing a series of sanctions on Syria. However, Turkey explicitly stated in November 2011 that the sanctions would not target or restrict Turkish water supply to Syria, guaranteeing the 500 m^3/s flow at the Syrian-Turkish border.[89] The Syrian Ministry of Irrigation has also reaffirmed that the water agreements between the riparian countries of the Euphrates and Tigris river basins are not affected by the recent conflicts.[90]

It is however likely that the current situation in the region and the Syrian crisis have hampered the continuation of periodic trilateral meetings on shared water in general, and negotiations over the Euphrates River flow in particular in the near future.

Consecutive years of drought have affected all riparian countries and may also have contributed to the rural unrest and exodus of rural polulations, especially in northern Syria. The current situation suggests that water withdrawals will continue to rise in the foreseeable future, while water quality will further deteriorate, particularly given pressures from growing demand for food, rising energy needs and socioeconomic developments. Cooperative mechanisms to address these issues are not well established and progress is therefore likely to remain slow in the near future, unless more concerted efforts are made towards basin-wide management of water resources. This could include a comprehensive reservoir operation strategy and the development of a pollution control plan for the basin.

The Euphrates valley at the Syrian-Turkish border, Syria, 2009. Source: Andreas Renck.

Notes

1. Basin area was estimated from a digital elevation model (HydroSHEDS) similar to Lehner et al., 2008. In contrast to Lehner, neither the ACSAD and UNEP-ROWA, 2001 report, nor other basin descriptions consider Jordan to be part of the Euphrates River basin. Yet in terms of basin distribution, their numbers match Lehner et al., 2008. By contrast, Kibaroglu, 2002b, p. 162 speaks of 33% of the river being located in Turkey, 19% in Syria and 46% in Iraq, while Kolars and Mitchell, 1991 claim 40% lies in Turkey, 25% in Syria and 35% in Iraq. Isaev and Mikhailova, 2009, p. 384 estimate the percentage of the drainage basin lying in Turkey at 33%, 20% in Syria and in 47% in Iraq. Generally, such discrepancies between basin area estimates arise due to problems in delineating the not necessarily similar topographical and hydrogeological boundaries. In addition, large parts of the Euphrates Basin topography are flat, making the watershed less distinct.
2. The length of the Euphrates River was calculated tracing the Karasu from its source to the confluence with the Tigris.
3. The Karasu (Kara-su or Euphrates su), or Western Euphrates, originates in the Kargapazari Mountains, north of the city of Erzurum. It flows westwards over the Erzurum Plateau for more than 300 km before abruptly veering south, where it merges with the Murat.
4. The Murat or Murat-su River, also called Eastern Euphrates, is formed by the convergence of many springs in the Ala-dag area. The Urat Spring, west of Mount Ararat to the north of Lake Van, is one of the Murat's main sources. From here the river flows westwards through the Armenian Highlands over a distance of almost 500 km (other sources speak of 650 km: Medzini and Wolf, 2005, p. 111). A few kilometres north of the city of Keban and near the city of Ekbazari, the river encounters the Karasu.
5. See Chap. 2.
6. Medzini and Wolf, 2005, p. 112.
7. Kibaroglu, 2002b, p. 161.
8. Ünal et al., 2009, p. 48; Naff and Matson, 1984; FAO, 2009, p. 65. Other sources estimate that 93% of the Euphrates sources are located in Turkey (ACSAD and UNEP-ROWA, 2001), while some sources even suggest that 98% of the Euphrates flow originates in Turkey (Kolars and Mitchell, 1991).
9. Some sources assume Iraq does not contribute to the Euphrates at all (Ünal et al., 2009, p. 48).
10. It is estimated that about 72% of the total water resources of the Euphrates come from this area (ACSAD and UNEP-ROWA, 2001, p. 20). Beaumont, 1998, p. 70 goes further and estimates that precipitation in Turkey accounts for at least 95% of the total flow.
11. ACSAD and UNEP-ROWA, 2001.
12. Kolars and Mitchell, 1991 note that the observed "diminution of discharge during that time in Syria cannot be explained through reservoir filling alone and is undoubtedly climatic in origin. Had this information been known at the time, near confrontation between Syria and Iraq over the diminished river flow might have been avoided."
13. A similar grouping is found at ACSAD and UNEP-ROWA, 2001.
14. These large dams not only divert a large quantity of water for irrigation, but also have high levels of evaporation from their reservoirs. For instance, it is estimated that around 1,500 MCM/yr are lost due to evaporation from Lake Assad, the largest surface water reservoir in Syria built on the Euphrates near Tabqa in 1974 (Wakil, 1993).
15. Ministry of Irrigation in the Syrian Arab Republic, 2012; Ministry of Water Resources in Iraq, 2012.
16. Ministry of Water Resources in Iraq, 2010.
17. ACSAD and UNEP-ROWA, 2001; Kolars and Mitchell, 1991.
18. See also ACSAD and UNEP-ROWA, 2001.
19. The two springs are Ras al Ain at 40 m^3/s and Ain al Arous at 6 m^3/s. For more information on groundwater in Syria, see Burdon, 1954 and Chap. 2.
20. Jassim and Goff, 2006, p. 264. See also Chap. 25.
21. Sabkha is the Arabic word for salt pan or clay flat. See 'Overview: Shared Water Resources in Western Asia', Box 3 for further information.
22. Jassim and Goff, 2006.
23. FAO, 2009.
24. Turkey launched the ambitious Southeastern Anatolia Project (Güneydoğu Anadolu Projesi or GAP) in 1977 as a national initiative to harness the water of the Euphrates and Tigris Rivers for hydropower and agricultural production and thus provide economic stimulus to the south-east Anatolia region.
25. Kolars and Mitchell, 1991; Altinbilek, 2004, p. 24; Aydin and Ereker, 2009, p. 608.
26. ACSAD and UNEP-ROWA, 2001.
27. Numbers are based on the General Directorate of State Hydraulic Works in Turkey, 2009, p. 61. In order to place these figures in a national context it is interesting to note that arable land in Turkey is estimated at around 28 million ha of which 8.5 million ha have been identified as economically irrigable. In 2008, 5.28 million ha were under irrigation (see General Directorate of State Hydraulic Works in Turkey, 2009, p. 51).
28. The Urfa-Harran project (in the Sanliurfa-Harran region in Turkey) on the Balikh was one of the first projects implemented as part of GAP. It is currently the largest irrigation project in operation, with an irrigated area of about 140,000 ha. The Mardin-Ceylanpinar project in the Khabour Basin aims to increase the irrigated area to 388,000 ha, of which 60,000 ha will be irrigated by groundwater.
29. Beaumont, 1998.
30. Lake Assad has a maximum storage capacity of 11.7 km^2. During the filling of the reservoir in 1975, the flow of the Euphrates below the Tabqa Dam was reduced. This sparked tensions between Syria and Iraq which were resolved through intervention from Saudi Arabia and the Soviet Union.
31. Kolars & Mitchell state that the Soviet proposal claimed that 850,000 ha of land could be irrigated by Lake Assad, but German experts reduced this figure to 650,000 ha and Syria further revised it to 640,000 ha. Kolars and Mitchell, 1991, p. 145 estimate that only 208,000 ha were irrigated by the mid-1980s.
32. Several irrigation projects exist on the Balikh River (see Chap. 2). However, it should be noted that Syrian agriculture was and still is predominantly rain-fed.
33. Salman, 2004, p. 63.
34. Ministry of Irrigation in the Syrian Arab Republic, 2012.

35. Ministry of Irrigation in the Syrian Arab Republic, 2000 in ACSAD and UNEP-ROWA, 2001. However it is important to note that these numbers most likely do not refer to irrigated land exclusively and therefore also include large areas of supplementary irrigation.
36. The estimations for annual water requirements are published by the Ministry of Irrigation in Syria, 2000 in ACSAD and UNEP-ROWA, 2001.
37. Ministry of Irrigation in the Syrian Arab Republic, 2012.
38. See Beaumont, 1996.
39. Salman, 2004, p. 3. However, Barnes, 2009, p. 519 states that 70-80% of the country's water comes from the Euphrates.
40. Turkey focused on western Anatolia up until this time. See Kolars, 1986, p. 62 for more information.
41. Kienle, 1990, p. 93.
42. Kliot, 1994.
43. ACSAD and UNEP-ROWA, 2001.
44. Ubell in Beaumont, 1998, p. 178.
45. ACSAD and UNEP-ROWA, 2001.
46. Altinbilek, 2004, p. 20 refers to estimates made by the US Army Corps of Engineers revealing that 1-1.3 million ha are irrigated. Kolars and Mitchell state that over 1 million ha of land is irrigated by Euphrates water in Iraq (Kolars and Mitchell, 1991, p. 3) and FAO, 2009 estimates 1 million ha of land is irrigated by surface water from the Euphrates.
47. Kliot, 1994.
48. ACSAD and UNEP-ROWA, 2001.
49. FAO, 2009. The river water is mainly polluted by irrigation return waters, which often have a higher salt content and are contaminated by fertilizers and/or pesticides.
50. Florea and Al-Joumaa, 1998.
51. ACSAD and UNEP-ROWA, 2001 and Zaitchik et al., 2002.
52. Yesilnacar and Uyanik, 2005 and Al-Dulaimi, 2007.
53. For further information, see Chap. 3 and 5.
54. Alp et al., 2010; Odemis et al., 2010. The TDS recommended guideline for irrigation water is set at <450 ppm by FAO, 1994.
55. Kattan, 2008.
56. For more information, see Chap. 2.
57. ACSAD and UNEP-ROWA, 2001; Beaumont, 1996; Kattan, 2008.
58. ICARDA and IWMI, 2008; Almohamed and Doppler, 2008.
59. Kattan, 2008, Ministry of Water Resources in Iraq, 2012; Ministry of Irrigation in the Syrian Arab Republic, 2012.
60. For more information see Chap. 3.
61. ACSAD and UNEP-ROWA, 2001; Fattah and Abdul-Baki, 1980.
62. Rahi and Halihan, 2010; Al-Dulaimi, 2007. The salinity of these drains range between 2,065 and 4,262 ppm.
63. Rahi and Halihan, 2010.
64. Odemis et al., 2010.
65. Al Bukamal is located in Syria near the Iraqi-Syrian border.
66. ACSAD and UNEP-ROWA, 2001, p. 123.
67. These are the Atatürk Dam in 1990 as well as the Karkamis, Birecik and Tishreen Dams completed in 1999-2000. However increased salinity could also be due to a drought in 1998-2000. FAO, 2003 in Rahi and Halihan, 2010.
68. Such as the filling of the Fallujah Dam in the mid-1980s, the Atatürk Dam in 1990 as well as the Karkamis, Birecik and Tishreen Dams completed in 1999-2000 (Table 3).
69. The Iraqi Foundation, 2003 in Rahi and Halihan, 2010.
70. Ministry of Irrigation in Iraq in Rahi and Halihan, 2010, p. 27.
71. In Turkey, the high levels of coliform bacteria observed in Lake Atatürk are a result of the direct discharge of untreated wastewater into the dam lake. In addition, an increase in total nitrogen and phosphorus levels recorded since 1996 may cause eutrophication in the long term (Yazgan, 2001 in Yesilnacar and Uyanik, 2005). This is also a problem in the Keban Dam reservoir, where the high level of nutrients can be ascribed to the inflow of rivers such as the Murat which supports extensive agricultural activities. The pollution poses a threat to aquatic organisms (Akbay et al., 1999; Ural and Özdemir, 2011).
72. Erdem, 2003.
73. Nevertheless, water issues in the basin have to be seen in the context of overall relations between the three main riparians, and in particular take into account the following factors: historical animosity between Syria and Turkey (and general East-West tension until the 1990s); the Kurdish question; the rivalry between the Iraqi and Syrian Ba'ath parties, as well as the 1990 and 2003 Gulf wars.
74. The 1946 treaty even included a mandate for a committee to implement the agreements. Such an entity was however never created due to disputes between the riparians (Kaya, 1998).
75. Signatory parties regard this as an interim agreement until allocation of the Euphrates waters among the three riparian countries is finalized (Scheumann, 1998a). "The Arab states argue that since three states are sharing the river's flow, each is entitled to one-thirds, giving the two Arab states a total of around 667 m^3/s" (Gruen in Warner, 2008).
76. Kibaroglu et al., 2008.
77. Scheumann, 1998b, p. 110 stresses that integrated development of the Euphrates Basin was hindered by the conflicting interests of the Eastern and Western blocs.
78. Aydin and Ereker, 2009; Scheumann, 1998b; Kaya, 1998.
79. After Syria completed the Tabqa Dam in 1973, the filling of the reservoir reduced the flow of the Euphrates entering Iraq by 25%, causing serious tension between the two riparians. To prevent military escalation, Saudi Arabia and the former Soviet Union mediated the conflict. The tension eased when Syria increased water flow to 450 m^3/s (Scheumann, 1998a, p. 121; Schulz, 1995, p. 105). "Although the terms of the agreement were never made public, Iraqi officials have privately stated that Syria agreed to take only 40% of the water of the river, leaving the remainder for Iraq" (Naff & Matson, 1984 in Kaya, 1998, p. 3). Similar tension arose between Turkey, Syria and Iraq when Turkey filled the Atatürk Reservoir. Even though Turkey notified the two downstream countries, it could not prevent a pan-Arab outcry (Aydin and Ereker, 2009, p. 611).
80. Aydin and Ereker, 2009, p. 608.
81. Kibaroglu, 2002b, p. 227.
82. Ibid.
83. As the riparians positioned themselves differently with regard to terminologies and descriptions of the rivers, JTC's objective to achieve a trilateral agreement on the "sharing" of common watercourses was abandoned. See Box 6 for further information.

84. Kibaroglu et al., 2011 in Chapter 21.
85. The initiative comprises a group of scholars and professionals from Iraq, Syria and Turkey who promote cooperation for technical, social and economic development. In line with its overall objective, ETIC has organized joint trainings, capacity building programmes and research projects in recent years. See ETIC, 2012 for more information.
86. A series of meetings were conducted between 2007 and 2009. See Kibaroglu et al., 2011 for more information.
87. Syria Today, 2010.
88. Turunc, 2011.
89. Bloomberg Businessweek, 2011.
90. Ministry of Irrigation in the Syrian Arab Republic, 2012.

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Chapter 2

Shared Tributaries of the Euphrates River

Shared Tributaries of the Euphrates River

EXECUTIVE SUMMARY

The Euphrates River has three main shared tributaries: the Sajur and the Balikh/Jallab are shared between Syria and Turkey, while the Khabour sub-basin is shared between Iraq, Syria and Turkey.

With an average annual discharge of 97 MCM, the Sajur is the smallest of the three tributaries. Originally, the Balikh/Jallab was fed primarily by the karstic Ain al Arous Spring, but it increasingly receives irrigation return flows from intensive agricultural projects, mainly in Turkey.

The Khabour is the largest of the three shared Euphrates tributaries in terms of length and mean annual discharge. However, annual flow has decreased dramatically over recent decades from 2,120 BCM before 1980 to 924 MCM around 2000, with values constantly decreasing since then. The Khabour river dries up seasonally at several locations as a result of intensive irrigated agriculture in Syria and Turkey.

While the three Euphrates tributaries used to make up around 8% of annual Euphrates flow, today their contribution has dropped to 5% or less due to decreased flow of the Khabour. In all three sub-basins water is mainly used for irrigation purposes.

The Sajur River in Syria, 2009. Source: Andreas Renck.

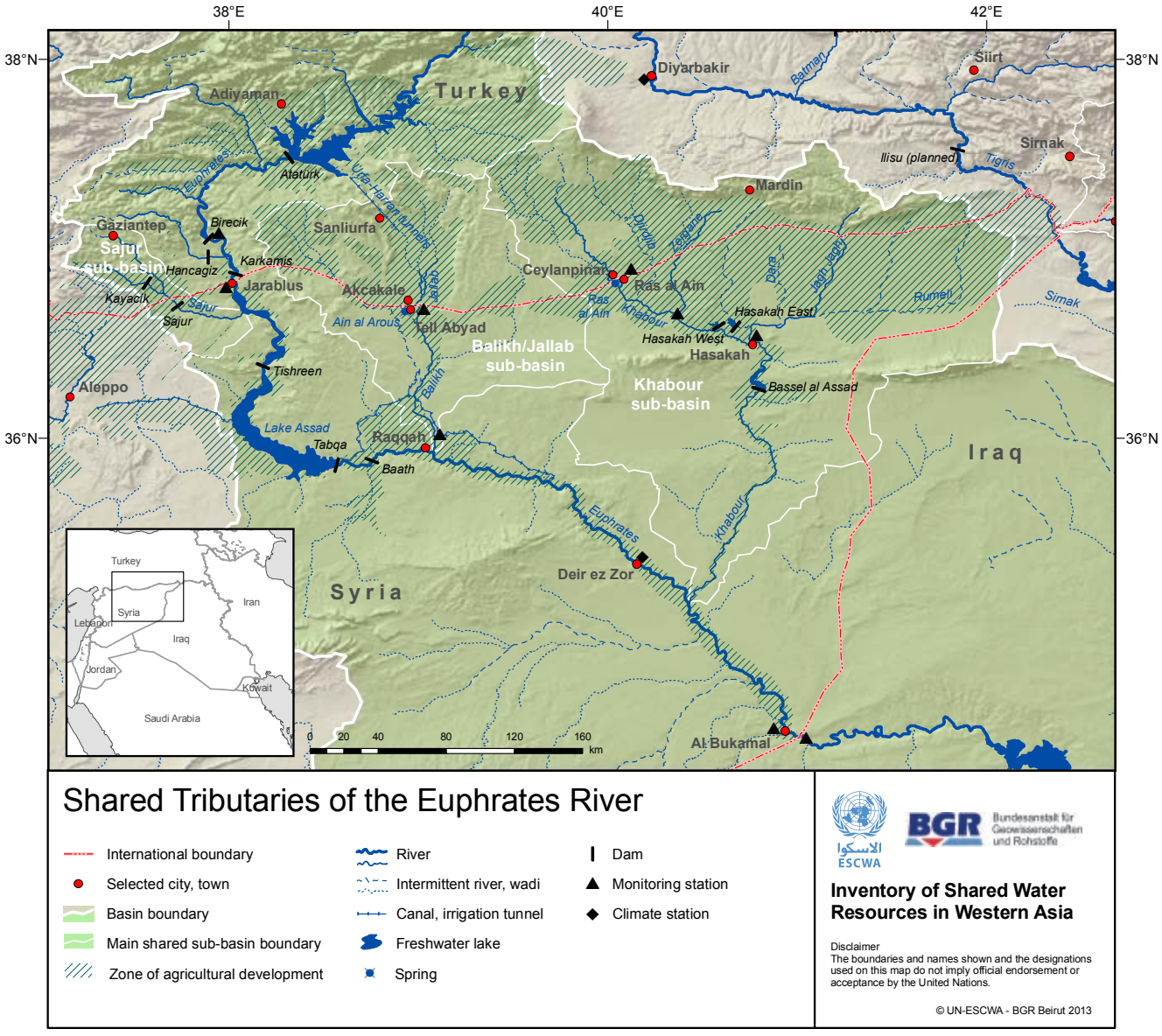
In the Balikh/Jallab sub-basin, the Turkish Urfa-Harran Project imports water from the Atatürk Dam reservoir to irrigate large areas of land which have transformed the Jallab River from an intermittent stream into a perennial river. In the Khabour sub-basin both riparians developed extensive irrigation schemes that have transformed land use patterns and the natural flow regime of the river.

There are no specific water agreements in place for any of the three shared tributaries.

SUB-BASIN FACTS

RIVER	SAJUR	BALIKH/JALLAB	KHABOUR
BASIN AREA SHARES	Syria 40% Turkey 60%	Syria 38% Turkey 62%	Iraq 6% Syria 66% Turkey 28%
BASIN AREA	2,860 km^2	13,600 km^2	36,200 km^2
RIVER LENGTH	108 km	196 km	388 km
MEAN ANNUAL FLOW VOLUME	98 MCM	~140-210 MCM	924 MCM
MAIN DAMS	2	Unregulated to date	3
PROJECTED IRRIGATED AREA	..	~330,000 ha	~404,000 ha

OVERVIEW MAP



Shared Tributaries of the Euphrates River

- International boundary
- Selected city, town
- Basin boundary
- Main shared sub-basin boundary
- Zone of agricultural development
- River
- Intermittent river, wadi
- Canal, irrigation tunnel
- Freshwater lake
- Spring
- Dam
- Monitoring station
- Climate station

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Inventory of Shared Water Resources in Western Asia

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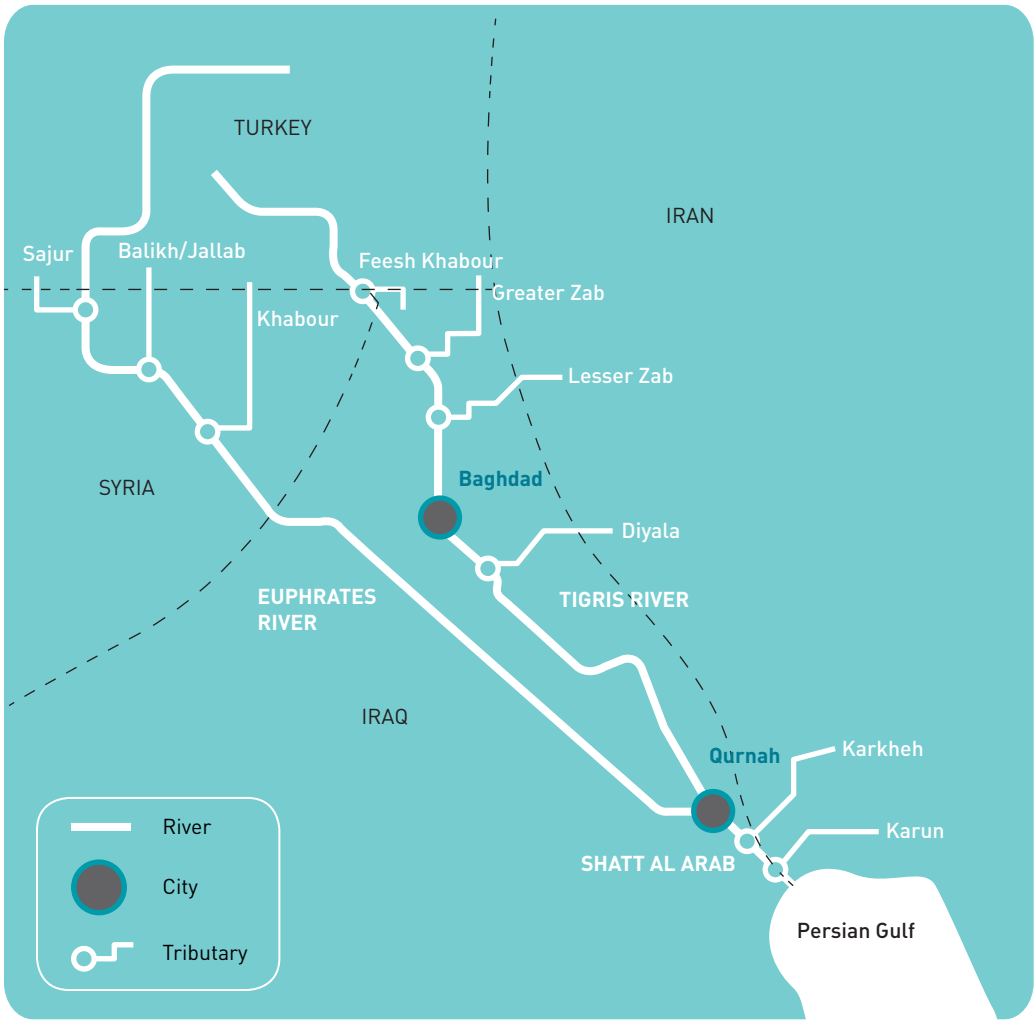
Defining the Euphrates-Tigris-Shatt al Arab Basins

The Euphrates-Tigris-Shatt Al Arab river system constitutes by far the largest surface water resource in the study area. Its combined topographic catchment covers more than 900,000 km^2 from the headwaters in the Taurus-Zagros Mountain Range to the Mesopotamian lowlands and the only outlet to the Persian Gulf, the Shatt Al Arab (Fig. 1). The overall basin is also home to around 54 million people in Iran, Iraq, Syria and Turkey. Given its importance and in order to adequately reflect the specific conditions as well as its complex hydrology, the Inventory dedicates five chapters to this river system.

The Euphrates River Basin (Chap. 1) and Tigris River Basin (Chap. 3) each have a different dynamic and set of characteristics, particularly with regard to their riparian countries, tributaries and contribution to discharge, as well as water use patterns and water quality. The shared tributaries of the Euphrates River (Chap.2) and the major shared tributaries of the Tigris River (Chap. 4) are covered in more detail in two separate chapters in order to highlight the role of these rivers and draw attention to local water issues and transboundary impacts. Chapter 4 also provides information on water use in Iran, which does not share the watercourse of the Tigris River itself but hosts important tributaries within the Tigris Basin. Finally, the Shatt al Arab River is discussed together with two additional major tributaries, the Karkheh and the Karun Rivers, which discharge directly into the Mesopotamian Marshes or the Shatt al Arab itself, and are hence neither part of the Euphrates or Tigris River basins (Chap. 5).

Figure 1. Sketch of the Mesopotamian river system



Source: Compiled by ESCWA-BGR.

Introduction

The Euphrates River Basin has three major tributaries: the Sajur, the Balikh/Jallab and the Khabour Rivers (see Overview Map, Fig. 1).

The only right-bank tributary, the Sajur, is the smallest of the three rivers in terms of length and discharge.

The second tributary is the left-bank Balikh/Jallab River, which can be divided into two parts: the northern, nowadays perennial Jallab River, which originates in the Urfa Heights in Turkey, and the southern Balikh River, which originates at the Ain al Arous Spring in Syria.

The Khabour River originates on the south-facing slopes of the Taurus Mountains in Turkey and is formed by the confluence of the Ipramiye and Güzelyat Rivers. It is the largest of the three tributaries in terms of length and mean annual discharge. All three Euphrates tributaries form shared basins between Syria and Turkey.

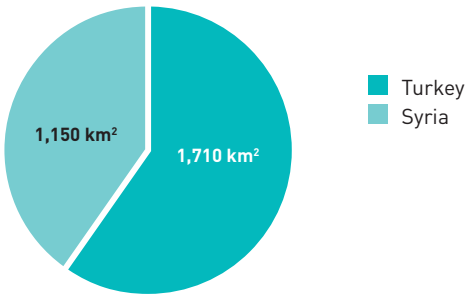
The Sajur River in Syria, 2009. Source: Andreas Renck.

Sajur

The Sajur River stems from the confluence of two streams in Turkey, the Ayfinar Deresi and the Bağırsak Deresi. It flows south-eastwards, entering Syria at Kusek and discharging into the Euphrates about 20 km downstream of the city of Jarablus.[1] This confluence is usually flooded by the Tishreen Dam reservoir (see Overview Map).

The river has a total length of 108 km, of which 48 km lie in Syria and 60 km in Turkey. The Sajur River drainage basin covers 2,860 km^2, 40% of which lies in Syria and 60% in Turkey (Figure 2).[2]

Figure 2. **Distribution of the Sajur Basin area**



Source: Compiled by ESCWA-BGR.

HYDROLOGICAL CHARACTERISTICS

Hydrological data for the Sajur sub-basin is limited. Table 1 compiles discharge estimates for different periods in Turkey and Syria. The river's maximum discharge usually occurs in February and March, while the minimum falls between June and October. According to estimates, the mean discharge of the Sajur in Syria usually lies below 3 m^3/s, with maximum discharge values of 25 m^3/s recorded during flood periods in the 1960s and a minimum discharge of 0-0.5 m^3/s during dry periods. According to the Central Bureau of Statistics in Syria, the mean discharge of the Sajur was 3.1 m^3/s between 2002 and 2006, which amounts to an annual mean of about 98 MCM.[3] The Sajur River flow contribution to the Euphrates is almost negligible and represents just 0.39% of annual Euphrates flow.

WATER RESOURCES MANAGEMENT

Both riparian countries have over the past century increased their water use for irrigation along the Sajur. As a result, flow volumes have diminished along the river's course and in summer the Sajur periodically runs dry due to intensive irrigation abstractions. Syria and Turkey have also constructed dams on the river. The Kayacik Dam was built on the Ayfinar Deresi as part of the Southeastern Anatolia Project (GAP) in Turkey. It has a reservoir capacity of 117 MCM. The Sajur Dam in Syria was inaugurated in 2005 and has a capacity of 14.5 MCM. It is used for the irrigation of approximately 10,000 ha, mainly along the river's downstream banks.

WATER QUALITY & ENVIRONMENTAL ISSUES

The Sajur River's water quality is good compared to that of the two other tributaries. According to the Syrian Ministry of Irrigation, the water is suitable for agricultural use, with Electrical Conductivity (EC) values ranging between 661 µS/cm and 823 µS/cm in 2010.

Table 1. **Mean annual flows of the Sajur River**

COUNTRY	LENGTH (km)	PERIOD	FLOW (m^3/s)			FLOW (MCM/yr)	SOURCE
			MEAN	MINIMUM	MAXIMUM		
Turkey	60	1980	4.4	..	..	138.6	GAP in Kolars and Mitchell, 1991, p. 109.
Syria	48	1966	3.0	0.5	25.0	94.5	FAO in Kolars and Mitchell, 1991, p. 109.
		1980	1.9	—	13.6	59.9	SAR in Kolars and Mitchell, 1991, p. 109.
	..	1980	2.8	..	..	88.0	USAID in Kolars and Mitchell, 1991, p. 109.
	..	2002-2006	3.1	..	..	97.7	Central Bureau of Statistics in the Syrian Arab Republic, 2010.
..	108	..	4.2	0.5	15-20	132.5	ACSAD and UNEP-ROWA, 2001, p. 22.

Source: Compiled by ESCWA-BGR.

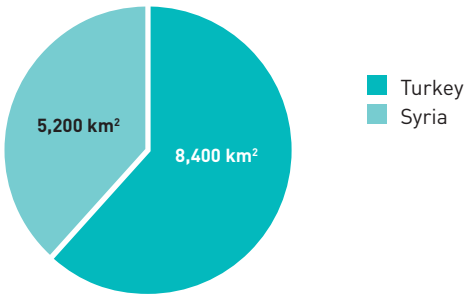
Balikh/Jallab

Covering a total surface area of 13,600 km^2, the Balikh/Jallab sub-basin is shared between Syria (38%) and Turkey (62%) (Figure 3).[4] The Jallab originates in the Urfa Heights in Turkey[5] and flows south for 15 km[6] before joining the Balikh River which originates in Syria.[7] The two rivers form a tributary to the Euphrates with a total length of about 196 km, of which 107 km lie in Syria and 89 km in Turkey.[8]

The primary source of the Balikh is the karstic Ain al Arous Spring near the Syrian border town of Tell Abyad. The river also receives water from a number of intermittent streams and ephemeral wadis, including the Wadi Qaramogh and the Wadi al-Kheder. The Jallab River also contributes to Balikh flow and has over recent decades become perennial due to the inflow of agricultural drainage water from the Urfa-Harran region in Turkey. The Balikh discharges into the Euphrates downstream of Lake Assad near the city of Raqqah, around 80 km south of the Turkish border.

Precipitation levels in the basin decrease from north to south, with an annual average of more than 450 mm in the north and less than 150 mm in the south-east.

Figure 3. **Distribution of the Balikh/Jallab Basin area**



Source: Compiled by ESCWA-BGR.

HYDROLOGICAL CHARACTERISTICS

The Jallab used to be an intermittent stream with an annual discharge of around 111 MCM (Table 2). Today it has become a perennial river that carries irrigation return flows from intensive agricultural projects in the Urfa-Harran Plain in Turkey. While no official data is available, it is likely that the discharge has increased significantly since the projects were established in the late 1980s, with mean discharges of around 10-20 m^3/s.[9] The flow regime of the Jallab varies strongly throughout the year, depending on precipitation and irrigation in Turkey.

In the 1980s, the Ain al Arous Spring near the Syrian town of Tell Abyad was the primary source of water for the Balikh, with an average discharge of 6 m^3/s or about 189 MCM/yr, which is equivalent to twice the mean annual flow volume of the entire Sajur River (Table 2). However, extensive groundwater abstraction for irrigated agriculture in the upper basin has had a far-reaching impact on spring and river flow. The Ain al Arous Spring currently falls dry for most of the year, while the upper Balikh River[10] no longer flows year round.[11] It is not clear whether the recent and projected diversion of irrigation water from the Euphrates River (through the Urfa tunnels in Turkey and from Lake Assad in Syria) will alter the water balance again. Today, the flow of the upper Balikh River mainly consists of untreated wastewater from Tell Abyad.

In general, the lower Balikh has a wide riverbed. The import of irrigation water from Lake Assad to the Balikh sub-basin also impacts the river's hydrology. The Balikh essentially acts as a drain for the return flows from the Balikh Irrigation Projects (see below). According to official figures, the Balikh has an average discharge of 6.8 m^3/s (214 MCM/yr), with a maximum discharge of up to 35 m^3/s during floods (1,104 MCM/yr).[12] However, values in the lower basin could well be higher as the measurement location was not specified. The Balikh River flow contribution to the Euphrates is estimated at

Ain al Arous Spring, Syria, 2009. Source: Andreas Renck.

Table 2. Mean annual flows of the Balikh River

COUNTRY	RIVER	PERIOD	FLOW (m^3/s)			FLOW (MCM/yr)	SOURCE
			MEAN	MINIMUM	MAXIMUM		
Turkey	Jallab	1980s	3.5	..	..	111	GAP 1980 in Kolars and Mitchell, 1991, p. 112.
Syria	Ain al Arous Spring		6.0	..	..	189	USAID 1980 in Kolars and Mitchell, 1991, p. 112.
	Total Balikh		..	..	..	300	Kolars and Mitchell, 1991, p. 112; Beaumont, 1996, p. 142.
Syria, Turkey	Balikh/Jallab	2001	4.4	0.5	20.0	139	ACSAD and UNEP-ROWA, 2001, p. 22.
Syria	Balikh	2002-2006	6.8	—	35.2	214	Central Bureau of Statistics in the Syrian Arab Republic, 2010.

Source: Compiled by ESCWA-BGR.

around 0.86% of annual Euphrates flow. Flooding is an issue in many parts of this relatively flat sub-basin, and flood protection dams have been built along the whole river course, even across the Syrian-Turkish border.

WATER RESOURCES MANAGEMENT

Land use patterns in the Syrian and Turkish parts of the Balikh/Jallab sub-basin were traditionally centred on rain-fed agriculture and livestock grazing with limited irrigation in the major floodplains. However, the development of large-scale irrigation projects in the late 1980s has led to widespread development of irrigated agriculture.[13]

The Urfa-Harran Project is the largest irrigation project in the Turkish part of the Balikh/Jallab sub-basin. As one of the first projects within GAP, it imports irrigation water through the Urfa-Harran tunnels from the Atatürk Dam reservoir, and irrigates 140,000 ha of land, with a further 8,000 ha under construction.[14] The project currently encompasses about half of the established irrigated areas (277,123 ha) in GAP irrigation projects on the Euphrates.[15] A project of this size requires an estimated water import of 1,481 MCM/yr into the Balikh/Jallab sub-basin.[16] Consequently, and as mentioned above, the Jallab has been transformed from an intermittent stream into a perennial river, carrying irrigation return flows from GAP.

Irrigated agriculture is also practiced in the Syrian part of the basin, though satellite imagery suggests it appears to be less intensive and more scattered. Syria has been pursuing an irrigation development strategy in the Euphrates Basin since the 1980s. One of the largest projects is the Balikh Irrigation Project, which imports irrigation water from Lake Assad on the Euphrates River.[17] Original plans aimed to irrigate a total of 185,000 ha of land, requiring the annual import of 1,850 MCM from the Euphrates.[18] So far about 90,000 ha are irrigated, of which 57,000 ha drain towards the Balikh River.[19] This results in an annual import of 570 MCM from the Euphrates.[20] Together with the Turkish import of approximately 1,481 MCM/yr, the total amount of water imported into the Balikh/Jallab sub-basin is almost seven times as high as the total natural flow of the Balikh/Jallab. This obviously has an increasingly significant impact on the basin.

WATER QUALITY & ENVIRONMENTAL ISSUES

While water flow is increasing as a result of agricultural developments in the upper catchment of the Jallab, water quality is deteriorating due to saline drainage waters from Syrian and Turkish irrigation activities. Data from 1996-1999 shows that the salinity level of the Jallab was already high when it entered Syria, with a mean EC value of 1,528 µS/cm (Table 3).[21] Recent information indicates that the salinity of the Jallab is at least double that of the Ain al Arous Spring, the source of the Balikh in Syria. Downstream salinity increases further with the return waters from the Balikh Irrigation Project and other agricultural activities along the river. The discharge of sewage water from urban areas such as Akcakale and Harran in Turkey, and Tell Abyad in the upper Balikh further contribute to the river's salinization and pollution. While detailed long-term information on water quality is not available, predictions from the 1990s concerning the increase in nutrients in the river are probably accurate.[22]

The increased salinity does not necessarily affect agricultural activities in the lower Balikh Basin, as the large irrigation schemes do not use water from the Balikh, and receive relatively clean water from the Euphrates. Nevertheless, in the long term salts and other pollutants in the Balikh will impact Euphrates water quality after the confluence of the two rivers just downstream from Raqqah. At this stage, however, it is difficult to determine the extent of this problem. The absolute volume of Balikh irrigation return flow is small compared to the total Euphrates river flow and thus unlikely to affect water quality considerably. However, irrigation return flows may have significant impact during periods of maximum irrigation (i.e. late spring and early summer) when the Euphrates flow is reduced.

Table 3. **Mean Electrical Conductivity (EC) values for Ain al Arous Spring, Jallab and Balikh Rivers for different years**

PERIOD	STATION	EC (µS/cm)	SOURCE
2010	Ain al Arous Spring	760	BGR, 2010.
1996-1999	Jallab[a]	1,528 (680-2,830)	ACSAD and UNEP-ROWA, 2001.
2010		1,800	BGR, 2010.
		1,729	Ministry of Irrigation in the Syrian Arab Republic, 2012.
2010	Balikh	2,750 (1,486-3,100)	BGR, 2010; Ministry of Irrigation in the Syrian Arab Republic, 2012.

Source: Compiled by ESCWA-BGR.
Notes:
- The mean values from BGR, 2010 refer to measurements taken in October 2010, whereas the value from the Ministry of Irrigation in the Syrian Arab Republic, 2012, is the yearly average.
- The values in brackets refer to the range.
(a) Measured at Tell Abyad.

The Jallab River on the Syrian-Turkish border, Syria, 2010. Source: Andreas Renck.

Khabour

The Khabour River is the largest of the three shared Euphrates tributaries in terms of length and mean annual discharge. The Khabour Basin is often described as the most complicated element of the Euphrates system as the river's different branches originate both in Syria and in Turkey (see Overview Map).[23]

The Khabour Basin is shared by Syria and Turkey, with a small part of the basin in Iraq. The drainage basin covers a surface area of almost 36,200 km^2, of which 28% lies in Turkey and 66% in Syria (Figure 4).[24] To the south-east, around 6% of the basin falls within Iraqi territory.[25]

The Khabour River has a total length of 388 km of which 308 km lie in Syria.[26] The river discharges into the Euphrates near Deir ez Zor.[27] Several wadis contribute to the Khabour, creating the upper Khabour or Khabour Triangle. They include the Djirdjib, the Zergane and the Jagh Jagh – permanent streams which are important for irrigation during the summer months. Others streams such as Breibitch, Jarrah, Khneizir and Rumeli are intermittent and only flow during the rainy season.

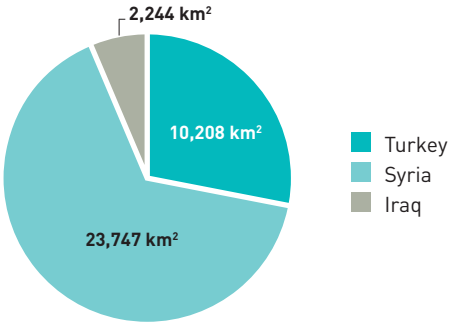
The Khabour sub-basin is characterized by a Mediterranean climate with dry, hot summers and wet, cool winters. From north to south, yearly precipitation decreases from more than 400 mm to less than 200 mm.

HYDROLOGICAL CHARACTERISTICS

The Khabour River is fed by rainfall and snow-melt from the Armenian Highlands. Precipitation and groundwater are the main sources of runoff in the basin.[28] After the river crosses the Syrian-Turkish border, the stream receives substantial input from several major karstic springs[29] near the town of Ras al Ain.

With regards to flow rates, the earliest period covered in the literature refers to a location on the Khabour near the confluence with the Euphrates: for the period 1943-1961, the mean discharge was 50.7 m^3/s (1,599 MCM/yr)[30] (Table 4). A detailed analysis of 1966 data concluded that the natural discharge of the Khabour River and its tributaries was 57.5 m^3/s (1,813 MCM/yr), of which 47.7 m^3/s (83%) were attributable to Turkey and 9.8 m^3/s (17%) to Syria.[31] Similar values were maintained during the period 1961-1980, with mean annual discharge values ranging from 46.9 m^3/s (1,477 MCM) at Ras al Ain near the Syrian-Turkish border, to 67.2 m^3/s (2,117 MCM) at Hasakah after the confluence of all Khabour tributaries.

Figure 4. **Distribution of the Khabour Basin area**



Source: Compiled by ESCWA-BGR.

In the following period 1981-2000, mean annual discharge volumes at Ras al Ain, Tal Tamer and Hasakah declined by 55%, 52.4% and 44% respectively compared to pre-1980 periods. Discharge at the Ras al Ain Spring – once the single-most important source of the Khabour and one of the largest karst springs in the world – declined from a mean annual discharge of 40 m^3/s in the 1980s[32] to only 14 m^3/s in 1998 and 7.38 m^3/s in 2003.[33] This decline has been widely attributed to the overexploitation of groundwater for irrigation purposes in the Turkish part of the Khabour catchment area.[34] A three-year regional drought between 1998 and 2001 could also explain the reduction in flows during this period. Since 1999, the lower Khabour reportedly runs dry in July and August.[35] According to recent data from the Syrian Central Bureau of Statistics, the mean annual discharge of the Khabour River in Syria at Ras al Ain between 2008 and 2010 was

The Khabour near Tell Halaf, Ras al Ain, Syria, 2009. Source: Bertramz.

Table 4. **Mean annual flows of the Khabour River in Syria**

STATION	PERIOD	FLOW (m^3/s)	FLOW (MCM/yr)	SOURCE
Calculated total	1966	57.5	1,813	Kolars and Mitchell, 1991, p. 191.
Near Euphrates confluence	1943-1961	50.7	1,600	ACSAD and UNEP-ROWA, 2001.[b]
Ras al Ain Spring	1961-1980	46.9	1,477	Oresic and Bahnan, 2005.
	1981-2000	25.8	813	
Tal Tamer	1961-1980	53.2	1,675	
	1981-2000	27.9	878	
Hasakah	1961-1980	67.2	2,117	
	1981-2000	29.3	924	
Ras al Ain Spring	2008	3.6	113.5	Central Bureau of Statistics in the Syrian Arab Republic, 2010.
	2009	4.3	135.6	
	2010	2.09	65.9	

Source: Compiled by ESCWA-BGR.
(a) Kolars and Mitchell, 1991, p. 191, states that 47.7 m^3/s or 1,504 MCM is attributed to Turkey and 9.8 m^3/s or 309 MCM to Syria.
(b) ACSAD and UNEP-ROWA, 2001, p. 22 indicates that the average values refer to the Souar station. Maximum and minimum values were given for Tal Tamer and Shadadah locations, respectively.

between 2.09 and 4.3 m^3/s[36] – less than 5-10% of the near-natural pre-1980 values (Table 4).

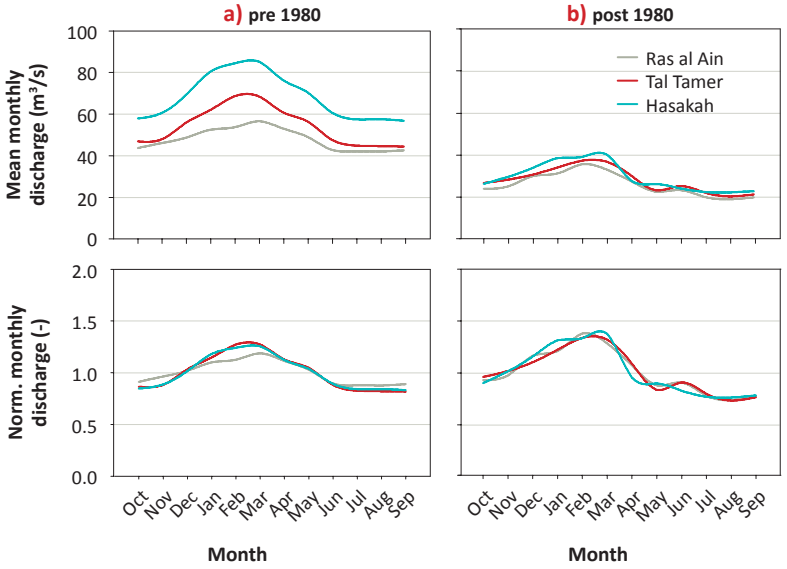
The Khabour River and its tributaries once played a significant role in determining the quantity and quality of Euphrates water, contributing up to 12% of annual Euphrates flow.[37] However, other calculations suggest that the Khabour only contributed a 7% share, if one assumes that the natural annual flow of the Euphrates River at the Syrian-Turkish border was 30 BCM before 1973 (see Chap. 1), and that the near-natural flow of the Khabour was around 2.1 BCM (see pre-1980 value at Hasakah, Table 4). Current values and shares are probably far lower, suggesting a flow contribution to the Euphrates River of 3.7% for the period 1980-2000. This contribution may have dropped further since 2000 (see 2008-2010 discharge values for Ras al Ain, Table 4).

Parts of the upper Khabour Basin in Turkey (Mardin-Ceylanpinar Plains) receive increasing amounts of Euphrates water that is imported from Lake Atatürk more than 260 km away. It is not clear how return flows and changes in abstraction patterns will affect local hydrology and water quality in Syria and Turkey in the long term.

Flow regime

Generally, the flow regime of the Khabour River at different gauging stations (Ras al Ain, Tal Tamer, Hasakah) shows a subtle high-flow season coinciding with winter rainfall from January to March and a prolonged but stable low-flow season from April to December. This limited seasonal variation compared to the main stem of the Euphrates or Tigris River can be ascribed to the strong groundwater influence[38] with relatively steady flow contributions throughout the year. The pre-1980 (1961-1980) and post-1980 (1981-2000) river flow regimes presented in Figure 5 show subtle changes with increased peak values in winter (February) and decreased low flows starting in April, possibly as a result of intensified irrigation in the catchment. However, engineering works in the catchment date back to the early 1960s and therefore the pre-1980 flow regimes may already reflect the effect of regulation to some extent. Changes to the snowfall and snow-melt regime as a result of climate variability and higher

Figure 5. **Mean monthly flow regimes of the Ras al Ain Spring and Khabour River at different gauging stations (pre- and post-1980)**



Source: Compiled by ESCWA-BGR based on data published in Oresic and Bahnan, 2005.

temperatures may have triggered an early snow-melt contribution to stream-flow. However, this phenomenon requires more in-depth research.

WATER RESOURCES MANAGEMENT

For millennia, rain-fed agriculture was prevalent in the upper Khabour Basin. Along the lower Khabour, nomadic tribes and small settled communities practised a limited amount of gravity irrigation for cultivation. In the 1940s this began to change and extensive irrigation schemes in both Syria and Turkey reshaped land use, the natural water regime and the basin's character. Today intensive irrigated agriculture dominates the landscape, dams have been built to support those initiatives and the Khabour steppe no longer exists in its original form.[39]

Turkey

Turkey developed dams and extensive irrigation schemes in the Turkish part of the Khabour Basin as part of GAP (see Chap.1). The main schemes in the Khabour Basin are the Mardin-Ceylanpınar Projects, which are designed to irrigate 302,000 ha.[40] Another planned irrigation project will import water from the Tigris River into the Khabour Basin and irrigate 89,000 ha upon completion.[41] Euphrates water from the Atatürk Dam is also being used for irrigation purposes in the Turkish part of the Khabour Basin.[42]

As Turkish irrigation water imports will increase with every completed scheme, high quantities of irrigation return water will continue to alter the river's flow regime, in addition to reducing water quality due to agro-chemicals and higher salinity.[43]

Syria

When Syria began to invest in irrigated agriculture in the 1950s and 1960s, heavy emphasis was laid on the development of the lower Khabour region and parts of the upper Khabour. In the following decades, large parts of Hasakah Governorate that lie in the Khabour Basin were equipped with dams and canals. Three dams were built as part of the Khabour River Basin Irrigation Project: the Hasakah East and Hasakah West Dams were built on tributaries of the Khabour between the Ras al Ain Spring and Hasakah. The Bassel al Assad Dam was built on the Khabour River, 25 km south of Hasakah (Table 5). These diversion and storage structures supply comprehensive irrigation systems such as the Hasakah East and West Irrigation Projects. As a result, land irrigated by surface water gravitation in Hasakah Governorate increased eightfold from 7,400 ha to 65,000 ha between 1990 and 2000.[44] Over this period, Hasakah became the most important agricultural region in Syria, producing around 40% of the country's wheat and cotton supply, two of the main irrigated crops in Syria.[45] Agricultural land use in the Khabour Basin has undergone significant change in recent years, with major developments between 1990 and 2000. According to a remote sensing study that covers this period, changes in the distribution of irrigation projects in the Khabour Basin have led to significant social shifts.[46] Rain-fed agriculture in the upper Khabour and floodplain irrigation by gravity along the lower Khabour were replaced by groundwater irrigation and/or canal networks in scattered areas in the steppe. This drastic change is linked to the introduction of diesel pumps, which tapped deep groundwater reservoirs, as well as the subsequent establishment of dams and canals.

Total irrigated land area in Hasakah Governorate in 2010 was officially estimated at 358,000 ha, of which about 45,000 ha were irrigated by rivers and springs, while 313,000 ha were irrigated by wells.[47] Irrigated land from surface water resources in Hasakah seems to have diminished slightly from 65,000 ha in 2000[48] to 45,000 ha in 2010. Lands irrigated by the Khabour were estimated at 55,550 ha in 2010, in addition to 4,000 ha irrigated by the Jagh Jagh River, a Khabour tributary.[49] This amounts to nearly 60,000 ha of surface-irrigated land, in Hasakah Governorate but probably also beyond.

As groundwater is the main source of irrigation water in the basin, it is important to note that more water is being used from underground sources than is naturally replenished.[50] This is reflected in pumping from wells that are more than 100 m deep, in addition to greater differences between water levels before and after the irrigation season.[51] Summer cultivation using groundwater has reportedly been banned in Syria but not details are available and full

Table 5. **Main dams in the Khabour Basin in Syria**

NAME	COMPLETION YEAR	CAPACITY (MCM)	PURPOSE[a]	BACKGROUND INFORMATION
Bassel al Assad (Hasakah South or Khabour)	..	605	I	On the Khabour River. Projected irrigated area: 50,000 ha
Hasakah East (8 March)	1990	233	I	On a Khabour tributary.
Hasakah West (7 April)	1990	91	I	On a Khabour tributary. Projected irrigated area: 48,000 ha

Source: Compiled by ESCWA-BGR based on Ministry of Irrigation in the Syrian Arab Republic, 2010; Ministry of Irrigation in the Syrian Arab Republic, 2006.
(a) Irrigation (I).

The Khabour near Tell Sheikh Hamad, Syria, 2009. Source: Bertramz.

implementation remains rather unlikely.[52] In 2009, Syria launched the Al Khabour River Basin Irrigation Development Project to further enhance agricultural productivity and create jobs in one of the country's poorest areas, the region around Hasakah, Deir ez Zor and Raqqah.[53]

The new development project plans to bring water from the Tigris River into the Khabour Basin by means of an integrated inter-basin transfer system. The water will irrigate about 150,000 ha of land in the Hasakah region, in addition to generating electricity.[54] No details are known regarding the state of implementation of this project in view of the current events.

Iraq

Iraq has no significant projects in the Khabour Basin as it has limited possibility to develop water resources in this area. However, discharge from the Euphrates tributaries affects water quantity and quality in Iraq.

WATER QUALITY & ENVIRONMENTAL ISSUES

Very little information is available regarding water quality of the Khabour. At its source in Syria, the river water is considered suitable for drinking according to Syrian standards. However farther downstream, it is threatened by pollution from untreated wastewater that is directly discharged into the river from surrounding urban settlements.[55] Water samples from the Bassel al Assad Dam reservoir have revealed extremely high Biochemical Oxygen Demand (BOD) values reaching 490 mg/L.[56]

Groundwater in the Euphrates Sub-Basins

The two main tributaries of the Euphrates River in Syria, the Balikh and Khabour, are fed by two large springs, the Ain al Arous and the Ras al Ain, which originate along Syria's northern border from the Jezira Limestone Aquifer (Midyat Aquifer) of mainly Eocene age (see Figure 6 below and Chap. 24). The aquifer's main recharge areas are located in south-eastern Anatolia in Turkish territory. The Ain al Arous and Ras al Ain Springs previously had an average discharge of 6 m^3/s and 40 m^3/s respectively,[57] but spring discharge has been significantly reduced due to groundwater extraction from a large number of wells in Syria and Turkey. Recent estimates cited a discharge of 3 m^3/s for the Ras al Ain Spring area.[58]

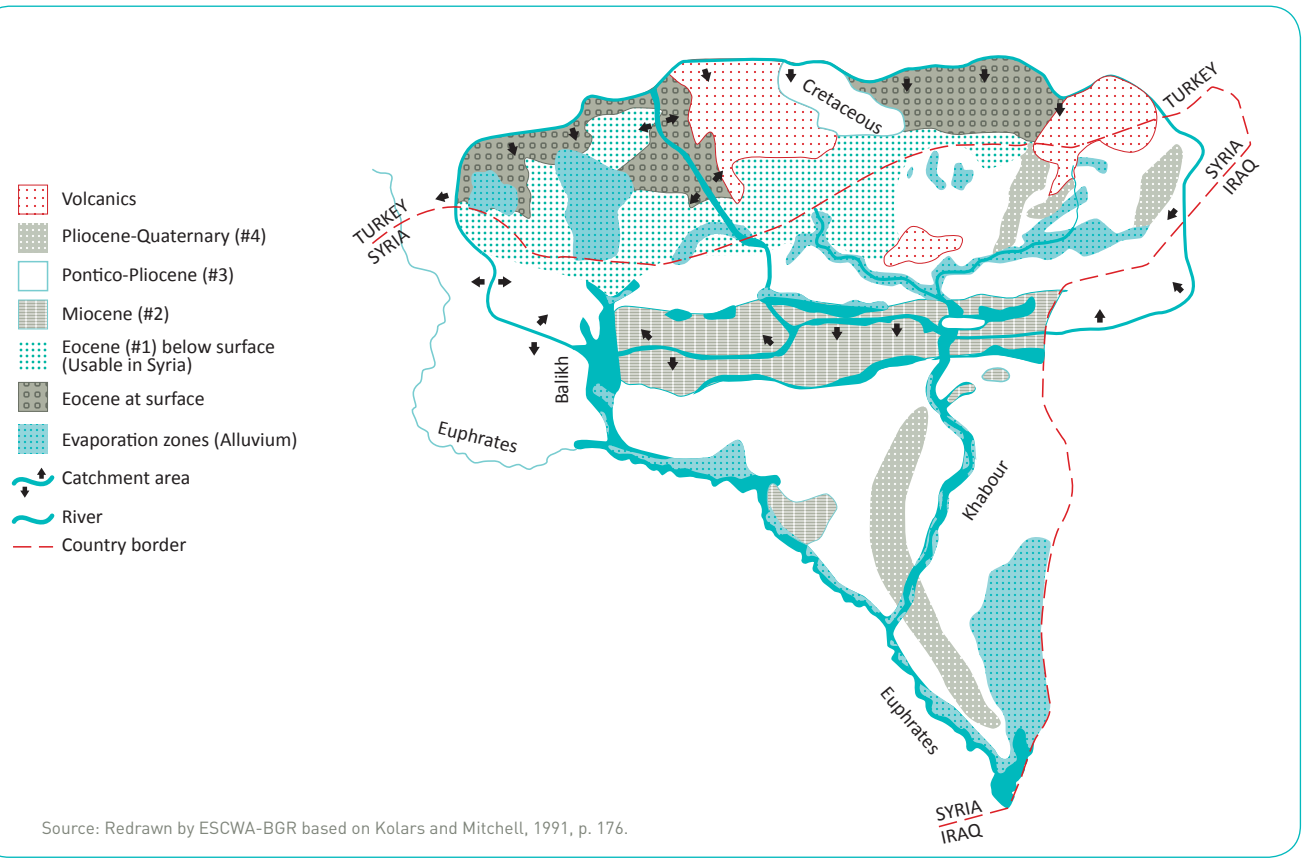
The Jagh Jagh River, a tributary of the Khabour, is fed by springs in the Miocene Limestone aquifer in Turkey and flows into the Syrian Jezira[59] with a mean flow volume of 2-3 m^3/s. The water of the Jagh Jagh River is consumed by irrigation and lost to evaporation in swamps in the area of the Quaternary Radd Aquifer in the northern Syrian Jezira. The Ar Rad Aquifer dominates the north-eastern part of the Khabour Basin. Aquifer productivity decreases to the south as water salinity increases.[60]

Estimates by FAO assess renewable groundwater resources in the Khabour Basin at 650 MCM/yr, though more recent estimates are much higher.[61]

Groundwater flow southward across the Syrian-Turkish border is significant and has been estimated at 1,200 MCM/yr.[62] It can be assumed, however, that flow dynamics have changed significantly as a consequence of large-scale groundwater abstractions in both countries over recent decades.

Base flow in the Sajur River is fed by Paleogene carbonate aquifers in the Gaziantep area in south-eastern Turkey.

Figure 6. **Aquifers in the Jezira catchment area**



Source: Redrawn by ESCWA-BGR based on Kolars and Mitchell, 1991, p. 176.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no agreements in place between the riparian countries that specifically refer to the tributary rivers discussed in this chapter.

COOPERATION

There is no information on cooperation between the riparian countries regarding the three tributaries discussed in this chapter.

OUTLOOK

Over the last four decades both the Balikh/Jallab and Khabour sub-basins have experienced far-reaching changes that impacted flow trends and water quality. As irrigation return water from large agricultural development projects in Syria and Turkey continues to increase, the sub-basins are likely to be affected in the future as well.

Prior to the Syrian crisis that erupted in March 2011, transboundary issues such as the water quality of the Balikh were put aside in the interest of continued good relations between the two countries. The relationship between Syria and Turkey has seriously deteriorated since then, and it is not clear how the two countries will handle cross-border water issues in the future, particularly as the two sub-basins are important for the socio-economic development of both riparians.

The Sajur River, Syria, 2009. Source: Andreas Renck.

Notes

1. Medzini and Wolf, 2005.
2. Basin area was estimated from a digital elevation model (HydroSHEDS) similar to Lehner et al., 2008.
3. Central Bureau of Statistics in the Syrian Arab Republic, 2010.
4. Basin area was estimated from a digital elevation model (HydroSHEDS) similar to Lehner et al., 2008.
5. ACSAD and UNEP-ROWA, 2001. Urfa is also referred to as Sanliurfa (Yesilnacar and Gulluoglu, 2007).
6. Syrian Geographical Society, 2010.
7. For Syria, the Balikh River starts at the point where the Ain al Arous Spring feeds the river.
8. Kolars and Mitchell, 1991, p. 112; Central Bureau of Statistics in the Syrian Arab Republic, 2010.
9. Kolars and Mitchell, 1991, p. 111 predicted that return flows from the Sanliurfa-Harran region would increase the flow of the Balikh to 368-928 MCM. Interviews in Syria (UN-ESCWA and BGR, 2010) have confirmed this trend, and mean discharge in the Jallab was estimated at 10-20 m^3/s (315-630 MCM/yr) with maximum discharge of about 100 m^3/s after heavy rains in the upper catchment.
10. The upper Balikh River consists of the 12 km stretch from Ain al Arous to the confluence with the Jallab.
11. According to ACSAD and UNEP-ROWA, 2001, Ain al Arous has completely dried up since 1985.
12. ACSAD and UNEP-ROWA, 2001; Central Bureau of Statistics in the Syrian Arab Republic, 2010.
13. Hole, 2009; Beeley in Beaumont, 1996, p. 140: agricultural activities in the Turkish part of the Balikh focused mainly on the cultivation of rain-fed cereals.
14. Ministry of Environment and Forestry in Turkey, 2009, p. 61.
15. The total planned irrigated areas within the entire GAP region adds up to 1.2 million ha.
16. According to Turkish Government estimates in Beaumont, 1996, p. 142. In 2002, the water conveyed to the plain for irrigation amounted to 1,048 MCM. See Yesilnacar and Gulluoglu, 2007, p. 208.
17. Hole, 2009, p. 145.
18. According to an assumed water application rate of approx. 10,000 m^3/ha/yr. Beaumont, 1996, p. 143, 144.
19. According to internal report by UN-ESCWA and BGR, 2010.
20. Applying the same rate of water requirements for land as Beaumont, 1996, p. 144.
21. The recommended EC limit value for irrigation water is set at 700 µS/cm by FAO, 1994.
22. Beaumont, 1996; Kolars and Mitchell, 1991 had predicted that the salt and nutrient loads of the river would increase substantially if both the Syrian and Turkish irrigation projects in the Balikh Basin were implemented as planned.
23. Kibaroglu et al., 2005, p. 163.
24. Basin area was estimated from a digital elevation model (HydroSHEDS) similar to Lehner et al., 2008.
25. Kolars and Mitchell, 1991, p. 168. According to Daoudy, 2005, p. 65 and a report issued by the Ministry of Environment in Iraq et al., 2006, p. 71 the Khabour Basin covers 36,900 km^2.
26. For Kolars and Mitchell, 1991, p. 168 the river extends 120 km in Turkey and flows for 486 km in Syria. According to the Central Bureau of Statistics in the Syrian Arab Republic, 2010, the Khabour has a total length of 477 km of which 402 km lie in Syria.
27. Zaitchik et al., 2002, p. 4.
28. Kolars and Mitchell, 1991, p. 179.
29. Burdon and Safadi, 1963.
30. ACSAD and UNEP-ROWA, 2001.
31. Calculations by Kolars and Mitchell, 1991, p. 191 were based on data from 1966.
32. Hole, 2009, p. 6; a similar value is given by Burdon and Safadi, 1963 for the Ras al Ain Spring.
33. FAO, 2005 in Hole, 2009, p. 6.
34. ACSAD and UNEP-ROWA, 2001.
35. Zaitchik et al., 2002.
36. Central Bureau of Statistics in the Syrian Arab Republic, 2010.
37. Kolars and Mitchell, 1991, p. 81.
38. Kolars and Mitchell, 1991.
39. Hole, 2009; Zaitchik et al., 2002.
40. Ministry of Development in Turkey, 2011.
41. Beaumont, 1996, p. 142 refers in this context to the Nusaybin-Cizre-Idil Project.
42. Hole, 2009, p. 10.
43. Beaumont, 1996, p. 142.
44. Oresic and Bahnan, 2005.
45. Ibid.
46. Zaitchik et al., 2002.
47. Central Bureau of Statistics in the Syrian Arab Republic, 2011.
48. Oresic and Bahnan, 2006.
49. Ministry of Irrigation in the Syrian Arab Republic, 2012.
50. Oresic and Bahnan, 2006.
51. Ibid. Barnes, 2009 reports that during the 1990s, the lower reaches of the Khabour ran dry completely as a result of an expansion in the number of wells in the region. Groundwater pumping close to rivers can induce seepage from the riverbed with an increased hydraulic gradient towards groundwater aquifers.
52. Hole, 2009, p. 8.
53. IFAD, 2009, p. 7.
54. Ministry of Irrigation in the Syrian Arab Republic, 2010.
55. Ministry of Irrigation in the Syrian Arab Republic, 2012.
56. Ibid.
57. FAO and UNDP, 1966.
58. Al-Charideh and Abou-Zakhem, 2009. See Chap. 24.
59. The Khabour Basin in Syria is known as the Jezira. It is divided into the Lower Jezira which stretches north from the city of Deir ez Zor on the Euphrates to Jebel Abdel Aziz in the west and the Sinjar Mountains to the east of the Khabour. The Upper Jezira is located north of these mountains, extending from the city of Hasakah in Syria at the confluence of the Khabour and Jagh Jagh Rivers to the Anti-Taurus Mountains in Turkey (Kolars and Mitchell, 1991, p. 168).
60. Wakil, 1993.
61. Ibid.
62. FAO, 2009.

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Chapter 3

Tigris River Basin

Tigris River Basin

The Tigris at Baghad, Iraq, 2010. Source: Larisa Epatko.

EXECUTIVE SUMMARY

The Tigris River is the second largest river in Western Asia. Its basin is shared by four countries: Iran, Iraq, Syria and Turkey. Besides contributions from precipitation that originates in the Armenian Highlands, the Tigris is fed by numerous tributaries that rise in the Zagros Mountains in Iran, Iraq and Turkey.
The Tigris has a higher water yield than the Euphrates River. Historically, the natural annual flow of the Tigris at the Iraqi-Syrian-Turkish border was around 21 BCM. In recent years, Tigris flow volumes have been affected by large water development projects in Iraq and Turkey. The flow volume records for Kut show a significant negative trend. Water supplies to the Mesopotamian Marshlands have also dwindled over the past 40 years.

In addition to Turkey's use of the Tigris River for the Southeastern Anatolia Project (GAP), Iraq has built several dams and diversion projects on the river, centring on the Tharthar Canal between the Euphrates and Tigris. Water from the Tigris is mainly used for agriculture, with irrigation projects in all riparian countries.
Water quality in the basin is primarily threatened by rising salinity rates resulting from intensive irrigated agriculture and high evaporation rates.
Apart from historic agreements that jointly address the Euphrates and Tigris Rivers, water resources in the Tigris Basin have not received much attention at the negotiation table. There is no basin-wide agreement in place, and the Tigris River has been the subject of only one bilateral agreement.

BASIN FACTS

RIPARIAN COUNTRIES	Iran, Iraq, Syria, Turkey
BASIN AREA SHARES	Iran 19%, Iraq 56.1%, Syria 0.4%, Turkey 24.5%
BASIN AREA	221,000 km^2
RIVER LENGTH	1,800 km
MEAN ANNUAL FLOW VOLUME	26 BCM (at Kut)
MAIN DAMS	14 (max. storage capacity 116.5 BCM)
PROJECTED IRRIGATED AREA (IN BASIN)	~4.6 million ha
PROJECTED IRRIGATED AREA (OUTSIDE OF BASIN)	150,000 ha
BASIN POPULATION	23.4 million

MAIN AGREEMENTS

IRAQ - TURKEY	1946 – The Treaty of Friendship and Good Neighbourly Relations is the first legal instrument of cooperation on water between the two riparian countries. Among others, it addresses flow regulation on the Tigris and Euphrates and their tributaries and the monitoring of flow data. The parties also commit to the principle of prior notification with regards to water infrastructure projects.
IRAN - IRAQ	1975 – Agreement on the use of shared watercourses in which the signatory parties agree on the division of a number of shared Tigris tributaries.
IRAQ - SYRIA	2002 – Agreement on the establishment of a pumping station on the Tigris River in Syria, specifying project area and volume of water extracted.
SYRIA - TURKEY	2009 – The Turkish-Syrian Strategic Cooperation Council Agreement covers water issues and can be regarded as the Turkish approval of Syria's pumping project on the Tigris River.

KEY CONCERNS

WATER QUANTITY

Water use for irrigation and hydropower production is constantly increasing, with numerous operational and planned projects along the river's main course and its tributaries placing pressure on flow regimes in the basin. Periodic droughts affect water supply and may impact water allocation to different sectors in the future. There is no basin-wide agreement and no common approach or consensus on how to regard the Euphrates and Tigris Rivers (i.e whether the two rivers should be considered part of a single watercourse system or as separate basins).

While the development of new infrastructure along the river course has in general not sparked disputes among basin countries, the Ilisu Dam Project in Turkey remains controversial. Iran's damming of the Wand River has also caused tensions between Iran and Iraq.

WATER QUALITY

Water quality is relatively good in the upper part of the basin, but salinity levels increase in the Iraqi part of the basin.

Rising pollution from domestic and industrial sources is a cause for concern.

BIODIVERSITY

The Mesopotamian Marshes have suffered severe damage as a result of upstream damming projects in the 20th century, reducing the marshes to 14% of their original size. More than half of the original area of this unique freshwater system has recently been rehabilitated in a joint effort by the Iraqi Government and international organizations.

OVERVIEW MAP

Tigris River Basin

- International boundary
- Capital
- Selected city, town
- Basin boundary
- River
- Intermittent river, wadi
- Canal, irrigation tunnel
- Freshwater lake
- Saltwater lake
- Spring
- GAP project
- Wetland
- Dam
- Monitoring station
- Climate station

ESCWA BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

Disclaimer
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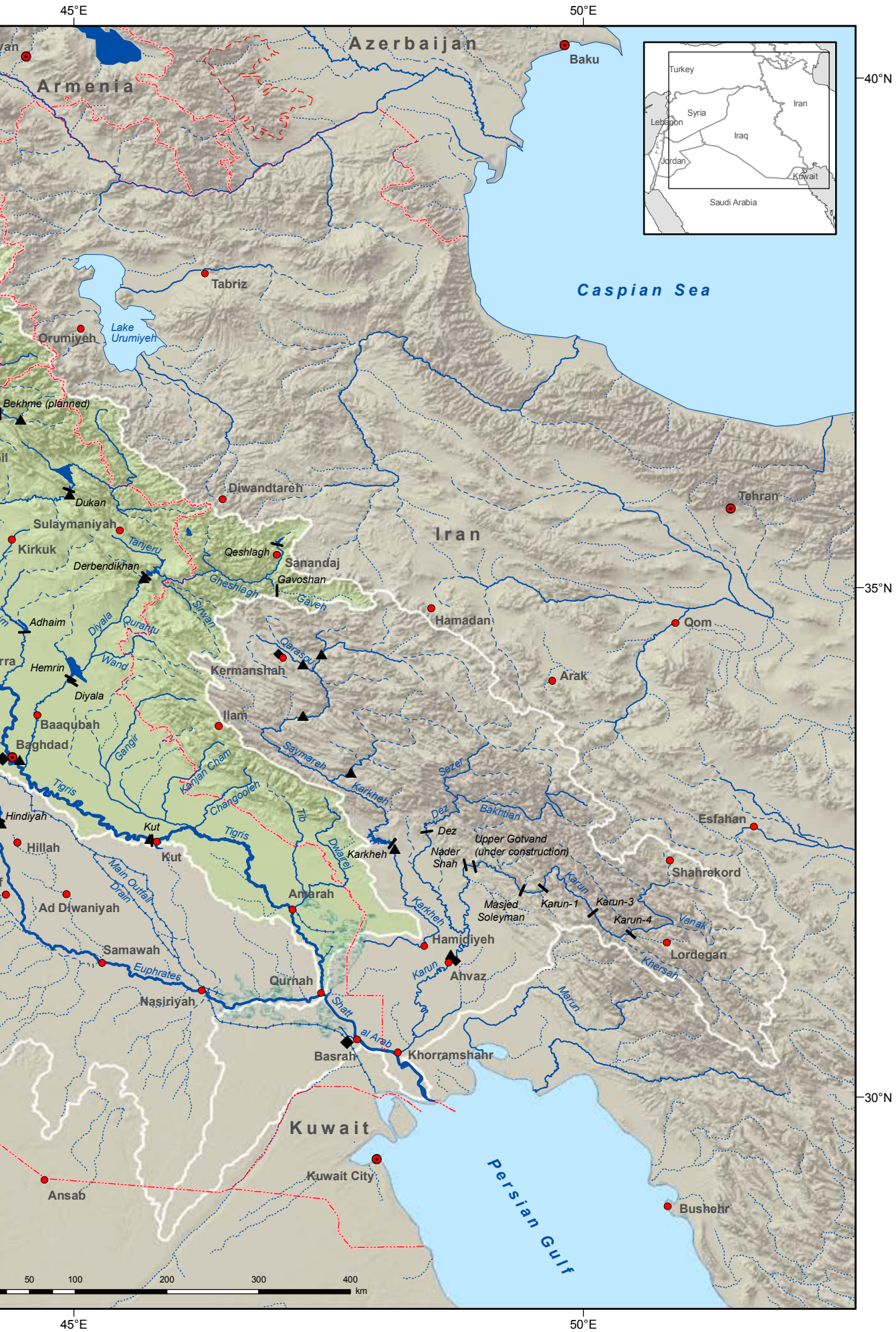
45°E
50°E
40°N
35°N
30°N
Azerbaijan
Armenia
Baku
Caspian Sea
Tabriz
Lake Urumiyeh
Orumiyeh
Bekhme (planned)
Dukan
Diwandareh
Sulaymaniyah
Kirkuk
Tanjeru
Derbendikhan
Qeshlagh
Sanandaj
Gavoshan
Gheshlagh
Gaveh
Sirwan
Diyala
Qurahtu
Adhaim
Hemrin
Wand
Diyala
Qarasu
Kermanshah
Iran
Tehran
Hamadan
Qom
Arak
Ilam
Baaqubah
Baghdad
Gangir
Saymareh
Kanjan Cham
Changooleh
Tigris
Sezer
Karkheh
Dez
Bakhtiari
Esfahan
Hindiyah
Kut
Hillah
Tigris
Tib
Dwairej
Karkheh
Dez
Upper Gotvand (under construction)
Nader Shah
Shahrekord
Main Outfall Drain
Ad Diwaniyah
Amarah
Karun
Masjed Soleyman
Karun-1
Karun-3
Karun-4
Vanak
Samawah
Euphrates
Hamidiyeh
Lordegan
Khersan
Qurnah
Ahvaz
Karun
Marun
Nasiriyah
Shatt al Arab
Basrah
Khorramshahr
Kuwait
Kuwait City
Ansab
Persian Gulf
Bushehr
50
100
200
300
400
km
Turkey
Syria
Iran
Lebanon
Iraq
Jordan
Kuwait
Saudi Arabia

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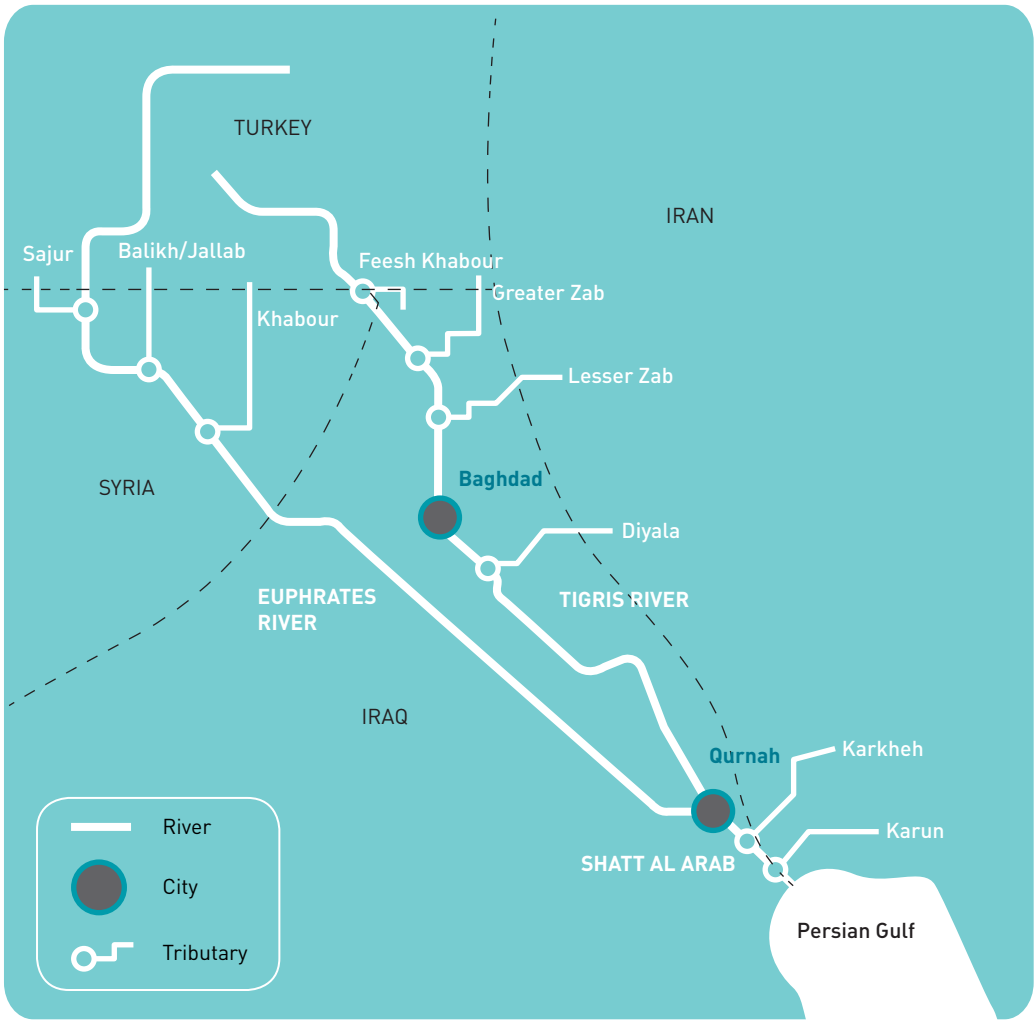
Defining the Euphrates-Tigris-Shatt al Arab Basins

The Euphrates-Tigris-Shatt Al Arab river system constitutes by far the largest surface water resource in the study area. Its combined topographic catchment covers more than 900,000 km^2 from the headwaters in the Taurus-Zagros Mountain Range to the Mesopotamian lowlands and the only outlet to the Persian Gulf, the Shatt Al Arab (Fig. 1). The overall basin is also home to around 54 million people in Iran, Iraq, Syria and Turkey. Given its importance and in order to adequately reflect the specific conditions as well as its complex hydrology, the Inventory dedicates five chapters to this river system.

The Euphrates River Basin (Chap. 1) and Tigris River Basin (Chap. 3) each have a different dynamic and set of characteristics, particularly with regard to their riparian countries, tributaries and contribution to discharge, as well as water use patterns and water quality. The shared tributaries of the Euphrates River (Chap.2) and the major shared tributaries of the Tigris River (Chap. 4) are covered in more detail in two separate chapters in order to highlight the role of these rivers and draw attention to local water issues and transboundary impacts. Chapter 4 also provides information on water use in Iran, which does not share the watercourse of the Tigris River itself but hosts important tributaries within the Tigris Basin. Finally, the Shatt al Arab River is discussed together with two additional major tributaries, the Karkheh and the Karun Rivers, which discharge directly into the Mesopotamian Marshes or the Shatt al Arab itself, and are hence neither part of the Euphrates or Tigris River basins (Chap. 5).

Figure 1. Sketch of the Mesopotamian river system

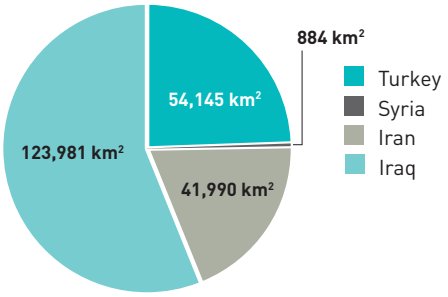


Source: Compiled by ESCWA-BGR.

Geography

The Tigris River originates in the Armenian Highlands in Turkey and flows south-east along a short stretch of the Syrian-Turkish border before entering Iraq (see Overview Map, Fig. 1). The river merges with the Euphrates River in southern Iraq to form the Shatt al Arab, which discharges into the Persian Gulf. The Tigris has four basin riparians: Iran, Iraq, Syria and Turkey. The basin extends over approximately 221,000 km^2, of which 24.5% is located in Turkey, 0.4% in Syria, 56.1% in Iraq and 19% in Iran (Figure 2).[1]

Figure 2. **Distribution of the Tigris Basin area**



Source: Compiled by ESCWA-BGR.

RIVER COURSE

The Tigris River is the second longest river in Western Asia, with a length of 1,800 km.[2] The river originates in the Taurus Mountains in Turkey, south of the Armenian Highlands and the city of Elazig, which lies at an altitude of 1,500 m asl. It is formed by the confluence of two headwater tributaries, the Batman, which drains from an altitude of approximately 4,000 m asl, and the Botan.

In general, the course of the Tigris is less meandering than that of the Euphrates. After covering a distance of almost 400 km in Turkey, it forms the Syrian-Turkish border[3] for about 47 km and then flows through Iraq for more than 1,350 km.

The Tigris Basin has a number of tributaries, most of which are shared by Iraq and Turkey or Iran and Iraq (Table 1).[4]

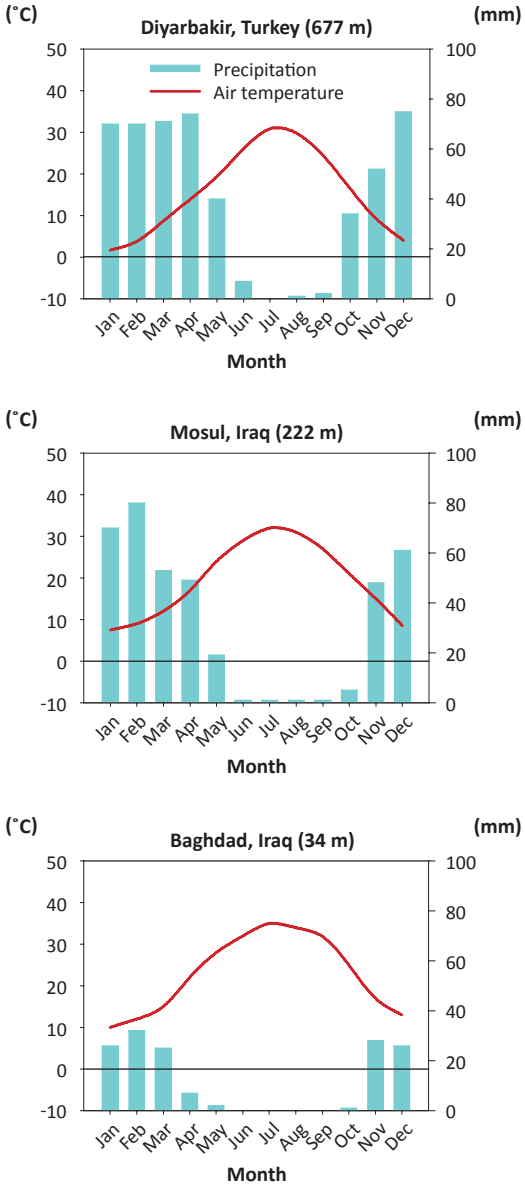
Table 1. **Main tributaries of the Tigris River**

HEADWATERS	
Batman	This river is a major tributary of the Tigris and originates in the Anti-Taurus Mountains in Turkey at an altitude of 2,500-4,500 m asl. The region is known for its oil fields.
Botan	This is a tributary of the Tigris in south-eastern Turkey. It comprises several small tributaries, some of which originate around Lake Van at an elevation of 1,000-1,500 m asl.
LOWER TRIBUTARIES	
Feesh Khabour	This tributary is shared between Iraq and Turkey. It rises in Sırnak, Turkey, and flows through Zakho, Iraq, before its confluence with the Tigris at the Iraqi-Turkish border. The Feesh Khabour delineates the international border between Iraq and Turkey. Its mean annual flow volume at the confluence with the Tigris is approximately 2 BCM.
Greater Zab	This river, which is shared by Iraq and Turkey, originates in Turkey and is the largest Tigris tributary. It supplies the Tigris River with an average annual flow volume of 12.7 BCM.
Lesser Zab	The Lesser Zab is shared by Iran and Iraq. It originates in Iran, not far from the Iraqi border. The average annual flow volume of the Lesser Zab is about 7.8 BCM, contributing an average of 249 m^3/s to the Tigris.
Adhaim	While not a shared tributary in itself, the Adhaim is an intermittent stream that drains an area of about 13,000 km^2 in Iraq. The river generates about 0.79 BCM annually at its confluence with the Tigris and is subject to flash flooding.
Diyala	Shared by Iran and Iraq, this tributary also forms the border between the two countries for about 30 km. The Diyala has a mean annual flow volume of 4.6 BCM.
Tib	The Tib is shared by Iran and Iraq. Its average annual discharge is about 1 BCM.
Dwairej	The Dwairej originates in Iran and is shared with Iraq. Its average annual discharge is less than 1 BCM. The Dwairej meets the Tib in the city of Amarah.

Source: Compiled by ESCWA-BGR based on USGS, 2012; ACSAD and UNEP-ROWA, 2001; Shahin, 2007; FAO, 2009; UN-ESCWA, 1981; Ministry of Environment in Iraq et al., 2006a.

Six main tributaries and several smaller rivers join the Tigris in Iraq. The river receives water from its first upstream tributary, the Feesh Khabour,[5] in the border region before flowing through Iraqi Kurdistan for almost 190 km and crossing Mosul, the largest city in northern Iraq. Downstream from Mosul, two shared tributaries, the Greater and Lesser Zab (or Little Zab), contribute to the Tigris. Farther downstream, the smaller Adhaim River, which originates in Iraq, joins the Tigris. North of Baghdad, a barrage diverts water from the Tigris to the Euphrates via the Tharthar Canal. Downstream of Baghdad, the Tigris flows through a flat landscape for 343 km, where it receives water from the shared Iranian-Iraqi Diyala River and several wadis before forming the Shatt al Arab at the confluence with the Euphrates near the city of Qurnah.

Figure 3. Climate diagrams for Diyarbakir in Turkey, Mosul in Iraq and Baghdad in Iraq



Source: Compiled by ESCWA-BGR based on data provided by WorldClim, 2011; Climate Diagrams, 2009; Phytosociological Research Center, 2009.

CLIMATE

The climate in the Tigris Basin ranges from semi-humid in the headwaters to the north, to semi-arid close to the confluence with the Euphrates in southern Iraq. Mean annual basin precipitation is estimated between 400 and 600 mm (Figure 4). However, values of 800 and 150 mm have been registered in the upper and lower parts respectively. Figure 3 illustrates the shift from a more humid climate to an increasingly hot and dry climate (see Overview Map for locations). Mean precipitation in the Tigris Basin is significantly higher than in the Euphrates Basin (approx. 300 mm/yr). This difference can be attributed to the high precipitation rates in the Zagros Mountains in the east of the Tigris Basin, which contributes to Tigris stream-flow. Precipitation mostly occurs between November and April, with snowfall in the mountains from January to March.[6]

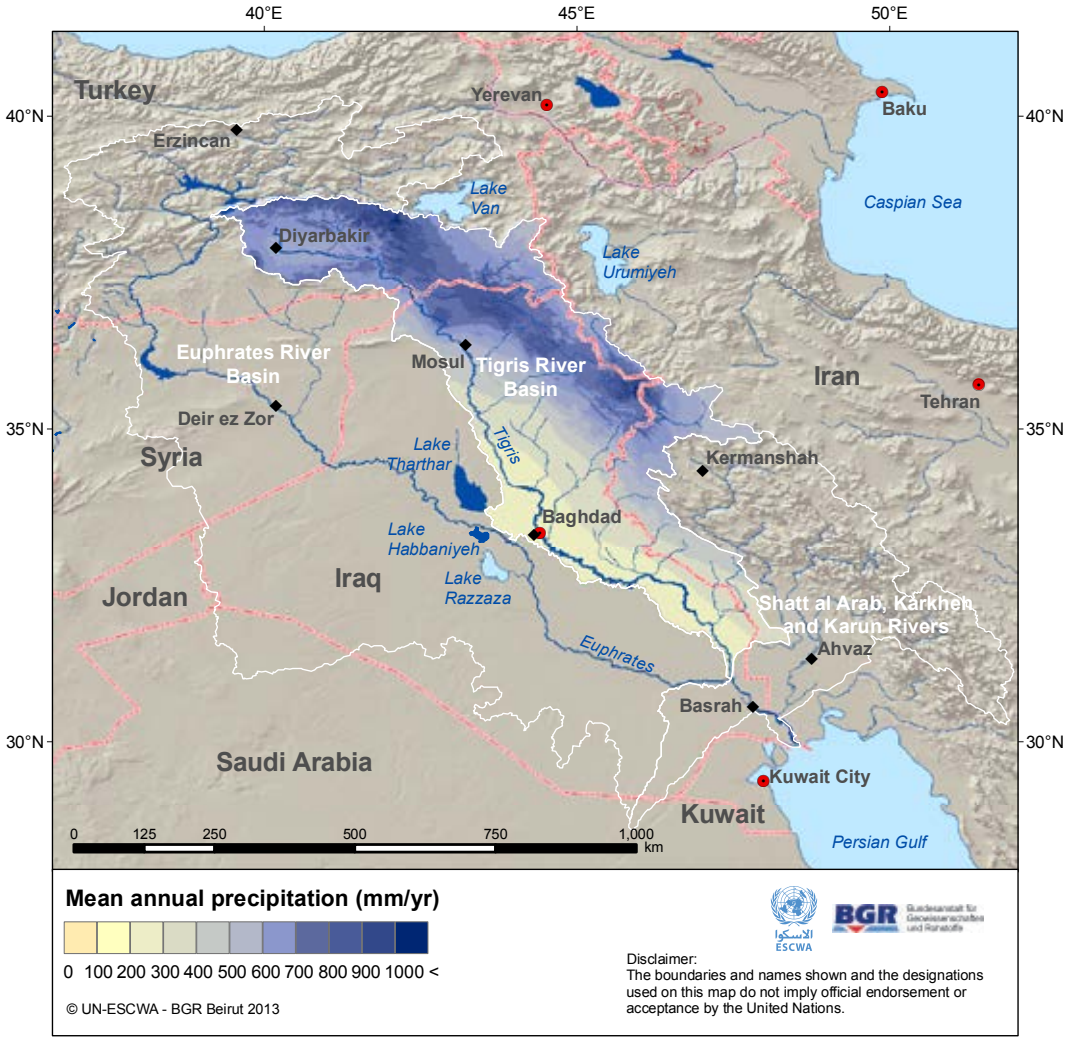
Given the semi-arid to arid climate in the lowlands of Iraq and Syria, evapotranspiration causes considerable water loss in the Mesopotamian region.[7] Air temperatures in the Tigris Basin range from -35°C in winter in the Armenian Highlands to 40°C in summer on the Jezira Plateau.[8]

POPULATION

The Tigris Basin comprises a total population of approximately 23.4 million inhabitants, of which more than 18 million live in Iraq, 1.5 million in Iran and 3.5 million in Turkey. Only 50,000 people reside in the Syrian part of the basin.

Hasankeyf, Turkey, 1992. Source: Ed Kashi/VII.

Figure 4. **Mean annual precipitation in the Tigris Basin**



Source: Compiled by ESCWA-BGR based on data provided by WorldClim, 2011.

Table 2. **Estimated basin population**

RIPARIAN COUNTRY	COUNTRY POPULATION (MILLIONS)	ESTIMATED POPULATION IN THE BASIN		SOURCE
		MILLIONS	AS PERCENTAGE OF TOTAL BASIN POPULATION	
Turkey	73.7	3.47	14.8	Turkstat, 2010.[a]
Syria	20.9	0.05	0.2	Central Bureau of Statistics in the Syrian Arab Republic, 2010.[b]
Iraq	32	18.4	78.7	Central Organization for Statistics in Iraq, 2010.[c]
Iran	..	1.48	6.3	Statistical Center of Iran, 2006.[d]
Total		23.4		

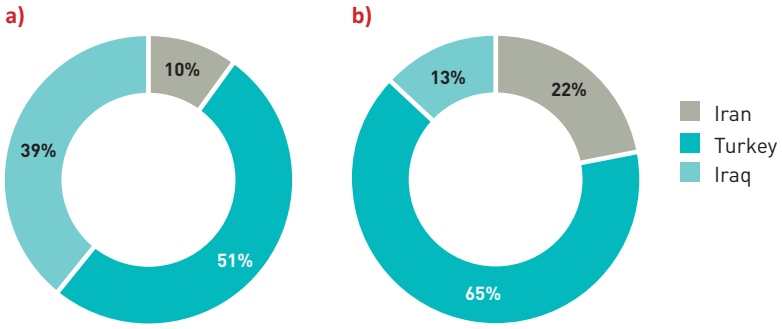
Source: Compiled by ESCWA-BGR.
(a) The population estimate for the area of the basin situated in Turkey is based on a 2010 census and includes populations living in the Turkish provinces of Batman, Diyarbakir, Hakkari, Siirt, as well as parts of the provinces of Bitlis, Mardin and Van.
(b) The population figures for the area of the basin situated in Syria is based on a 2010 estimate and only covers parts of Hasakah Governorate.
(c) The population figures for the area of the basin located in Iraq is based on a 2009 estimate and includes populations living in the following governorates: Arbil, Baghdad, Diyala, Dahuk, Kirkuk and Sulaymaniyah. Parts of Basrah, Maysan, Ninewa, Salah ad Din and Wasit Governorates are also included.
(d) The basin population estimate for Iran's share of the Tigris Basin is based on a 2006 assessment and includes populations living in the province of Ilam, and parts of Kermanshah and Kurdistan Provinces.

Hydrological Characteristics

The Tigris River waters mainly originate in Iran, Iraq and Turkey. Syria does not contribute any significant discharge to the river. In the absence of measured water balance data, riparian contributions are expressed as ranges: upstream Turkey contributes an estimated 40-65% of the river's annual discharge,[9] Iraq 10-40%,[10] while Iranian headwaters and tributaries are estimated to contribute between 5% and 25% to Tigris river flow. The most recent estimates are represented in Figure 5.[11]

The Tigris is mainly fed by precipitation that falls in the Armenian Highlands and Zagros Mountains in Turkey, near the country's south-eastern border with Iran.[12] While the Tigris headwaters lie in Turkey, most of its tributaries originate in Iran and join the Tigris in the Iraqi Lowlands.

Figure 5. **Riparian contribution to annual discharge of the Tigris based on published data**



Source: Compiled by ESCWA-BGR based on (a) MacQuarrie, 2004, p.7, (b) FAO, 2009; El-Fadel et al., 2002, p. 101.

Table 3. **Summary of annual flow volume statistics for the Tigris River in Iraq (1931-2011)**

STATION (DRAINAGE AREA, km²)	PERIOD	MEAN (BCM)	MINIMUM (BCM)	MAXIMUM (BCM)	CV[a] (-)
Mosul (56,000)	1931-2011	20.0	6.5	43.1	0.36
	1931-1973	**21.3**	**11.7**	**43.1**	**0.34**
	1931-1952	19.4	12.2	27.6	0.25
	1953-1984	22.0	11.7	43.1	0.35
	1974-2005	**19.5**	**6.5**	**41.7**	**0.38**
	1985-2005	**19.1**	**6.5**	**41.7**	**0.45**
Kut (173,000)	1931-2005	25.7	4.2	59.2	0.51
	1931-1973	**32.0**	**15.2**	**59.2**	**0.36**
	1931-1952	36.8	15.2	59.2	0.29
	1953-1984	24.5	13.2	50.3	0.37
	1974-2005	**16.7**	**4.2**	**47.5**	**0.58**
	1985-2005	**13.9**	**4.2**	**47.5**	**0.76**

Source: Compiled by ESCWA-BGR based on USGS, 2012; Ministry of Water Resources in Iraq, 2012.
(a) Coefficient of Variation. For information on the definition and calculation of the CV see 'Overview & Methodology: Surface Water' chapter.

ANNUAL DISCHARGE VARIABILITY

Available flow data for the Tigris River covers the period 1931-2011 and comes from the Mosul and Kut gauging stations (see Overview Map for location). In order to allow for comparison of the flow along the Tigris main stream, common periods have been selected (Table 3) for both stations. The period 1931-1973 was selected as it represents the near-natural flow of the river. The records for the station at Mosul represent the river's natural flow after crossing the border between Turkey and Iraq as no dams were built on the Turkish stretch of the Tigris until the 1990s. During the second period from 1974 until 2005 major water infrastructure projects were implemented in the basin, though the Tharthar Dam was already built in the 1950s.

The mean annual flow for the entire period of record is 20 BCM at Mosul and 25.7 BCM at Kut. Maximum flow levels were recorded in 1969 with 43.1 BCM at Mosul and 59.2 BCM at Kut in 1946. This contrasts with the lowest annual flow of 6.5 BCM at Mosul in 1999 and 4.2 BCM at Kut in 2001.

Tributary contribution

In contrast to the Euphrates River which has few tributaries, the numerous tributaries originating in the Zagros Mountains make significant contributions to runoff along the course of the Tigris River.[13] Flow contribution to the mean annual flow volume of the Tigris from tributaries located between Mosul and Kut amount to an estimated 25 BCM.[14] In the literature these contributions are often referred to as significant, accounting for 50% of the Tigris flow in Baghdad.[15]

The addition of 25 BCM to the near-natural mean annual flow volume of the Tigris at Mosul (approx. 21 BCM for the period 1931-1973,

Table 3) would be expected to produce a 46 BCM flow volume at Kut. However, the actual mean annual Tigris flow volume at Kut for the same period was around 32 BCM. There are various explanations for this surprisingly large difference, including hydrological measurement errors, and large-scale abstraction between Mosul and Kut for flood control or other purposes.

Negative trend

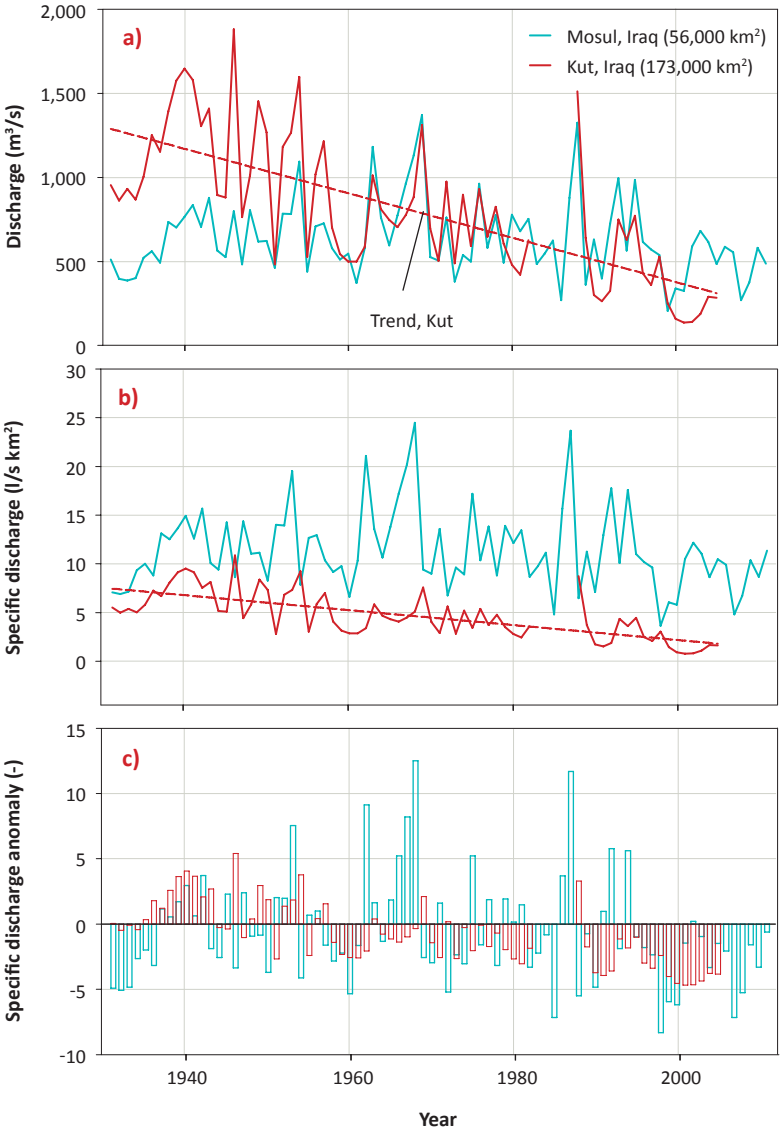
Figure 6 shows the mean annual discharge time series for gauging stations near the city of Mosul and farther downstream near Kut in Iraq over the period 1931 to 2011. Based on the available discharge data, mean water yield of the Tigris River appears to exceed Euphrates water yield. No trend can be observed at Mosul, while at Kut the records show a significant negative trend. It should be noted, however, that the data record at Kut exhibits more data gaps and missing values than the discharge record at Mosul, which may bias the trend analysis.[16] In terms of discharge anomalies (Figure 6c), a major wet period in the 1960s is more pronounced compared to the overall mean. Below average values since the 1990s can also be observed.

Comparison

Table 3 provides no clear evidence that the mean annual flow volume has decreased significantly upstream of Mosul since 1974. However, river runoff is currently controlled by several dams in Iraq (Table 4), with more dams under construction and in planning stages (Table 5). This may have led to a significant reduction in flow volumes farther downstream, especially between Mosul and the confluence with the Euphrates in Qurnah. This is evident from the increased flow variability that may be caused by reservoir operations at Kut since 1973[17] and the reduction in mean annual flow volume (from 32 BCM before 1973 to 16.7 BCM after 1973).

According to the New Eden Master Plan for the Sustainable Development of the Iraqi Marshlands (a joint project between three Iraqi ministries),[18] there is also a significant difference between pre- and post-1990 measurements in terms of annual flow volumes. The natural Tigris water regime has been affected by the construction of large water control structures in Iraq and Turkey. A report published by the New Eden Master Plan claims that flow peaks in southern Iraq have disappeared since the construction of new dams in the 1990s (Table 4). This has in turn impacted the ecosystem of the Mesopotamian Marshlands in Iraq, which depend on regular high flows and floods. Before 1990, annual water availability in the Mesopotamian Marshlands was estimated

Figure 6. a) Mean annual discharge, b) specific mean annual discharge and c) discharge anomaly time series of the Tigris (1931-2011)



Source: Compiled by ESCWA-BGR based on data provided by Hydrological Survey of Iraq, 1958; Ministry of Irrigation in Iraq in ACSAD and UNEP-ROWA, 2001; USGS, 2012; Ministry of Water Resources in Iraq, 2012.

at 47.5 BCM. After 1990, this figure dropped to a maximum of 24 BCM, with minimum flows of 4.2 BCM recorded in 2001.

The comparison of available data records for the station in Kut supports the claim by the New Eden Master Plan. Table 3 shows a decrease in annual flow volume of around 10 BCM between the 1953-1984 period and the 1985-2005 period.

FLOW REGIME

The Tigris river flow regime can be considered natural before the 1970s, with limited water regulation in the runoff generation area in Turkey, Iran and Iraq upstream of Mosul. This natural flow regime is represented in Figure 7a and shows a high-flow season from February

to June and a low-flow season from July to January. The increased discharge during the high-flow period is typically generated by snow-melt and increased precipitation in the Turkish and Iraqi-Iranian mountains. Such a rainfall/snow-melt regime was typical for the 1931-1973 period of record at Mosul and farther downstream at Kut. However, if the stream-flow regime is split into a pre-1973 and post-1973 period, a significant modification with largely reduced high flows and increased low flows becomes apparent at Kut. No significant changes in the stream-flow regime are discernible at Mosul for the same period.

Compared to the Euphrates flow regime, the Tigris high-flow season is much longer and more pronounced due to higher winter precipitation over a much greater basin area.[19] The gradual melting of snow cover in the headwater region of the Tigris River and its tributaries helps to maintain water levels. Peak discharge in the Tigris Basin generally occurs in April, a month before the peak of the Euphrates River. One study based on measurements from Iraq claims that the March-May high-flow season accounts for more than half of the mean annual flow volume of the Tigris.[20]

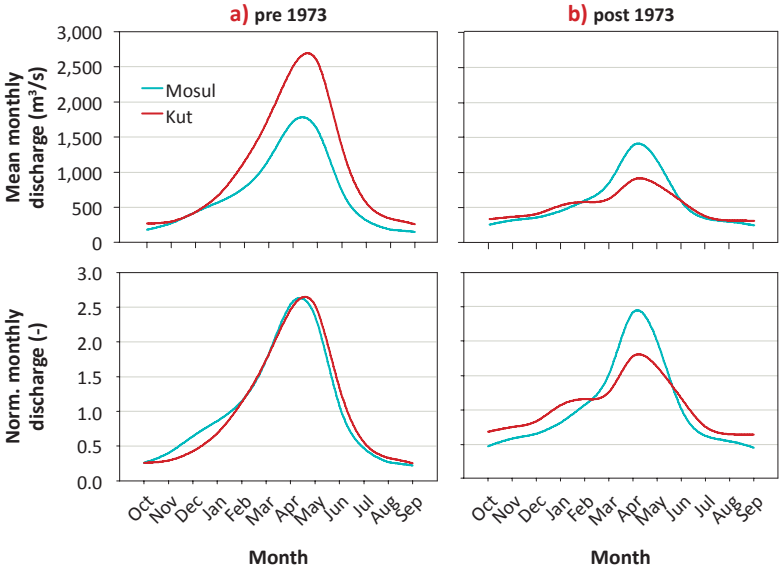
Minimum flow generally occurs in September. In Mosul, a lowest monthly discharge of 87.7 m^3/s was recorded in September 1935, while measurements at the station near Kut indicated a minimum monthly discharge of 219 m^3/s for the same period.[21]

GROUNDWATER

Little is known about hydrogeological connectivity between Iraq and Turkey in the Tigris Basin.[22] However, piezometric water levels in the Jezira Aquifer, which is located north-east of the Tigris Basin, suggest a hydraulic connection, with water flowing towards Turkey and possibly entering the country via outcropping aquifers.

A minor inflow of groundwater may occur in the area where the river runs along Syria's north-eastern border, with water flowing in from the unconsolidated Pliocene aquifer. The water of small springs issuing from aquiferous basalts or from underlying Pliocene conglomerates in that area is generally consumed before it reaches the Tigris River.[23] As such, there are virtually no exploitable groundwater resources in the small Syrian section of the Tigris Basin.

Figure 7. **Mean monthly flow regime of the Tigris River at different gauging stations for different time periods (1931-2011)**



Source: Compiled by ESCWA-BGR based on data provided by Hydrological Survey of Iraq, 1958 and Ministry of Irrigation in Iraq, 1999 in ACSAD and UNEP-ROWA, 2001, p. 59; USGS, 2012; Ministry of Water Resources in Iraq, 2012.

There is limited evidence that groundwater flows south-west from the southern part of the Taurus-Zagros Aquifer System towards Iraq. Additionally, it is assumed that some groundwater moves between Iraq and Iran in the south-western Mesopotamian Plain. It has also been suggested that the lower part of the Mandali-Badra-Tib Aquifer lies within Iraq, whereas the higher parts of this aquifer system are mostly located in Iran.[24]

In north-western Iraq, groundwater from Neogene Aquifers discharges mainly into the Tharthar Depression (Wadi Tharthar and Lake Tharthar), extending west of the Tigris River. Natural conditions have changed due to the diversion of water from the Tigris into the Tharthar Depression, with Lake Tharthar presently recharging the Quaternary Mesopotamian aquifer south of the lake.[25]

Between Fatha and Tikrit in north-western Iraq, the Tigris River drains groundwater from the Neogene and Quaternary aquifers on both banks. Between Tikrit and Samarra, the effluent conditions along the river seem to be retained on its western bank only, while the eastern bank becomes influent.[26] Groundwater moves in the Quaternary aquifer from the Tigris River to local depressions in the east.

Water Resources Management

Several major dams and diversion structures have been built on the Tigris and its main tributaries since the 1930s. They serve multiple purposes, but the most important is to regulate river flow. These structures have paved the way for large irrigation projects, including integrated irrigation-drainage systems. Maximum capacity of the main dams in the Tigris Basin is estimated at 116.5 BCM (Table 4 and 6).

DEVELOPMENT & USE: TURKEY

The Tigris River was the last major river system in Turkey to be developed, as geographic conditions in the basin made large-scale developments more difficult than in the Euphrates Basin. Nevertheless, due to its upstream riparian potential, Turkey has started to make more use of the Tigris in recent years.

Initial projects launched in the 1940s focused on hydroelectric power production and support for irrigated agriculture in the lower parts of the basin.[27] In the early 1970s, Turkey developed a series of ambitious schemes on the Euphrates and Tigris Rivers as part of the Southeastern Anatolia Project (GAP).[28] Plans for dams, power plants and irrigation areas in the Turkish part of the Tigris Basin were first touted as the "Western Tigris Development Plan".[29] At a later stage, GAP also included infrastructural development in the lower section of the Turkish Tigris Basin. Turkey has to date built eight large dams and eight hydroelectric power plants on the Tigris River and its tributaries as part of GAP.

The project also aims to establish a reservoir system on the upper Tigris River for flow regulation. The Ilisu Dam Project lies at the heart of this system, with a hydroelectric power generation capacity in the range of 1,200 MW.

The Ilisu Dam is assumed to substantially attenuate floods and increase seasonal low flows.[30] However, the project, which includes

Table 4. **Main dams on the Tigris River in chronological order of construction**

COUNTRY	NAME	COMPLETION YEAR	CAPACITY (MCM)	PURPOSE[a]	BACKGROUND INFORMATION
Iraq	Kut	1939	-	I	This barrage was constructed in the city of Kut to provide irrigation water for the surrounding area.
	Tharthar (Samarra Barrage)	1954	85,000	FC, I, HP	Diverts floodwater through a 64 km canal to Lake Tharthar. Water is then conveyed to the Euphrates through a 37 km canal with a 550 m^3/s capacity. Lake Tharthar (the reservoir) covers an area of 2,420 km^2, with estimated evaporation losses of 2.86 km^3/yr.
	Mosul (Chambarakat, formerly Saddam Dam)	1985	11,100	HP, FC, I	Located upstream of the city of Mosul, this is the largest dam in Iraq. It is mainly a hydroelectric dam with a capacity of 350 MW that provides electricity to the estimated 1.7 million inhabitants of Mosul.
Turkey	Goksu	1991	600	I	The dam supports the Cinar-Goksu Irrigation Project that irrigates an area of 3,582 ha.
	Kralkizi	1997	1,900	HP	Hydropower capacity: 90 MW
	Tigris (Dicle)	1997	6,000	HP, I, WS	Hydropower capacity: 110 MW Projected irrigated area: 128,080 ha
	Batman	1999	1,200	I, HP, FC	Hydropower capacity: 198 MW Projected irrigated area: 37,744 ha
	Garzan	..	..	HP, I	Hydropower capacity: 89 MW Projected irrigated area: 60,000 ha

Source: ESCWA-BGR based on ACSAD and UNEP-ROWA, 2001, p. 78-80; Ministry of Water Resources in Iraq, 2009; General Directorate of State Hydraulic Works in Turkey, 2009; Isaev and Mikhailova, 2009, p. 384; Ministry of Environment in Iraq et al., 2006a.
(a) Irrigation (I), Flood Control (FC), Hydropower (HP) and Water Supply (WS).

the planned downstream Cizre Dam, has sparked public controversy resulting in building freezes and protests. In 2010, construction work restarted despite ongoing protests (Box 1).

In the long term, GAP irrigation schemes in the Tigris Basin aim to cover an area of 600,000 ha with a potential water consumption of 5.6 BCM.[31] Most of this capacity remains in the planning stages. According to the Turkish State Hydraulic Works (DSI), approximately 42,000 ha of the GAP irrigation network sourced from the Tigris are operational, while 53,400 ha are currently under construction (Figure 8).[32]

Due to its geographic position, Turkey controls about a third of the total Tigris flow[33] and its influence on the river's water regime is constantly growing. Theoretically, Turkey could also use the Greater Zab headwaters, as this tributary originates in Turkey before it flows into Iraq. The region's topography, however, would make this a challenging endeavour.

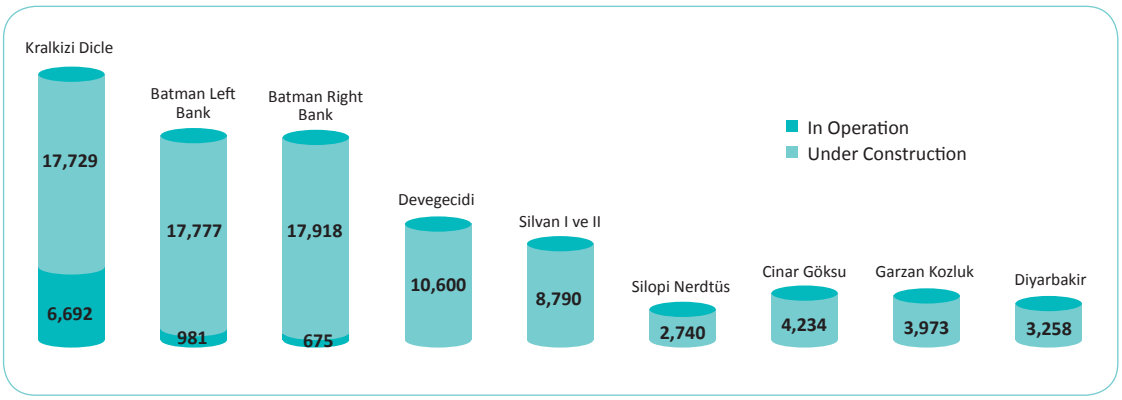
The Tigris River at Baghdad, Iraq, 2006. Source: James Gordan.

Table 5. **Planned dams in the Tigris Basin in Turkey**

NAME	STATUS	CAPACITY (BCM)	PURPOSE[a]	BACKGROUND INFORMATION
Ilisu	Construction started in 2006, but was suspended in 2008. Work resumed in March 2010.	10.41	HP	Planned hydropower capacity: 1,200 MW Projected irrigated area: 313,000 ha
Cizre	Construction was to begin in June 2008. Completion scheduled: 2017.	0.36	HP	The downstream Cizre Dam will work in parallel with the Ilisu Dam. Planned hydropower capacity: 240 MW Projected irrigated area: 121,000 ha
Silvan	Construction started in 2012.	..	HP	Planned hydropower capacity: 150 MW
Kayseri	Master plan completed.	..	HP	Planned hydropower capacity: 90 MW

Source: Compiled by ESCWA-BGR based on ACSAD and UNEP-ROWA, 2001, p. 78-80; Ilisu Environment Group, 2005, p. 17; Spiegel Online, 2010 (on Ilisu); Angell, 2009; Environmental Consultancy Co., 2005, p. 4; General Directorate of State Hydraulic Works in Turkey, 2009; Ministry of Environment in Iraq et al., 2006a.
(a) Hydropower (HP).

Figure 8. **Irrigated area as part of GAP in the Tigris Basin in Turkey (ha)**



Source: Compiled by ESCWA-BGR based on data provided by General Directorate of State Hydraulic Works in Turkey, 2009.

BOX 1

The Ilisu Dam Project

The controversial Ilisu Dam Project has raised concerns among a wide range of stakeholders including the main Tigris riparians, local residents who will be displaced, export credit agencies and international non-governmental organizations. While the dam's design was finalized in 1982, social, historical, environmental and financial concerns have stalled its implementation for decades.

As one of a total of 22 dam projects in the Southeastern Anatolia Project (GAP), the Ilisu Dam will be located near the Kurdish village of Ilisu, about 65 km from the Syrian-Turkish border. It will be the largest hydroelectric power plant in GAP with a hydropower capacity of 1,200 MW, producing an expected 3,800 GWh/yr. With a planned height of 135 m, the dam will have a 10.4 BCM reservoir. The Ilisu Project includes plans to build the smaller Cizre Dam for irrigation purposes and additional hydropower production.

The entire project cost was estimated at USD 1.7 billion and was initially supported by an international consortium of export credit agencies from Austria, Germany, Italy, Japan, Portugal, Sweden, Switzerland, the United Kingdom and the United States of America. The project itself and the policies of the consortium were heavily criticized by several environmental and human rights groups.

Critics of the project claim that the region's cultural heritage will suffer irreparable damage with the flooding of the ancient city of Hasankeyf and neighbouring areas and the involuntary resettlement of about 50,000 people, while at the same time causing further environmental damage to the Mesopotamian Marshlands.

Construction began in August 2006, but was interrupted two years later following a successful campaign launched by environmental groups and international organizations. This led to the cancellation of international funding support from European governments and several private firms.

Determined to see the project through, Turkey sought other lenders, both domestically and abroad. Construction work resumed in 2010. The project aims to meet the country's rising energy demand, create jobs and stimulate economic growth in Turkey's impoverished south-east.

DEVELOPMENT & USE: SYRIA

Syria is a minor Tigris riparian as the river defines only a short stretch of the Syrian-Turkish border. The country only exploits the basin's water resources for small-scale agricultural activity and domestic use.

However, in mid-2010, Syria launched the first phase of an irrigation project on the Tigris River.[34] The project is based on a 2002 agreement between Syria and Iraq, which authorizes Syria to pump an annual 1,250 MCM from the Tigris River.[35] The water is to be used to irrigate approximately 150,000 ha of land in Hasakah Governorate in the upper part of the Khabour Basin (see Chap. 2)[36] through an inter-basin water transfer.[37] The project also aims to generate hydroelectricity and strengthen the local economy by improving agricultural yield.[38]

DEVELOPMENT & USE: IRAQ

Iraq has a long history of water use in the Tigris Basin and was also the first riparian to develop irrigation projects, and construct dams, barrages and cross regulators on the river and its tributaries. Early engineering projects

Table 6. Main constructed dams on the Tigris tributaries in Iraq

NAME (RIVER)	COMPLETION YEAR	CAPACITY (MCM)	PURPOSE[a]	BACKGROUND INFORMATION
Dukan (Lesser Zab)	1961	6,800	I, HP	The purpose of the dam is to store and regulate flows for the Kirkuk Irrigation Project. Hydropower capacity: 400 MW
Dibis (Lesser Zab)	1965	3,000	I	The Dibbis Regulator project has four primary components: the main dam, the spillway and fish pass, the fuse plug (emergency spillway) and the head regulator for the Kirkuk Irrigation Project.
Derbendikhan (Diyala)	1962	3,000	I, HP, FC	Hydropower capacity: 240 MW
Hemrin (Diyala)	1981	2,400	I, HP	Hydropower capacity: 50 MW
Diyala (Diyala)	1969	..	I, FC,HP	-
Adhaim (Adhaim)	1999	1,500	FC, I, HP	The Adhaim Dam project is located about 70 km upstream from the Adhaim's confluence with the Tigris. It diverts water at the confluence of the Adhaim and the Aq Su Rivers. Hydropower capacity: 28 MW

Source: Compiled by ESCWA-BGR based on ACSAD and UNEP-ROWA, 2001, p. 78-80; General Directorate of State Hydraulic Works in Turkey, 2009; Ministry of Environment in Iraq et al., 2006a; The Iraq Foundation, 2003.
(a) Irrigation (I), Hydropower (HP) and Flood Control (FC).

included the 1939 Kut Barrage and the 1956 Tharthar System Barrage, two water regulation projects with limited irrigation capabilities. The Tharthar Dam and Canal were constructed north-west of Baghdad in the 1950s to protect it from flooding. The scheme diverts floodwater from the Tigris through the 64 km Tharthar Canal to the Euphrates River. Completed in 1977, the project is regarded as the cornerstone of Iraq's surface water management system.[39]

A number of important reservoirs and regulating structures were built on the eastern tributaries of the Tigris between the 1960s and 1980s, including the Dukan and Dibis Dams on the Lesser Zab, and the Derbendikhan Dam on the Diyala. Other dam projects followed, including the Mosul Dam, which has one of the largest reservoirs in Iraq.[40] It is mainly used for hydropower production, but also serves irrigation and flood control purposes (Table 4).

The Tharthar Canal, which connects the Tigris to the Euphrates, is the cornerstone of Iraq's water development system. The Tharthar Dam has allowed Iraq to overcome water shortages in the Euphrates Basin by diverting water from the Tigris to the Euphrates via Lake Tharthar. The capacity of Lake Tharthar is twice that of the Atatürk Dam reservoir in Turkey and equal to the operating capacity of the Aswan Dam in Egypt.[41] The Main Outfall Drain, formerly known as the Saddam River, was constructed to collect drainage water from more than 1.5 million ha of agricultural land between the Euphrates and Tigris Rivers (see Chap. 1, Box 4).[42] Iraq constructed several other canals in the Tigris Basin, including the East al Gharraf Drain and the Tigris East Drain, for the purpose of land reclamation and drainage. The main irrigation canal in the Tigris Basin is the 170 km Shatt al Gharraf which irrigates an area of 700,000 ha.[43]

Table 7. Planned dams in the Tigris Basin in Iraq

NAME (RIVER)	STATUS	CAPACITY (MCM)	PURPOSE[a]	BACKGROUND INFORMATION
Badush (Tigris)	Partially constructed. Completion scheduled: 2015	10,000	HP	Planned hydropower capacity: 170 MW
Bekhme Dam (Greater Zab)	Partially constructed	17,000	HP	Planned hydropower capacity: 150 MW
Mandawa (Greater Zab)	Completion scheduled: 2015	..	HP, I	-
Taq Taq (Lesser Zab)	Completion scheduled: 2015	..	HP, I	-

Source: Compiled by ESCWA-BGR based on UNESCO, 2009.
(a) Hydropower (HP) and Irrigation (I).

Agriculture in the region of Arbil, Iraq, 2007. Source: Ben Barber, USAID.

Agriculture

In the mid-1970s, Iraq irrigated approximately 5.6 million ha of land, of which almost 70% (3,825,000 ha) were located in the Tigris Basin.[44] The river currently irrigates around 4 million ha of land in Iraq.[45]

The largest irrigation projects in the Tigris Basin in Iraq include the Kirkuk Irrigation Project in the Adhaim Basin, the North Jezira Irrigation Project and the East Jezira Irrigation Project. Launched in 1983, the Kirkuk Irrigation Project initially irrigated 87,500 ha, with plans to expand to a total of 300,000 ha. The North Jezira Irrigation Project was initiated in the early 1990s to supply approximately 60,000 ha with water from the Mosul Dam. The East Jezira Irrigation Project created irrigation networks on about 70,000 ha of rain-fed land near Mosul. The latter two projects were part of a scheme to irrigate 250,000 ha of land in the Jezira Plain.[46] Iraq launched several other irrigation projects before the 1991 Gulf War, most of them focused on draining the Iraqi marshlands (Box 2).

In recent decades, Iraq's agricultural and water resources policies have focused on land reclamation with the expansion of irrigation networks and drainage systems to improve soil productivity. As a result, an area of approximately 1 million ha was reclaimed, in addition to 1.5 million ha of semi-reclaimed land.[47] Land reclamation projects in the Tigris Basin are situated in Kirkuk and Diyala Governorates and in the area south of Baghdad.

In an attempt to rehabilitate agricultural infrastructure, the ministries responsible for water resources, irrigation and agriculture are planning to implement several integrated irrigation projects using both surface and groundwater resources. Planned projects include the reclamation of 920,000 ha by 2015 and the irrigation of 134,000 ha of new land in Kirkuk Governorate and in the eastern and southern Jezira. Irrigation rehabilitation projects have also been implemented on almost 800,000 ha.[48]

WATER QUALITY & ENVIRONMENTAL ISSUES

Rising salinity in the basin is causing soil degradation and impacting surface and groundwater quality. Salinization is mainly caused by intensive irrigated agriculture and high evaporation rates.[49] However, water resources in the Tigris Basin are also threatened by other sources of pollution, such as untreated sewage and contamination by heavy metals.

In Turkey, salinity poses no threat to agricultural activities in the basin. Here the Tigris exhibits acceptable Electrical Conductivity (EC) values, with a mean value of 330 µS/cm for the period between 1971 and 2002[50] and 433 µS/cm for the period between 1995 and 2002.[51] However, other forms of pollution occur in this upstream part of the river, with a number of large urban settlements directly discharging untreated domestic and industrial wastewater into the river.[52] Pollution sources also include effluents from a copper plant, agricultural runoff and irrigation return flows.[53] The high levels of heavy metals in the river sediments can accumulate in aquatic organisms, which may in turn enter the human food chain and cause toxicity.[54] Moreover, samples taken in 2008 have shown that mean concentrations of Total Phosphorus (TP) were above 0.075 mg/L in most places, indicating the onset of eutrophication.[55] The increase in phosphorus concentrations coupled with the constant discharge of untreated wastewater has led to the depletion of Dissolved Oxygen (DO) in the river, particularly in the town of Diyarbakir, where wastewater from domestic and industrial sources drain directly into the Tigris.[56]

Downstream in Iraq, untreated wastewater from urban areas is released into the river, carrying discharges from domestic and industrial users, as well as hotels and hospitals.[57] Return flows from irrigated agriculture further affect water quality.[58] Pollution rates are highest near major cities such as Baghdad and Mosul.[59]

Salinity poses a greater problem in Iraq than in Turkey. Based on salinity data compiled from different sources, the general trend displays a gradual increase in salinity along the course of the Tigris, as shown in Figure 9. The effect of salinization is amplified in the central and southern parts of the Mesopotamian Plain as a result of higher evaporation rates and intensive irrigation in the area.[60] Moreover, salinity values increase sharply downstream of Baghdad, making the water unsuitable for agricultural use.[61] In addition to pollution from human sources in this area, the river also receives saline groundwater from the floodplains that extend to the south-west until Basrah.[62] The problem is exacerbated during summer months when the river's discharge is reduced. Water quality is further threatened by irrigation return flows from the Tigris tributaries originating in Iran.[63] With regard to temporal variations in salinity, no clear trend can be deduced based on the available data (Figure 9 and Table 8), even though some sources suggest an increase over the years.[64]

The water quality of the Tigris in Iraq has also been affected by bacterial contamination, with levels of coliform bacteria exceeding maximum recommended limits[65] (faecal coliform counts reached levels as high as 170,000 cfu/100 ml)[66] as a result of contamination from untreated sewage discharges. Poor infrastructure, including damage to wastewater treatment plants during the 1991 Gulf War, also plays a role in the deterioration of water quality.[67] An estimated 400,000 m^3 of untreated wastewater is discharged daily at Mosul.[68] The situation is similar in Baghdad, with coliform levels far above the permissible limits.[69] The presence of chlorophenols has also been reported in the river at Baghdad.[70] This compound is an industrial by-product that becomes toxic and carcinogenic when coupled with chlorine (Cl).[71] Moreover, high levels of heavy metals were detected in Tigris water samples between Mosul and Kut.[72]

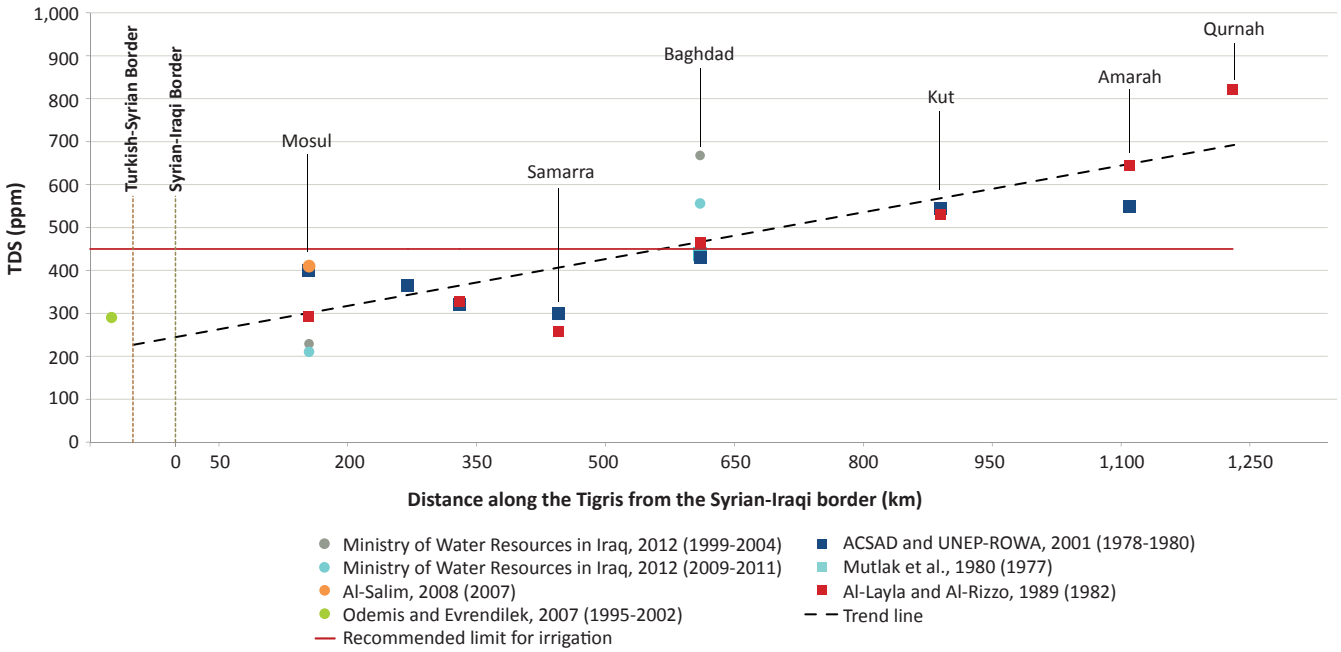
The Tigris at Diyarbakir, Turkey, 2007. Source: Raki Man.

Table 8. Mean Total Dissolved Solids (TDS) values of the Tigris River at different stations (1999-2011)

STATION	TDS (ppm)								
	1999	2000	2001	2002	2003	2004	2009	2010	2011
Mosul Dam	224	209	226	..	256	..	237	197	199
Baghdad	851	739	637	597	..	514	560	475	632

Source: Compiled by ESCWA-BGR based on Ministry of Water Resources in Iraq, 2012.

Figure 9. Salinity variations along the Tigris River before 1983 and after 1995



Source: Compiled by ESCWA-BGR based on the sources mentioned above.
Notes:
- This graph aims only to provide a general overview of salinity variations along the Tigris River and should not be considered fully accurate: data was extracted from a number of literature sources and official data provided by riparian countries; for some stations only individual measurements were available. The margin of error may be significant as readings could differ depending on the methodology used, location and date of measurement, rounding off of means, etc. Interpretation of the salinity data is further hampered by the fact that values cannot be compared with river flow data due to information gaps.
- The years in brackets refer to the sampling years. Square and round markers refer to the pre-1983 and post-1995 periods respectively. The TDS value for Turkey was converted from an initial Electrical Conductivity value. The location of cities/stations and distances between them along the river were estimated using Google Earth.

BOX 2

The Mesopotamian Marshes

The area along the confluence of the Tigris and the Euphrates Rivers in southern Iraq was once home to the largest wetland ecosystem in Western Asia. However, by 2002, over 85% of the Mesopotamian Marshes had been destroyed[a] as a result of heavy damming and massive drainage projects in the second half of the 20th century.

Historically, the marshes constituted a sequence of interconnected marshlands and lake systems. The heart of the marshes comprised three main areas: the Hammar Marshes south of the Euphrates, the Haweizeh Marshes east of the Tigris River and the Qurnah (or Central) Marshes situated between the two rivers. The Qurnah Marshes were the largest of the marshland formations. Before the marshes were drained, they acted as a natural wastewater treatment system for the Euphrates and Tigris Rivers, filtering out fertilizers before the water drained into the Persian Gulf.

The regular annual flooding of the Euphrates and Tigris inundated the marsh lowlands over an area of more than 10,000 km^2. During low-flow periods, the area would shrink to a few thousand square kilometres. The damming of the Euphrates and Tigris during the 1970s diminished water flow to the downstream ecosystems. In the early 1990s, the Iraqi Government embarked upon a large-scale water diversion scheme designed to drain the southern marshes. The project was driven by the prevailing belief at the time that the Mesopotamian Marshes were a source of diseases such as malaria and an obstacle to human development in the area.

Originally the Mesopotamian Marshes were home to 250,000 Marsh Arabs. By draining the marshes, the Iraqi Government displaced the Marsh Arabs, who were regarded as opponents to Iraq's former regime. Today only 40,000 indigenous people still live in the region, adding a human dimension to the environmental disaster.

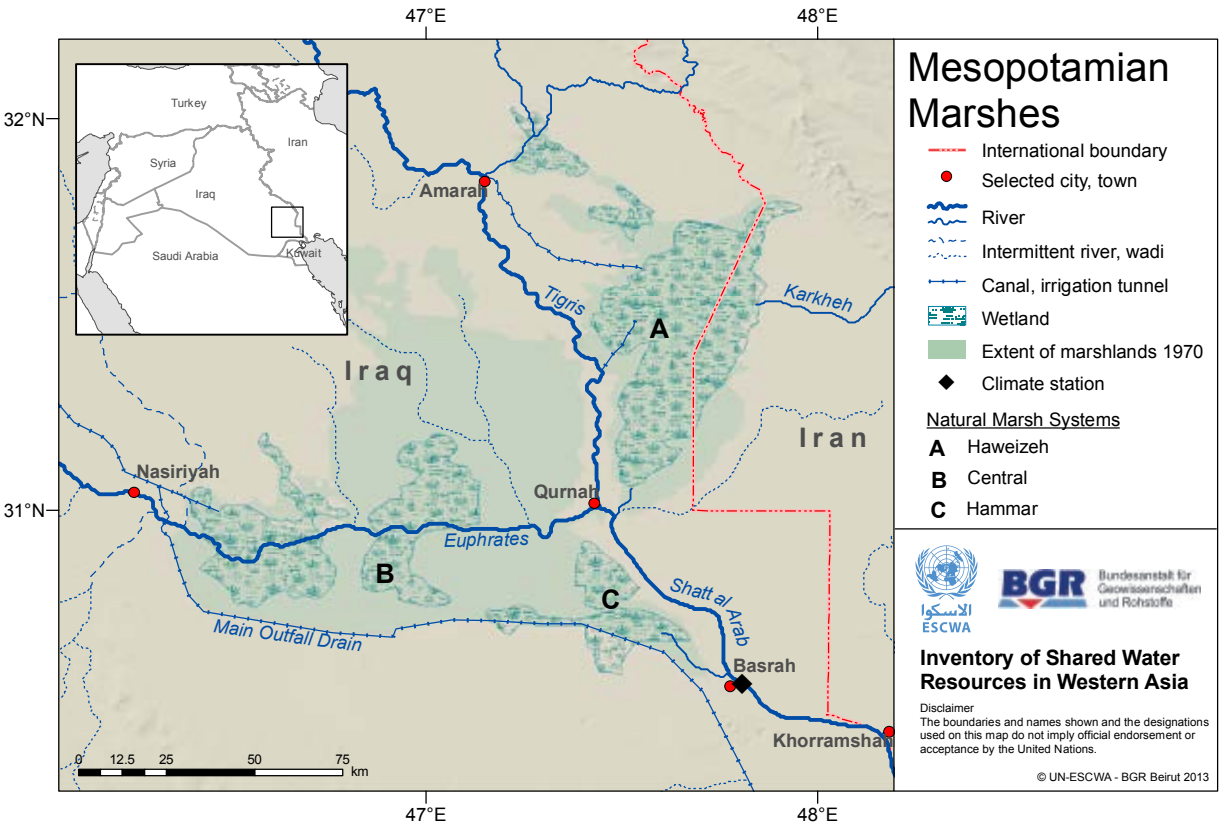
The draining of the Mesopotamian Marshes also destroyed a unique freshwater ecosystem that once formed a habitat for wildlife and migratory birds, and supported coastal fisheries along the Persian Gulf coast. Today most of the territory has become barren land and salt crusts.

In 2002, the marshes had shrunk to 14% of their original size. Only 35% of the Haweizeh Marshes remained, while the Central and Hammar Marshes had been almost completely drained. After the fall of Saddam Hussein's regime, locals began to destroy dikes. This was followed by joint restoration efforts by the Iraqi Government, UN agencies and other donors. Record precipitation in Turkey also contributed to the success of the initiative. By 2006, more than half of the original marshland area was flooded again. Today the damming of the Karkheh River in Iran is seen as a critical challenge, as the river directly feeds into the marshes. The construction of a levy along the Iran-Iraq border poses an additional threat to the area as it runs through the Haweizeh Marshes and disrupts natural flow in the ecosystem.

Despite all the negative developments over recent decades, experts are hopeful and claim that the marshes have shown astonishing resilience to past droughts and diversions and can be restored to their natural state.

(a) Satellite-based assessment studies carried out by the United Nations Environment Program (UNEP) provide striking evidence of the decline of the marshlands. See UNEP-DEWA, 2001.

Figure 10. The Mesopotamian Marshes in 2012



Agreements, Cooperation & Outlook

AGREEMENTS

The Tigris has received much less attention at the negotiation table than the Euphrates. While the few agreements forged among riparian countries have generally addressed both the Euphrates and the Tigris, the focus has always been on the Euphrates.[73] There is no basin-wide agreement in place that includes the four Tigris riparians or that allocates Tigris water resources among the four riparians. Besides a 2002 agreement between Syria and Iraq, there are no bilateral agreements that deal exclusively with the river (Table 9).

The 2002 agreement is also the only one to address water quantity issues in the Tigris Basin. The agreement allowed Syria to establish a pumping station on the Syrian side of the river. After Turkish approval in 2009,[74] Syria launched the project, which aims to withdraw 1,250 MCM annually from the Syrian part of the Tigris River (provided that the river's flow is average) and irrigate an area of 150,000 ha.[75]

Although Turkey refers to the Euphrates and Tigris as part of a single water basin, it has only guaranteed flow levels of the Euphrates, and provided no statement or commitment regarding

Table 9. **Water agreements on the Tigris River**

YEAR	NAME	SIGNIFICANCE	SIGNATORIES
1920	Franco-British Convention	Mandatory powers agreed to establish a committee to examine and coordinate the use of the Euphrates and Tigris Rivers.	France (Syria), Great Britain (Iraq)
1923	Lausanne Treaty	Article 109 confirms that issues related to transboundary water should be dealt with separately and with mutual respect. It also includes a provision that Turkey must consult Iraq before undertaking any hydraulic works.	Allied powers, Turkey
1930	Turko-French Protocol (on Commission of Delimitation)	The Final Delimitation Protocol states that the border between the two countries is to follow the thalweg principle, establishing the border in the middle of the Tigris, regardless of shifts in the river's course.[a]	France (Syria), Turkey
1946	Treaty of Friendship and Good Neighbourly Relations	This was the first legal instrument of cooperation. Both parties agreed that Turkey shall install and operate permanent flow measurement facilities and inform Iraq periodically about the recorded data (article 3) and water infrastructure projects.[b]	Iraq, Turkey
1980	Protocol for Technical and Economic Cooperation	The protocol mandates establishment of a joint technical committee to study the issue of regional waters – particularly the Euphrates and Tigris Rivers.	Iraq, Turkey (Syria signed in 1983)
1987	Protocol on Economic Cooperation	Article 7 of the protocol states that Syria and Turkey shall work together with Iraq to allocate Euphrates and Tigris water within the shortest possible timeframe. Article 9 asserts the intention of the two states to construct and jointly operate irrigation and hydropower projects on the two rivers.[c]	Syria, Turkey
2002	Agreement on the Creation of a Pumping Station in Syria on the Tigris	The agreement governs the establishment of a Syrian pumping station on the Tigris River. It also specifies project area and volume of water extracted.	Iraq, Syria
2009	Turkish-Syrian Strategic Cooperation Council Agreement	The agreement states that water is a focus point for cooperation between the two countries with specific emphasis on improvements to water quality, the construction of water pumping stations (on the Syrian stretch of the Tigris) and joint dams, as well as the development of joint water policies.	Syria, Turkey

Source: Compiled by ESCWA-BGR based on Oregon State University, 2010; ORSAM, 2009a; ORSAM, 2009b.
(a) The protocol states: "Since the sharing of both sides of the Tigris River mandates special responsibilities on the owners of both sides, and mandates the establishment of regulations with regard to the rights of each of the two countries which have sovereignty over their mutual relationships. Therefore, the resolving of all issues such as navigation, fishing, the utilization of water for industrial and agricultural purposes, and river policing have to be on the basis of complete equality" (ACSAD and UNEP-ROWA, 2001).
(b) Scheumann, 1998, p. 120. Hager states that while the treaty has demonstrated the two countries' best intentions, it has not been applied by either Turkey or Iraq (Hager in Elhance, 1999, p. 141).
(c) Syrian Arab Republic and Turkey, 1993.

flow levels of the Tigris. In the late 2000s, prior to the uprising in Syria, Syrian-Turkish relations had improved considerably with the establishment of the Turkish-Syrian Strategic Cooperation Council Agreement in 2009 (Table 9). Under this umbrella, the parties signed several protocols, projects and memorandums, mainly on security issues. They also agreed to cooperate in the domain of water, with specific reference to the construction of a pumping station on the Syrian stretch of the Tigris River, the improvement of water quality and the pursuit of joint efforts to combat drought.[76]

COOPERATION

At the Joint Economic Committee meeting in 1980 (Table 9), Iraq and Turkey set up a Joint Technical Committee (JTC) for Regional Waters to determine how they would allocate a reasonable amount of water to each country and exchange data.[77] In 1983, Syria joined JTC, creating a trilateral forum.

The work of the JTC experts focused mainly on the Euphrates River rather than the Tigris. After 16 meetings, JTC came to a deadlock in 1992 over the question of whether the Euphrates and Tigris Rivers constitute a single system or not (Box 3).

Since 2004, a number of meetings have been convened at ministerial and technical levels, indicating a thaw in basin relations. For instance, relations between Syria and Turkey played a crucial role in advancing the current Syrian project on the Tigris, with construction only starting after Turkish approval was secured. Iraq and Syria then experienced a remarkable rapprochement in recent years, with reciprocal visits leading to a number of agreements, mainly on economic cooperation and security issues.

Little is known about cooperation between Iran and Iraq on the issue of shared water (i.e. tributaries of the Tigris). However, both countries met regularly to discuss pressing water issues of mutual concern. Following Iran's exploitation and diversion of shared rivers without prior notification (e.g. on the Karkheh River), the two states decided to form a joint technical committee in order to address issues of mutual concern. Iraq's Ministry of Water Resources reports that this committee holds regular meetings and organizes technical exchange visits.[78]

OUTLOOK

Relations between Syria and Turkey have seriously deteriorated since 2011 on the backdrop of the Syrian crisis. It can be assumed that the periodic trilateral meetings on water issues and other matters have been put on hold. A crucial issue for Iraqi-Turkish relations on the Tigris River will be the completion of the Ilisu Dam and reservoir as it is likely to impact overall discharge and flow regime of the river significantly especially in downstream Iraq.

Shared water resources are a recurring point of discussion in Iran-Iraq relations. For instance, in 2011 Iraq accused Iran of diverting the water of the Wand River (a tributary of the Diyala) for agricultural purposes.[79] In addition, Iraq recently disregarded the bilateral Agreement Concerning the Use of Frontier Watercourses between Iran and Iraq, which specifically addresses the division of seven shared rivers.[80] The development of water resources in Iran has the potential to impact relations between riparians. In periods of drought, rising tension and local protests cannot be ruled out, as witnessed in 2011 and 2012 in the border region.[81]

BOX 3 Differing Positions on the Euphrates and Tigris

IRAQ & SYRIA

- Syria and Iraq favour the term "shared waters" and consider the Euphrates to be an international river that all riparians should treat as a shared entity.
- Syria and Iraq consider the Euphrates and Tigris as separate basins. Syria opposes the inclusion of the Orontes River in negotiations regarding shared water resources, while Iraq does not want waters flowing into the Tigris Basin from Iran to be included in the overall equation.

TURKEY

- Turkey speaks of transboundary waters when referring to the Euphrates or Tigris Rivers, emphasising that both rivers fall under Turkish sovereignty while they flow through Turkish territory.
- Turkey argues that the Euphrates and Tigris form a single river basin system and that the basin's total water discharge should therefore be included as the basis for any allocation calculations.

Bridge spanning Tigris River in Baghdad, Iraq, 2010. Source: Larisa Epatko.

Notes

1. The Tigris Basin area (221,000 km^2) was estimated based on a digital elevation model (HydroSHEDS) similar to Lehner et al., 2008 and does not include the Lake Van and Karkheh River sub-basins. This explains the difference in basin size compared to other estimates which calculate a basin area of 375,000 km^2 (FAO, 2009, p. 65; Isaev and Mikhailova, 2009, p. 384), 387,600 km^2 (Kibaroglu, 2002a, p. 162) or even 471,606 km^2 (Al-Ansari et al., 1979; UN-ESCWA, 1981, p. 77). However, it should be noted that there is a limited connection between the Karkheh and the Tigris during high-flow periods when Karkheh overflow is channelled through the Haweizeh Marshlands and canals into the Tigris.
2. The length of the Tigris was calculated by tracing the Butan from its source to the confluence of the Tigris with the Euphrates. Different literature sources establish the length of the river at 1,850 km (Kibaroglu, 2002a; Kliot, 1994b; FAO, 2009) and 1,718 km (Shahin, 2007; Al-Ansari and Knutsson, 2011).
3. According to the Syrian Ministry of Irrigation, the Tigris defines the Syrian-Turkish border for 39 km and the Iraqi-Syrian border for 5 km (Daoudy, 2005, p. 65).
4. See Chap. 4.
5. ACSAD and UNEP-ROWA, 2001; Shahin, 2007, p. 248.
6. This snow does not melt until air temperatures increase in the late spring.
7. For more information on climate, including comprehensive climatological data for the Iraqi part of the Tigris Basin, see Ministry of Environment in Iraq et al., 2006a.
8. Isaev and Mikhailova, 2009.
9. Kibaroglu, 2002b, p. 168 states a figure of 40%, while Kolars, 1992, p. 108 and Beaumont, 1998, p. 170 refer to 43% and 44% (including the Greater Zab) respectively. Others estimate the Turkish contribution at 51% (FAO, 2009, p. 65; Daoudy, 2005, p. 66), 53% (Altinbilek, 2004, p. 18) and 65% (MacQuarrie, 2004, p. 7, also quoted in Isaev and Mikhailova, 2009).
10. FAO, 2009, p. 65; El-Fadel et al., 2002, p. 101 refer to 39%. Kibaroglu, 2002a, p. 168 states a 51% contribution to total annual flow, while MacQuarrie, 2004 claims that Iraq contributes only 13.2% to the Tigris discharge.
11. Kibaroglu, 2002a, p. 168 speaks of 9%, El-Fadel et al., 2002, p. 101 and FAO, 2009, p. 65 both refer to 10%. By contrast, MacQuarrie, 2004, p. 7 states that the Iranian contribution to Tigris Basin discharge is 21.7%, a figure which probably includes the Karkheh River's discharge.
12. Shahin, 2007, p. 247.
13. UN-ESCWA, 1981.
14. Including mean annual flow volume of the Greater Zab (12.7 BCM), Lesser Zab (7.8 BCM) and the Diyala River (4.6 BCM) according to data provided by USGS, 2012; Ministry of Water Resources in Iraq, 2012. See Chap. 4.
15. Kliot, 1994a; Shahin, 2007; ACSAD and UNEP-ROWA, 2001.
16. A Student T-test was performed to assess whether the mean values of the two sampling periods are significantly different (at significance level $p<0.01$).
17. CV = 0.58 compared to CV = 0.36 before 1973.
18. Ministry of Environment in Iraq et al., 2006b.
19. The flow regime figures in Chap. 1 and 3 are directly comparable.
20. Beaumont, 1998, p. 169; Isaev and Mikhailova, 2009, p. 386 state that from March until August-September, the flood season accounts for 56%-75% of annual Tigris runoff.
21. Hydrological Survey of Iraq, 1958 and Ministry of Irrigation in Iraq 1999 in ACSAD and UNEP-ROWA, 2001, p. 59.
22. FAO, 2009.
23. FAO and UNDP, 1966, p. 26.
24. Wagner, 2011.
25. Jassim and Goff, 2006, p. 268.
26. Ibid.
27. Ozis, 1983, p. 343.
28. In Turkish: Güneydoğu Anadolu Projesi.
29. For more information on the first projects on the Tigris see Ozis, 1983.
30. Ilisu Environment Group, 2005.
31. ACSAD and UNEP-ROWA, 2001 states a figure of 5,595 MCM, similar Beaumont, 1998 with 5,580 MCM.
32. Ministry of Environment and Forestry in Turkey, 2009.
33. Beaumont, 1998, p. 176.
34. Also referred to as the Khabour River Basin Irrigation Development Project.
35. Ministry of Irrigation in the Syrian Arab Republic and Ministry of Irrigation in Iraq, 2002.
36. The Khabour is a sub-basin of the Euphrates Basin. See Chap. 2.
37. IFAD, 2009.
38. Ministry of Irrigation in the Syrian Arab Republic, 2010.
39. ACSAD and UNEP-ROWA, 2001, p. 78.
40. Recent data suggest that the hydropower capacity of the Mosul Dam is 320 MW, and not 1,050 MW as originally planned. Furthermore, the dam was declared unsafe due to its location. A 2006 United States Army Corps of Engineers report declared that the dam is the most dangerous in the world (The Washington Post, 2007).
41. Kibaroglu, 2002a, p. 210.
42. FAO, 2003.
43. Al-Sakhaf in Isaev and Mikhailova, 2009.
44. Ibid.
45. ACSAD and UNEP-ROWA, 2001, p. 99.
46. FAO Aquastat, 2008.
47. Ministry of Planning in Iraq, 2010.
48. FAO, 2008.
49. FAO, 1988.
50. Odemis et al., 2010.
51. Odemis and Evrendilek, 2007. Based on FAO, 1994, the EC guideline for irrigation water was set at <700 µS/cm.
52. Varol, 2011. The main Turkish cities which pollute the Tigris are Bismil, Cizre, Diyarbakir and Hasankeyf.
53. Ibid.; Gumgum et al., 1994.
54. Varol, 2011; Unlu and Gumgum, 1993.
55. Varol et al., 2011.
56. DO levels at Diyarbakir have reached 1.9 mg/L (Varol et al., 2011).
57. These are the major contributing factors to the pollution of the Tigris in Iraq (Al-Rawi, 2005).

58. FAO Aquastat, 2008; Al-Rawi, 2005.
59. These are major sites where untreated wastewater is discharged. Alobaidy et al., 2010; Thana et al., 2009; World Bank, 2006; Al-Salim, 2008; Al-Layla and Al-Rizzo, 1989.
60. UN-ESCWA et al., 1996, p. 157.
61. Mutlak et al., 1980. Based on FAO, 1994, the TDS recommended guideline for irrigation water is set at <450 ppm.
62. ACSAD and UNEP-ROWA, 2001, p. 130, 136.
63. UNDG, 2005. ACSAD and UNEP-ROWA, 2001, p. 134 cite sources that ascribe increased salinity south of the Samarra Barrage and up to Baghdad to the high salinity of the Adhaim River. The construction of the Adhaim Dam has improved water quality.
64. For instance, ACSAD and UNEP-ROWA, 2001, p. 134 suggest a considerable increase in salinity at Amarah when comparing pre-1978 values with salinity in later years.
65. The guideline for irrigation water is 1,000 cfu/100 ml, and 10,000 cfu/100 ml for bathing. Based on European Union guidelines in World Bank, 2006; Chapman, 1996.
66. Woerden and Berkel, 2004 in World Bank, 2006. The sampling location and period are not mentioned.
67. World Bank, 2006.
68. Al-Rawi, 2005.
69. Thana et al., 2009.
70. Al-Janabi et al., 2011.
71. Goodman, 2001 in Al-Janabi et al., 2011. Chlorine is commonly used to disinfect water for drinking purposes, and when in contact with phenols (not effectively removed by water treatment plants) it reacts to form chlorinated phenols that are dangerous to human health.
72. Al-Lami and Al-Jaberi, 2002.
73. This may also be linked to Turkey's desire to treat the Euphrates-Tigris as a joint basin. While Syria and Iraq have never officially agreed to this approach for various reasons, the international scientific community studying conflict and cooperation on the two rivers follows the joint basin approach.
74. Droubi, 2010.
75. Ministry of Irrigation in the Syrian Arab Republic and Ministry of Irrigation in Iraq, 2002.
76. ORSAM, 2009b.
77. The idea of JTC dates back to 1946 when experts from Iraq and Turkey met to discuss flow guarantees on the Euphrates (see Chap. 1). The committee was subsequently established based on a Turkish-Iraqi Joint Economic Committee meeting protocol.
78. Ministry of Water Resources in Iraq, 2012.
79. ORSAM, 2011.
80. Ministry of Water Resources in Iraq, 2012.
81. AINA, 2011; Iraq Business News, 2012; ORSAM, 2012.

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Chapter 4

Shared Tributaries of the Tigris River

Shared Tributaries of the Tigris River

EXECUTIVE SUMMARY

The Tigris River Basin has several sub-basins that are shared between Iraq and Turkey or between Iran and Iraq. The main shared tributaries are the Feesh Khabour, the Greater Zab, the Lesser Zab and the Diyala.

With more than 27 BCM, the Tigris tributaries significantly contribute to total Tigris river flow. The main contribution to discharge originates from the Greater and Lesser Zab Rivers, which contribute 40-60% of total Tigris flow in Baghdad. In general, the four shared tributaries exhibit similar flow regimes, with normal fluctuations of wet and dry years around the mean annual flow. Although the Lesser Zab and the Diyala have been dammed since the 1960s, there is currently no evidence of a regulated stream-flow regime.

Water resources management differs from one shared basin to another. While the Greater Zab is to date unregulated, several of the dams and regulators on the Lesser Zab and the Diyala support irrigated agriculture projects in the region. No specific water agreements govern any of the four tributaries.

The Greater Zab, Turkey, 2010. Source: Caracas.

SUB-BASIN FACTS

RIVER	FEESH KHABOUR	GREATER ZAB	LESSER ZAB	DIYALA
BASIN AREA SHARES	Iraq 43% Turkey 57%	Iraq 65% Turkey 35%	Iran 24% Iraq 76%	Iran 25% Iraq 75%
BASIN AREA	6,143 km^2	26,310 km^2	19,780 km^2	33,240 km^2
RIVER LENGTH	181 km	462 km	302 km	574 km
MEAN ANNUAL FLOW VOLUME	2 BCM	12.7 BCM	7.8 BCM	4.6 BCM
DAMS	Unregulated to date	Unregulated to date	2 (~7 BCM capacity)	4 (>7 BCM capacity)
PROJECTED IRRIGATED AREA	~37,000 ha	..	..	..

OVERVIEW MAP

Shared Tributaries of the Tigris River

- International boundary
- Capital
- Selected city, town
- Basin boundary
- Main shared sub-basin boundary
- Zone of agricultural development
- River
- Intermittent river, wadi
- Canal, irrigation tunnel
- Freshwater lake
- Saltwater lake
- Spring
- Dam
- Monitoring station
- Climate station

الاسكوا ESCWA

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

Disclaimer
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

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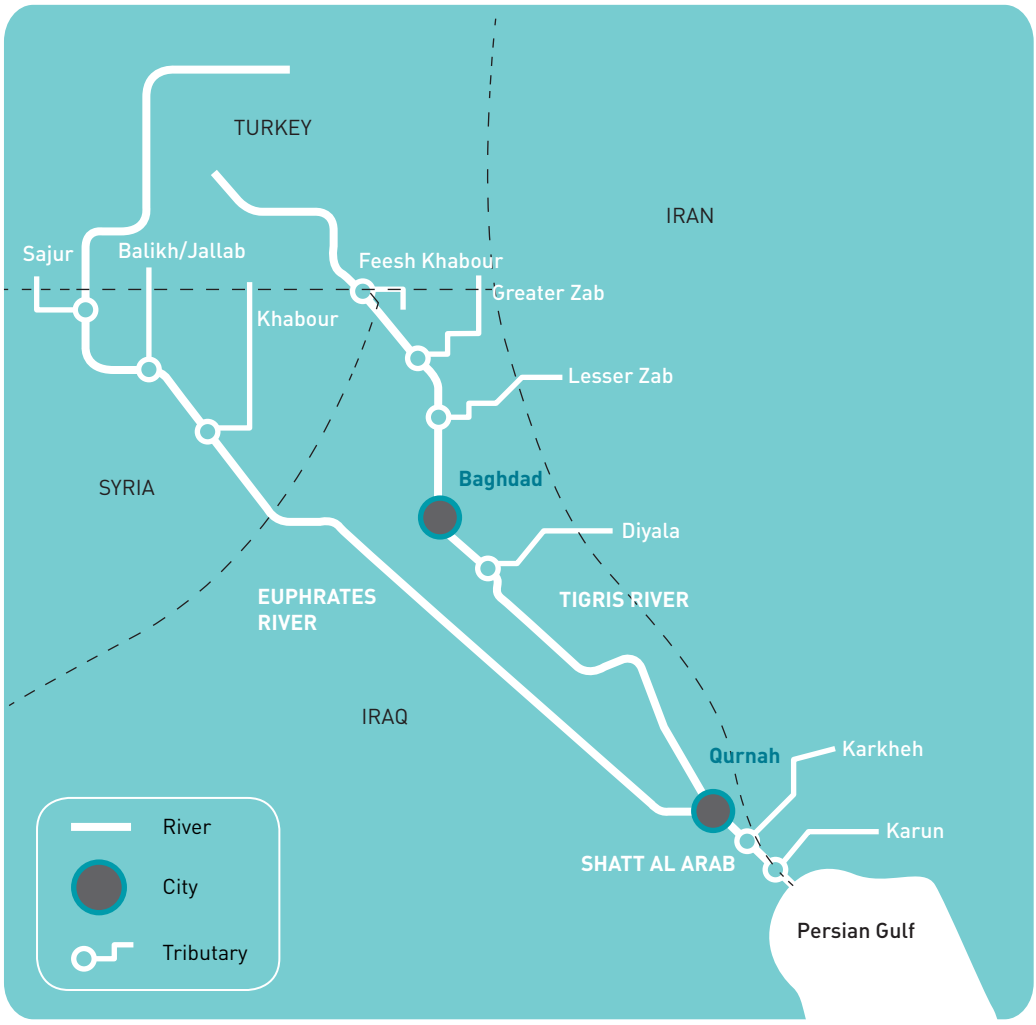
Defining the Euphrates-Tigris-Shatt al Arab Basins

The Euphrates-Tigris-Shatt Al Arab river system constitutes by far the largest surface water resource in the study area. Its combined topographic catchment covers more than 900,000 km^2 from the headwaters in the Taurus-Zagros Mountain Range to the Mesopotamian lowlands and the only outlet to the Persian Gulf, the Shatt Al Arab (Fig. 1). The overall basin is also home to around 54 million people in Iran, Iraq, Syria and Turkey. Given its importance and in order to adequately reflect the specific conditions as well as its complex hydrology, the Inventory dedicates five chapters to this river system.

The Euphrates River Basin (Chap. 1) and Tigris River Basin (Chap. 3) each have a different dynamic and set of characteristics, particularly with regard to their riparian countries, tributaries and contribution to discharge, as well as water use patterns and water quality. The shared tributaries of the Euphrates River (Chap.2) and the major shared tributaries of the Tigris River (Chap. 4) are covered in more detail in two separate chapters in order to highlight the role of these rivers and draw attention to local water issues and transboundary impacts. Chapter 4 also provides information on water use in Iran, which does not share the watercourse of the Tigris River itself but hosts important tributaries within the Tigris Basin. Finally, the Shatt al Arab River is discussed together with two additional major tributaries, the Karkheh and the Karun Rivers, which discharge directly into the Mesopotamian Marshes or the Shatt al Arab itself, and are hence neither part of the Euphrates or Tigris River basins (Chap. 5).

Figure 1. Sketch of the Mesopotamian river system



Source: Compiled by ESCWA-BGR.

Introduction

The Tigris River has a number of tributaries, most of which are shared between Iraq and Turkey, or Iran and Iraq (see Chap.3, Table 1). Their contribution to Tigris river flow is significant. In general, there is limited information on the Tigris tributaries and few in-depth studies exist on these rivers. This Inventory focuses on four of the shared Tigris tributaries. They have been selected on the basis of their size, significance and the availability of information.

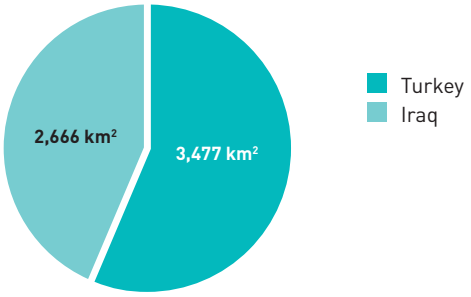
The Feesh Khabour is shared between Iraq and Turkey and forms the smallest of the four tributaries discussed here, both in terms of river length and basin size. The Greater and Lesser Zab are not only the most prominent Tigris tributaries, but also contribute the largest flow volume to the Tigris River. Finally, the Diyala, which is shared between Iran and Iraq, is regulated by four dams.

The Lesser Zab in Bekhme, Iraq, 2005. Source: Ed Kashi/VII.

Feesh Khabour

The Feesh Khabour River (also known as the Little Khabour or Habur in Turkish) originates in Sirnak, in eastern Anatolia in Turkey. The river flows south into Iraq, flowing through Iraqi Kurdistan and then west through the city of Zakho. Downstream from Zakho, the river is joined by its main tributary the Hezil Suyu, which forms the Iraqi-Turkish border for approximately 20 km from here on. The river discharges into the Tigris at the three-country border between Iraq, Syria and Turkey (see Overview Map).

Figure 2. **Distribution of the Feesh Khabour Basin area**



Source: Compiled by ESCWA-BGR.

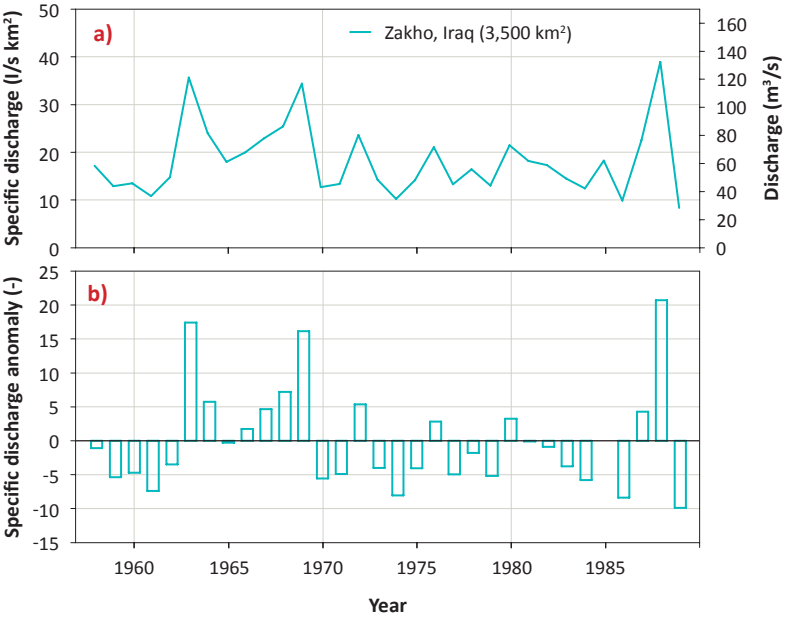
HYDROLOGICAL CHARACTERISTICS

With a length of about 181 km, the Feesh Khabour River has a catchment area of 6,143 km², of which 57% are located in Turkey and 43% in Iraq (Figure 2).[1]

The mean annual flow volume at Zakho is around 2 BCM (Table 1). However, total flow contribution to the Tigris is probably higher as the Zakho gauging station is situated upstream from the Hezil Suyu, a tributary to the Feesh Khabour. Measurements of the Feesh Khabour at the Zakho gauging station for the period of record 1958-1989 show three major wet years (1963, 1969 and 1988) and one extremely dry year in 1989 (Figure 3). The annual river flow time series shows a normal fluctuation of wet and dry years around the mean annual flow, with no statistically significant trend.[2]

The flow regime of the Feesh Khabour shows a distinct high-flow season with a peak in May and a low-flow season from July to December. This can be considered a typical near-natural nival regime dominated by winter precipitation in the form of snow, and snow-melt in the spring months (Figure 4).

Figure 3. **a) Mean annual discharge and b) discharge anomaly time series of the Feesh Khabour (1958-1989)**



Source: Compiled by ESCWA-BGR based on data provided by USGS, 2012; Ministry of Water Resources in Iraq, 2012.

Table 1. **Summary of annual flow volume statistics for the main Tigris River tributaries in Iraq**

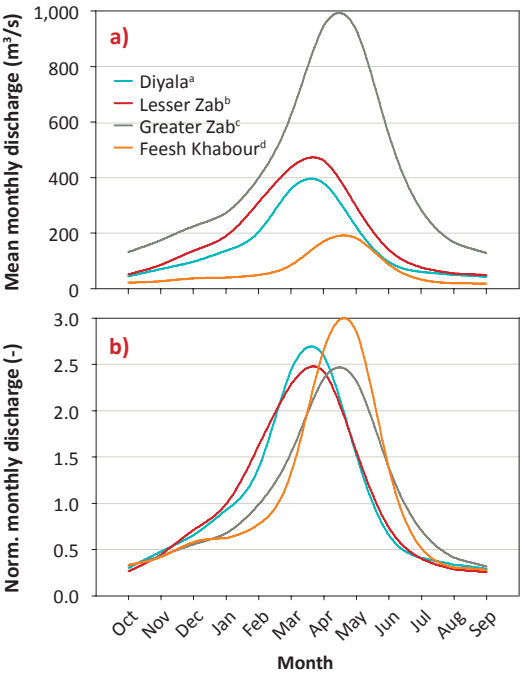
RIVER (DRAINAGE AREA, km²)	STATION (DRAINAGE AREA, km²)	PERIOD	MEAN (BCM)	MINIMUM (BCM)	MAXIMUM (BCM)	CV[a] (-)
Feesh Khabour (6,143)	Zakho (3,500)	1958-1989	2.0	0.9	4.3	0.41
Greater Zab (26,310)	Eski Kalak (20,500)	1931-2011	12.7	3.7	23.6	0.31
Lesser Zab (19,780)	Dukan (11,500)	1931-2011	6.0	1.7	15.1	0.42
Diyala (33,240)	Derbendikhan (17,800)	1931-2011	4.6	1.2	14.4	0.48

Source: Compiled by ESCWA-BGR based on data provided by USGS, 2012; Ministry of Water Resources in Iraq, 2012.
(a) Coefficient of Variation. For information on the definition and calculation of the CV see 'Overview & Methodology: Surface Water' chapter.

WATER RESOURCES MANAGEMENT

No dams or regulators have to date been built on the Feesh Khabour River or its tributaries. Information on water use in the basin is scarce and no water resources management studies are available for the sub-basin. However, satellite images show that agriculture, and particularly irrigation, play a major role in the basin with a projected irrigated surface of about 37,000 ha (see Overview Map). Intensive irrigated agriculture is practised along the entire course of the river in both Iraq and Turkey. The irrigated areas stretch roughly from the city of Zakho to the east to the tri-border point in the west, with a slightly larger irrigated area in the Turkish part of the basin.

Figure 4. **Mean monthly flow regimes of the main Tigris River tributaries at different gauging stations (1931-2011)**



Source: Compiled by ESCWA-BGR based on USGS, 2012; Ministry of Water Resources in Iraq, 2012.
(a) At Derbendikhan.
(b) At Dukan.
(c) At Eski Kalak.
(d) At Zakho.

Greater Zab

The Greater Zab River is the largest Tigris tributary in terms of water yield. Its headwaters originate in the Ararat Mountains in Turkey at an altitude of 4,636 m asl.[3] The headwater topography is characterized by steep slopes, with several tributaries and wadis (Khazir, Rubar-i-Shin, Rukuchuk and Rubat Mawaran Rivers) flowing into the Greater Zab. This perennial stream has a total length of 462 km and flows mainly in Iraq before discharging into the Tigris River 49 km south of Mosul.[4]

HYDROLOGICAL CHARACTERISTICS

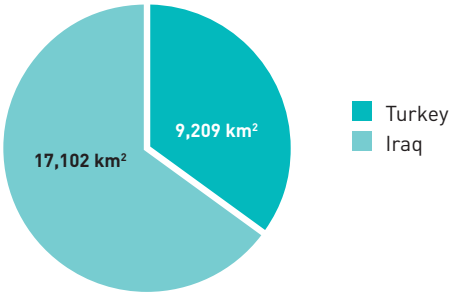
The Greater Zab and its tributaries cover a basin area of around 26,310 km^2 of which 35% is located in Turkey and the remainder in Iraq (Figure 5).[5] Annual precipitation ranges between 350 and 1,000 mm.[6] Rainfall and snow-melt result in a typical flow regime similar to that of the Feesh Khabour, with a high-flow season in spring (Figure 4). Peak flows of the Greater Zab occur in May. The Greater Zab supplies the Tigris River with an average annual flow volume of 12.7 BCM measured at Eski Kalak and 12 BCM farther upstream at the Bekhme Dam. However, total Tigris flow contribution is probably higher as another tributary joins the river downstream of the Eski Kalak gauging station. According to some estimates, 33% of the Tigris flow at Baghdad originates from the Greater Zab.[7]

Measurements of the Greater Zab at Eski Kalak and at the upstream Bekhme Dam station for the period of record 1931-2011 are similar to those of the Feesh Khabour, with three major wet years (1963, 1969 and 1988) and one extremely dry year in 1989 (Figure 6). The annual river flow time series shows a normal fluctuation with no discernible trend of wet and dry years around the mean annual flow.

WATER RESOURCES MANAGEMENT

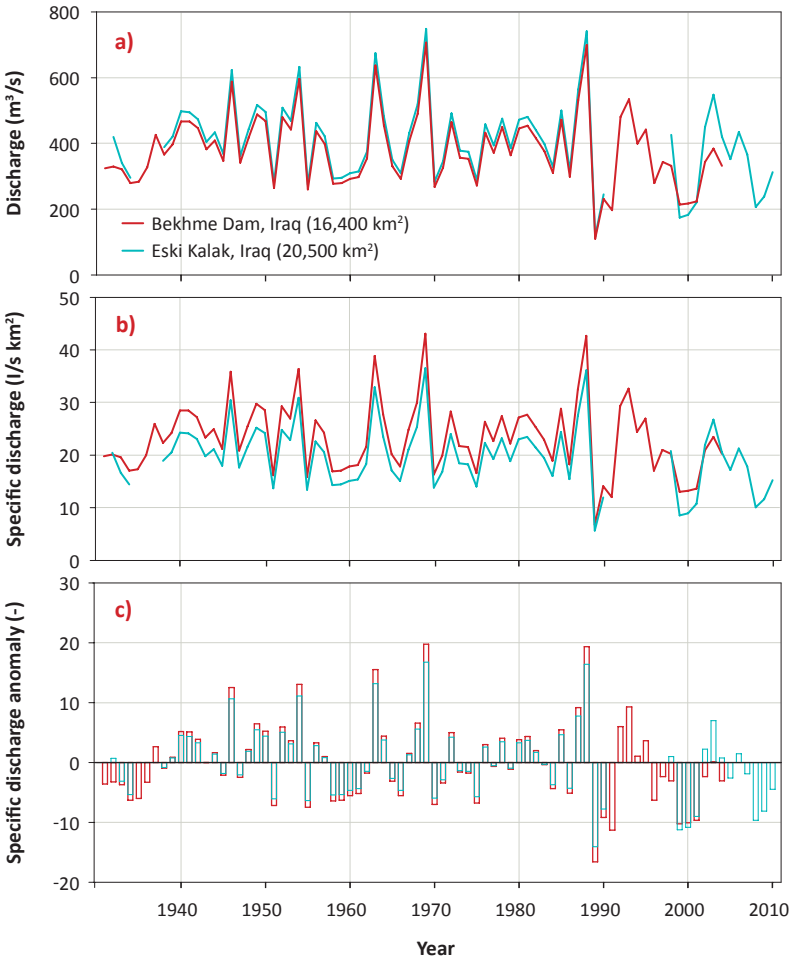
The Greater Zab is one of the few unregulated rivers in the region as no dams have been built on the river to date. However, both riparian countries have plans to exploit the Greater Zab (Table 2). Iraq has planned two dams in the basin: the Bekhme and Mandawa Dams.[8]

Figure 5. **Distribution of the Greater Zab Basin area**



Source: Compiled by ESCWA-BGR.

Figure 6. **a) Mean annual discharge, b) specific mean annual discharge and c) discharge anomaly time series of the Greater Zab (1931-2011)**



Source: Compiled by ESCWA-BGR based on data provided by USGS, 2012; Ministry of Water Resources in Iraq, 2012.

The Bekhme Dam was originally designed for flood control and irrigation in the 1940s, and later evolved to include a storage facility that could replace the storage system at Lake Tharthar (see Chap. 3). The dam was redesigned several times over the years until construction finally started in 1988.[9] The aim of the project was to create a large reservoir that would be used to supply irrigation water and hydropower to the mainly Kurdish population in northern Iraq. However construction was suspended in 1990 due to the outbreak of the Gulf War. Today the Bekhme Dam is once again being considered as a potential source of electricity for 1.5 million homes in Iraqi Kurdistan.[10] According to the Iraqi National Development Plan 2010-2014, construction will take three years and the dam will have a hydropower generation capacity of 1,500 MW.[11]

The Greater Zab River, at Zahko, Iraq, 2012. Source: James Gordon.

Lesser Zab

Located to the south of the Greater Zab, the Lesser Zab River (also Little Zab or Lower Zab) originates in the north-eastern Zagros Mountains in Iran, near the Iraqi border. In the upper basin, the river flows through deep canyons where a number of tributaries such as the Banah and Qazlaga contribute to discharge.[12] With a total length of around 302 km,[13] the Lesser Zab joins the Tigris near the city of Fatha, 220 km north of Baghdad (see Overview Map).

HYDROLOGICAL CHARACTERISTICS

The Lesser Zab covers a basin area of 19,780 km^2, of which about 76% lie in Iraq and 24% in Iran (Figure 7).[14]

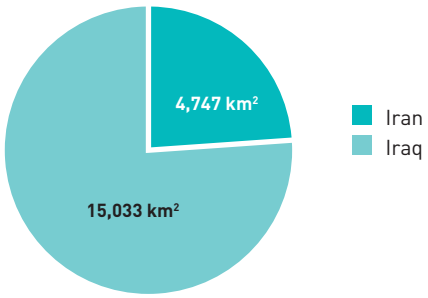
The average annual flow volume of the Lesser Zab at Dukan and at the downstream gauging station of Altun Kupri-Goma is about 6 BCM and 7.8 BCM respectively, with an average discharge contribution to the Tigris of around 191 m^3/s and 249 m^3/s for the two stations.

Figure 8 shows the mean annual discharge variability and anomalies of the Lesser Zab, which is characterized by regular oscillation of wet and dry periods at both gauging stations. While lower-than-average water yield since 1999 may indicate intensified stream regulation, no significant long-term trend can be detected. Compared to the Greater Zab, peak flows generally occur earlier in spring (April), mainly as a result of lower snowfall levels and earlier snow-melt. Generally, the Lesser Zab flow regime shows the same dynamics and seasonality as other Tigris tributaries. While dams have been in operation on the river since the 1960s, a comparison of pre-1960 and post-1960 mean monthly discharge shows no evidence of a regulated stream-flow regime to date.

WATER RESOURCES MANAGEMENT

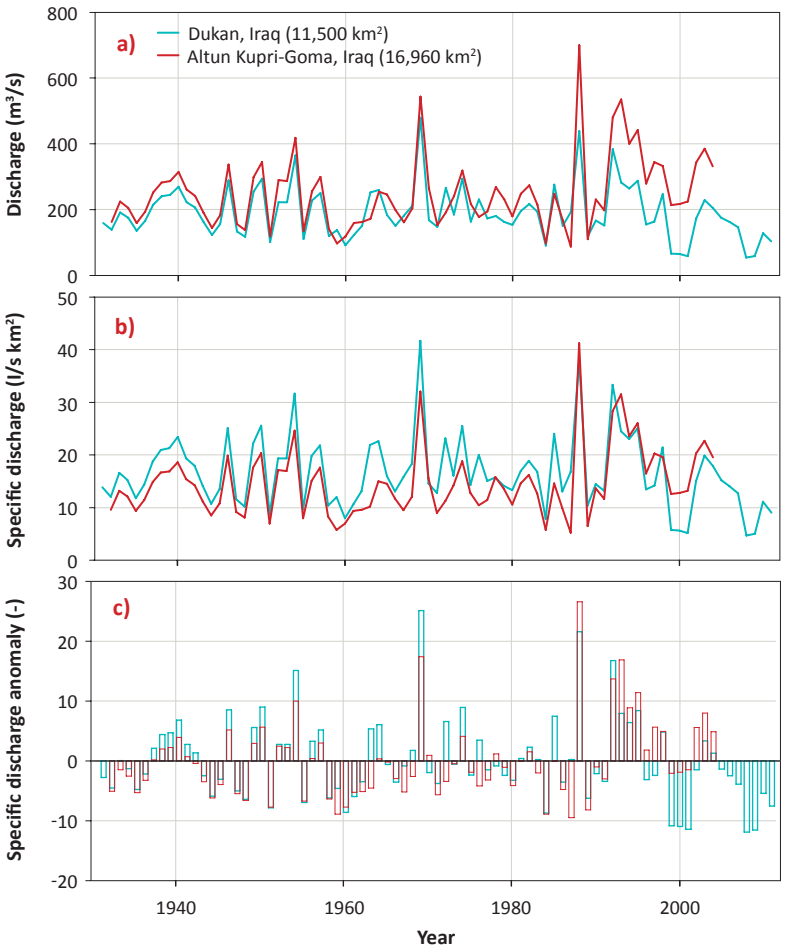
Two dams have been built in the Iraqi part of the Lesser Zab sub-basin: the Dukan and the Dibis (Table 2). The former was built in 1961 as an arch dam upstream of the city of Dukan and has a maximum storage capacity of 6,970 MCM.[15] It is used to regulate Tigris flow and also provides water for irrigation and hydropower generation. The Dibis Dam regulates discharge to the Kirkuk Irrigation Project. Built between 1960 and 1965, it is located about 130 km upstream from the confluence of the Lesser Zab with the Tigris. The Kirkuk Irrigation Project is one of the most important irrigation projects in the region. It was developed in the late 1960s and uses water from the Lesser Zab and Lake Dukan to irrigate 300,000 ha of land. Around 87,500 ha had been implemented by 1983.[16]

Figure 7. **Distribution of the Lesser Zab Basin area**



Source: Compiled by ESCWA-BGR.

Figure 8. **a) Mean annual discharge, b) specific mean annual discharge and c) discharge anomaly time series of the Lesser Zab (1931-2011)**

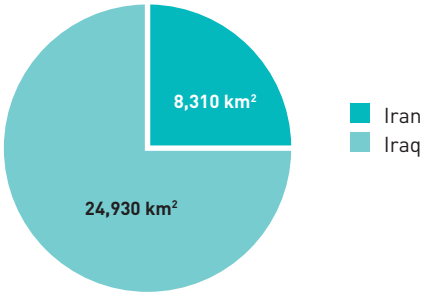


Source: Compiled by ESCWA-BGR based on data provided by USGS, 2012; Ministry of Water Resources in Iraq, 2012.

Diyala

The Diyala River originates near Sanandaj in the Zagros Mountains in Iran, forming the Iran-Iraq border for over 30 km. With a total length of 574 km,[17] the river has a drainage area of 33,240 km², of which 25% are located in Iran and 75% in Iraq (Figure 9).[18] The Diyala joins the Tigris 15 km south of Baghdad (see Overview Map). Its principal tributaries are the Tanjeru, Sirwan and Wand Rivers.[19] Many of the Diyala's smaller tributaries are shared between Iran and Iraq.

Figure 9. **Distribution of the Diyala Basin area**



Source: Compiled by ESCWA-BGR.

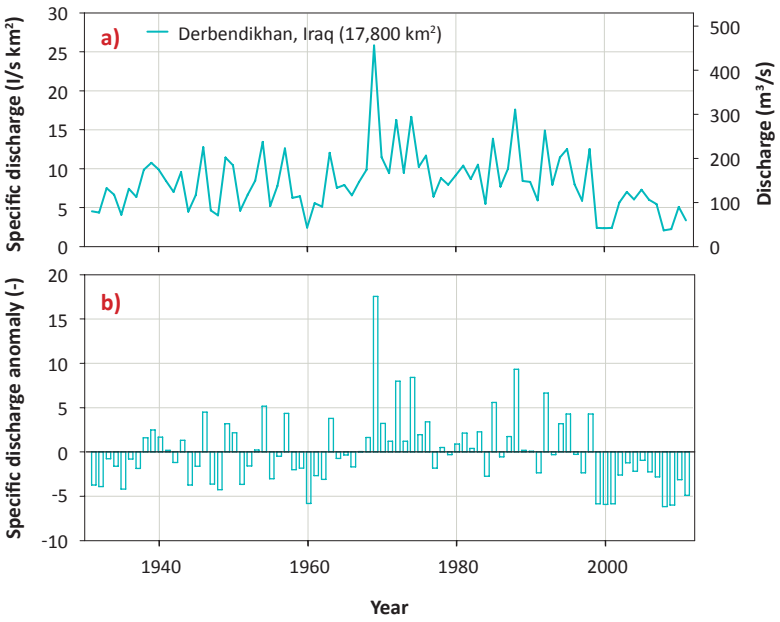
HYDROLOGICAL CHARACTERISTICS

Measured at the Derbendikhan gauging station for the period of record 1931-2011, the Diyala River has a mean annual flow volume of 4.6 BCM. However, the river's total flow contribution to the Tigris is probably significantly larger as various tributaries are not taken into account at this upstream gauging station. Despite the construction of a major reservoir in the upper Diyala catchment in 1962, no significant impact on flow volumes and flow regime can be detected. As with the other Tigris tributaries, 1963 is one of the wettest years within the period of record. Since 1999 below-average flow volumes mark a dry period in the catchment, which potentially indicates intensified stream regulation (Figure 10). However, no long-term trend is detectable over the whole period of record from 1931 to 2011. The Diyala stream-flow is very similar to that of the Lesser Zab. It is characterized by peak flows in April and a low-flow season from July until November.

WATER RESOURCES MANAGEMENT

The Diyala River and its tributaries have more dams along their course than any other Tigris tributary, with three dams in the Iraqi part of the basin and two in Iran (Table 2).

Figure 10. **a) Mean annual discharge and b) discharge anomaly time series of the Diyala (1931-2011)**



Source: Compiled by ESCWA-BGR based on data provided by USGS, 2012; Ministry of Water Resources in Iraq, 2012.

The Derbendikhan Dam was constructed in 1962 as a multi-purpose dam on the upper course of the Diyala in Iraq. Besides flood protection and power generation, the dam secures domestic water supply and irrigation water.[20] The 17,850 km² catchment area lies mainly in Iran.[21] Iraq built the Hemrin Dam in the early 1980s, creating Lake Hemrin with a storage capacity of over 2 BCM. Inflows originate primarily from the Wand River in Iran and runoff from Iraq is only generated during the rainy season.[22]

Irrigation canal near the town of Taweela in the Diyala Basin, Iraq, 1992. Source: Ed Kashi/VII.

In recent years, the Wand River has been at the centre of disputes between Iran and Iraq. In 2008, news agencies reported that Lake Hemrin lost about 80% of its capacity due to the damming of the Wand River in Iran,[23] sparking protests and demonstrations at the Iranian-Iraqi border. In 2011, the Iraqi parliament addressed the issue and subsequently Iraqi officials discussed solutions to the problem with their Iranian counterparts.[24]

Built in the late 1960s, the Diyala Weir is located about 10 km downstream of the Hemrin Dam and about 130 km from the confluence of the Diyala with the Tigris. The main purpose of this dam is to divert the outflow of the Hemrin Dam to irrigation canals.[25]

In Iran, two dams are located in the headwaters of the Diyala: the Qeshlagh (or Vahdat) Dam is located on the Gheshlagh River, while the Gavoshan Dam lies on the Gaveh River. The Qeshlagh Dam was completed in 1979 with a potential reservoir volume of 224 MCM.[26] The Gavoshan Dam was built between 1992 and 2004, primarily for irrigation purposes (Table 2). In addition to supporting a hydroelectric power station, the dam also provides drinking water for the city of Kermanshah. Water is diverted through a tunnel from the Gavoshan Dam reservoir to the Razavar River basin.[27]

Table 2. **Constructed and planned dams on the main shared Tigris River tributaries in chronological order of construction**

COUNTRY	NAME	RIVER	COMPLETION YEAR	CAPACITY (MCM)	PURPOSE[a]	BACKGROUND INFORMATION
Iraq	Dukan	Lesser Zab	1961	6,970	I, FC, HP	The dam is part of the Kirkuk Irrigation Project.
Iraq	Derbendikhan	Diyala	1962	3,000	I, FC, HP, WS	Most of the dam's 17,850 km^2 catchment area lies in Iran.
Iraq	Dibis	Lesser Zab	1965	..	FD	A regulator dam that diverts water from the Lesser Zab to the Kirkuk Irrigation Project. The dam's spillway capacity is 4,000 m^3/s.
Iraq	Diyala Weir	Diyala	1969	..	FD	This regulating structure is located downstream of the Hemrin reservoir and distributes water into the lower Diyala River and irrigation canals.
Iran	Qeshlagh (Vahdat)	Gheshlagh (headwater of the Diyala)	1979	224	I, HP, WS	-
Iraq	Hemrin	Diyala	1981	4,000	..	In 2008, Lake Hemrin lost 80% of its capacity following Iran's damming of the Wand River.
Iran	Gavoshan	Diyala	2004	550	I, HP, WS	The dam was constructed to supply 395 MCM to irrigate 31,000 ha of land, generate 11 MW of hydropower and supply 63 MCM of potable water to the city of Kermanshah.
Iraq	Taq Taq	Lesser Zab	Completion scheduled: 2015	..	..	-
Iraq	Bekhme	Greater Zab	Completion scheduled: 2015	..	I	Partially constructed.
Iraq	Mandawa	Greater Zab	Completion scheduled: 2015	..	..	-
Turkey	Cukurca	Greater Zab	Planned	..	HP	Planned hydropower capacity: 245 MW
Turkey	Doganli	Greater Zab	Planned	..	HP	Planned hydropower capacity: 462 MW
Turkey	Hakkari	Greater Zab	Planned	..	HP	The dam is in its final design phase. Planned hydropower capacity: 245 MW

Source: Compiled by ESCWA-BGR based on General Directorate of State Hydraulic Works in Turkey, 2009; Ministry of Environment in Iraq et al., 2006; FAO, 2009; IRIN, 2008; UNESCO, 2009.
(a) Irrigation (I), Flood Control (FC), Hydropower (HP), Flow diversion (FD), Water Supply (WS).

Water Quality & Environmental Issues

Except for data on salinity levels, limited information is available about the water quality of the Tigris tributaries. Available data on this parameter indicates that water quality in the tributaries in Iraq is acceptable. Variations in Total Dissolved Solids (TDS) values for the Feesh Khabour (Table 3), Greater Zab and Lesser Zab Rivers (Figure 11) show that no significant change in salinity has occurred over the shown time period, and that the water was suitable for agricultural use. However no recent data is available for the Greater and Lesser Zab and changes may have occurred (see also Diyala River).

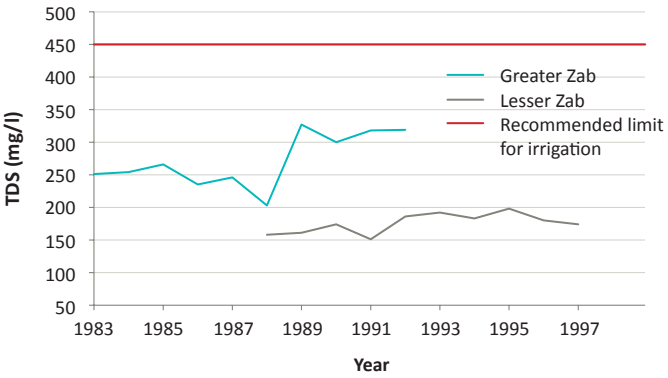
The Diyala River (Figure 12), also showed an average TDS value of 233 mg/L in 1989-1998.[28] However, higher salinity values were measured in 2009 in Lake Hemrin,[29] possibly as a result of the reduction in the lake's capacity since 2008 following Iran's damming of the Wand River.

Table 3. Mean Total Dissolved Solids (TDS) values of the Feesh Khabour in Iraq for different years

YEAR	TDS (ppm)	SOURCE
1982	275	Al-Layla and Fathalla, 1989.
2009	139	Ministry of Water Resources in Iraq, 2012.
2010	125	
2011	125	

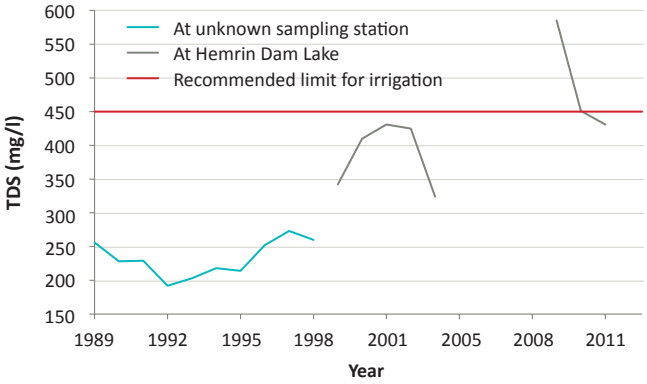
Source: Compiled by ESCWA-BGR.

Figure 11. Mean Total Dissolved Solids (TDS) values of the Greater Zab and Lesser Zab in Iraq (1983-1997)



Source: Compiled by ESCWA-BGR based on UNESCO, 2009.

Figure 12. Mean Total Dissolved Solids (TDS) values of the Diyala River in Iraq (1989-2011)



Source: Compiled by ESCWA-BGR based on UNESCO, 2009; Ministry of Water Resources in Iraq, 2012.

The village of Firuzan, Zakho, Iraq, 2012. Source: James Gordon.

Groundwater in the Tigris Sub-Basins

The four major tributaries of the Tigris River, the Feesh Khabour, Greater Zab, Lesser Zab and Diyala, originate in the Taurus-Zagros Mountains in Iran and Turkey. In the higher mountain area, groundwater is discharged from the main karstic aquifers (Bekhme and Pila Spi Aquifers) into springs. In the inter-mountain basins, groundwater also enters stream-beds through overlying unconsolidated deposits (see Chap. 23). Most of this spring-water is probably diverted upstream for irrigation and water supply purposes.

In the Taurus-Zagros foothill area, groundwater from the Bai Hassan-Mukdadia Aquifers (see Chap. 23) discharges prevailingly into the main Tigris tributaries.

The **Feesh Khabour** rises from a catchment in the eastern Taurus Mountains west of Hakkari, in an area with peaks above 3,000 m asl. The relatively small catchment area on Turkish territory is covered mainly by flysch deposits of the Hakkari complex and the upper Feesh Khabour probably carries no significant base flow from groundwater discharge on its course into the neighbouring area in northern Iraq. In the Zakho Basin in north-western Iraq, the Feesh Khabour River is generally effluent, receiving an inflow of groundwater from Tertiary to Quaternary aquifers. At the lower end of the Zakho Basin, in the border area between Iraq, Syria and Turkey, groundwater in shallow aquifers possibly flows toward the Tigris River in the area of the Hezil Suyu. This river's catchment is mainly covered in limestones and marls of the Upper Cretaceous-Paleogene Kermav Formation. No details on groundwater/surface water relationships are available for the area.

The source of the **Greater Zab** lies at an altitude of approximately 3,000 m asl in the Zagros Mountains east of Lake Van in Turkey. No information is available on the contribution of transboundary flow to the discharge of the Greater Zab, nor on proportions of seasonal runoff and base flow from aquifer discharges in the upper catchments of the river system. Extensive groundwater drainage into the Greater Zab riverbed occurs in the Arbil Basin in the foothills of the Zagros Mountains.

The main source of the **Lesser Zab** lies at an altitude of around 3,000 m asl on the eastern margin of the Zagros Mountains in Iran. Interrelations between groundwater and surface water may be expected, particularly in the upper catchment area through discharge of groundwater from aquiferous carbonate formations and in shallow aquifers of the Ranya Plain, which is partly inundated by Lake Dukan.

In addition to the transboundary flow of the **Diyala**, subsurface inflow appears to reach the Halabja Plain from the mountains of Iran, discharging into the large Zulum Spring. The groundwater/surface water regime within the plain is probably influenced by interconnections between shallow aquifers, stream-beds and other sources. Interaction between groundwater flow in shallow aquifers and surface water possibly occurs in the middle Diyala Basin in the border area between Iran and Iraq.

Agreements, Cooperation & Outlook

AGREEMENTS

There is no comprehensive water agreement in place for the Tigris tributaries discussed in this chapter. However in the 1976 'Agreement between Iran and Iraq Concerning the Use of Frontier Watercourses', the two countries agreed to divide certain shared water resources (including headwaters of tributaries discussed in this chapter). For instance, the agreement states that the Wand River (referred to as Alvend) is to be divided between Iran and Iraq on the basis of the reports of the 1914 Commission on the Delimitation of the Iranian-Ottoman frontier and in accordance with customs.[30] The agreement also foresees the establishment of a permanent joint technical commission composed of an equal number of experts from both countries. However, Iraq has recently expressed reservations regarding the 1976 Agreement.[31]

COOPERATION

There is no information on cooperative measures between Iran and Iraq regarding the four tributaries discussed in this chapter.

OUTLOOK

In periods of drought, rising tension between the riparian countries and local protests cannot be ruled out, as witnessed in 2011 and 2012 along the Iran-Iraq border.[32]

The Greater Zab in Bekhme, Iraq, 2005. Source: Ed Kashi/VII.

Notes

1. Based on estimates from a digital elevation model (HydroSHEDS) similar to Lehner et al., 2008.
2. A Student T-test was performed to assess whether the mean values of the two sampling periods are significantly (at significance level $p<0.01$) different.
3. ACSAD and UNEP-ROWA, 2001, p. 26.
4. Shahin, 2007, p. 249; FAO, 2009, p. 65; Kliot, 1994, p. 109. By contrast, ACSAD and UNEP-ROWA, 2001, p. 26; Isaev and Mikhailova, 2009, p. 386 state a river length of 473 km.
5. Based on estimates from a digital elevation model (HydroSHEDS) similar to Lehner et al., 2008.
6. Abdulla and Al-Badranih, 2000, p. 15; ACSAD and UNEP-ROWA, 2001, p. 26.
7. Kehreman, 2006, p. 2.
8. Kolars, 1994.
9. Kehreman, 2006, p. 2.
10. Ibid. p. 4.
11. Ministry of Planning in Iraq, 2010.
12. ACSAD and UNEP-ROWA, 2001, p. 27.
13. Based on estimates from a digital elevation model (HydroSHEDS) similar to Lehner et al., 2008. By contrast, Isaev and Mikhailova, 2009, p. 386; ACSAD and UNEP-ROWA, 2001, p. 26 refer to a river length of 456 km. UN-ESCWA, 1981, p. 79; Shahin, 2007, p. 249 state a length of 400 km.
14. Based on estimates from a digital elevation model (HydroSHEDS) similar to Lehner et al., 2008. Other estimates are slightly higher: 21,475 km^2 in FAO, 2009, p. 65; and 22,250 km^2 UN-ESCWA, 1981, p. 79. ACSAD and UNEP-ROWA, 2001, p. 26.
15. Ministry of Environment in Iraq et al., 2006, pp. 15-16.
16. FAO Aquastat, 2008.
17. Based on estimates from a digital elevation model (HydroSHEDS) similar to Lehner et al., 2008. According to UN-ESCWA, 1998, p. 18; ACSAD and UNEP-ROWA, 2001, p. 27 the length of the river is 386 km.
18. Based on estimates from a digital elevation model (HydroSHEDS) similar to Lehner et al., 2008. According to UN-ESCWA, 1998, p. 18; ACSAD and UNEP-ROWA, 2001, p. 27; FAO, 2009, the basin size is slightly smaller at 31,896 km^2. According to Shahin, 2007, p. 249 basin size is no more than 29,700 km^2.
19. Also called Alwind or Al Wand.
20. ACSAD and UNEP-ROWA, 2001, p. 27.
21. Ministry of Environment in Iraq et al., 2006, p. 13.
22. Ibid., p. 22.
23. IRIN, 2008.
24. Iraqi News, 2011; Iraq Energy, 2011.
25. Ministry of Environment in Iraq et al., 2006, pp. 33-34.
26. Motiei et al., 2000.
27. Iran Ministry of Energy News Agency, 2011.
28. UNESCO, 2009.
29. Ministry of Water Resources in Iraq, 2012.
30. The Imperial Government of Iran and the Government of the Republic of Iraq, 1975.
31. Ministry of Water Resources in Iraq, 2012.
32. AINA, 2011; Iraq Business News, 2012; ORSAM, 2012.

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Chapter 5

Shatt al Arab, Karkheh and Karun Rivers

Shatt al Arab, Karkheh and Karun Rivers

EXECUTIVE SUMMARY

The Shatt al Arab River is formed by the confluence of the Euphrates and Tigris Rivers near the city of Qurnah in southern Iraq. Downstream of Qurnah, the area draining to the Shatt al Arab region is shared between Iran and Iraq. In addition to the Euphrates and Tigris Rivers, the Karkheh and the Karun sub-basins contribute water to the Shatt al Arab. Both the Karkheh and the Karun Rivers originate in the Zagros Mountains in Iran and discharge into the Shatt al Arab.

The Shatt al Arab River forms the main source of freshwater for the Persian Gulf and plays an important role for marine habitats in the Gulf's north-eastern coastal areas. However, the large-scale development of upstream water regulation and dam structures, together with the drainage of the Mesopotamian Marshes have caused severe salinization of the river. This not only threatens marine ecosystems in the Gulf, but also jeopardizes agricultural activity along the Shatt al Arab.

There are no water agreements in place for the Shatt al Arab, Karun or Karkheh Rivers. However, Iran and Iraq have agreed to cooperate on issues of common concern.

KEY CONCERNS

WATER QUANTITY

Intensive water resource development (mainly dams and irrigation infrastructure) in the upstream areas of the Euphrates and Tigris Basins has resulted in a reduction of flows to the Shatt al Arab River and Mesopotamian Marshes.
Iraq has voiced concern over recent Iranian plans to construct a levy along the Iran-Iraq border through the Haweizeh Marshes. Such a levy would reduce freshwater flow to Iraq, further threatening the marsh ecosystems.

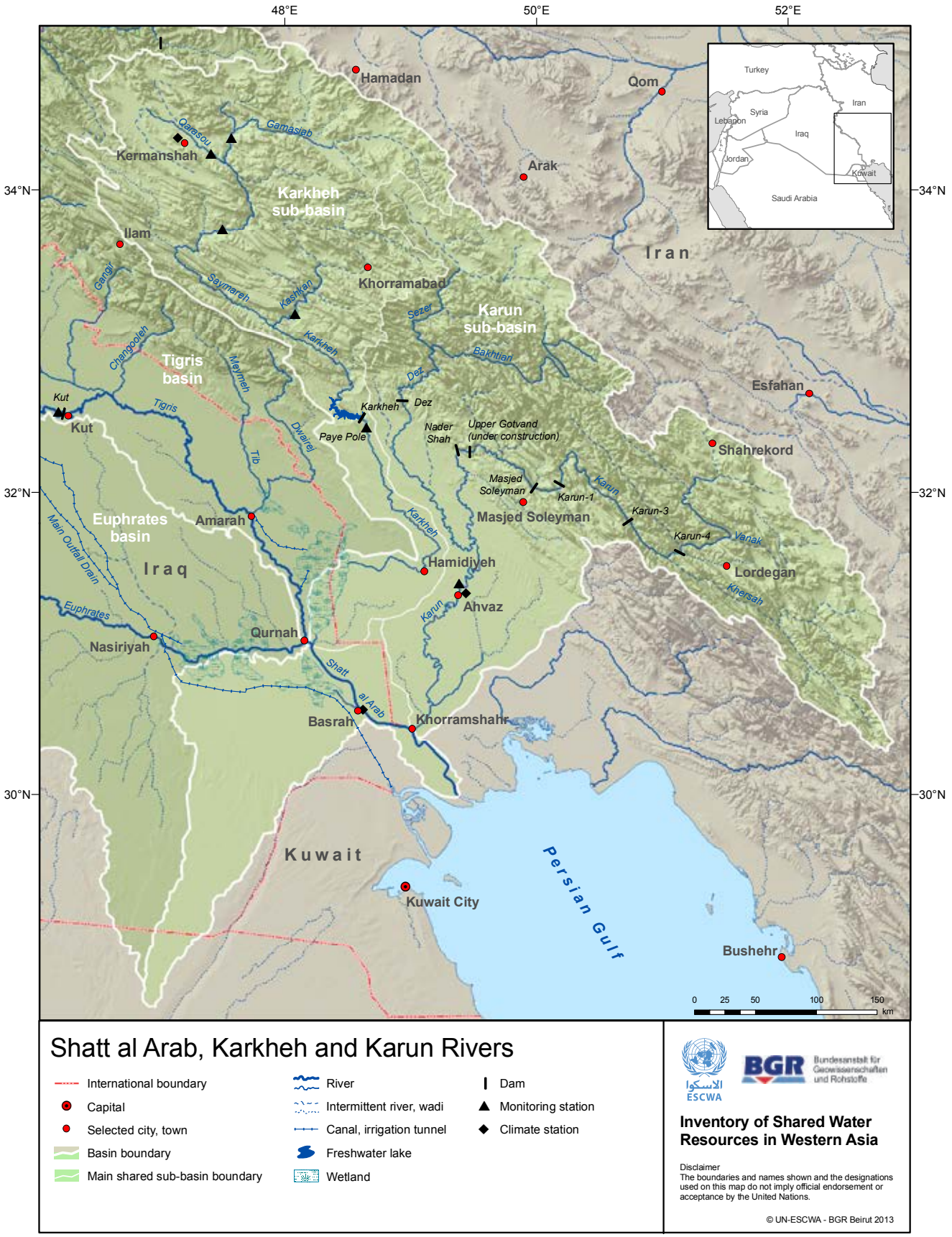
WATER QUALITY

The drainage of the Mesopotamian Marshes has had a negative impact on the Shatt al Arab and the Persian Gulf: the increase in salinity levels in the Shatt al Arab has caused noticeable degradation of coastal areas in Kuwait due to the presence of toxic sediments in the Gulf. Increased pollution from agricultural, industrial and domestic effluents forms an additional problem.

FACTS

RIVER	SHATT AL ARAB RIVER	KARKHEH RIVER BASIN	KARUN RIVER BASIN
RIPARIAN COUNTRIES	Iran, Iraq	Iran, Iraq	-
BASIN AREA SHARES	-	Iran 98%, Iraq 2%	Iran
BASIN AREA	-	51,110 km^2	71,980 km^2
RIVER LENGTH	192 km	964 km	867 km
MEAN ANNUAL FLOW VOLUME	..	5.8 BCM	24.5 BCM
MAIN DAMS	-	2 (max. storage capacity 7.9 BCM)	6 (max. storage capacity 12.4 BCM)
PROJECTED IRRIGATED AREA	..	..	..
BASIN POPULATION	-	4 million	3.5 million

OVERVIEW MAP



Shatt al Arab, Karkheh and Karun Rivers

- International boundary
- Capital
- Selected city, town
- Basin boundary
- Main shared sub-basin boundary
- River
- Intermittent river, wadi
- Canal, irrigation tunnel
- Freshwater lake
- Wetland
- Dam
- Monitoring station
- Climate station

ESCWA

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

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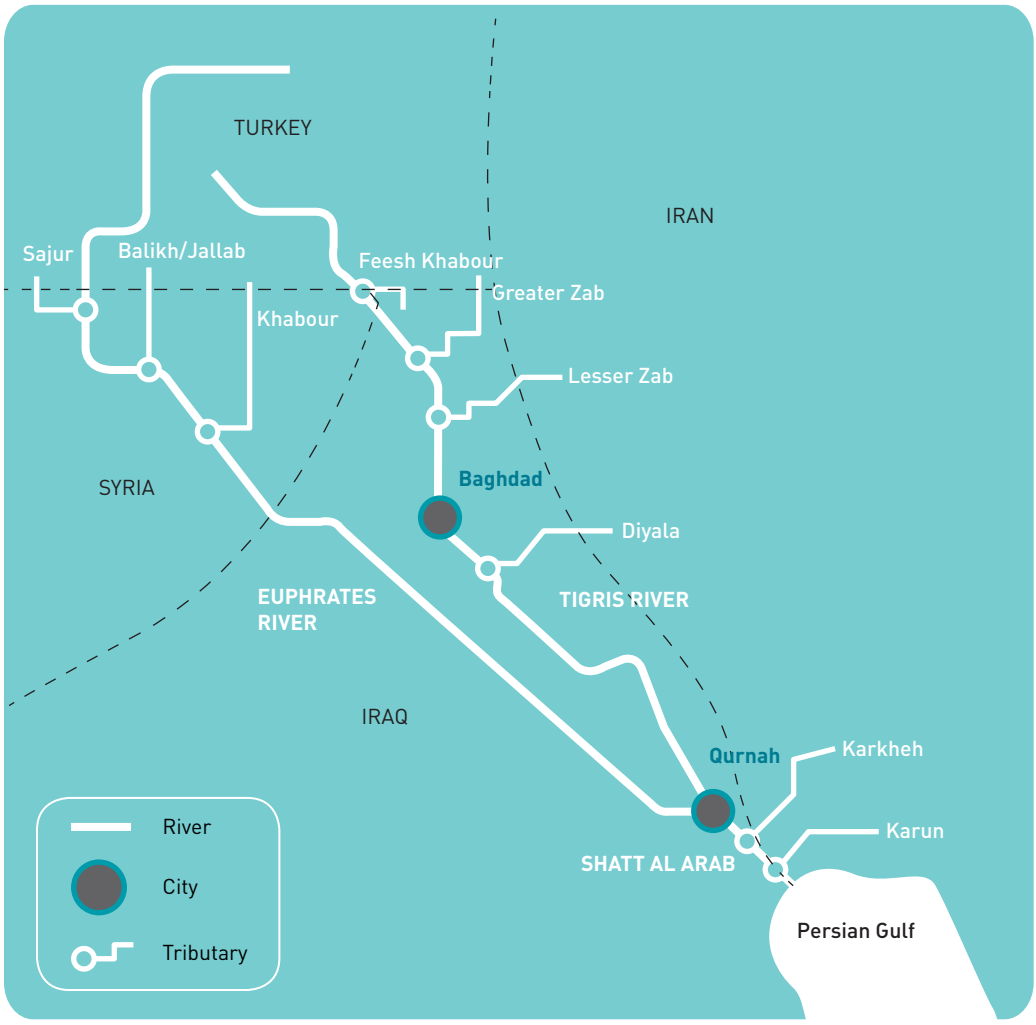
Defining the Euphrates-Tigris-Shatt al Arab Basins

The Euphrates-Tigris-Shatt Al Arab river system constitutes by far the largest surface water resource in the study area. Its combined topographic catchment covers more than 900,000 km^2 from the headwaters in the Taurus-Zagros Mountain Range to the Mesopotamian lowlands and the only outlet to the Persian Gulf, the Shatt Al Arab (Fig. 1). The overall basin is also home to around 54 million people in Iran, Iraq, Syria and Turkey. Given its importance and in order to adequately reflect the specific conditions as well as its complex hydrology, the Inventory dedicates five chapters to this river system.

The Euphrates River Basin (Chap. 1) and Tigris River Basin (Chap. 3) each have a different dynamic and set of characteristics, particularly with regard to their riparian countries, tributaries and contribution to discharge, as well as water use patterns and water quality. The shared tributaries of the Euphrates River (Chap. 2) and the major shared tributaries of the Tigris River (Chap. 4) are covered in more detail in two separate chapters in order to highlight the role of these rivers and draw attention to local water issues and transboundary impacts. Chapter 4 also provides information on water use in Iran, which does not share the watercourse of the Tigris River itself but hosts important tributaries within the Tigris Basin. Finally, the Shatt al Arab River is discussed together with two additional major tributaries, the Karkheh and the Karun Rivers, which discharge directly into the Mesopotamian Marshes or the Shatt al Arab itself, and are hence neither part of the Euphrates or Tigris River basins (Chap. 5).

Figure 1. Sketch of the Mesopotamian river system



Source: Compiled by ESCWA-BGR.

Geography

The area draining to the Shatt al Arab includes the Euphrates Basin, the Tigris Basin, and two major sub-basins: the Karkheh and the Karun (see Chap. 1, Overview Map, Fig. 1). The Shatt al Arab River is born from the confluence of Euphrates and Tigris Rivers near the Iraqi town of Qurnah and is shared between Iran and Iraq. The area draining to the Shatt al Arab covers about 145,190 km^2, excluding the Euphrates and Tigris Basins (upstream of Qurnah), but including the Karkheh and Karun sub-basins (see Overview Map).[1]

The Karkheh and Karun Rivers both originate in the Zagros Mountains in Iran and discharge into the Shatt al Arab. Unlike the Karkheh Basin, the Karun Basin lies entirely in Iran. The Karun is nevertheless included in this chapter as it contributes significantly to the Shatt al Arab, which defines part of the Iran-Iraq border.

CLIMATE

The climate in the Shatt al Arab region is hot and arid. Based on data from the city of Basrah, average temperatures in the Shatt al Arab region vary from 9°C to 41°C; temperature lows occur in January, highs in July.[2] Annual precipitation rates range from 100 mm in the western part of the delta to about 200 mm in the east.[3] The city of Basrah has a mean annual precipitation of about 100 mm.

By contrast, cold winters and mild summers are the norm in the northern, more mountainous areas. Temperatures across the basin vary from a minimum of -25°C in winter to a maximum of 50°C in summer. Mean annual precipitation in the Karkheh Basin was estimated at 450 mm, ranging from 150 mm in the lower plains to 750 mm in the upper mountainous regions.[4] Rain- and snowfall occur mainly in winter and spring.[5]

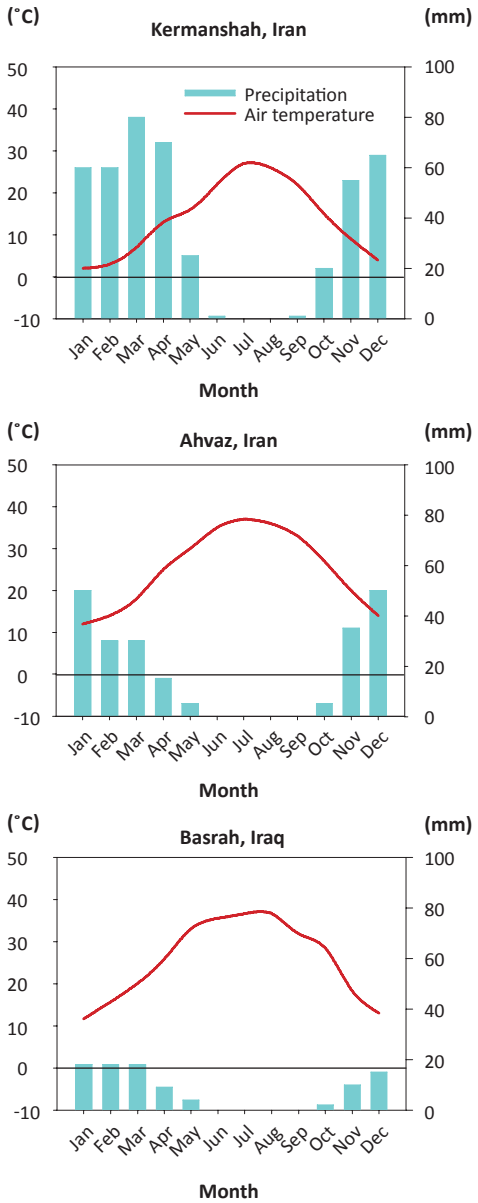
The Karkheh sub-basin has a varied climate that is strongly influenced by the basin's diverse topography. The Khuzestan Plain and the southern parts of the basin are arid, with mild winters and long, hot summers (Figure 2, Ahvaz climate diagram).

The Karun sub-basin covers three climatic zones: a mountainous zone, a zone of foothills and inland desert, and a coastal desert zone.

The climate ranges from extremely hot, dry summers with air temperatures above 50°C to cold winters with sub-zero temperatures.

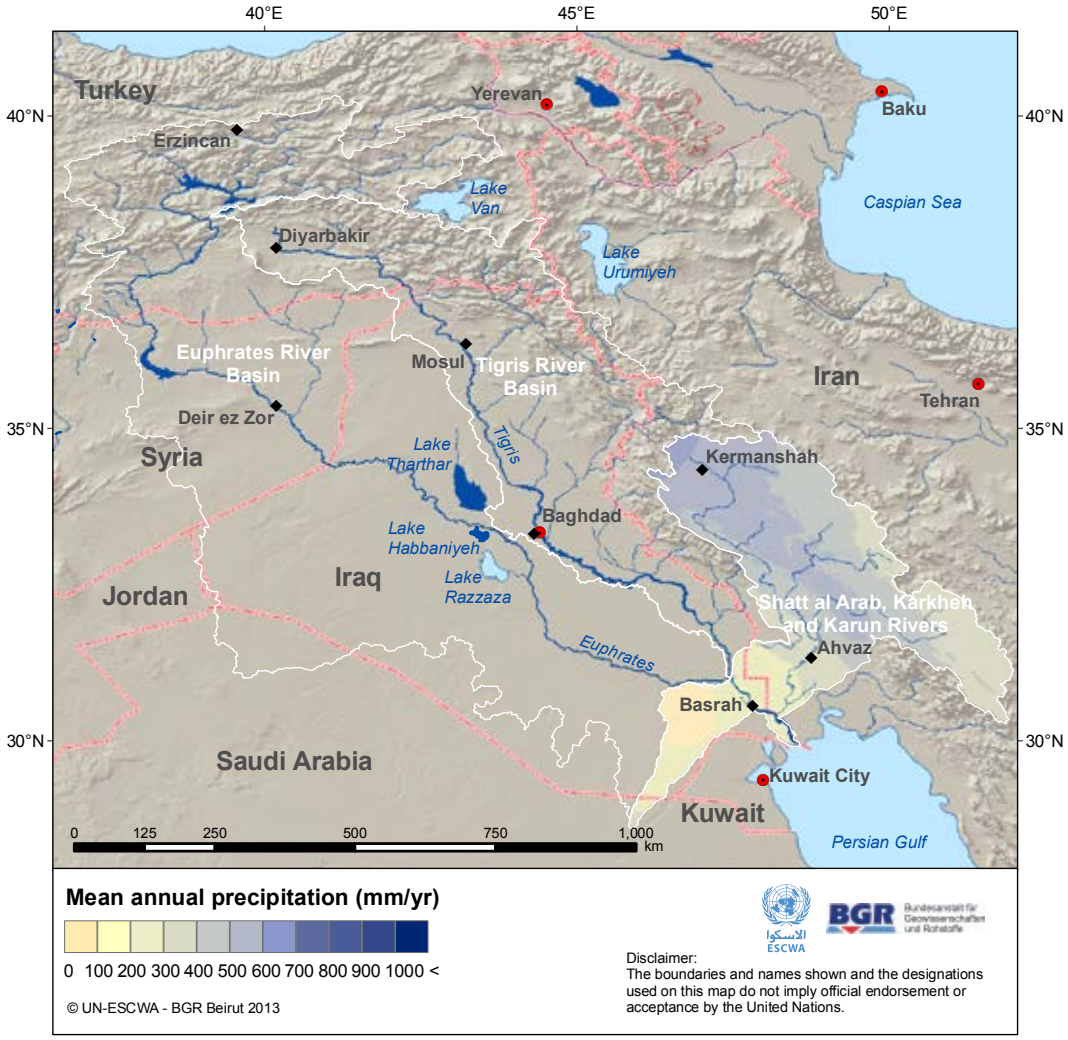
Total annual precipitation ranges from 150 mm in the plain to 1,200 mm in the mountains.[6] As in the Karkheh Basin, precipitation falls mainly between November and April.

Figure 2. Climate diagrams for Kermanshah in Iran, Ahvaz in Iran and Basrah in Iraq



Source: Compiled by ESCWA-BGR based on data provided by WorldClim, 2011; Climate Diagrams, 2009; Phytosociological Research Center, 2009; Masih, 2011.

Figure 3. Mean annual precipitation in the Shatt al Arab region, including the Karkheh and Karun Basins



Source: Compiled by ESCWA-BGR based on data provided by WorldClim, 2011.

POPULATION

Exact population figures are not available for the Shatt al Arab region. However, the largest city in the region, Basrah, has 3.5 million inhabitants, giving an indication of population numbers in the area.

The Karkheh Basin population[7] was estimated at 4 million in 2002, of which about one third resides in rural areas.[8] The basin's annual population growth rate is estimated at around 2.6%.[9] The Karun Basin has a population of about 3.5 million.[10]

Shatt al Arab

The Shatt al Arab River is formed after the confluence of the Euphrates and the Tigris Rivers near the city of Qurnah in southern Iraq (see Overview Map). The southern part of the river constitutes the border between Iran and Iraq until it discharges into the Gulf.

With a total length of 192 km, the Shatt al Arab widens over its course, expanding from a width of 250-300 m near the Euphrates-Tigris confluence to almost 700 m near the city of Basrah and more than 800 m as it approaches the river mouth. An area of 145,190 km^2 drains directly to the Shatt al Arab region downstream of the Euphrates-Tigris confluence (excluding the Euphrates and Tigris Basin areas). Several tributaries join the Shatt al Arab during its course, most importantly the Karkheh and the Karun Rivers.

The Shatt al Arab Delta area is classified as estuarine-deltaic because the river's sediment seeps into a shallow, narrow part of the Persian Gulf.[11]

The Shatt al Arab Delta is 140 km wide and splits into more than 10 branches.[12] The landscape is characterized by green marshy areas, lakes, lagoons and estuaries, bordered by irrigated lands and date palm plantations and surrounded by desert.[13]

BOX 1

Evolution of the Shatt al Arab Delta

The Shatt al Arab River is one of Earth's newest geological features, created by the relentless retreat of the shoreline. Research suggests that the Persian Gulf did not exist in its present form at the beginning of the Holocene (12,000 years ago), with the Euphrates and Tigris Rivers flowing through a marshy area and draining into the Arabian Sea at the Strait of Hormuz.[14] During the Holocene Period, seawater poured into the low-lying marsh area, flooding the land at a rate of up to one kilometre per year. Approximately 6,000 years ago, the shoreline had retreated more than 400 km beyond its present location, flooding most of lower Mesopotamia.[15] Vast quantities of alluvial deposit from the Euphrates, Tigris, Karkheh and Karun Rivers eventually restored the shore to its present-day location, although the four rivers continued to drain separately into the Gulf.[16] It was only in the early modern period (16th-18th century) that these rivers merged to form the modern Shatt al Arab.[17]

The Coast of the Arabs

Shatt al Arab means the riverbank/coast of the Arabs. In the past, this region of lakes and marshes was home to the Marsh Arabs, a population group composed of different tribes. Most of these populations were displaced when the marshes were drained in the 1990s. The Shatt al Arab is referred to as Arvand Rud in Persian.

HYDROLOGICAL CHARACTERISTICS

Figure 4 shows estimates of the potential long-term mean annual discharge (73.6 BCM or approx. 2,340 m^3/s) of the Shatt al Arab into the Gulf. The total flow volume is calculated as the sum of the long-term mean annual flow estimates of the four Shatt al Arab tributaries, with the following values:[18] the Karun contributes 24.5 BCM (measured at Ahvaz gauging station), the Karkheh 5.8 BCM,[19] the Euphrates 17.6 BCM (measured at Hindiyah

The Shatt al Arab, Iraq, 1992. Source: Ed Kashi/VII.

gauging station)[20] and the Tigris 25.7 BCM (measured at Kut).[21] However, these long-term mean annual flow contributions, specifically from tributaries such as the Karkheh and Karun, are not measured directly at the Shatt al Arab confluence and it is likely that actual flow contributions vary significantly (e.g. due to abstractions and evaporation) from the estimates given here.[22] Detailed investigations on this topic, including process-based modelling studies and measurements of the water balance components, could therefore be valuable. In the absence of more precise data, values from Figure 4 can only be considered potential flow contributions, indicating each major tributary's relative contribution to the total Shatt al Arab flow volume and not taking into account abstractions and important evaporation losses.[23]

A 2009 study that includes annual water balance data for a common Euphrates-Tigris-Shatt al Arab Basin before regulation assumes large water losses through evaporation.[24] The same study points to discrepancies between runoff measurements on the Euphrates and Tigris Rivers and the point where the Shatt al Arab discharges into the Gulf. Estimated runoff formed in the Taurus and Zagros Mountains was about 3,500 m^3/s, while the Shatt al Arab discharged 1,450 m^3/s (45.7 BCM/yr), indicating total runoff losses of around 60% (2,050 m^3/s)[25] as a result of surface evaporation from lakes and swamps in the Mesopotamian Marshes.

WATER RESOURCES MANAGEMENT

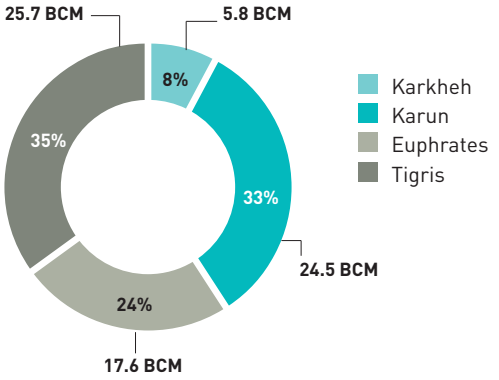
The Shatt al Arab is an important water body as it allows for agricultural production in an arid area with a hot and humid climate. In the 1970s the Shatt al Arab Delta had the largest date palm forest in the world with around 18 million date palms. Thirty years later more than 80% of this palm forest had disappeared due to reduced freshwater flows, increased salinity and damage caused by the Iran-Iraq war.[26]

There is limited information on water resource development projects in the Shatt al Arab region. However, in 2011 the Iraqi Ministry of Water Resources announced plans to construct a 129-km channel to divert water from the Shatt al Arab River for irrigation purposes. The irrigation channel will transfer about 30 m^3/s of water for use on agricultural land in Basrah Governorate.[27]

WATER QUALITY & ENVIRONMENTAL ISSUES

The Shatt al Arab River is the Persian Gulf's main source of freshwater and therefore plays a major role in maintaining the ecological balance of marine habitats in the northern Gulf.[28]

Figure 4. **Potential mean annual flow contributions to the Shatt al Arab**



Source: Compiled by ESCWA-BGR based on data provided by Ministry of Environment in Iraq et al., 2006; GRDC, 2011; Masih, 2011.

The drainage of the Mesopotamian Marshes has had a negative impact on the Persian Gulf, which is now noticeably degraded along the Kuwaiti coast. According to a study of sediment quality in Kuwait's northern coastal zones, the drainage of the Mesopotamian Marshes resulted in a rise in toxic sediments between 2001 and 2003.[29] The study concluded that under normal conditions the marshes would act as a filter, removing pollutants before the water flows into the Shatt al Arab and on to the Gulf. The deterioration of the Mesopotamian Marshes has also caused the decline of coastal fisheries, probably due to increased pollution, which has affected spawning areas and nursery grounds for species such as the penaeid shrimp.[30] This has in turn affected the area's lucrative shrimp business.

The salinization of the Shatt al Arab first became an issue in the 1960s. The situation further deteriorated from the 1970s onwards with the construction of dams and reservoirs on the Euphrates and Tigris Rivers. The regulation of the Euphrates and, to a lesser extent, the Tigris, led to a decrease in runoff, which eventually resulted in the degradation of the delta, as accumulated salt was no longer adequately drained.[31] Low river runoff and high evaporation rates up to 41% in the extreme north-western part of the Gulf further contribute to high salinity.[32] The average salinity value (in TDS) of the Shatt al Arab at Sayhan (south of Khorramshahr) was 1,945 mg/L in 2010 and 2,408 mg/L in 2011.[33] These values far exceed the guidelines for irrigation,[34] limiting agricultural activities to highly salt-tolerant date palms.[35]

The oil pipelines running along the Shatt al Arab River pose a further pollution risk, as do Kuwait's oilfields near the river mouth.

Karkheh

The main headwaters of the Karkheh, the Saymareh and Kashkan Rivers (see Overview Map), originate in the middle and south-western Zagros Mountain range in western Iran. These two tributaries join at Pole Dokhtar to form the Karkheh River. Before the river reaches the Haweizeh Marshes,[36] a large wetland shared by Iran and Iraq, it meanders through a flat plain. After covering a distance of about 964 km, the Karkheh discharges into the Shatt al Arab south of the city of Qurnah and the Euphrates-Tigris confluence.

The Karkheh River is the third largest river in Iran (in terms of water yield), after the Karun and Dez Rivers. The Karkheh drains a large catchment of 51,110 km^2.[37]

HYDROLOGICAL CHARACTERISTICS

The Karkheh River Basin lies almost entirely in Iran (>95% basin area) and most likely contributes close to 100% of discharge. Hydrologically, the basin can be divided into five sub-basins: the Gamasiab, Kashkan, Qarasou, Saymareh and South Karkheh. The major tributaries of the Karkheh River are the Gamasiab, Kashkan, Qarasou and Saymareh Rivers.

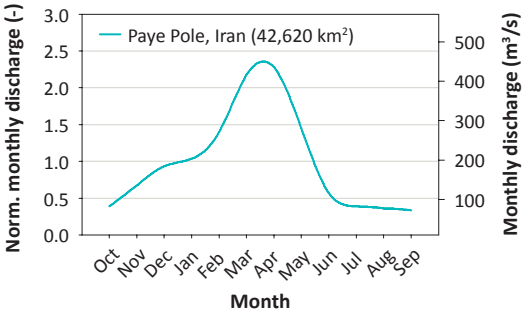
Annual discharge variability

The five Karkheh River sub-basins exhibit dry and wet periods. The analysis of long-term river flow data from 1961 to 2001 shows that all sub-basins experienced a maximum flow during the 1968/1969 wet year (e.g. 12.59 BCM for the Karkheh River at Paye Pole, Table 1) and minimum flows during the 1999/2000 drought year (e.g. 1.92 BCM for the Karkheh River at Paye Pole). During this drought the Gamasiab River ran dry for two to three months.

Flow regime

The flow regime of the Karkheh River shown in Figure 5 can be considered near natural, as operation of the Karkheh Dam only started at the end of the observation period in 2001. However, widespread irrigation in the upper and middle part of the basin is likely to have affected the flow regime, specifically during low-flow periods in the dry summer months. Peak flows in winter and early spring (March and April) are dominated by snow-melt and rainfall. Peak flows are probably not significantly affected by agricultural activities as irrigation demand is very low during this period.

Figure 5. **Mean monthly flow regime of the Karkheh River at the Paye Pole gauging station (1961-2001)**



Source: Compiled by ESCWA-BGR based on Masih, 2011.

Table 1. **Summary of annual flow volume statistics for the Karkheh River and its major tributaries in Iran (1961-2001)**

SUB-BASIN	RIVER	STATION (DRAINAGE AREA, km^2)	MEAN (BCM)	MINIMUM (BCM)	MAXIMUM (BCM)
Gamasiab	Gamasiab	Pole Chehre (10,860)	1.08	0.198	2.85
Kashkan	Kashkan	Pole Dokhtar (9,140)	1.64	0.645	3.21
Qarasou	Qarasou	Ghore Baghestan (5,370)	0.72	0.104	1.91
Saymareh	Saymareh Karkheh	Holilan (20,863) Jelogir (39,940)	2.43 4.97	0.607 1.790	6.19 10.77
South Karkheh	Karkheh	Paye Pole (42,620) Hamidiyeh (46,121)	5.83 5.15	1.920 1.070	12.59 11.32

Source: Compiled by ESCWA-BGR based on Masih et al., 2009.

Groundwater

Due to the basin's complexity and limited data availability, groundwater flow and the interaction with surface water in the Karkheh Basin are not well documented. Generally, groundwater availability in the northern part of the basin is limited to valley floors, characterized by relatively large depths, high infiltration rates and good water quality. In the southern arid plains, the productivity of the aquiferous materials is reduced, mainly as a result of limited thickness and low infiltration rates, as well as increased salinity.[38]

WATER RESOURCES MANAGEMENT

Water in the Karkheh Basin is used for domestic purposes,[39] agricultural production and limited industrial activity. The basin ranks third in terms of surface water use in Iran and fourth in groundwater use.[40] It is considered the country's most productive basin, comprising 9% of Iran's total irrigated area and producing around 11% of its wheat supply.[41] A hydrology and water resources assessment from 1993-94 estimated the total amount of irrigation water diverted from surface and subsurface resources in the Karkheh Basin at 3.9 BCM, of which 63% were from surface water and 37% from groundwater.[42] The same study projected total planned water allocation in the basin for 2011 at 7.9 BCM, of which about 87% was allocated to agriculture with an upward trend (Table 2).[43] However, in reality, current actual water use is probably much lower as progress on project planning and implementation is slow.

Until the completion of the Karkheh Dam in 2001, the basin was not regulated by large dams. However, following the implementation of several major development and irrigation projects, land and water use in the basin are evolving and irrigated agriculture is playing an increasingly prominent role.[44]

BOX 2

Piping Karkheh Water to Kuwait

In December 2003, Iran and Kuwait signed a contract in which Iran committed to supplying Kuwait with drinking water for a period of 30 years. At a cost of USD 2 billion, 300 MCM of water from the Karkheh River is to be conveyed to Kuwait through a 540-km pipeline.[45] It is unclear whether this project is still being pursued.

The Karkheh Dam is a multi-purpose dam in north-western Khuzestan Province in Iran, not far from the city of Andimeshk. It is designed to produce 520 MW of hydroelectric power,[46] prevent downstream floods and provide irrigation water for about 350,000 ha in the Khuzestan Plains in the lower Karkheh region. The dam has been operational since 2002 and has a maximum storage capacity of about 4.7 BCM.[47] Accumulated dam outflow was measured at 2.8 BCM in November 2002 and October 2003.[48]

Several other dams and irrigation schemes are currently being studied and planned. These developments are likely to turn the Karkheh into a heavily regulated river.[49]

Today the basin faces several challenges, including growing competition for water between different sectors and between upstream and downstream users, as well as groundwater depletion, poverty and land degradation.[50]

Table 2. **Current and planned water allocations in the Karkheh Basin in Iran**

SECTORS	EVOLUTION OF WATER ALLOCATION (MCM/yr)					
	2001	2006	2011	2016	2021	2025
Rural areas	59	62	66	69	70	67
Urban areas	203	231	242	259	278	295
Mining	0	1	1	1	2	2
Industry	23	30	57	76	93	113
Agriculture	4,149	6,879	6,814	7,135	7,476	7,416
Fish farming	14	119	249	379	477	510
Environment	500	500	500	500	500	500
Total	4,949	7,822	7,929	8,419	8,896	8,902

Source: Compiled by ESCWA-BGR based on JAMAB, 1999 in Ahmad and Giordano, 2010.
Note: Water resources include surface water, groundwater and reservoirs.

Table 3. **Constructed dams in the Karkheh Basin in Iran**

NAME	RIVER	COMPLETION YEAR	CAPACITY (BCM)	PURPOSE[a]	BACKGROUND INFORMATION
Hamidiyeh	Karkheh	1957	..	I	Irrigated area: 20,000 ha
Karkheh	Karkheh	2002	4.7	HP, I, FC	Reservoir capacity: 7.5 BCM Live storage capacity: ~4.7 BCM According to plans from 2003, water from the dam reservoir will be pumped to Kuwait.
Saymareh	Saymareh	2009	3.2	HP, FC	Hydropower capacity: 380 MW

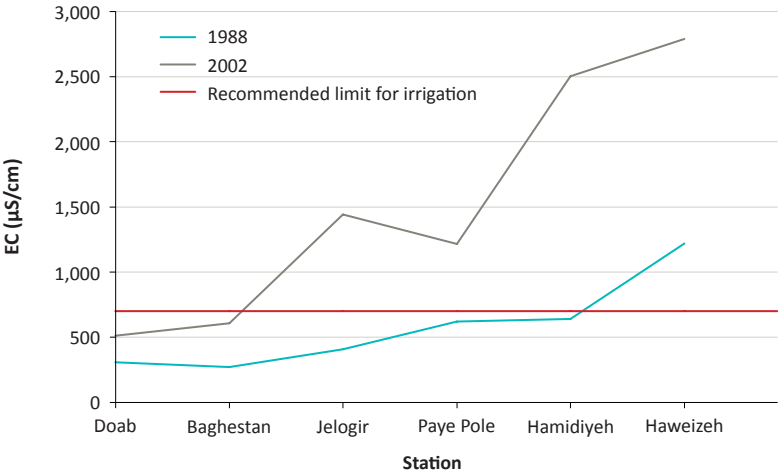
Source: Compiled by ESCWA-BGR based on Plants Around The World, 2010; Masih et al., 2009; Water Resources Directorate in Iran, 2009.
(a) Irrigation (I), Hydropower (HP) and Flood Control (FC).

WATER QUALITY & ENVIRONMENTAL ISSUES

Over the years, changes in land use, soil erosion and lack of rainfall have negatively impacted the watershed's biodiversity, resulting in the deterioration of water quality and increased flooding risk.[51] Water sampling at different stations revealed a steady deterioration of water quality along the river course. The difference in upstream and downstream salinity levels is significant. Figures from 2002 show that while Electrical Conductivity (EC) values in the upper Karkheh were around 500 µS/cm in 2002, they increased to >2,500 µS/cm at the Hamidiyeh and Haweizeh[52] stations, which are located downstream from a series of agricultural development zones.[53] More recent data (2003-2007) indicates that the highest salinity values along the river course were measured at the Haweizeh gauging station.[54]

More specifically, variations in the salinity of the river can be ascribed to the expansion of agricultural lands and urbanization in the basin.[55] Water quality data from 1988 and 2002 shows significant increases in salinity (Figure 6).[56] For instance, while the EC value at Hamidiyeh was around 600 µS/cm in 1988, it had increased to 2,500 µS/cm by 2002.[57] Rapid agricultural and urban development over recent decades has led to an increase in irrigation return flows, as well as a rise in domestic and urban sewage discharge in the river.[58] The 1999/2000 drought and the resulting decline in river discharge is considered an important further factor in reducing Karkheh River water quality.[59]

Figure 6. **Changes in mean Electrical Conductivity (EC) values along the Karkheh River (1988 and 2002)**



Source: Compiled by ESCWA-BGR based on Mahmoudi et al., 2010.

BOX 3

The Haweizeh Marshes

Reduced to an area of around 137,700 ha today, the Haweizeh Marshes (also Haur al Haweizeh) used to extend over a vast area of between 300,000 ha (in average conditions) and 500,000 ha (in flood periods).[60] While the Tigris River is an important contributor to the marshes, the Karkheh River is their main source of freshwater.[61] The Haweizeh Marshes are central to maintaining biodiversity in the Mesopotamian Marshes as a whole, as species retreat here to reproduce and subsequently recolonize the neighbouring Central and Hammar Marshes. Iran's construction of a levy running along the international border through the Haweizeh Marshes is likely to significantly reduce freshwater contribution from the Karkheh River and further jeopardize the subsistence of this important ecosystem.[62]

Karun

The Karun (historically known as the Ulai or the Rud-e Karun in Persian) is Iran's only navigable river[63] and forms the country's largest river basin.

The Karun has a total length of about 867 km and originates in the Zard Kuh Mountains in the Zagros Mountain range about 75 km south-west of Esfahan. From there it flows westwards through ridges and valleys to the Khuzestan Plain at Gotvand. Several tributaries including the Dez and the Kuhrang discharge into the Karun before it reaches Ahvaz, the capital of Khuzestan Province in Iran. From there the river continues towards the Shatt al Arab. The Karun Basin drainage area is estimated at 71,980 km^2 and is situated entirely in Iran. The Karun can, however, be considered a shared basin due to the fact that it discharges into the Shatt al Arab, which forms the Iran-Iraq border.

The Karun has a sinuous course, which has shifted repeatedly through history (Box 4). The coastal areas of some of the former riverbeds have filled with seawater.

Main Karun tributaries

With a length of 470 km, the Dez has two main tributaries. The Bakhtiari River (or Ab Zalaki River) originates in the Bakhtiari Mountains and runs north-east until it joins the Sezer River, the second main tributary of the Karun, which rises in the north of Lorestan Province.[64] After the Bakhtiari-Sezer confluence and below the Dez Dam, the Dez enters the Khuzestan and Dezful Plains, eventually discharging into the Karun River at Band e Ghir. Much of the Dez River is used for irrigation in Khuzestan Province, especially since the construction of the Dez Dam.

HYDROLOGICAL CHARACTERISTICS

The Karun has the highest discharge of Iran's rivers. Figure 7 shows long-term observed discharge for the Karun River at Ahvaz from 1894 to 1985 close to the confluence with the Shatt al Arab. The mean annual specific discharge time series shows a significant negative trend, most likely due to the construction of large hydropower dams in the basin since 1963. Another factor could be the impact of climate change, possibly driven by the decrease in precipitation in the study region, though this observation requires further detailed investigation. Mean annual discharge was reduced from a rate of 818 m^3/s (25.7 BCM) before 1963 to 651 m^3/s (20.5 BCM) after 1963. Generally, there is a frequent alternation of wet and dry years (approximately every two to three years). The only exceptions are the occurrence of a persistent wet period around 1920 and a long dry spell that lasted for more than five years from 1980. Maximum annual flows (1,581 m^3/s) were recorded in 1897, while minimum annual flows (344 m^3/s) occurred in 1966. The mean annual flow of the Karun is estimated at 24.5 BCM. More recent values mentioned in the

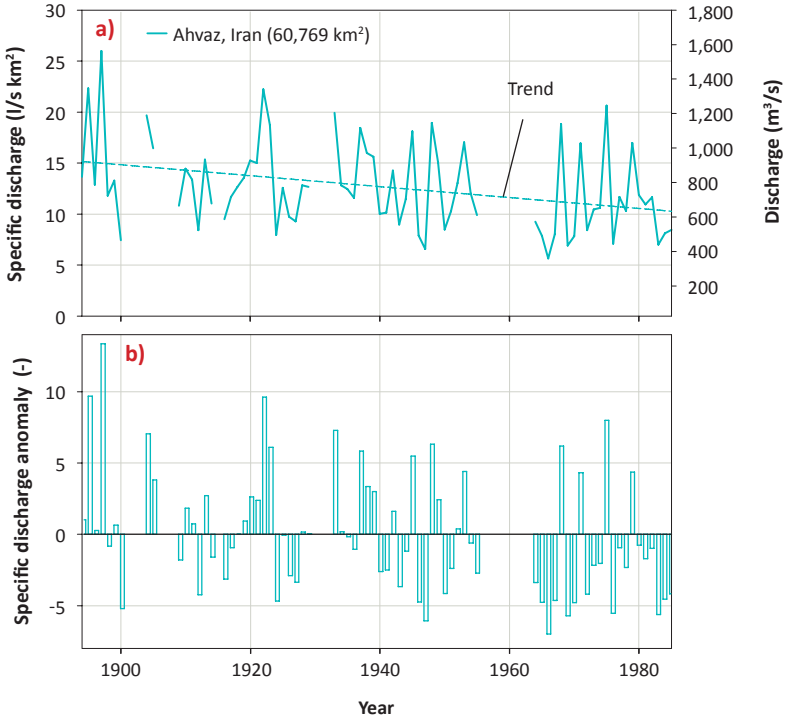
BOX 4

The Many Courses of the Karun

In the past, the Karun was not connected to the Shatt al Arab and instead flowed to the Persian Gulf through several channels, three of which are known today: the Shatt al Qadimi (Ancient River), the Shatt al Ameh (Blind River) and the Bahmanshir River. The first two channels are now filled with seawater, and the Karun flows through the artificial Haffar Channel built for navigational purposes in 1765. The shifting river course sparked border disputes between Iran and the Ottoman Empire that were settled only in 1847 with the signing of the Treaty of Erzurum, which gave Iran access to the Shatt al Arab and the right to use it as a waterway.

Source: Encyclopaedia Britannica, 1995.

Figure 7. a) Mean (specific) annual discharge, b) discharge anomaly time series of the Karun at Ahvaz (1894-1985)



Source: Compiled by ESCWA-BGR based on data provided by GRDC, 2011.

literature state a lower mean annual flow of 22 BCM, though the gauging station and time period are not specified.[65]

Flow regime

The natural mean monthly flow regime of the Karun River is characterized by snow-melt-dominated peak flows in March and April and low flows in September and October (Figure 8). The highest mean monthly discharge was recorded in April 1969 (2,995 m^3/s) and the lowest discharge in October 1949 (163 m^3/s). The river's flow regime changed following the construction of dams on the river after 1963, with a decrease in spring peak flows and summer low flows and an increase in (extreme) low flows in autumn.

WATER RESOURCES MANAGEMENT

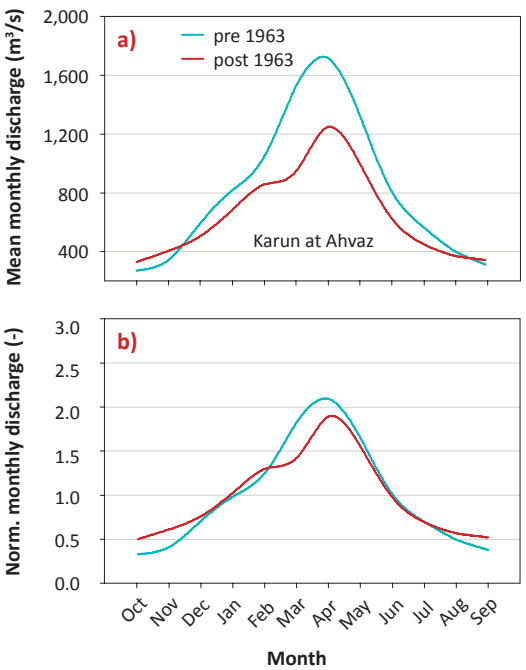
The Karun is an important commercial waterway in Iran, particularly for the transport of oil to the Persian Gulf. Both the Dez and Karun Rivers provide drinking and industrial water to users in the region.[66] Water from the Karun primarily serves large-scale irrigation projects, as well as fish-farming activities and domestic and industrial purposes.[67] Total water use in the basin is estimated at 11.2 BCM/yr (Figure 9).[68]

The Karun Basin is heavily regulated by six large multi-purpose dams that serve to generate hydropower, provide flood control and supply irrigation water in Iran (Table 4). There are five dams on the Karun River itself, with a distance of only 50 km between the Karun I and Masjed Soleyman Dams. In 1997, Iran started building the country's highest earth-fill dam, the Upper Gotvand Dam. Located between the Masjed Soleyman and Nader Shah Dams, the Upper Gotvand Dam is designed to generate hydroelectricity, control floods and mitigate drought impacts in the Khuzestan region.[69] The impounding of the dam started in July 2011, creating a reservoir with a length of 90 km.

Completed in 1963, the Dez Dam was designed to regulate the Dez River as part of the Dez Multi-Purpose River Project, which is a development programme in Khuzestan Province in Iran. In 1957 Iran requested a World Bank loan for the project that aimed to provide irrigation water for around 110,000 ha, supply electric power to several regional cities, and reduce peak floods and flood damage.[70] After the World Bank did an initial assessment of the project, Iran revised it and presented the Dez Irrigation Project, a 40,000 ha irrigation scheme that was to be implemented in two stages.[71] In 1960, the World Bank lent the country USD 42 million for the pilot phase. The Dez Irrigation Project is the largest of a number of irrigation projects in the basin.

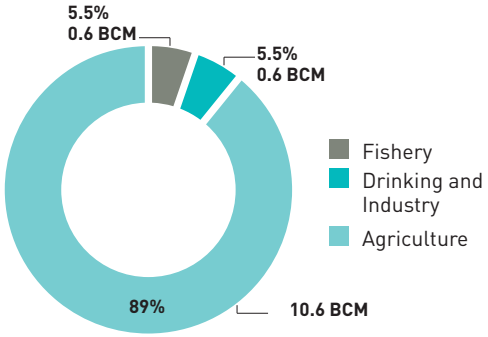
The Karun-3 Dam on the Karun River, Iran, 2008. Source: M. Samadi.

Figure 8. Mean monthly flow regime of the Karun River at Ahvaz for different time periods (1894-1985)



Source: Compiled by ESCWA-BGR based on data provided by GRDC, 2011.

Figure 9. Water use in the Karun Basin in 2007



Source: Compiled by ESCWA-BGR based on Afkhami et al., 2007.

Table 4. Main constructed and planned dams in the Karun Basin in Iran

NAME	RIVER	COMPLETION YEAR	CAPACITY (MCM)	PURPOSE[a]	BACKGROUND INFORMATION
Dez	Dez	1962	3,340	I, HP, WS	Accumulation of sediments from upstream areas is causing a loss in reservoir capacity. The area currently irrigated by the dam reservoir (16,000 ha) falls well short of the projected 80,000 ha.
Karun I (Shahid Abbaspour Dam)	Karun	1976	3,139	I, HP	The first in a series of dams on the Karun River. Reservoir capacity: ~3.1 BCM Reservoir surface area: 54.8 km^2
Masjed Soleyman (Godar e Landar)	Karun	2001	230	I, HP	Hydropower capacity: 2,000 MW The dam's spillway gates are said to be the largest of their kind in the world.
Karun III	Karun	2004	2,000	I, HP, FC	Reservoir capacity: 2,970 MCM Reservoir surface area: 48 km^2
Nader Shah	Karun	..	1,620	..	-
Karun IV	Karun	2010	2,190	HP	The Karun IV Dam is the highest dam in Iran. Its installed capacity increases Iran's hydropower potential by more than 1,000 MW. Reservoir surface area: 29 km^2
Upper Gotvand	Karun	2015 (expected)	4,500 (planned)	HP, I	Construction began in 1997. Once completed, the Upper Gotvand will be Iran's tallest earth-fill dam, supplying one of the country's largest power stations. The impounding of the dam started in July 2011.

Source: Compiled by ESCWA-BGR based on FAO, 2009; Iran Water and Power Resources Development Co., 2006; Karamouz et al., 2004; Naddafi et al., 2007.
(a) Irrigation (I), Hydropower (HP), Water Supply (WS) and Flood Control (FC).

WATER QUALITY & ENVIRONMENTAL ISSUES

As a navigable river, the Karun is severely impacted by pollution from agricultural, industrial and domestic sources, which increases along the river course. Agriculture and industries are the main polluters, and include sugar-cane plantations, fish-farming activities, petrochemical factories, as well as other heavy industries located along the river course.[72] A large proportion of irrigation water is returned to the Karun through agricultural and agro-industrial drainage.[73] Moreover, most industries discharge their effluents directly into the river without treatment, with an annual total of 315 MCM of industrial sewage flowing into the Karun.[74] Municipal wastewater collected from the different cities along the river is also released untreated, with an annual volume of 210 MCM discharging into the river.[75] As a result, the water quality of the Karun is rapidly deteriorating.[76] Besides increasing contamination from heavy metals, the rising salinity of the river is a key concern. While the Karun Basin's geological composition makes the river prone to salinization,[77] human activity is the main cause of current salinization rates, with extremely high levels that increase along the river course.[78] In 2001, an average EC value of 533 µS/cm was observed[79] in the basin's headwaters (Dez Dam). However, at the river's confluence with the Shatt al Arab at the city of Khorramshahr, the average salinity was almost seven times higher in the same year, and almost three times higher than in the 1970s.[80] The increased salinity means that the Karun is unsuitable for drinking water use for much of the year.[81]

Apart from salinity issues, high concentrations of three heavy metals (Cr, Ni, Cu) were observed in the downstream part of the Karun as a result of human activities.[82]

The various sources of pollution have endangered aquatic life in the basin.[83] In addition, the high salinity levels have destroyed flora and fauna habitats and affected local endemic species. The high level of pollution also threatens Ramsar-listed wetlands such as Shadegan wetland.[84]

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place on the Karkheh, Karun or Shatt al Arab Rivers. Control of the Shatt al Arab and the definition of an international border along the river course have caused tensions since the 1639 Peace Treaty between the Ottoman Empire and Persia. In 1975, Iran and Iraq signed the Algiers Agreement, which states that the international border between the two countries is defined by the thalweg of the Shatt al Arab. Five years later, the Iran-Iraq war was partly triggered by unresolved issues surrounding access to and control of the Shatt al Arab. Iraq did not accept the boundary until 1990 after its failed invasion of Kuwait.[85]

The Shatt al Arab remains a source of dispute: Iraq still questions the validity of the Algiers Agreement, while Iran carries out military operations in the Shatt al Arab and claims the river as part of Iranian territorial waters.[86]

COOPERATION

In 2004, Iraq's Ministry of Water Resources protested against Iranian plans to exploit the water of shared rivers and divert them without prior notice. The ministry underscored that dams on the Karkheh impact the environmental balance of the Haweizeh Marshes and reduce water flow to Iraq. Furthermore, dams in the Karun Basin and the diversion of the Karun River through the Hamanshir Canal impact the environment of the Shatt al Arab and agricultural activities nearby. Following these complaints, the two countries created a joint technical committee, which meets regularly to discuss shared water issues. This technical cooperation over shared water issues was further cemented by ministerial meetings in 2009 and 2011, during which officials from the ministries of Foreign Affairs and Water Resources from both countries met.[87]

OUTLOOK

Upstream water development projects in the Euphrates and Tigris Basins have implications for the sustainability of the Shatt al Arab River and associated ecosystems. Iran's ongoing development of water infrastructure projects in the Karkheh and Karun Basins will further impact water resources and ecosystems in the Shatt al Arab region and the Mesopotamian Marshes in the coming years. Initial discussions aimed at encouraging cooperation over water issues have to date not resulted in any joint measures to combat environmental degradation. The development of a joint water management strategy would help avert further environmental degradation and sustain socio-economic development activities in the Shatt al Arab region.

The Shatt al Arab, Iraq, 1992. Source: Ed Kashi/VII.

Notes

1. Basin area was estimated from a digital elevation model (HydroSHEDS) similar to Lehner et al., 2008.
2. The Iraq Foundation, 2003.
3. Isaev and Mikhailova, 2009, p. 391.
4. JAMAB, 1999 cited in Masih et al., 2009, p. 330.
5. Masih et al., 2009, p. 330.
6. Vali-Khodjeini, 1994.
7. The following Iranian provinces fall entirely or partly in the Karkheh Basin: Hamedan, Ilam, Kermanshah, Khuzestan and Lorestan.
8. Masih, 2011, p. 12.
9. Ibid.
10. The following Iranian provinces fall entirely or partly in the Karun Basin: Chaharmahal & Bakhtiari, Esfahan, Khuzestan and Lorestan. The basin population figure is based on a 2006 estimate by the Statistical Center of Iran, 2006.
11. Isaev and Mikhailova, 2009, p. 389.
12. Coleman and Huh, 2004.
13. Isaev and Mikhailova, 2009, p. 391.
14. Teller et al., 2000.
15. Cooke, 1985.
16. Isaev and Mikhailova, 2009.
17. The Iraq Foundation, 2003.
18. Discharge data from 1894 to 1985 provided by GRDC, 2011.
19. Masih et al., 2009; Masih, 2011.
20. See Chap. 1.
21. See Chap. 3.
22. For instance Muthuwatta et al., 2010, studied the Karkheh Basin from November 2002 to October 2003 and estimated the maximum amount of water lost from the whole Karkheh Basin at about 1.5 BCM, taking into account evapotranspiration from the Haweizeh Marshes in the basin. As for the Karun River, mean annual flow is reported as 22 BCM in Afkhami et al., 2007.
23. Some mean annual flow estimates in the respective literature are around 80 BCM for the Euphrates and Tigris Rivers together. See UNEP-DEWA and GRID, 2001; Jones et al., 2008.
24. Isaev and Mikhailova, 2009.
25. Ibid.
26. UNEP, 2010.
27. Iraq Business News, 2011.
28. Al-Yamani and Bishop, 2000.
29. Beg and Al-Ghadban, 2003.
30. Al-Yamani and Bishop, 2000.
31. Isaev and Mikhailova, 2009, p. 393.
32. Ibid. p. 389.
33. Ministry of Water Resources in Iraq, 2012. The salinity range was 1,112-3,645 mg/L in 2010 and 1,304-9,230 mg/L in 2011.
34. Based on FAO, 1994 the salinity guideline for irrigation water was set at <450 mg/L as TDS.
35. UNEP, 2010; FAO, 1993.
36. The Haweizeh Marshes, also known as Haur al Azim, are a complex of marshes along the Iran-Iraq border.
37. Masih et al., 2009, p. 330 give a value of 50,764 km^2. However, a publication from the Ministry of Environment in Iraq et al., 2006, p. 88 states 48,500 km^2 as the size of the drainage basin. Muthuwatta et al., 2010 mention 51,000 km^2.
38. Masih, 2011, p. 17.
39. Muthuwatta et al., 2010, p. 461.
40. Mirzaei et al., 2011.
41. Muthuwatta et al., 2010, p. 461.
42. Masih et al., 2009, p. 331. The total stream flow for the hydrological year 1993-94 was stated as 7.5 BCM.
43. JAMAB, 1999 in Ahmad and Giordano, 2010.
44. Masih et al., 2009, p. 330.
45. Haghiabi and Mastorakis, 2009, p. 120.
46. Plants Around The World, 2010.
47. Live storage capacity is about 4.7 BCM (Masih et al., 2009, p. 330).
48. Muthuwatta et al., 2010, p. 463.
49. Masih et al., 2009, p. 330.
50. Masih, 2011, p. 12.
51. Mahmoudi et al., 2010.
52. Ibid.
53. After the Karkheh Dam, the river passes through six main agricultural zones: Evan, Dosalegh, Erayez, Bagheh, Ghods and Karkheh Sofla (Karamouz et al., 2006).
54. Mirzaei et al., 2011.
55. Salajegheh et al., 2011; Mahmoudi et al., 2010.
56. Ibid.
57. Concentrations of anions and cations in the river also nearly doubled during this period (Mahmoudi et al., 2010).
58. Mahmoudi et al., 2010.
59. Ibid; Salajegheh et al., 2011.
60. UNEP-DEWA, 2001.
61. Ministry of Environment in Iraq et al., 2006, p. 99.
62. Ibid., p. 100.
63. Isaev and Mikhailova, 2009, p. 389.
64. Khosronejad and Ashraf, 2011.
65. Afkhami et al., 2007.
66. Afkhami, 2003.
67. Afkhami et al., 2007.
68. Afkhami et al., 2007 mentions plans to increase this amount by about 80% over the coming five years.
69. Iran Water and Power Resources Development Co., 2011.
70. World Bank, 2011.
71. Watkins, 2009.
72. Diagomanolin et al., 2004; Naddafi et al., 2007.
73. Karamouz et al., 2004; Naddafi et al., 2007.
74. Afkhami et al., 2007.
75. Ibid. Domestic sewage effluents entering the Karun from the cities of Ahvaz and Khorramshahr present salinity rates of 4,000 µS/cm and 5,400 µS/cm respectively.
76. Ibid.
77. Ibid.; Afkhami, 2003.
78. Diagomanolin et al., 2004; Afkhami, 2003; Naddafi et al., 2007.
79. Afkhami, 2003.
80. Afkhami, 2003 states that average salinity rose from 1,388 µS/cm in the 1970s to 3,607 µS/cm in 2001.

81. Naddafi et al., 2007; Afkhami, 2003.
82. Diagomanolin et al., 2004. Sampling was carried out in 1996 at different stations along the Karun River.
83. Naddafi et al., 2007.
84. Afkhami, 2003.
85. Martsching, 1998.
86. BBC News, 2007.
87. Ministry of Water Resources in Iraq, 2012.

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Chapter 6

Jordan River Basin

Jordan River Basin

The Jordan River at one of its narrowest points, Jordan, 1992. Source: Ed Kashi/VII.

EXECUTIVE SUMMARY

Originating from the Anti-Lebanon and Mount Hermon mountain ranges, the Jordan River covers a distance of 223 km from north to south and discharges into the Dead Sea. The river has five riparians: Israel, Jordan, Lebanon, Palestine and Syria.

The Jordan River headwaters (Hasbani, Banias and Dan) are fed by groundwater and seasonal surface runoff. The Lower Jordan River originally received its main inflow from the outlet of Lake Tiberias and the Yarmouk River, the largest tributary, as well as from several wadis and aquifers. The flow of the Upper Jordan River into Lake Tiberias remains nearly natural, but flow rates in the downstream part of the river have decreased sharply in the last 50 years due to the construction of a series of infrastructure and diversion schemes established in the basin. For instance, the mean annual historic flow of the Yarmouk that was estimated at 450-500 MCM in the 1950s has today decreased to 83-99 MCM. The current annual discharge of the Lower Jordan River into the Dead Sea is estimated at 20-200 MCM compared to the historic 1,300 MCM. Moreover, water quality in the Lower Jordan River is very low.

Water use in the Jordan River basin is unevenly developed. Palestine and Syria have no access to the Jordan River; hence their use of water resources from the river itself is nil. However, Syria has built several dams in the Yarmouk River sub-basin, which is part of the Jordan River basin. The country uses about 450 MCM/yr of surface and groundwater resources in the basin, mainly for agricultural purposes. Annual abstractions in the Hasbani sub-basin in Lebanon are estimated at 9-10 MCM, which are mainly used for domestic water supply. Israel is the largest user of water from the Jordan River basin, with an annual withdrawal of between 580 and 640 MCM. It is also the only user of water from Lake Tiberias. Jordan uses about 290 MCM/yr of water from the Jordan River basin. Water diverted from the Yarmouk River to the King Abdullah Canal is used for irrigation of crops in the Jordan Valley and for domestic use in Amman. Overall, the Jordan River basin has an estimated total irrigated area of 100,000-150,000 ha of which around 30% is located in Israel, Jordan and Syria, 5% in Palestine and 2% in Lebanon.

The quality of water in the Jordan River has severely deteriorated in recent decades. While the headwaters are relatively unaffected, the Lower Jordan River consists primarily of untreated sewage and agricultural return flows, groundwater seepage, as well as brackish water from springs diverted into the river away from the Lake Tiberias area. The Lower Jordan River in particular is extremely polluted. Other environmental concerns include water-level fluctuations in Lake Tiberias and the associated risk of saline water intrusion from below, and, more importantly, the decline of the Dead Sea, which all threaten the stability of the basin ecosystem.

Since the early 20th century, numerous attempts to foster cooperation between basin riparians have been hampered by the regional political conflict which continues to stand in the way of any basin-wide agreement on water. A number of bilateral agreements encourage cooperation over water between Israel and Jordan, and Israel and Palestine.

The Dead Sea, Jordan, 2010. Source: Martin Schäfer.

BASIN FACTS

RIPARIAN COUNTRIES	Israel, Jordan, Lebanon, Palestine, Syria
BASIN AREAS SHARES	Israel 10%, Jordan 40%, Lebanon 4%, Palestine 9%, Syria 37%
BASIN AREA	18,285 km^2
RIVER LENGTH	223 km
MEAN ANNUAL FLOW VOLUME	**Natural conditions (1950s)** Upper Jordan River: 605 MCM Yarmouk River: 450-500 MCM Lower Jordan River: 1,300 MCM **Current conditions** Upper Jordan River: 616 MCM Yarmouk River: 83-99 MCM Lower Jordan River: 20-200 MCM
MAIN DAMS	45 (max. storage capacity ~390 MCM)
PROJECTED IRRIGATED AREA	100,000-150,000 ha
BASIN POPULATION	7.18 million

MAIN AGREEMENTS

JORDAN - SYRIA	1953 and 1987 – On the use of the Yarmouk River, including the construction of the Wahdah Dam and 25 dams in Syria. The agreement also establishes a joint commission for the implementation of the provisions on the Wahdah Dam.
ISRAEL - JORDAN	1994 – Annex II of the Treaty of Peace concerns water allocation and storage of the Jordan and Yarmouk Rivers, and calls for efforts to prevent water pollution as well as the establishment of a Joint Water Committee.
ISRAEL - PALESTINE (PLO)	1995 – Article 40 of the Oslo II political agreement states that Israel recognizes Palestinian water rights in the West Bank only and establishes the Joint Water Committee to manage West Bank waters and develop new supplies. Palestinians are denied access to the Jordan River under this agreement.

KEY CONCERNS

WATER QUANTITY

Ensuring adequate quantities of water for all riparians is a key challenge in the basin given the relatively small volume of water available and the large population. River flow has been greatly reduced over the years as a result of increased exploitation of water resources in the basin. The rapid decline of the Dead Sea is an indicator that the region's ecosystem is at risk.

WATER QUALITY

Water quality rapidly deteriorates along the course of the Jordan River and its lower portion displays extremely high salinity and pollution rates.

GEOPOLITICAL

The question of water sharing in the Jordan River basin is inextricably linked to the ongoing conflicts between Israel and Syria, Israel and Lebanon, and Israel and Palestine, and while a wide range of issues are at stake, control over water in the basin has added to existing regional tensions.

OVERVIEW MAP

Jordan River Basin

- International boundary
- Armistice Demarcation Line
- Capital
- Selected city, town
- Basin boundary
- Main shared sub-basin boundary
- Zone of agricultural development
- River
- Intermittent river, wadi
- Canal, irrigation tunnel
- Freshwater lake
- Spring
- Mountain
- Dam
- Monitoring station

ESCWA الاسكوا

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

Disclaimer
The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

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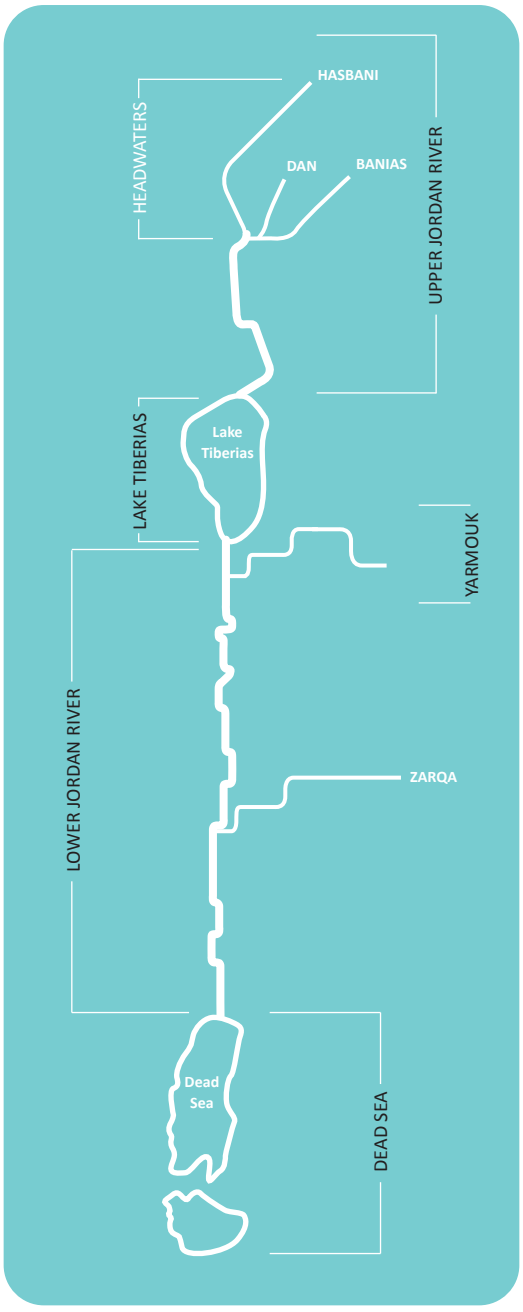
Geography

This chapter on the Jordan River basin covers the headwaters of the Upper Jordan River, the Upper Jordan River, Lake Tiberias, the Yarmouk River and the Lower Jordan River (Figure 1). This Inventory focuses on shared freshwater bodies and perennial rivers. The Dead Sea Basin,[1] which covers a total area of 43,280 km^2, is therefore not considered in this chapter.

Figure 1. Sketch of the Jordan-Yarmouk River System



Source: Compiled by ESCWA-BGR.

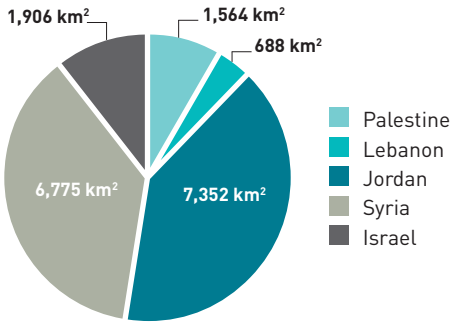
The Jordan River forms the axis of a basin system, flowing from the slopes of Mount Hermon in the north at the junctures of the borders of Israel, Lebanon and Syria to the Dead Sea in the south (see Overview Map). The basin is shared by five riparian countries: Israel, Jordan, Lebanon, Palestine and Syria.[2]

The area of the Jordan River basin is estimated at 18,285 km^2 including the Banias, Dan (Liddan)[3] and Hasbani headwater sub-basins and the basin of the largest tributary, the Yarmouk River.[4] The largest part of the basin is located in Jordan (40%) and Syria (37%), with the remainder situated in Israel (10%), Lebanon (4%) and Palestine (9%) (Figure 2). The river has a total length of 223 km measured from the confluence of the headwaters to the Dead Sea. North of Lake Tiberias, the river is generally designated as the Upper Jordan River, while the part that flows south from Lake Tiberias to the Dead Sea is referred to as the Lower Jordan River.

RIVER COURSE

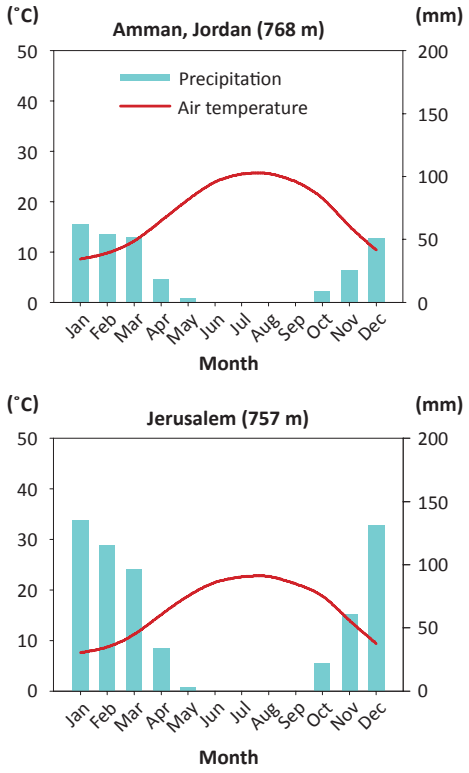
The Upper Jordan River is principally formed by the flow of three spring-fed rivers: the Hasbani, Banias and Dan. The Hasbani River originates in Lebanon, while the Banias River rises in the occupied Syrian Golan and the Dan Spring lies in Israel.[5] The Dan and the Banias Rivers meet north of the Hula Valley and upstream of the confluence with the Hasbani, where the three main headwaters form the Upper Jordan River. There is an ongoing discussion about the principal source of the Jordan River, revolving around the hydrological definition of various parameters such as water yield and river length.[6]

Figure 2. Distribution of the Jordan River basin area



Source: Compiled by ESCWA-BGR.

Figure 3. Mean monthly climate diagrams for Amman, Jordan, and Jerusalem



Source: Compiled by ESCWA-BGR based on data provided by WorldClim, 2011; Climate Diagrams, 2009; Phytosociological Research Center, 2009.

The Lower Jordan River flows from the outlet of Lake Tiberias and is joined about 5 km downstream by the Yarmouk, a river with a total length of 143 km. The Yarmouk River originates from sources in Jordan and in the eastern Golan in Syria. It forms the Jordanian-Syrian border for about 49 km and then flows through the Addasiya Triangle where it runs along the Israeli-Jordanian border for a few kilometres before joining the Lower Jordan River.

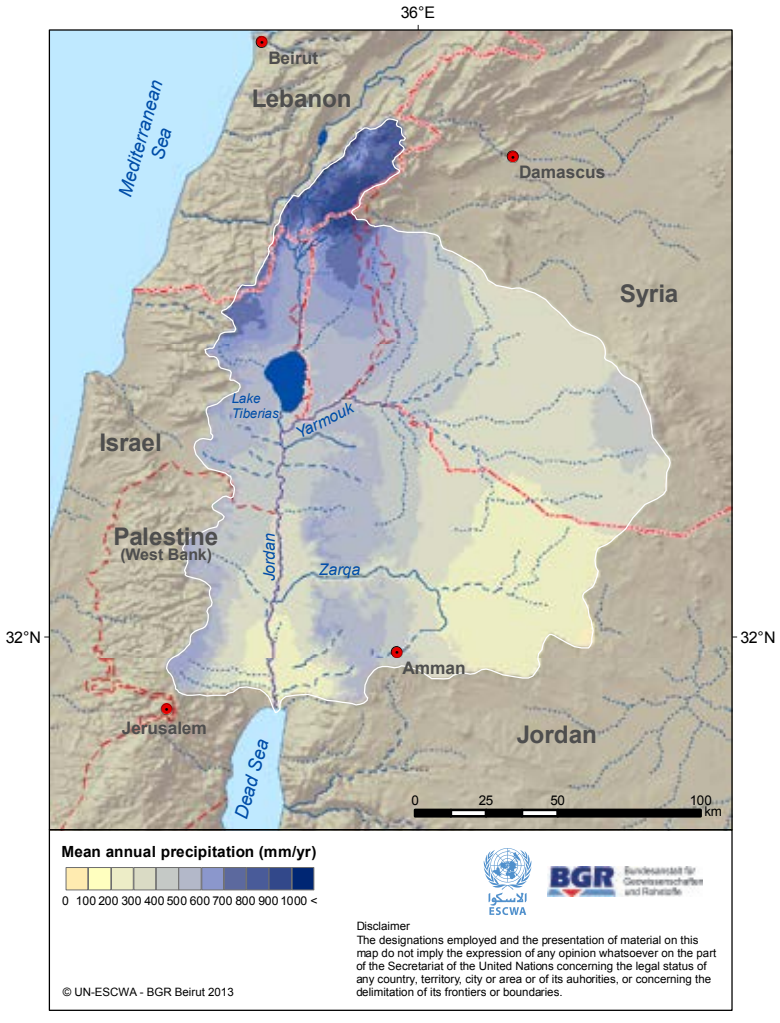
The Lower Jordan River covers a distance of 115 km from the outlet of Lake Tiberias to the Dead Sea, with several wadis joining the river from both sides and the Zarqa River discharging into it from the east.

CLIMATE

The Jordan River basin displays broad climatic variations within a relatively small area, which is typical of climatic conditions in the region. The rapidly changing topography with influences of Mediterranean and continental climates creates different microclimates in the basin. The steep west-east climate gradient gives rise to a sequence of Mediterranean, semi-arid and arid climates over a distance of just 10 to 20 km in places. The mountains in Lebanon and Syria, which extend over a small area in the northern part of the basin, are hardly influenced by the Mediterranean climate due to their altitude, while the slopes of the north-eastern mountain ridges and parts of the east bank of the Jordan River are characterized by a dry, temperate Mediterranean climate. The highest mean temperature lies around 22°C, with at least four months per year averaging above 10°C (Figure 3). The hillslopes of the West Bank and the Jordan Valley have a steppe climate with low precipitation and mean annual temperatures above 18°C. Parts of the Syrian plateaus and most of the Jordanian highlands have an arid climate.[7] High summer temperatures in parts of the basin account for the relatively high evaporation rates, which are estimated at 65% in winter and 45% in summer.[8]

Precipitation rates in the Jordan River basin vary from over 1,000 mm/yr on the eastern slopes of Mount Hermon in the north to less than 200 mm/yr in the lower West Bank and less than 100 mm/yr on the Dead Sea coast (Figure 4).[9] Rainfall declines from north to south and from west to east, which explains why the limited surplus water is confined to the northern and coastal uplands in Israel, Lebanon and Syria.[10] Precipitation is concentrated in the

Figure 4. Mean annual precipitation in the Jordan River basin



Source: Compiled by ESCWA-BGR based on data provided by WorldClim, 2011.

winter months between November and March. The basin has a pronounced seasonal climate variability, with strong fluctuations in rainfall from year to year.[11]

POPULATION

The Jordan River basin has a total population of more than seven million. The majority of the basin population lives in Jordan (71%), while 18% lives in the Syrian part of the basin, which includes parts of the Yarmouk sub-basin and the Golan Heights in Syria. The populations living in the three remaining riparian countries make up 11% of the basin population (Table 1).

Mount Hermon, Lebanon, 2009. Source: Eileen Maternowski.

Syrians Living in the Occupied Golan

Before the Israeli occupation of the Golan in 1967, the area was home to over 140,000 Syrians, most of who were displaced by the occupation. Today an estimated 20,000 Syrians live in small villages in the Israeli-occupied Syrian Golan.[a]

(a) Permanent Mission of the Syrian Arab Republic to the United Nations, 2010.
(b) Central Bureau of Statistics in Israel, 2010.

Israelis Living in the West Bank

Between 1996 and 2009, the number of Israelis living in settlements in the West Bank more than doubled from 140,000 in 1996 to 300,000 in 2009 (450,000 including East Jerusalem).[b]

Table 1. Estimated basin population

RIPARIAN COUNTRY	COUNTRY POPULATION (MILLIONS)	ESTIMATED POPULATION IN THE BASIN		SOURCE
		MILLIONS	AS PERCENTAGE OF TOTAL BASIN POPULATION	
Lebanon	4.5	0.105	1	Ministry of Energy and Water in Lebanon, 2011.
Syria	23.7	1.3	18	Central Bureau of Statistics in the Syrian Arab Republic, 2005; Central Bureau of Statistics in the Syrian Arab Republic, 2011.[a]
Israel	7.7	0.294	4	Central Bureau of Statistics in Israel, 2009.[b]
Jordan	6.1	5.05	71	Department of Statistics in Jordan, 2012.[c]
Palestine (West Bank)	4.1	0.431 (+30,000 Israeli settlers)	6	PCBS, 2012.[d]
Total		7.18		

Source: Compiled by ESCWA-BGR.
(a) The population estimation for the basin area situated in Syria is based on a 2004 population census and 2010 estimates and includes populations living in the Syrian governorates of Dar'a, Quneytra, Reef Dimashq and As Suwayda.
(b) The population estimate for the area of the basin situated in Israel is based on a 2008 population census and includes populations living in the Israeli districts/sub-districts of Golan, Kinneret, Yizre'el and Zefat.
(c) The population estimate for the basin area situated in Jordan is based on 2011 estimates by the Department of Statistics and includes populations in the governorates of Ajlun, Amman, Balqa, Irbid, Jarash, Mafraq and Zarqa.
(d) The population estimate for the basin area situated in Palestine (West Bank) is based on a 2007 population census by the Central Bureau of Statistics and includes populations in the West Bank governorates of Aghwar Jenin, Jericho, Jerusalem, Nablus, Ramallah & Al-Bireh and Tubas. In addition, about 30,000 Israeli settlers in the West Bank live within the boundaries of the Jordan River basin (PCBS, 2011).

Hydrological Characteristics

For the purpose of this Inventory, the hydrological characterization of the Jordan River basin is divided into four parts: Headwaters of the Upper Jordan River, Upper Jordan River, Yarmouk River and Lower Jordan River. This division allows for the presentation and discussion of available discharge data for each of the four basin parts and for the analysis of measured differences between gauging stations along the course of the river. Wherever possible, riparian contributions are presented before annual flow variability and flow regime data. Depending on data availability, the connection between surface and groundwater resources is also addressed.

Finally, findings from the hydrological characterization will enrich the subsequent comparison between the presumed near-natural flow regime of the Jordan River basin and its current state.

Available discharge data presented in this section covers the period from the hydrological year 1944 until 2008 for the three headwaters of the Upper Jordan River, and from 1948 until 2008 for other stations on the Upper Jordan River. For the Yarmouk, available discharge data covers the period 1963-2006, while data for the Lower Jordan River is only available for 20 years from 1979 to 1999.

Lake Tiberias from Umm Qais, Jordan, 2007. Source: Eileen Maternowski.

HEADWATERS OF THE UPPER JORDAN RIVER

DISCHARGE AND FLOW REGIME

The Hasbani,[12] Banias,[13] and Dan Rivers are the main contributors to the flow of the Upper Jordan River with respective surface catchment areas of 698 km^2, 189 km^2 and 17.6 km^2.[14] Although it has the smallest surface basin area, the Dan River contributes the largest flow volume to the Upper Jordan River (Table 2), most likely due to the presence of an important transboundary aquifer system that extends northward beyond the limits of the Dan surface water sub-basin into the Hasbani sub-basin and the Mount Hermon area.[15]

ANNUAL DISCHARGE VARIABILITY

The mean annual flow of the Dan (228 MCM) is about double that of the Hasbani and Banias Rivers (122 MCM and 113 MCM respectively). The mean annual flow of these headwater rivers has a measured total of 463 MCM for the entire period of record between 1944 and 2008 (Table 2). Maximum flows of the Hasbani and Banias sub-basins were observed in 1968/69 (232 MCM for the Banias), while minimum flows were recorded in 1989/90 (30 MCM for the Hasbani) and 2000/01 (47 MCM for the Banias). The Dan River displays a much lower annual variability, with the lowest annual

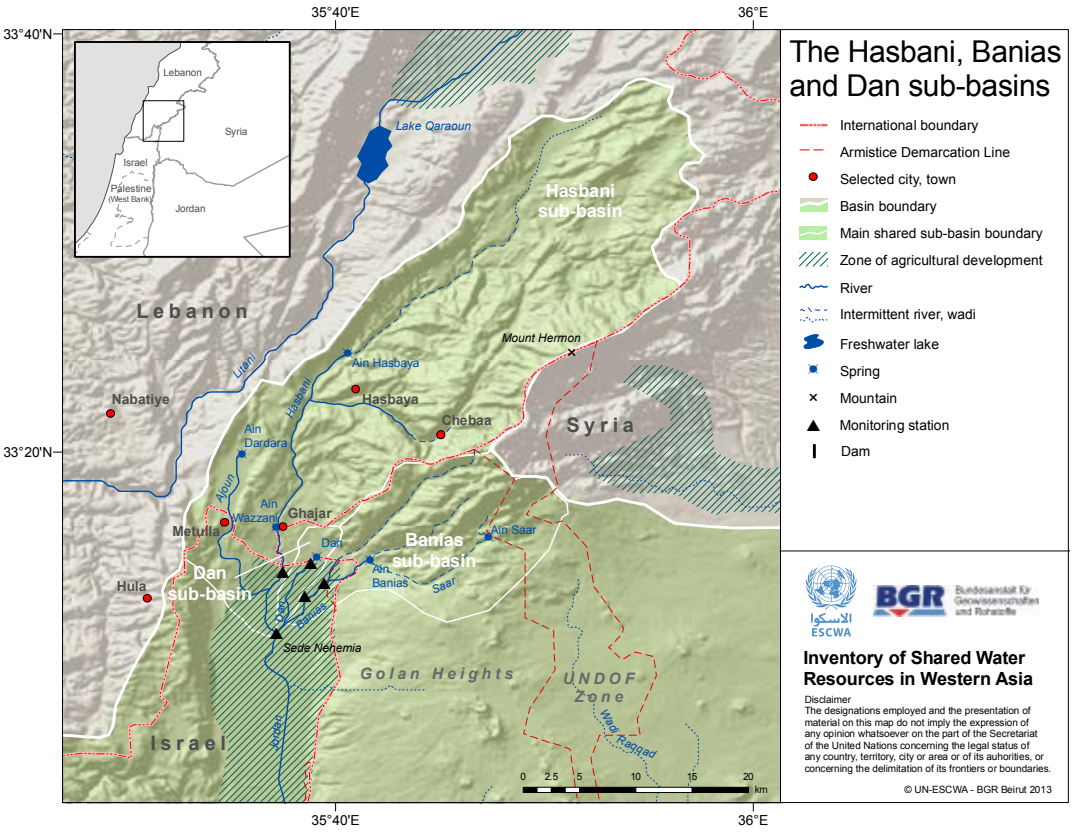
Table 2. Summary of annual flow volume statistics for the Hasbani, Banias and Dan Rivers (1944-2008)

SUB-BASIN (SURFACE DRAINAGE AREA, km^2)	MEAN (MCM)	MINIMUM (MCM)	MAXIMUM (MCM)	CV[a] (-)
Hasbani (698)	122	30	304	0.53
Banias (189)	113	47	232	0.35
Dan (17.6)	228	89	312	0.22
Measured total	463	-	-	-

Source: Compiled by ESCWA-BGR based on data published by HSI, 1944-2008.
Note: The period of record shows a consistent gap from 1946 until 1949.
(a) Coefficient of Variation. For information on the definition and calculation of the CV see 'Overview & Methodology: Surface Water' chapter.

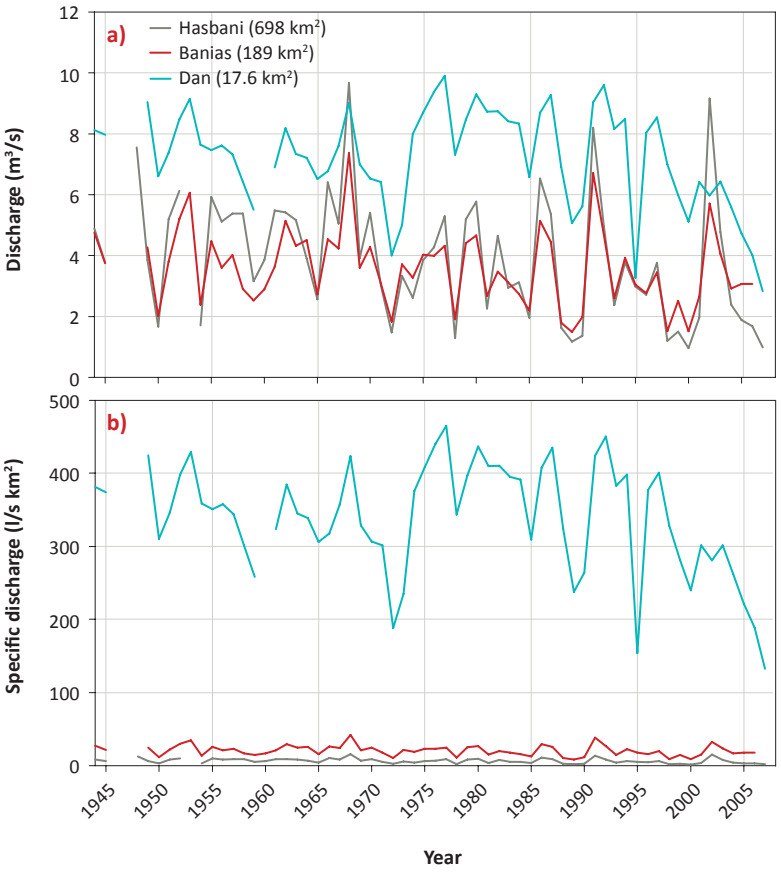
The Dan River, Israel, 2008. Source: Nethanel H.

Figure 5. The Hasbani, Banias and Dan sub-basins



flow volume recorded in 2008 (89 MCM) and the highest in 1996 (312 MCM). Figure 6a shows the long-term observed discharge of the three Jordan headwater rivers. Figure 6b presents a theoretical specific discharge per km² of the surface water catchment for these headwater rivers. The mean annual specific discharge anomaly time series shows a frequent oscillation between wet and dry years (Figure 7), which repeats every three to four years on average on the Hasbani and Banias Rivers. Only the period between 1995 and 2002 shows a prolonged drought of more than five years. The Hasbani and Banias Rivers exhibit similar annual dynamics. The annual stream-flow dynamics of the Dan River follows a different pattern, with longer wet and dry cycles (e.g. the wet period from 1974 to 1984) than the adjacent rivers. Since 1998 the Dan has experienced a sustained decrease in discharge, also in comparison to the Hasbani and Banias Rivers (Figure 7c). It is unclear whether the decrease is related to changes in the monitoring set-up (location of station, methodology), growing abstraction/water diversion upstream of the monitoring site or whether it reflects changing precipitation patterns (drought) and/or recharge dynamics in the catchment areas of the Dan Spring and River. However, no significant trend could be observed at the Dan monitoring station for the whole period of record.

Figure 6. a) Mean annual discharge and b) specific mean annual discharge of the Hasbani, Banias and Dan Rivers (1944-2008)

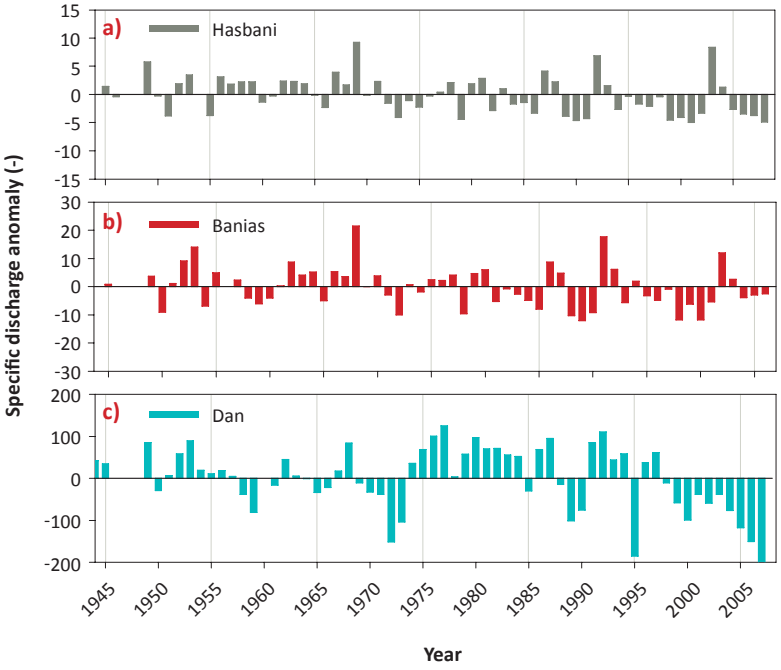


Source: Compiled by ESCWA-BGR based on data published by HSI, 1944-2008.

FLOW REGIMES

The mean monthly flow regime of the Banias and Hasbani Rivers is characterized by high winter precipitation and snow-melt-dominated peak flows in February and March, while minimum flows usually occur in September and October (Figure 8). The Hasbani exhibits higher mean monthly peak flows and lower flows in the dry months compared to the Banias. The flow regime of the Dan is much more balanced than that of the Banias and Hasbani, with only a slight increase in flows in March and April. This can be explained by the larger groundwater catchment that influences the flow of the Dan Spring. Generally, for the period of monitoring between 1944 and 2008, the three Jordan headwater rivers do not appear to be influenced by stream regulation, and flow regimes may be considered near-natural.

Figure 7. Specific discharge anomaly time series of the Hasbani, Banias and Dan Rivers (1944-2008)



Source: Compiled by ESCWA-BGR based on data published by HSI, 1944-2008.

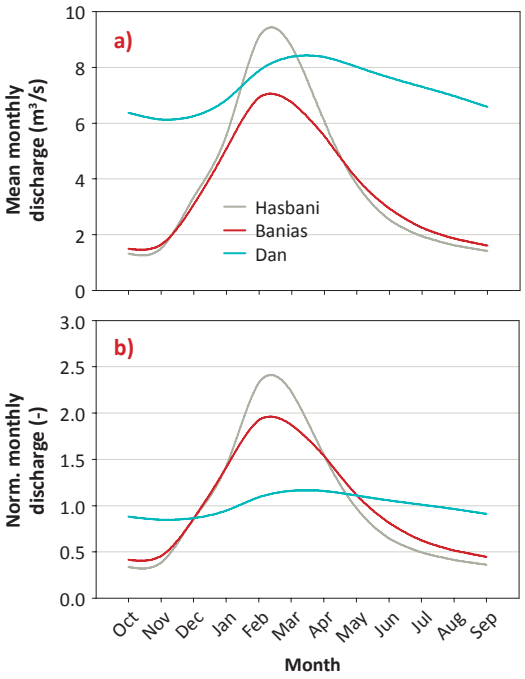
GROUNDWATER

The discharge of all three headwaters originates primarily from strong karstic groundwater springs which appear to be partially fed by the same aquifer or aquifer system on the eastern slopes of Mount Hermon. For the Hasbani River, the groundwater catchments of both springs, the Hasbani and Wazzani, are likely to extend

mostly in Lebanon, upstream of the respective springs. The discharge of the Dan Spring and probably of the Banias Spring originates from a transboundary aquifer or aquifer system, whose recharge area lies primarily in Lebanon and possibly also in Syria.

Furthermore, the Dan sub-basin, which covers a relatively small surface area (17.6 km^2), has a high mean discharge (228 MCM/yr) compared to the adjacent sub-basins such as the Hasbani, which extends over an area of 698 km^2 with an annual mean discharge of only 122 MCM. Recent hydrogeological studies suggest that the Dan may have a much larger actual subsurface recharge basin area of more than 1,320 km^2 (compared to an estimated 520 km^2 for the Banias) as the Dan Springs emerge from a deep and productive Jurassic limestone aquifer with outcrops in Lebanon and Syria.[16] This transboundary aquifer is recharged by rain and snow-melt, especially along the slopes of Mount Hermon.[17] A geological fault may divide the southern Mount Hermon recharge area into an eastern and western part which feed the Banias on one side and the Hasbani and Dan on the other.[18] Nevertheless, the flow regimes of the Hasbani and Banias headwaters appear to be very similar.

Figure 8. **Mean monthly flow regime of the Hasbani, Banias and Dan Rivers (1944-2008)**



Source: Compiled by ESCWA-BGR based on data published by HSI, 1944-2008.

The Banias River, Golan Heights, 2008. Source: Nethanel H.

A simple estimate of required effective rainfall recharge for the Dan Spring (13,000 mm/yr over 17.6 km²) reveals that the small surface water catchment cannot be sufficient to sustain flows. A combination of the surface water catchments of the Hasbani and Dan or even of all three headwaters results in more realistic estimates with a required effective rainfall of 489 or 512 mm/yr over the respective catchments. While this is clear evidence that the Dan and most likely also the Banias Spring groundwater catchments extend into Lebanon, further research is required to delineate the actual extent of the catchments.[19]

UPPER JORDAN RIVER

DISCHARGE AND FLOW REGIME

The Upper Jordan River formed at the confluence of the headwater streams in Sede Nehemia, Israel (Figure 5) flows into Lake Tiberias. Discharge data is available for two gauging stations along the course of the Upper Jordan River (Figure 9): Sede Nehemia for the period 1948-2008 and Obstacle Bridge for the period 1960-2008. The overlapping period of record covers 45 years.

ANNUAL DISCHARGE VARIABILITY

Discharge records from the Sede Nehemia and Obstacle Bridge gauging stations on the Upper Jordan River exhibit dry and wet periods. Maximum flows were observed at both stations in 1968/69 (1,096 MCM at Obstacle Bridge, Table 3) and minimum flows were recorded in 1972/73 (155 MCM at Sede Nehemia) and 1998/99 (215 MCM at Obstacle Bridge).[20]

The mean annual flow for the entire period of record at Sede Nehemia is 382 MCM, 81 MCM (approx. 17%) less than the measured total mean annual flow of the three headwater rivers (463 MCM) for the period 1944-2008 (Table 2). This discrepancy can most likely be explained by water diversions for irrigation and domestic use in the Dan sub-basin.[21] The mean annual flow of the Upper Jordan River increases from 382 MCM to 475 MCM between the stations Sede Nehemia and Obstacle Bridge. The increase may be the result of runoff from the northern Golan Heights and spring water feeding the Jordan River, but could also be due to the inflow of irrigation return water from the extensive agriculture developments in the Hula Valley (Box 9).[22]

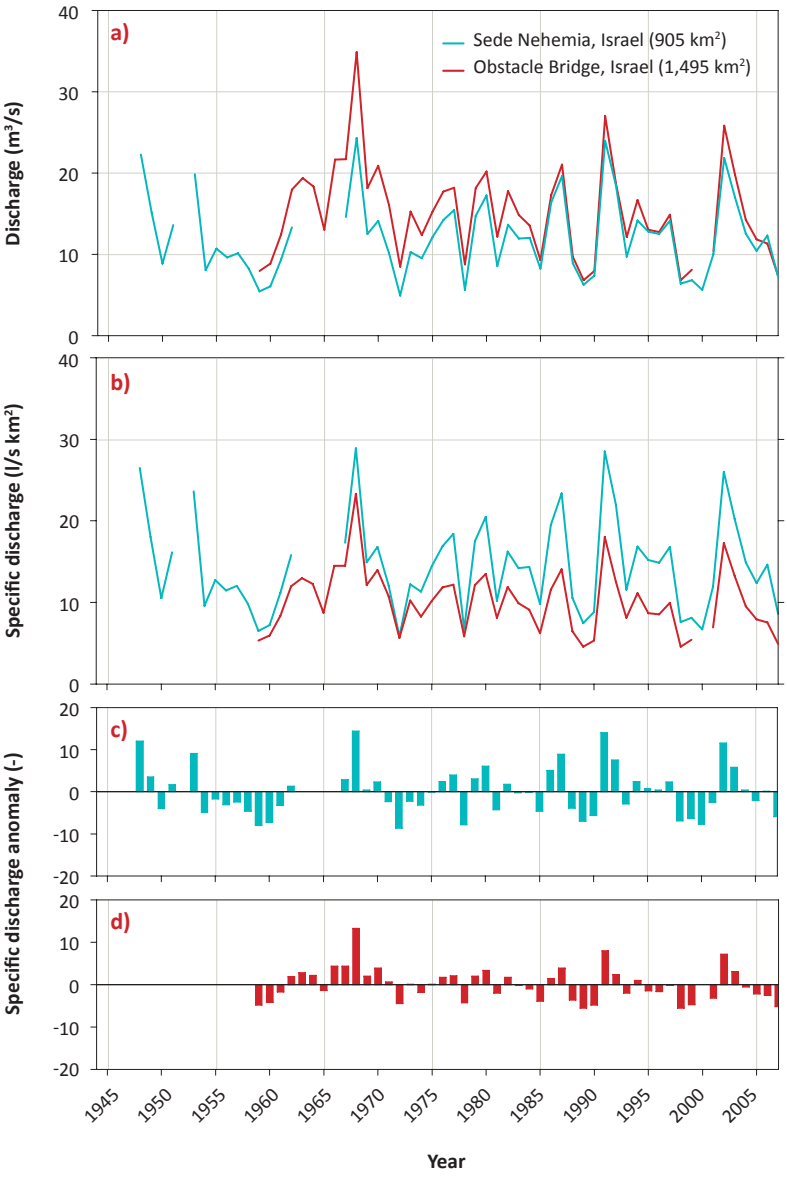
The mean annual specific discharge time series measured at the two gauging stations show frequently but almost identically oscillating wet and dry years (every two to three years) (Figure 9). Only the period from 1949 to 1961 shows a prolonged drought of more than five years at Sede Nehemia. Wet periods can be identified during most of the 1960s and the early 1990s (Figure 9c and d). The discharge data shows no significant trend.

Table 3. **Summary of annual flow volume statistics for the Upper Jordan River (1960-2008)**

STATION (DRAINAGE AREA, km²)	MEAN (MCM)	MINIMUM (MCM)	MAXIMUM (MCM)	CV[a] (-)
Sede Nehemia (905)	382	155	763	0.4
Obstacle Bridge (1,495)	475	215	1,096	0.38

Source: Compiled by ESCWA-BGR based on data published by HSI, 1944-2008.
(a) Coefficient of Variation. For information on the definition and calculation of the CV see 'Overview & Methodology: Surface Water' chapter.

Figure 9. **a) Mean annual discharge, b) specific mean annual discharge, c) and d) discharge anomaly time series of the Upper Jordan River (1948-2008)**

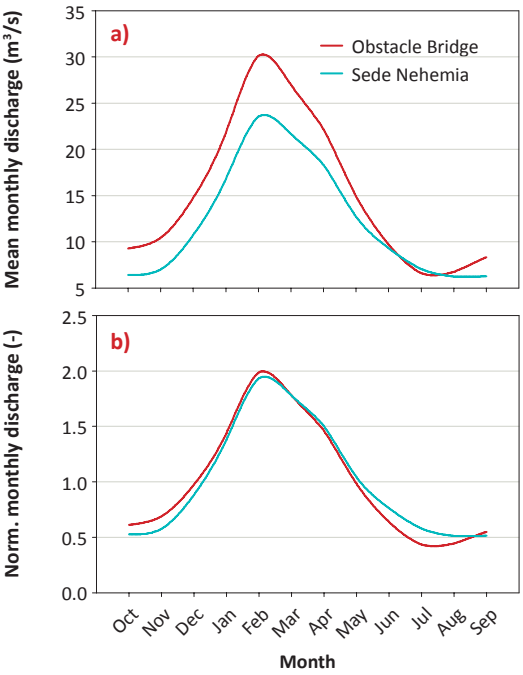


Source: Compiled by ESCWA-BGR based on data published by HSI, 1944-2008.

FLOW REGIME

The stream-flow regime of the Upper Jordan River at the Obstacle Bridge and Sede Nehemia gauging stations indicates a distinct dry and wet season, with low and high flows similar to the Hasbani River flow regime. Peak flow usually occurs between February and March depending on the volume of rainfall and snow-melt originating from the mountainous regions in southern Lebanon and Syria. The low-flow season extends from June to November with minimum flows occurring in July at Obstacle Bridge, and in August/September at Sede Nehemia. However, it is likely that the stream-flow regime presented in Figure 10, which covers the period from 1960 to 2008, already reflects stream regulations such as water abstractions and diversions, particularly the changes made as part of the Hula Valley Drainage Project (Box 9).

Figure 10. **Mean monthly flow regime of the Upper Jordan River at different gauging stations (1960-2008)**



Source: Compiled by ESCWA-BGR based on data published by HSI, 1944-2008.

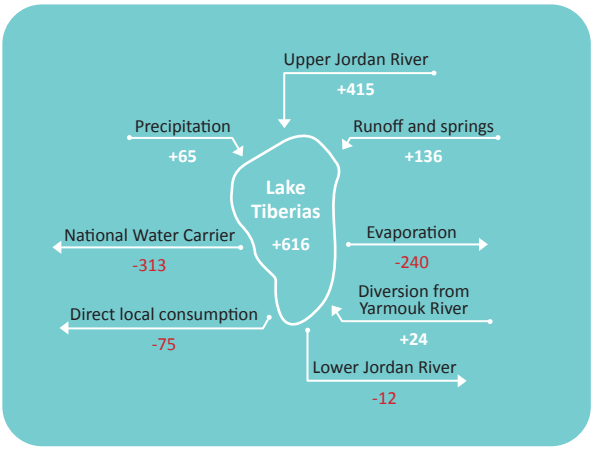
View over Lake Tiberias and Golan Heights, Jordan, 2011. Source: Tamra Hays.

BOX 1

Lake Tiberias

Lake Tiberias, originally a natural brackish water lake, extends over an area of around 170 km^2. The diversion of saline water from surrounding springs to the Lower Jordan River since the mid-1960s has led to a gradual reduction in salinity over the years.[a] Today, the lake is Israel's largest freshwater reservoir, supplying approximately one third of the country's annual water requirements.[b] It is also an important touristic and religious site. In addition to supplying water for domestic and agricultural purposes, the lake was until recently intensively used for commercial fishery, with yields of 1,000-2,500 tons a year,[c] a figure which has been considerably reduced in recent years.[d]

Figure 11. **Mean annual water balance of Lake Tiberias in MCM (1985-2008)**



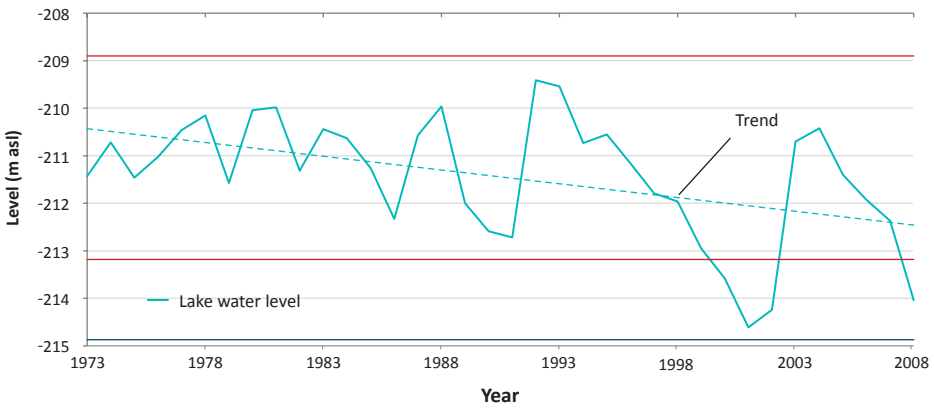
Source: Compiled by ESCWA-BGR based on HSI, 2008; IWA, 2010.

The average annual water inflow into Lake Tiberias for the period 1985-2008 (Figure 11) was 616 MCM, including supply from the Jordan River (415 MCM), precipitation (65 MCM) and side streams and springs (136 MCM). Water leaves the lake primarily through surface evaporation (240 MCM) and through Israel's National Water Carrier (313 MCM).[e]

Until 1986, Israel set the operational level of Lake Tiberias at -212 m asl, but after successive years of drought, it was lowered to -213.18 m asl. Rising demand and more frequent droughts caused the lake to drop to around -215 m asl in 2001, its lowest recorded level.[f] The 2002-2003 rainy period allowed for a small rise after 2003, but water levels dropped again to -214 m asl in 2008 (Figure 12).[g] Recent monitoring has shown that the lake's level had risen to -211.5 m asl in March 2012, its highest in nine years.[h] The constant fluctuation in water level negatively impacts ecosystem stability and water quality, and damages the local tourist industry.[i]

(a) FAO, 2009; Farber et al., 2004; FoEME, 2010. For further information, see section on Water quality & environmental issues below.
(b) Siebert et al., 2009.
(c) Representing around 5% of total fish production in Israel (Markel and Shamir, 2002).
(d) Blanchfield et al., 2012. A two-year fishing ban was announced in 2010 in order to restore the lake's ecological balance (The Telegraph, 2010).
(e) HSI, 2008. Israel's National Water Carrier is a 200 km conduit that conveys water from Lake Tiberias in the Jordan River basin to urban centres along the Israeli coast and further south to the Negev (Al Naqab). See section 'Water Development & Use: Israel' below and Box 7 for more information.
(f) Markel, 2005.
(g) It is important to stabilize the lake's level at around -213 m asl in order to prevent the highly saline water at the bottom of the lake from flowing up and mixing with the overlying freshwater. This would disrupt the ecological stability of the lake and compromise its use as a freshwater reservoir (Siebert et al., 2009; Markel, 2005; Israel Weather, 2012).
(h) Globes, 2012.
(i) Hambright et al., 2000; Markel, 2005; FAO, 2009.

Figure 12. **Water-level fluctuations in Lake Tiberias (1973-2008)**



Source: Compiled by ESCWA-BGR based on IWA, 2010.
Note: The red lines represent the minimum and maximum levels at which the National Water Carrier can operate.
The dark blue line represents the level below which water cannot be pumped without causing severe damage to Israel's long-term water supply.

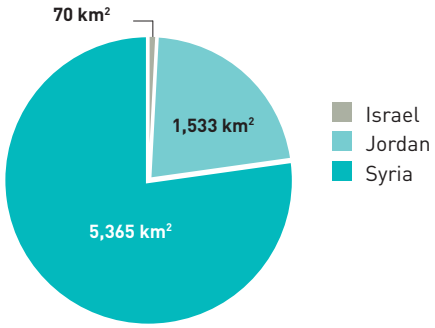
THE YARMOUK RIVER

DISCHARGE AND FLOW REGIME

The basin of the largest Jordan River tributary, the Yarmouk, covers a total estimated area of 6,968 km² and is shared between three riparian countries: Syria (77%), Jordan (22%) and Israel (1%) (Figure 13).

The Yarmouk Basin is mainly of volcanic origin and features mountainous regions and plains that have been affected by erosion. The catchment boundary is defined by the Jabal al Arab Mountains in the east and the Golan Heights in the west. In the western part of the basin, the middle and lower plateaus rise to altitudes of 1,500 m and are composed of basaltic rocks. This is also the origin of seasonal streams such as Wadi Raqqad and Wadi Allan.[23] The Yarmouk River gauging stations located farthest downstream are Maqarin (downstream of the Wahdah Dam) and Addasiya (close to the confluence with the Jordan River). Available monthly discharge data from the two stations covers the period 1963-2006 with interruptions.[24]

Figure 13. Distribution of the Yarmouk Basin area



Source: Compiled by ESCWA-BGR.

ANNUAL DISCHARGE VARIABILITY

Discharge records from the Maqarin and Addasiya gauging stations on the Yarmouk River are located below a number of major stream regulation features, including the recently completed Wahdah Dam and many smaller dams on upstream tributaries in Syria. Therefore available discharge records do not necessarily reflect earlier, natural flow conditions. In addition, the construction of the first dams and the increase in water use from the river predates available discharge records. Estimates for the annual historic flow of the Yarmouk range between 450 and 500 MCM,[25] though the river has a highly variable flow regime and is prone to severe flooding.

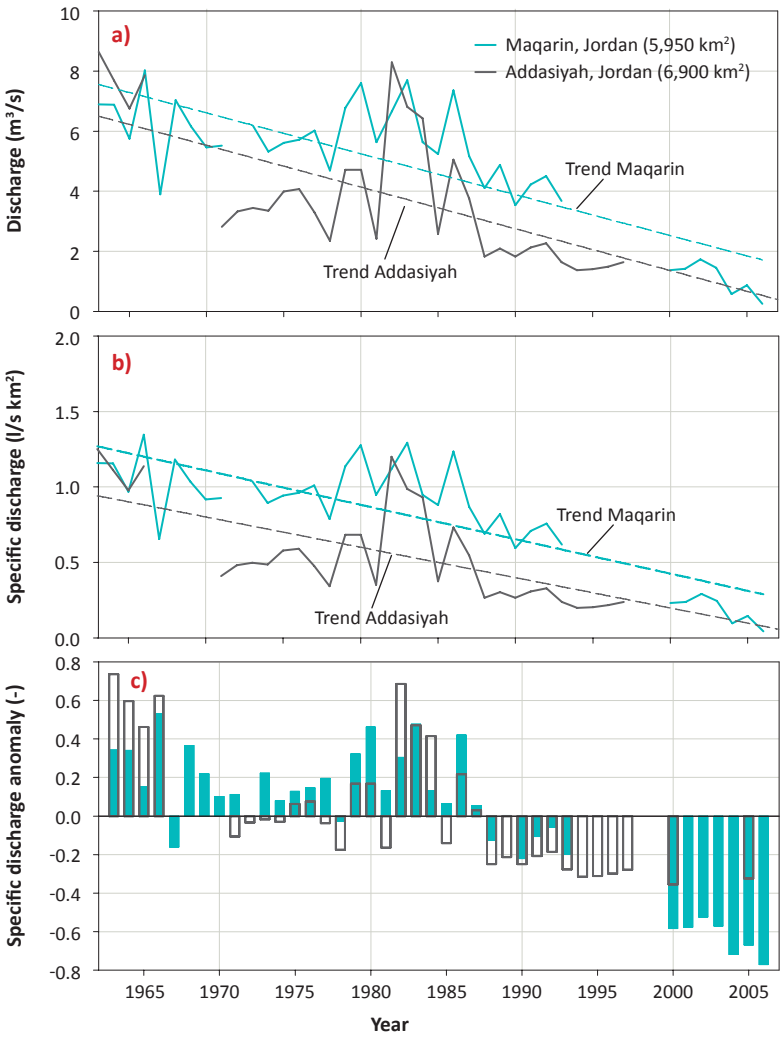
Maximum annual flows were observed in 1963 at Addasiya[26] and in 1966 at Maqarin (272 MCM at Addasiya, 253 MCM at Maqarin, Table 4), while minimum flows were recorded in 2000 at Addasiya (35 MCM) and in 2006 at Maqarin (7.6 MCM). The mean annual flow was 152 MCM at Maqarin and 120 MCM downstream at Addasiya (Figure 14).

Table 4. Summary of annual flow volume statistics for the Yarmouk River (1963-2006)

STATION (DRAINAGE AREA, km²)	PERIOD	MEAN (MCM)	MINIMUM (MCM)	MAXIMUM (MCM)	CV[a] (-)
Maqarin (5,950)	**1963-2006**	**152**	**7.6**	**253**	**0.44**
	1963-1984	193	123.0	253	0.17
	1985-2006	99	7.6	232	0.66
Addasiya (6,900)	**1963-2006**	**120**	**35.0**	**272**	**0.61**
	1963-1984	156	74.0	272	0.44
	1985-2006	83	35.0	225	0.69

Source: Compiled by ESCWA-BGR based on data provided by GRDC, 2011; Ministry of Water and Irrigation in Jordan, 2002a.
(a) Coefficient of Variation. For information on the definition and calculation of the CV see 'Overview & Methodology: Surface Water' chapter.

Figure 14. a) Mean annual discharge, b) specific mean annual discharge and c) discharge anomaly time series of the Yarmouk River (1963-2006)



Source: Compiled by ESCWA-BGR based on data provided by GRDC, 2011; Ministry of Water and Irrigation in Jordan, 2002a.

Yarmouk River, Jordan, 2004. Source: Benjamin.

Negative trend

The annual dynamics of the mean annual specific discharge time series of the Yarmouk River in Figure 14b is quite different from that of the Upper Jordan headwaters. Early records from both Yarmouk gauging stations for the period 1963-1984 show a certain degree of variation with high- and low-flow periods. From 1987, this dynamic is considerably muted and a significant negative trend can be observed in Figure 14a and 14b. The discharge anomaly plots in Figure 14c clearly show a below-average annual discharge since 1987.

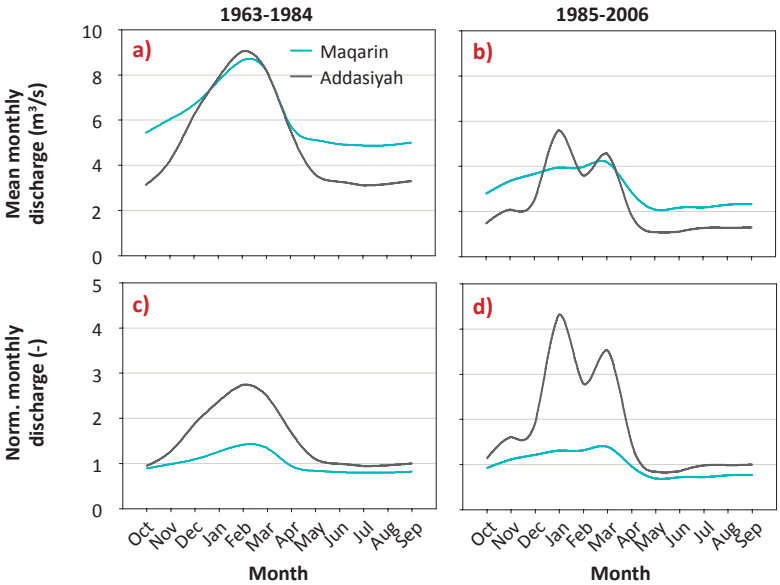
Comparison

Table 4 groups available discharge records in two 20-year observatory periods in order to allow a comparison of mean annual flow volumes in the periods before and after dams were built in the basin.[27] It is important to note that the period 1963-1984 does not represent the near-natural flow of the river as dam construction in the basin started in the 1970s. The near-natural flow is assumed to be much higher than the mean annual flow of 193 MCM at Maqarin.[28]

Differences in flow volumes are apparent, with the mean annual flow volume at both gauging stations decreasing by about 50% from one observatory period to the next (Table 4).

For instance, the mean annual flow dropped from 156 MCM for the period 1963-1984 to 83 MCM for the period 1985-2006. This is most likely due to droughts, large-scale water diversion from the Yarmouk River and upstream groundwater abstractions in the area feeding the river, mainly for agricultural purposes.[29]

Figure 15. **Mean monthly flow regime of the Yarmouk River at different gauging stations in Jordan (1963-2006)**



Source: Compiled by ESCWA-BGR based on data provided by GRDC, 2011; Ministry of Water and Irrigation in Jordan, 2002a.

FLOW REGIME

The flow regime of the Yarmouk River at the Maqarin and Addasiya gauging stations further highlights the impact of stream regulations. There is still a distinction between high- and low-flow periods, but the regimes differ significantly, with Addasiya exhibiting a double peak during winter high flows, while upstream Maqarin registers a damped winter high-flow period (Figure 15).

LOWER JORDAN RIVER

DISCHARGE AND FLOW REGIME

The Lower Jordan River has a length of around 105 km between Lake Tiberias and the Dead Sea and forms the border between Jordan to the east and Israel and Palestine to the west. In addition to contributions from the Yarmouk, the Lower Jordan River has two other main tributaries: Wadi Harod (Wadi Jallud in arabic, north of the West Bank foothills) and the Zarqa River in Jordan. Today only small quantities of water are recorded at the Degania Dam at the outflow of Lake Tiberias.[30]

ANNUAL DISCHARGE VARIABILITY

Discharge data for the Lower Jordan River is only available from the Naarayim gauging station downstream of the Yarmouk confluence for the period 1977-1999. The discharge record for the Lower Jordan River at Naarayim is impacted by stream regulations. Maximum annual flows were observed in 1992 (647 MCM) and minimum flows in 1991 (25.4 MCM, Table 5). The mean annual flow was 175 MCM.[31]

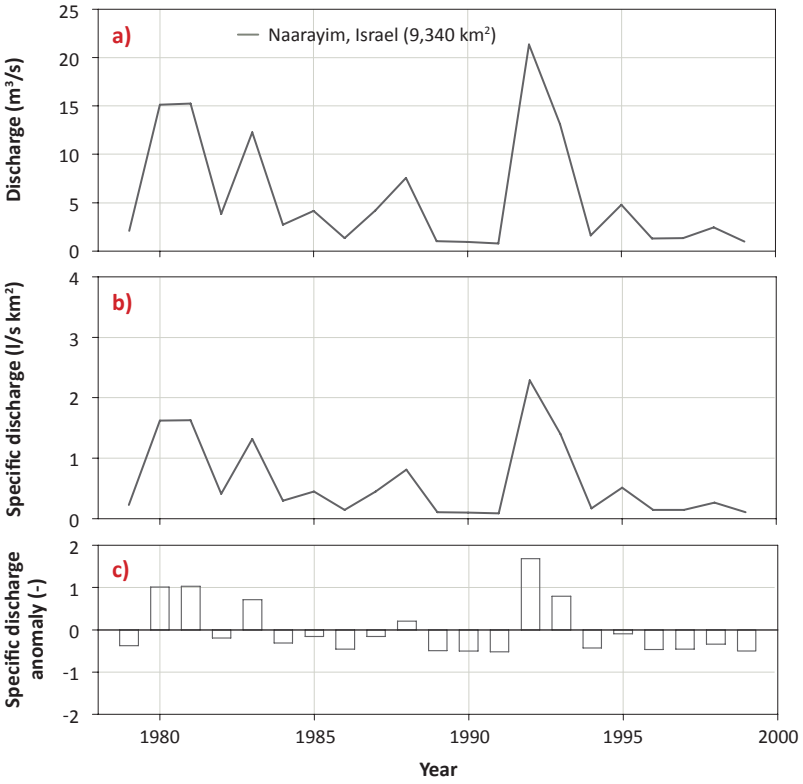
The mean annual specific discharge time series presented in Figure 16 shows an annual dynamic of wet and dry years with peak flows in 1992/93. This was followed by a prolonged dry period from 1993 until the end of the period of record in 1999. During most of the 1980s, discharge was below the mean annual flow of 175 MCM.

FLOW REGIME

The Lower Jordan River stream-flow regime at the Naarayim gauging station exhibits a pronounced but brief winter high-flow period in February and an extended stable low-flow period from June to October (Figure 17). The Naarayim flow regime differs significantly from the near-natural flow regimes of the Upper Jordan River, as recorded at the Obstacle Bridge gauging station for instance, underscoring the impact of heavy stream regulation, particularly in the upper part of the basin.

There is no hydrological station farther downstream. However, flow contributions downstream of Naarayim are minor and include outflow from fish ponds, agricultural runoff, groundwater seepage, and, more rarely,

Figure 16. a) Mean annual discharge, b) specific mean annual discharge and c) discharge anomaly time series of the Lower Jordan River (1979-1999)



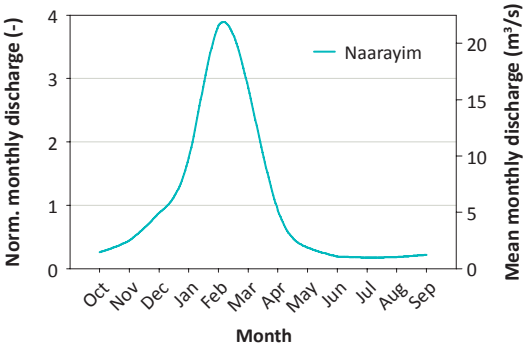
Source: Compiled by ESCWA-BGR based on data published by HSI, 1979-1999.

Table 5. Summary of annual flow volume statistics for the Lower Jordan River (1979-1999)

STATION (DRAINAGE AREA, km²)	MEAN (MCM)	MINIMUM (MCM)	MAXIMUM (MCM)	CV[a] (-)
Naarayim (9,340)	175	25.4	647	1.07

Source: Compiled by ESCWA-BGR based on data published by HSI, 1979-1999.
(a) Coefficient of Variation. For information on the definition and calculation of the CV see 'Overview & Methodology: Surface Water' chapter.

Figure 17. Mean monthly flow regime of the Lower Jordan River at Naarayim in Israel (1979-1999)



Source: Compiled by ESCWA-BGR based on data published by HSI, 1979-1999.

BOX 2

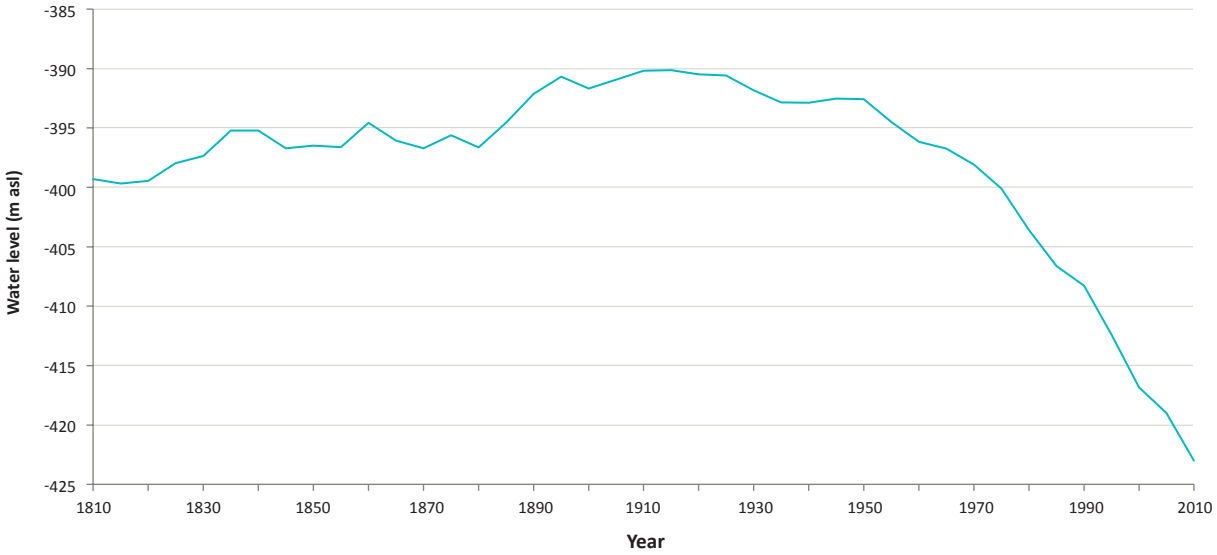
The Decline of the Dead Sea

As the lowest point on Earth (-422 m asl), the Dead Sea is an inland lake (endorheic) with no natural outflow. Historically, the Jordan River contributed an estimated 1,300 MCM/yr to the Dead Sea, equivalent to two thirds of the inflow.[a] Other contributions included primarily groundwater and water from Wadi Mujib, Wadi Hasa and limited amounts from Wadi Araba south of the Dead Sea. Inflow used to make up for the high evaporation rates in the Dead Sea.

The construction of large water diversion schemes in the Jordan River Basin since the 1960s has caused a sharp decrease in inflow into the sea, which has in turn led to a lowering of the sea level from -395 m asl in the 1970s[b] to -419 m asl in 2006 and -423 m asl in 2009, with an average decline of one metre per year. The drop in sea level has led to dewatering and sediment shrinkage, which has in turn resulted in the formation of sinkholes along the shores of the sea.[c]

(a) Libiszewski, 1995.
(b) Klein and Flohn, 1987.
(c) Oren, 2010; Khlaifat et al., 2010.

Figure 18. Decline in Dead Sea water levels (1810-2010)



Source: Compiled by ESCWA-BGR based on HSI, 2008; IWA, 2010.

The Dead Sea, Jordan, 2009. Source: Marc Haering.

floodwaters that are not captured by the numerous dams in the Jordan Valley. The Lower Jordan River's second largest tributary, the Zarqa River, is dammed and its water is mainly used for irrigation. The same goes for all major side wadis on the east bank of the Lower Jordan River. Coupled with the high levels of abstraction in the upper part of the basin, these factors have resulted in a dramatic drop in discharge from the Jordan River into the Dead Sea, which was measured at 20-30 MCM in 2009.[32]

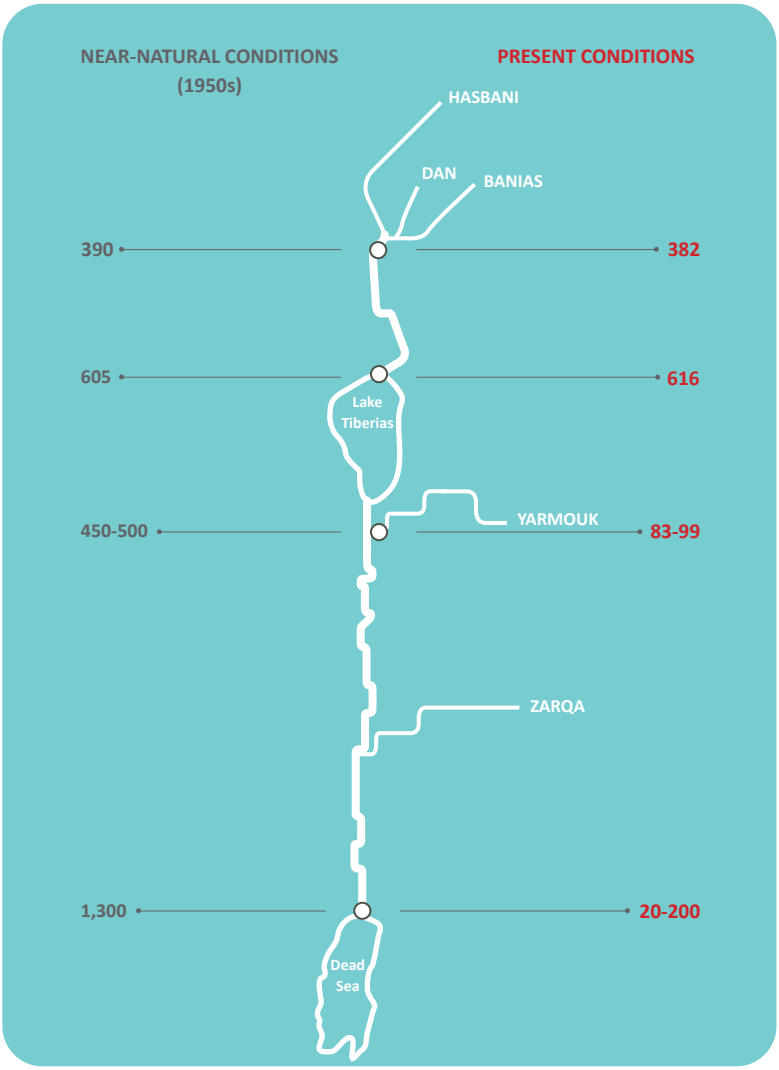
FLOW REGIME REGULATION IN THE JORDAN RIVER BASIN

Under natural conditions, the mean annual discharge of the Upper Jordan River system into Lake Tiberias amounted to 890 MCM, of which 285 MCM were lost to lake evaporation.[33] The Yarmouk catchment drained an area of almost 7,000 km^2, with an estimated mean annual discharge of 450-500 MCM[34] flowing into the Lower Jordan River. Water from several wadis and rivers originating in the mountain ranges to the east and west of the river and from aquifers also contributed perennial and seasonal flows to the Jordan River, resulting in a natural annual discharge of around 1,300 MCM (Figure 19).[35]

However, the natural state described above has been drastically altered as a result of human interference. While flow rates of the Upper Jordan River system are similar to the natural state and the inflow to Lake Tiberias remains fairly constant at 616 MCM (Box 1), the flow of the Lower Jordan River is affected by river diversions at several points along the course of the Jordan River. Israel diverts approximately 400 MCM from Lake Tiberias including limited amounts for irrigation purposes on the shores of the lake. Most of the abstracted water (329 MCM on average between 1969 and 2008) is transferred outside the basin through Israel's National Water Carrier for use in the agricultural, domestic and industrial sectors in the Mediterranean coastal plain (Table 8 and Box 7).

Moreover, the construction of a large number of storage and retention dams, excessive pumping and diversions from the Yarmouk River in Syria have diminished the river's annual flow from 450-500 MCM to less than 40 MCM downstream of Addasiya. Groundwater abstraction and an altered topography (infrastructure and civil structures) have reduced the share of the Yarmouk River in the Jordanian part of the catchment area. Jordan uses about 100 MCM/yr from the Yarmouk River and the Mukheibeh Wells to supply the King Abdullah Canal,[36] though recent data shows that it only diverted an average annual 30 MCM to the canal between 2002 and 2011.[37]

Figure 19. **Annual water flow of the Jordan River in near-natural conditions and in present conditons (MCM)**



Source: Compiled by ESCWA-BGR based on Courcier et al., 2005; GRDC, 2011; HSI 1944-2008.

All three riparians, Israel, Jordan and Syria, abstract large amounts of groundwater in the upper parts of the basin which further reduces the natural inflow into the river.

Farther downstream along the course of the Jordan River, reservoirs have been built in the major side wadis along the east bank and their water is mainly used for irrigation purposes. The result is a drastic reduction in runoff in the Lower Jordan River. The flow of the Lower Jordan River is today mainly made up of drainage water from fishponds, wastewater, fresh and saline spring water and irrigation return flows.

Present-day discharge into the Dead Sea is estimated between 20 MCM and 200 MCM[38] compared to the historic flow of approximately 1,300 MCM (Figure 19).

Water Resources Management

The Jordan River basin is one of the most contested river basins in the world, attracting considerable attention in political circles, the water community and the media. The basin has been the subject of numerous water development plans and studies (Table 6). The following two elements are frequently identified as root causes of the conflict over water resources in the region: water scarcity and the establishment of a Jewish State in British Mandate Palestine.[39]

Plans for the establishment of a Jewish State in Palestine in the early 20th century heralded a series of radical changes in the domain of water resources management in the basin.[40] From the 1950s onward, Israel, Jordan and Syria established and implemented national water schemes to develop their economy,[41] which created competition over the scare resources in the basin. Technological innovations, specifically the introduction of pumping technology, demographic developments in riparian countries and intensive agricultural development have also drastically altered the natural flow regime in the basin.

Due to political instability in the region, the sharing of water resources among riparian countries never materialized and thus none of the proposed plans were jointly implemented (Box 3). Instead, unilateral hydraulic development started in the 1950s and accelerated in the 1960s. In addition, political changes and the creation of the state of Israel in 1948 had far-reaching implications for water use in the basin. The 1967 Six-Day War fundamentally altered the power balance between riparians and greatly enhanced Israel's hydrostrategic position in the Jordan River basin.[42]

Changes in land and water use are also closely related to the demographic boom in the Jordan River basin. The 1948 Arab-Israeli war and the 1967 Six-Day War resulted in large-scale

Irrigation in the Jordan Valley, 2008. Source: Eileen Maternowski.

Table 6. **Proposed riparian water allocations in selected Jordan River basin development plans**

YEAR	NAME	COMMISSION	WATER ALLOCATION (MCM)				TOTAL (MCM)	BACKGROUND INFORMATION
			LEBANON	SYRIA	ISRAEL	JORDAN		
1913	Frangia Plan	Ottoman				-	-	Diversion channel from the Yarmouk to Lake Tiberias. Irrigation on both sides of the Jordan Valley; 21 hydropower plants.
1943/44	Lowdermilk proposals	USA				-	-	Development of the Jordan-Yarmouk Basin and the Litani River in Lebanon. A Mediterranean-Dead Sea canal; hydropower development.
1948	Hays Plan	Israel		-	50% of Yarmouk River water, 100% from Jordan River	50% of Yarmouk River	-	Diversion channel from the Yarmouk to Lake Tiberias to replace water diversions from the Upper Jordan River. Supply of 2 BCM of water to Israel for the irrigation of 240,000 ha; hydropower development.
1952	Bunger Plan	UNRWA[a]/ Jordan/Syria					-	Construction of the Maqarin Dam on the Yarmouk River; irrigation of 43,500 ha in Jordan and 6,000 ha in Syria; diversion dam at Addasiya; hydropower development.
1953	Main Plan (Unified Plan)	USA	-	45	394	774	1,213	Integrated basin approach with regard to irrigation. Irrigation of 41,000 ha in Israel, 49,000 ha in Jordan and 3,000 ha in Syria.[b]
1954	Arab Plan	Arab League	35	132	289	975	1,431	Water storage on the Yarmouk at Maqarin and Addasiya; water diversions for irrigation of 23,400 ha in Israel, 49,000 ha in Jordan, 3,500 ha in Lebanon and 11,900 ha in Syria; hydropower development for Arab countries only.
1954	Cotton Plan	Israel	451	30	1,290	575	2,346	Use of the Litani River; hydropower development; diversions for irrigation of 179,400 ha in Israel, 41,600 ha in Jordan, 36,400 ha in Lebanon and 2,600 ha in Syria.
1955	Johnston Plan	USA	35	132	616[c]	720[d]	1,503	A dam on the Yarmouk; Lake Tiberias as storage for the Jordan and Yarmouk Rivers; diversion dam at Addasiya; feeder canal from Lake Tiberias to the East Ghor Canal; a siphon across the Jordan to convey water from the East Ghor Canal to the west.

Source: Compiled by ESCWA BGR based on Phillips et al., 2007; Kliot, 1994.
Note: For a comprehensive list of historical development plans of the Jordan River basin see: PLO, 2012.
(a) The United Nations Relief and Works Agency for Palestine Refugees in the Near East.
(b) The Main Plan also proposed (i) a dam on the Hasbani to provide power and water, (ii) dams on the Dan and Banias Rivers, (iii) drainage of the Hula Marshes, (iv) a dam at Maqarin, (v) a dam at Addasiya to divert water to Lake Tiberias and the East Ghor Canal, (vi) a small dam at the outlet of Lake Tiberias to increase its storage capacity.
(c) Phillips et al., 2007 found that Johnston calculated a residual flow of 466 MCM/yr for Israel and another 150 MCM/yr of local water.
(d) Some sources note that the Johnston Plan did not explicitly define the water rights of Palestinians in the West Bank as the West Bank was under Jordanian administration during that period. Nevertheless, the West Ghor Canal was planned (as part of the Yarmouk-Jordan Valley Project) to supply 240 MCM of water for irrigation in the Jordan Valley (Naff and Matson, 1984). Although the canal was never built, there are estimates that assess the Palestinian share under the Johnston Plan between 240 and 257 MCM/yr (PWA, 2012; Sherman, 1999).

population displacements and the resettlement of refugees from outside the basin. Around 1950, an estimated 450,000 people lived in the region. Agriculture was essentially limited to subsistence farming on both banks of the Jordan River, covering an area of about 10,000 ha and consuming less than 9% of the river's annual flow. Since that time there have been several waves of immigration and birth rates have remained high. Thus, the population in the basin has increased more than tenfold, resulting in the rapid growth of cities such as Amman, Irbid and Zarqa in Jordan, and the large-scale development of irrigated agriculture.[43]

BOX 3

A Short History of Water-Related Conflicts in the Jordan River Basin

Following the 1948 Arab-Israeli War and the signing of the General Armistice Agreements in 1949, Jordan and Israel launched several initiatives to develop water resources in their areas of control. In 1951, Jordan announced a plan to irrigate the Jordan Valley's East Ghor region by diverting water from the Yarmouk River through the East Ghor Canal. In response, Israel launched in the same year the first part of the All Israel Plan to drain the Hula Marshes, a wetland area that was partly located in the demilitarized zone created after the 1949 armistice agreement between Israel and Syria. Israel's initiative led to the first of many military clashes between Israel and Syria in 1951. Two years later, Israel embarked on the construction of the National Water Carrier, a project to divert water from Lake Tiberias to urban centres and agricultural areas farther south in Israel. In the early stages of the project, Israel planned the outlet in the demilitarized zone between Israel and Syria. However, Syria thwarted the plans by attacking the construction and lodging a formal complaint at the United Nations against Israel's unilateral move to transfer water out of the Jordan River basin. As a result, Israel was forced to relocate the works to the north-western shore of Lake Tiberias.

The regional tensions prompted the United States Government to appoint Eric Johnston as a special ambassador to the region, with the task of devising a unified water allocation plan for the Jordan Valley. The outcome, known as the Johnston Plan, was issued in 1955 and proposed annual allocations of 616 MCM to Israel, 720 MCM to Jordan, 35 MCM to Lebanon and 132 MCM to Syria.[a] While the plan was never ratified, it remains a point of reference for water management in the basin and riparian countries often use it as a basis for negotiations.

Some scholars claim that water-related conflict in the basin was a major cause of the Six-Day War in June 1967. Following the inauguration of the National Water Carrier and the first water diversions from the Jordan River in 1964, the Arab states decided to launch the Headwater Diversion Project to transfer water from the Hasbani and Banias Rivers to the Yarmouk. Israel bombed the site of this diversion project in 1965 soon after the works started and further military attacks followed. These events are seen by some as one of the triggers of the 1967 Six-Day War, through which Israel gained effective control of the Golan Heights, the West Bank and the Gaza Strip, as well as the headwaters of the Jordan River and significant groundwater resources.

In the following decade, Israel confronted both Jordan and Lebanon in armed conflicts over the control of Jordan River water. In 1969, Israel launched raids in the area of the East Ghor Canal (currently known as the King Abdullah Canal) in Jordan after it suspected Jordan of diverting excess amounts of water.

Nine years later, Israel invaded Lebanon, gaining and maintaining control over the Wazzani Springs in the Jordan River headwaters region until it withdrew its troops in 2000. Tensions persisted in this area though, especially when Lebanon announced plans to build a pumping station at the Wazzani Springs in 2002 (Box 5).

Source: Compiled by ESCWA-BGR based on Murakami, 1995; Amery and Wolf, 2000; FAO, 2009; Zeitoun et al., 2012; Phillips et al., 2007.
(a) Phillips et al., 2007.

The shift from traditional land uses to entrepreneurial, market-oriented agricultural practices and generally improved living standards have led to an exponential increase in water demand, placing severe stress on the basin's limited water resources and fragile ecosystem.

At present, an estimated 100,000-150,000 ha are equipped for irrigation in the Jordan River basin. About 30% of this irrigable surface area is located in each of the Israeli, Jordanian and Syrian parts of the basin, while Lebanon and Palestine use respectively 2% and 5% of the irrigable area in the basin.[44] That translates into a basin-wide agricultural water withdrawal of around 1,200 MCM. A 2010 environmental flow study[45] found that Israel, Jordan and Syria divert over 98% (1,248 MCM) of the historic flow of the Lower Jordan River, mainly for agricultural use.[46]

The Hasbani River, Lebanon, 2003. Source: Ralf Klingbeil.

DEVELOPMENT & USE: LEBANON

To date, Lebanon has made limited use of the Hasbani River, one of the main Jordan River headwaters. Before the 1978 Israeli occupation, the Lebanese Government did not prioritize the development of the South.[47] South Lebanon was further isolated during the Lebanese civil war and the 22 years of Israeli occupation, which led to the deterioration of infrastructure and the disruption of water supplies. After the end of the civil war in 1990, Israel maintained its military presence in southern Lebanon for a further 10 years, in part to safeguard the security zone established after the 1978 Litani Invasion.[48] The Israeli troop withdrawal in May 2000 heralded a new era of reconstruction and development in the south,[49] but the Hasbani region remains one of the poorest in Lebanon.[50]

Israel's control of the Hasbani River and Wazzani Springs until 2000 precluded Lebanese use and development of those water resources. Following the Israeli withdrawal from the area, the Lebanese Government planned a series of projects including the Wazzani Water Supply Project, the Hasbaya-Habbarieh Water Project

and the Ibl al Saqi Dam Project (Box 4).[51] While the dam project has not been implemented to date, the first phase of the Wazzani pumping station was completed in 2002, sparking tensions between Israel and Lebanon (Box 5). According to the Lebanese Ministry of Energy and Water, the country annually abstracts almost 7 MCM from the Hasbani sub-basin of which 2.7 MCM are used for domestic purposes and 4.2 MCM for irrigation.[52] This figure includes abstractions from the river and groundwater abstraction in the basin. Public and private wells in the basin abstract an estimated 5.1 MCM/yr of groundwater.[53] Most of the water is used for domestic purposes, with only limited amounts allocated to the agricultural sector. Since 2002, Lebanon has abstracted a maximum of 2.45 MCM/yr via the Wazzani pumping station (Box 5).

BOX 4

The Ibl al Saqi Dam Project

The village of Ibl al Saqi in southern Lebanon is surrounded by agricultural plains. About 500 ha of land is currently irrigated by the Hasbani River.[a] In a bid to expand irrigation networks in the region, the Lebanese Government has over the years commissioned several studies to assess the viability of a water storage dam on the Hasbani River. The capacity of various versions of the proposed Ibl al Saqi Dam varies between 30 and 80 MCM/yr. A feasibility study completed in 2010 outlines the design of a 50 MCM/yr capacity dam with an irrigation potential of about 2,600 ha in the Hasbani Plain and in the area of El Meri and Khiam.[b]

(a) Comair, 2009, p. 258-259.
(b) Ministry of Energy and Water in Lebanon, 2011.

BOX 5

The Wazzani Dispute

After the Israeli withdrawal from Lebanon in May 2000, Lebanon launched a reconstruction and development programme for southern Lebanon. In a bid to develop water resources in the region, the Council of the South installed two small pumps at the Wazzani Springs in March 2001. This immediately sparked protests from Israel, which threatened to intervene militarily if any water was withdrawn from the Hasbani River.[a] Tensions subsided until the Council of the South announced the construction of a pumping station at the Wazzani Springs in August 2002. The project was part of the Lebanese Government's plan to rebuild the South and ensure the reintegration of the local population by meeting domestic water needs in 13 villages in the region and creating jobs in the agricultural sector.[b] The Wazzani Water Supply Project featured two components: the construction of two pumping stations at the Wazzani Springs and Maysat Junction (part I) and the construction of a pipe network from the Maysat pumping station to the Ibl al Saqi Reservoir and other village reservoirs in the area (part II).[c] The Wazzani pumping station was designed to operate at a capacity of 12,000 m^3/d, which results in a total capacity of 4.4 MCM/yr.[d]

Already before its inauguration, the Wazzani Project caused tensions to rise as Israel declared that any water abstractions from the Hasbani were a casus belli.[e] Analysts explained Israel's statement in the broader context of the Jordan River basin and said Lebanon's move to abstract water from the river could set a precedent for future water infrastructure projects in the Hasbani region, which would affect water flow to Lake Tiberias.[f] Lebanon retorted that the planned abstraction was only a fraction of the share of Jordan River basin water allocated to Lebanon in the Johnston Plan (35 MCM/yr).[g] The dispute attracted extensive media coverage.

Mediation efforts by the United States, the United Nations and the European Union failed to resolve the dispute or address future abstraction quotas and water rights.[h] Though Lebanon was able to complete the pumping station and officially inaugurate it in 2002, the incident demarcated clear de facto limits to the country's plans for further water development schemes on the Hasbani River and at the Wazzani Springs.[i] Since then, to avoid confrontation with Israel, Lebanon has not further developed the Wazzani pumping project or any other project in the Hasbani/Wazzani region. Donor countries providing support to the Lebanese water sector have remained similarly reserved on the issue.[j]

The Wazzani pumping station has probably never reached its design capacity of 4.4 MCM/yr. Constant power shortages and a lack of maintenance mean that annual abstractions from the Wazzani pumping station are 2.45 MCM at most, assuming that the two generator-operated pumps run 24 hours per day.[k]

(a) Morrow, 2002.
(b) Republic of Lebanon, 2002, p. 14.
(c) Ibid., p. 16.
(d) Ibid. Given a 24-hr pumping cycle.
(e) BBC News, 2002.
(f) ICG, 2002, p. 10 and Blanford in MERIP, 2002 states: "Numerous Israeli officials claimed that Lebanon cannot be allowed to change the status quo governing the flow of the Hasbani."
(g) The Johnston Plan has never been implemented. See Box 9.
(h) Zeitoun et al., 2012.
(i) Maternowski, 2006. For information and an analysis of the Wazzani dispute see Zeitoun, 2004 and Zeitoun et al., 2012.
(j) Such as the Italian Development Cooperation.
(k) Ministry of Energy and Water in Lebanon, 2011.

The Wazzani pumping station, Lebanon, 2006. Source: Eileen Maternowski.

Total annual abstractions from the Hasbani Basin (representing Lebanon's current use from the Jordan River basin) can therefore be estimated between 9 and 10 MCM.

With its fertile soils and high-quality water, southern Lebanon has a huge agricultural potential, which has remained largely untapped to date. According to a 1999 agricultural census, potential agricultural land surface in the basin amounted to around 30,000 ha. However, only an estimated 15,000 ha was cultivated and 1,124 ha irrigated.[54] Another study based on a remote sensing exercise from 2002 states that an area of 17,600 ha was used for agriculture, of which about 9,150 ha received full or supplementary[55] irrigation.[56]

DEVELOPMENT & USE: SYRIA

Water resources development in the Syrian part of the Jordan River basin is restricted to the Yarmouk River and its many tributaries. Since the Israeli occupation of the Golan in 1967, the country has not been able to access water resources in the Banias Basin, Lake Tiberias or other wadis on the east bank of the Jordan River. Therefore Syria does not use any of the Upper Jordan River flow.[57]

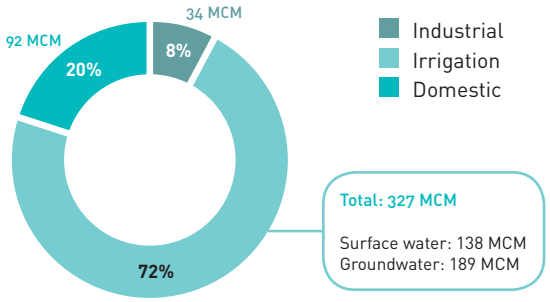
In the late 1960s and early 1970s, Syria built numerous small dams on Yarmouk tributaries, using 50-60 MCM/yr in the upper part of the basin.[58] By the mid-1970s, Syria used an estimated 90 MCM/yr from the Yarmouk River, mainly in the agricultural sector.[59]

BOX 6 The Wahdah Dam

The Wahdah Dam was designed to generate hydropower and provide irrigation water for agricultural activities in Jordan and Syria. The generated electricity from the dam was to be divided between the two riparians, with Jordan receiving 25% and Syria 75%.[a] The 225 MCM/yr capacity dam, which was planned for completion in the early 1990s,[b] encountered long delays and was only completed in 2009 at less than half the design capacity.[c] The project was jointly funded by Jordan and Syria. With a storage capacity of 110 MCM/yr,[d] the Wahdah Dam has never reached full design capacity since it became operational in 2006. The maximum stored volume was measured at 20 MCM/yr in 2009/2010.[e] Possible reasons for the low intake include prolonged droughts since 2000, a high number of upstream dams retaining water from the Yarmouk wadis (Table 7),[f] as well as widespread groundwater abstraction.[g]

(a) The Syrian Arab Republic and Jordan, 1987, Article 7.
(b) Murakami, 1995.
(c) Al-Taani, 2011.
(d) Ministry of Water and Irrigation in Jordan, 2002a.
(e) Ibid., 2011.
(f) However all these dams were built before the Wahdah Dam.
(g) JVA, 2004.

Figure 20. Mean annual water use across sectors in the Yarmouk Basin in Syria (1999-2009)



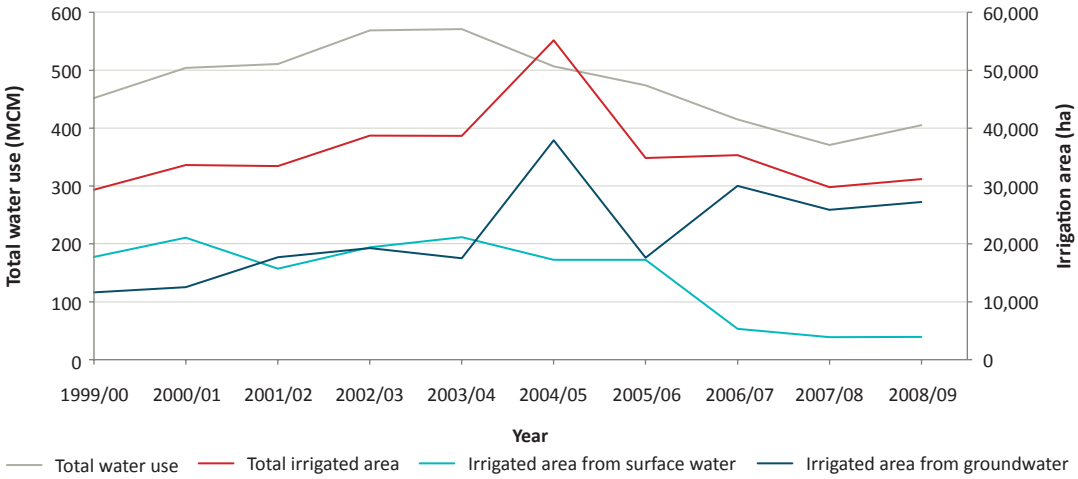
Source: Compiled by ESCWA-BGR based on data provided by Ministry of Irrigation in the Syrian Arab Republic, 2012.

Table 7. Main constructed dams in the Yarmouk Basin in Syria

COUNTRY	NAME (RIVER)	COMPLETION YEAR	CAPACITY (MCM)	PURPOSE[a]	BACKGROUND INFORMATION
Syria	Dar'a East (Wadi Zaydi)	1970	15	I	Projected irrigated area: 1,100 ha
	Room Jawlayeen[b] (Wadi Dhahab)	1977	6.4	D, F	-
	Ghariyah al Sharqiyah (Wadi Dhahab)	1982	5	I	Projected irrigated area: 250 ha
	Sheikh Miskin (Wadi Arram)	1982	15	I	Projected irrigated area: 1,100 ha
	Tasil (Wadi Allan)	1982	6.65	I	Projected irrigated area: 700 ha
	Adwan (Wadi Arram)	1986	5.85	I	Projected irrigated area: 700 ha
	Sahwat al Khidr (Wadi Zaydi)	1986	8.75	LW	-
	Ghadir al Bustan (Wadi Raqqad)	1987	12	I	Projected irrigated area: 700 ha
	Abidin (Wadi Raqqad)	1989	5.5	I, LW	-
	Al Qanawat[b] (..)	1989	6.1	D	-
	Al Allan[b] (Wadi Allan)	1990	5.0	I	Projected irrigated area: 530 ha
	Jisr al Raqqad (Wadi Raqqad)	1994	9.2	I	Projected irrigated area: 1,800 ha
	Saham al Golan (Wadi Allan)	1995	20	I	-
	Kudnah (Wadi Raqqad)	1995	30	I, LW	-
Jordan / Syria	Wahdah (Yarmouk)	2009	110	D, I, HP	-

Source: Compiled by ESCWA-BGR based on The Syrian Arab Republic and Jordan, 1987; Ministry of Irrigation in the Syrian Arab Republic, 2006.
(a) Irrigation (I), Livestock Watering (LW), Domestic (D), Fisheries (F), Hydropower (HP).
(b) These dams are not listed in the 1987 agreement.

Figure 21. Evolution of total water use and irrigated areas in the Yarmouk Basin in Syria (1999-2009)



Source: Compiled by ESCWA-BGR based on data provided by Ministry of Irrigation in the Syrian Arab Republic, 2012.

The dam projects were designed to boost agricultural production in the parts of the Golan and its vicinity which remained under Syrian jurisdiction after the 1967 Six-Day War.

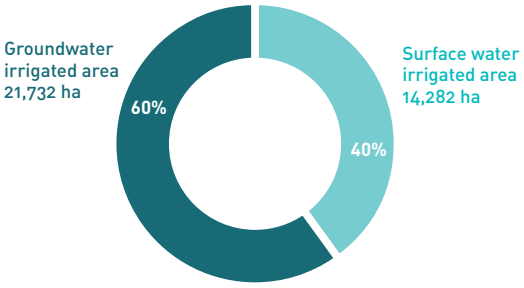
From the mid-1970s until the 2000s, annual use of Yarmouk water in Syria rose to 200 MCM.[60] In 1987, Jordan and Syria renewed the 1953 Agreement for the Utilization of the Yarmouk River,[61] in which they agreed to jointly build the Unity Dam, today known as the Wahdah Dam.[62] An annex to the 1987 agreement provides a list of 25 constructed and planned dams in Syria. With storage capacities ranging from 0.035 to 30 MCM, these dams are distributed across five wadis in the Upper Yarmouk Basin.[63] Together, the listed dams have a potential maximum storage capacity of 155 MCM.

Most of the dams mentioned in the agreement have been completed and additional structures have been built on northern tributaries of the Yarmouk River, amounting to a total of 38 dams.[64] This brings the current total dam capacity in the Syrian part of the Jordan River basin to an estimated 117 MCM, excluding the Wahdah Dam.[65] Fifteen of the 38 dams have a capacity of 5 MCM or above (Table 7).

The absence of official data from Syria on the amount of water diverted from the Yarmouk has left much room for speculation over the years. A review of sources from the 1990s estimated a total withdrawal of 90-250 MCM/yr.[66] The 1987 agreement between Jordan and Syria on the construction of a high dam on the Yarmouk River (Wahdah Dam)[67] does not give a specific water allocation to Syria, but the amount that Syria was diverting at the time was estimated at 170 MCM/yr.[68]

For the period 1999-2009, total annual water use in the Syrian part of the Yarmouk Basin (including surface and groundwater) was estimated at an average of 453 MCM,[69] of which

Figure 22. Irrigated area in the Yarmouk Basin in Syria (1999-2009), by source



Average total irrigated area: 36,014 ha

Source: Compiled by ESCWA-BGR based on data provided by Ministry of Irrigation in the Syrian Arab Republic, 2012.

327 MCM was used for irrigated agriculture, 92 MCM for domestic purposes and 34 MCM for industry (Figure 20). During this period, irrigation water use in the basin fluctuated, with an increase in 2002/2003 and a subsequent drop back to 1999 levels in 2009 (Figure 21).

Figure 22 shows that the total irrigated area for the period 1999-2009 adds up to 36,000 ha, of which 60% is irrigated by groundwater and 40% by surface water.[70] Those values correspond with FAO data, which estimates a total irrigated area of 30,000-45,000 ha in the Syrian part of the basin.[71]

DEVELOPMENT & USE: ISRAEL

Israel's use of the Jordan River is concentrated in the Upper Jordan River area and Lake Tiberias, the only major freshwater reservoir in the Jordan River basin. Long before the state of Israel was established, Zionist leaders in Europe made the quest for water in Palestine a priority, with plans to transfer water from the Jordan River to the Mediterranean coastal plain for irrigation and drinking purposes. The water company Mekorot was founded in 1937 to realize

this vision. In the following decades, Israel invested millions of dollars in the construction of the National Water Carrier (NWC), an ambitious scheme to divert an annual 120-520 MCM – about 60% of the Jordan River's total flow – from Lake Tiberias and transfer it outside the basin (Box 7, Table 8).[72] Besides the water it diverts through NWC, Israel also uses water from Lake Tiberias locally and abstracts water from the Jordan River headwaters and the Upper Jordan River.

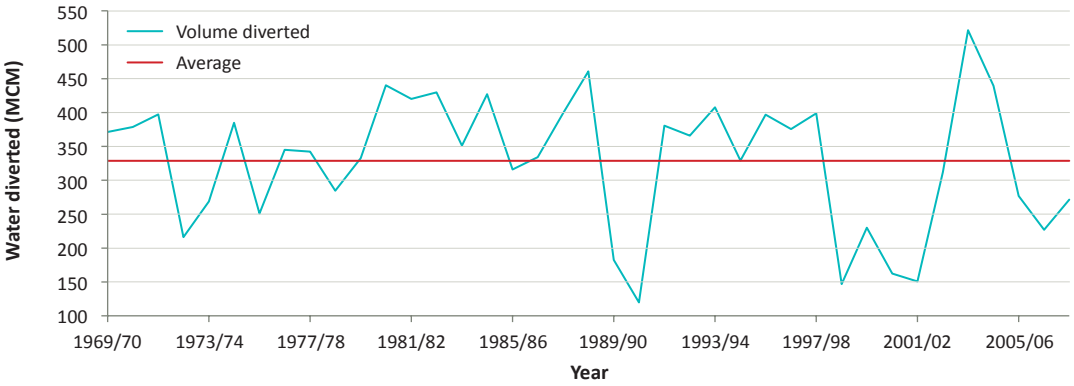
Water infrastructure in the Israeli part of the basin includes the Degania and Alumot Dams. In the late 1950s, Israel raised the level of the Degania Dam in order to increase the capacity of Lake Tiberias and ensure the operation of NWC.

Table 8 lists statistical data and literature estimates on water abstractions in different parts of the basin. The table shows that total annual water use in the Israeli part of the basin ranges between 583 and 640 MCM, most of which is diverted by NWC. In addition, Israel abstracts 70-206 MCM annually from the Upper Jordan River (mainly for irrigation), 39-90 MCM for local consumption in the Lake Tiberias basin area as well as limited abstractions from the Lower Jordan River. Israel is the only user of Lake Tiberias.[73]

Official Israeli data for the period 1969-2007 states that average annual water transfers from Lake Tiberias through NWC amounted to about 329 MCM, with minimum abstractions of 151 MCM and maximum abstractions of 521 MCM (Figure 23). Abstraction rates depend on water levels in the lake, and abstraction is restricted when levels drop to -212 m asl or lower, as was the case in the late 1980s.

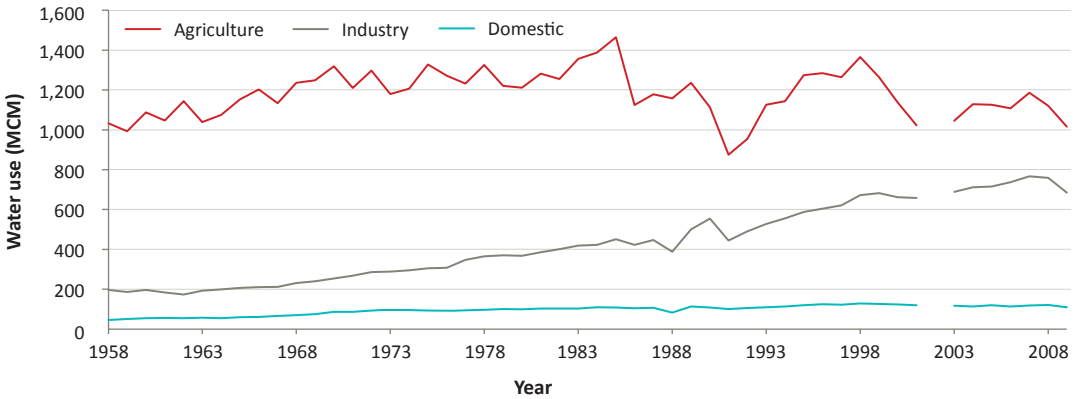
No information is available on the sectoral allocation of the water which Israel abstracts from the basin. According to Israeli data on national water use across sectors for the period 1958-2009, 69% of available water resources (1,180 MCM/yr) are used in agriculture, 25% (428 MCM/yr) for domestic purposes and 6% (96 MCM/yr) for industrial purposes. While water use for agriculture shows no clear trend over the last 50 years, domestic use has increased sharply, especially since the 1980s (Figure 24). Obviously, those figures cannot be used to precisely indicate water use in the Israeli part of the Jordan River basin; however, they may suggest use patterns.

Figure 23. **Volume of water diverted from Lake Tiberias to the National Water Carrier in Israel (1969-2007)**



Source: Compiled by ESCWA-BGR based on ACSAD and UNEP-ROWA, 2001; Ministry of Water Resources in Iraq, 2012.

Figure 24. **Total national water use across sectors in Israel (1958-2009)**



Source: Compiled by ESCWA-BGR based on Ministry of National Infrastructures in Israel et al., 2002; Central Bureau of Statistics in Israel, 2003-2009; HSI, 2008.

Irrigated agriculture in the Jordan Valley, Israel, 2010. Source: Cara Flowers.

Table 8. Annual water use in the Jordan River basin in Israel (MCM)

SOURCE	DIRECT USE FROM UPPER JORDAN RIVER BASIN	NATIONAL WATER CARRIER	DIRECT LOCAL USE FROM LAKE TIBERIAS	DIRECT USE FROM LOWER JORDAN RIVER BASIN	TOTAL
HSI, 1985-2009.	..	313	75	..	..
PASSIA, 2002.	130	420	90	..	640
UNEP, 2003.	..	500	..	..	..
Central Bureau of Statistics in Israel, 2003-2009.	206[a]	314	..	..	520 (in the Upper Jordan Basin)
Courcier et al., 2005.	100	440	..	..	540 (in the Upper Jordan basin)
FoEME, 2011.	70-150	290	39[b]	196	595
Zeitoun et al., 2012.	175	345	57-69[c]	..	~583

Source: Compiled by ESCWA-BGR.
(a) This is referred to as "upper water" and in some years as "additional surface water".
(b) A total of 89 MCM/yr are used in the vicinity of Lake Tiberias of which 50 MCM/yr are transferred to Jordan as part of the peace treaty between Israel and Jordan.
(c) This number refers to groundwater abstractions within the Lake Tiberias Basin (including the Golan) between 1999 and 2001, as estimated by the Israeli Government.

While Israel uses increasing amounts of treated wastewater and desalinated water for irrigation, freshwater still constitutes by far the largest share of the country's total annual agricultural water quota.[74] As indicated above, no detailed information is available regarding the land surface area irrigated directly by Lake Tiberias or the volume of water transferred through NWC. However, the irrigated area in the northern part of the basin in Israel[75] is estimated at around 56,000 ha.[76] Therefore water requirement estimates for irrigated agriculture in the north range from 100[77] to 560 MCM/yr.[78] While it is difficult to trace how much water from Lake Tiberias is used for irrigation activities in southern Israel, water transfer through NWC has undoubtedly allowed for the large-scale expansion of irrigated areas in the arid south.[79] In total, an estimated 60,000 ha/yr are irrigated in the arid southern districts.[80] Israel's total irrigated area is estimated at 183,000 ha.

BOX 7

Israel's National Water Carrier

Israel's National Water Carrier (NWC) was designed to divert runoff from the upper catchment of the Jordan River to highly populated areas and agriculturally productive regions in other parts of the country. This complex water conveyance system pumps water from the north-western shore of Lake Tiberias to the southern part of the country, through more than 120 km of tunnels and open canals and across an elevation of 370 m (see Overview Map). The system, which supplies cities along the Mediterranean coast and irrigated land in the coastal plain and the Negev (Al Naqab) Desert, has an annual capacity of 450 MCM.[a]

Originally Israel had planned to divert water from an intake near the Jordan River headwaters, but Syria's vehement opposition to the plan forced it to relocate the diversion site to the Upper Jordan River at Jisr Banat Yaqub in 1949. However, Syria once again voiced objections and Israel established the NWC intake site on the north-western shore of Lake Tiberias.[b] In 1964, NWC was officially inaugurated and started to abstract water from the lake.

The project is Israel's largest water management scheme and today forms the backbone of the country's water distribution system as various other, smaller water supply and distribution schemes are linked to the NWC network. The volume of water conveyed through the system has gradually increased from 172 MCM in 1964/65 to 379 MCM in 1970/71 with an average of 329 MCM/yr between 1969 and 2007.[c]

Water abstracted from Lake Tiberias enters NWC through an underground pipeline. It is then split into two parts: one conveyor transfers water to the Negev, while the other directs water to Jerusalem and the Dan region. On its way to the country's south, NWC also transfers water from other sources, including admixed groundwater and treated wastewater. In the future, Israel plans to transfer desalinated water from the Mediterranean Sea to the east and south of the country.[d]

Israel's current water development strategy prioritizes the expansion of the country's desalination capacity, which is currently estimated at 315 MCM/yr and expected to increase to 650 MCM/yr by 2020.[e] While desalination activities are mostly located outside the Jordan River basin, the increase in desalinated water availability is likely to impact the basin's water balance. In the long term, desalination may replace water transfer from Lake Tiberias as the main source of water In Israel.

(a) Mekorot, 2012.
(b) Kliot, 1994.
(c) HSI, 2008.
(d) Mekorot, 2012.
(e) Dreizin et al., 2008.

The National Water Carrier in the Galilee, Israel, 1992. Source: Ed Kashi/VII.

DEVELOPMENT & USE: JORDAN

Jordan's urban, industrial and agricultural activities are predominately concentrated within the Jordan River basin.[81] Consequently, Jordan has relied almost exclusively on the basin's water resources for its socio-economic development. In the mid-1950s, a US-led initiative to support Jordan's socio-economic development commissioned the Yarmouk-Jordan Valley Project,[82] which included the creation of canals on two sides of the Jordan Valley, two dams at Maqarin and Mukheibeh on the Yarmouk and several smaller dams to capture runoff from side valleys.[83]

Known today as the King Abdullah Canal (KAC),[84] the canal on the east side of the valley was built in three phases between 1957 and 1966 and initially covered 70 km from the Yarmouk to the Zarqa River.[85] Following the completion of the King Talal Dam on the Zarqa River in 1977 (see below), KAC was extended to a total length of 110 km to provide irrigation water to the southern parts of the Jordan Valley in Jordan.[85] The canal captures runoff from the Yarmouk River, the Mukheibeh Wells[86] and several wadis. In addition, it receives discharge from the King Talal Dam, which is a mix of freshwater from the Zarqa River and effluent from the Samra wastewater treatment plant which processes over 75% of Jordan's domestic wastewater.[87] The capacity of KAC ranges between 20 m^3/s at the intake (630 MCM/yr) and 2.3 m^3/s at its southern end.

The canal plays a central role in Jordan's agricultural development as it supplies irrigation water via pumping stations to farmers in an area of 400-500 ha.[88] However, as domestic demand continues to rise, water from KAC is increasingly pumped to the Greater Amman area over an elevation of 1,300 m. Between 2002 and 2011, Amman received an average annual amount of 47 MCM from KAC.[89] This transfer constitutes around one-third of water supplied to Amman and also corresponds to one third of the water diverted to KAC.[90]

The King Talal Dam was designed to store runoff from the Zarqa River, the Lower Jordan River's second largest tributary after the Yarmouk. The dam was raised in 1987 to increase the annual storage capacity from 56 to 75 MCM and capture an estimated 50 MCM/yr from the Samra wastewater treatment plant.[91]

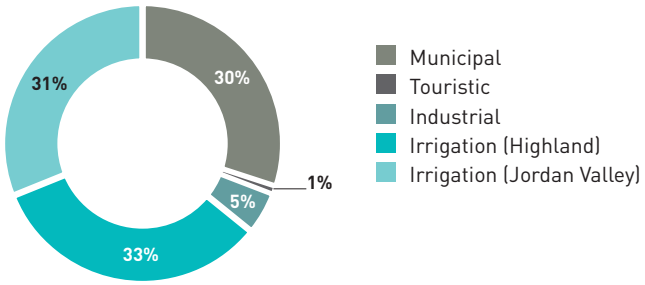
Figure 25 presents total water use in Jordan and shows that Jordan's agricultural sector consumed 64% of the country's total water resources in 2007.[92] Agricultural activities in Jordan are concentrated in the Jordan Valley and the highlands.[93] Besides some rain-fed agriculture in the highlands, commercial agriculture is irrigated, both in the highlands and in the Jordan Valley. Over the last 60 years, irrigated areas in the Jordan Valley have steadily expanded from 9,300 ha in 1950 to over 23,000 ha in 2006 as part of public irrigation schemes.[94] In 2009, the Ministry of Water and Irrigation in Jordan stated that there was 33,000 ha of irrigated land in the Jordan Valley.[95] Cultivated crops in the Jordan Valley include vegetables, citrus fruits, bananas, field crops

Table 9. Main constructed and planned dams in the Jordan River basin

COUNTRY	NAME (RIVER)	COMPLETION YEAR	CAPACITY (MCM)	PURPOSE[a]
Israel	Degania (Jordan River)[b]	1932	..	Regulation of Lake Tiberias
Jordan	Kafrein (Wadi Kafrein)	1967	8.5	I
	King Talal (Zarqa)	1977	75	I, HP
	Wadi Arab (Wadi Arab)	1986	16.8	I, D, HP
	Karameh (Wadi Mallaha)	1997	53	I
	Addasiya (Yarmouk)	1998	10	D, I
Jordan & Syria	Wahdah (Yarmouk)	2006	110	D, I, HP
Jordan	Kufrinjah (Wadi Kufrinjah)	planned	6	D, I

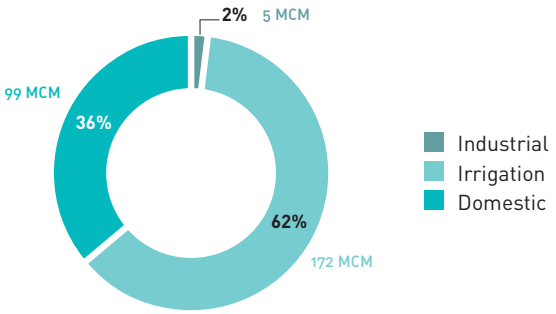
Source: Compiled by ESCWA-BGR based on Ministry of Water and Irrigation in Jordan, 2002a; Courcier et al., 2005; Amman Net, 2012; Jordan Times, 2011.
Note: For dams constructed in the Yarmouk Basin in Syria, see Table 7.
(a) Irrigation (I), Hydropower (HP), Domestic (D).
(b) Situated at the outflow of Lake Tiberias.

Figure 25. Water allocations across sectors in Jordan (2007)



Source: Compiled by ESCWA-BGR based on Ministry of Water and Irrigation in Jordan, 2009.

Figure 26. Water use across sectors in the Jordan Valley in Jordan (2010)



Source: Compiled by ESCWA-BGR based on JVA Annual Report, 2010.

and trees among others.[96] Irrigated areas in the highlands add up to about 44,100 ha[97] of which about half are situated in the Jordanian part of the Jordan River basin. Other sources state that groundwater irrigation has been developed on about 14,000 ha over the last 30 years, mainly via private wells.[98]

Data from 2010 on water use in the Jordan Valley shows that agriculture is the main user with 172 MCM/yr (Figure 26). Water for domestic use (99 MCM/yr) probably includes water pumped from the Jordan Valley to Amman.[99]

While the total water use for irrigation in Jordan has remained constant over the last two decades, the use of ground- and surface water for irrigation has decreased as irrigated agriculture in the Jordan Valley increasingly uses treated wastewater.[100]

To sum up, available surface water resources in the Jordanian part of the basin are used for agriculture in the Jordan Valley, and, since 1986, for domestic purposes in the Greater Amman area. Groundwater in the highlands is used mainly for agricultural purposes but also for municipal and industrial purposes. Total annual water use in the Jordanian part of the Jordan River basin is estimated at around 290 MCM.[101]

DEVELOPMENT & USE: PALESTINE

Before the 1967 Six-Day War, the Jordan River was an important source of water for Palestinians in the West Bank, who used it for domestic and agricultural purposes. Palestinians used Jordan River water to irrigate about 10,000 ha in the Jordan Valley.[102] The Yarmouk-Jordan Valley Project that was outlined in the late 1950s included not only an East Ghor Canal (known today as King Abdullah Canal), but also a West Ghor Canal, which was to cover 47 km and be equipped with a siphon across the Jordan River to supply irrigation water to fields in the West Bank.[103] The West Ghor Canal was initiated in 1967 but construction was halted after the Israeli occupation of the West Bank.[104]

Since then, Israel has introduced and maintained a system of direct control over the development and use of water resources, which has resulted in the creation of a restrictive permit regime for the development of water-related infrastructure. Palestinian water rights on the Jordan River have been progressively curtailed since 1967 and today the Palestinian part of the Jordan River basin (1,564 km^2) is either a "closed military area"[105] or part of the areas in the West Bank that are controlled and administered by Israel (Area C). Thus most of the fertile Jordan Valley is off limits to Palestinians as it falls under Area C. In areas controlled and/or administered by the Palestinian Authority (Area A and B), all water-related projects still require permission from Israel.[106] As a result, Palestinians cannot access or use any water from the Jordan River itself[107] and are severely restricted in the implementation of water-related projects in the basin.

For the coming two decades, Palestine has planned around 30 projects in its share of the Jordan River basin, mostly focusing on the rehabilitation of springs, wells and canals. The Red Sea-Dead Sea project (Box 8) as well as the rehabilitation of the West Ghor Canal to transfer water from the Jordan River to the agricultural lands are planned for completion in 2030 pending available funds and appropriate political conditions.[108]

King Talal Dam which supplies water to Jordan Valley farms, Jordan, 1992. Source: Ed Kashi/VII.

BOX 8 Planned Infrastructure Projects to Save the Dead Sea

The Dead Sea is severely affected by large-scale mismanagement and over-exploitation of the scarce water resources in the Jordan River basin (Box 2). In addition to the alarming drop in water levels in the Dead Sea, surface and groundwater bodies in the basin have been severely affected in terms of quantity and quality. The public debate on the shrinking of the Dead Sea tends to bypass the root causes of the crisis, and governments are keen to focus on large-scale infrastructural solutions without examining the legacy of past and current water management strategies in the region. For instance, Israel's use of the National Water Carrier (Box 7), which transfers significant amounts of water out of the Jordan River basin, is largely overlooked in the current debate. By contrast, technical solutions to the decline of the Dead Sea and water shortage in the basin at large are capturing media attention and generating a lively debate in the region. One of these projects is the Jordan Red Dead Sea Project (JRDP).

The idea of connecting the Dead Sea to the Red Sea or the Mediterranean goes back to the mid-19th century. In Jordan it has been under discussion since the 1980s in response to Israel's Mediterranean-Dead Sea projects. Concrete discussions about the construction of a conduit connecting the Red Sea to the Dead Sea started only after Israel and Jordan signed a peace treaty in 1994. The ambitious Red Sea-Dead Sea Conduit Project has since then received extensive international attention as a solution to the decline of the Dead Sea and a regional cooperation project.

Covering a distance of approximately 200 km, the proposed conduit would pump seawater from Aqaba on the Red Sea coast through the Arava Valley in Jordan where it would then be carried down to the Dead Sea through gravity. The project includes water desalination plants and a hydropower plant. Part of the Red Sea water would be desalinated and transported to Amman. The remaining brine, the by-product of desalination, would be released into the Dead Sea, with the aim of replenishing the rapidly shrinking sea.

In 2005 Israel, Jordan and the Palestinian Authority signed an agreement to proceed with a project feasibility study, which was administered by the World Bank and financed by various donors. The USD 15.5 million study comprises a technical, environmental and social assessment,[a] and was expanded in December 2007 to include a study of alternatives.[b] The study programme was scheduled for completion in 2012.[c]

With an estimated cost of USD 4.2 billion,[d] excluding the costs of transferring the desalinated water to urban centres, the project is extremely expensive in comparison to other, less drastic proposals to reverse the decline of the Dead Sea.

Besides issues of cost, the project has also raised serious environmental and technical concerns over potential damage to the marine environment in the Gulf of Aqaba[e] and the risk of damage to the 200 km conduit in this area of high tectonic activity.[f] The mixing of waters with two different chemical compositions and salinities can negatively influence the sea's biological environment. The change in the sea's chemical composition could also damage the potash industry on the southern shores as well as the tourism industry in Israel and Jordan.[g] Furthermore, raising the water level of the Dead Sea might reverse hydrostatic gradients and contaminate surrounding groundwater tables.

Following Jordan's announcement of the Jordan Red Sea Project (JRSP) in 2009,[h] the three-way cooperation between Israel, Jordan and Palestine has taken a back seat. According to the Jordanian Government, JRSP can be regarded as the first phase of the Red Sea-Dead Sea Conduit Project. The project is designed to abstract about 400 MCM/yr of seawater from the Red Sea, and desalinate about 200 MCM/yr. The additional seawater and brine from desalination will be discharged into the Dead Sea. The project also includes the development of a series of residential and commercial areas, industrial centres, tourist resorts and other business support functions between the Red Sea and the Dead Sea in Jordan.[i] Israel is said to be participating in the coordination and planning of JRSP, and will become more closely involved at a later stage.

(a) World Bank, 2005.
(b) FoEME, 2007.
(c) World Bank, 2011.
(d) Israel Ministry of Foreign Affairs, 1995.
(e) RSS, 2007.
(f) Geological Survey of Israel, 2006.
(g) Gavrieli et al., 2005; Asmar and Ergenzinger, 1999; FoEME, 2007.
(h) JRSP Company, 2010.
(i) Ministry of Water and Irrigation in Jordan, 2012.

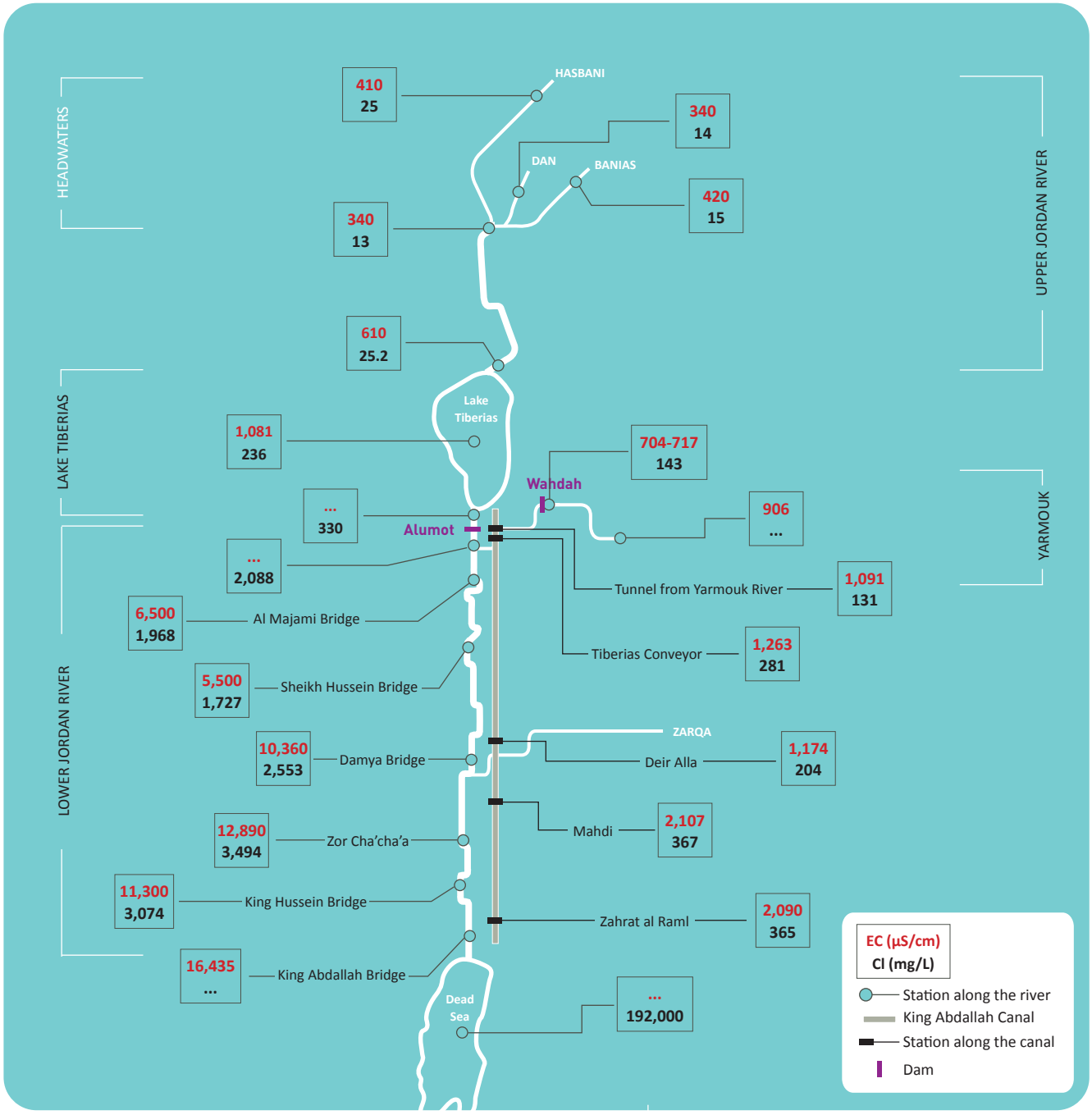
The Dead Sea, 2009. Source: Marc Haering.

WATER QUALITY & ENVIRONMENTAL ISSUES

While the Jordan River headwaters are a source of good-quality, low-salinity water, most of the rest of the river is heavily polluted by sewage, agricultural return flows, groundwater seepage and brackish/saline water diverted from springs around Lake Tiberias. Moreover, the Lower Jordan River has suffered a 50% loss in biodiversity due to the disappearance of fast-flow habitats and dramatically heightened salinity levels.[109]

Figure 27 shows recent salinity data for the Jordan River and King Abdullah Canal (KAC). Table 10 summarizes available salinity data for the Upper Jordan River including the headwaters and for the Yarmouk River, while Table 11 presents the same information for the Lower Jordan River.

Figure 27. Sketch of salinity levels along the Jordan River and the King Abdullah Canal



Source: Compiled by ESCWA-BGR based on the references listed in Table 10 and Table 11.
Note: Due to minor gaps in the available salinity information, the values displayed in this figure are all based on data from 2009, except for the stations at Lake Tiberias (2006), the Wahdah Dam (2010) and KAC (2010). Data for the Yarmouk River is based on Ministry of Water and Irrigation in Jordan, 2002b but the exact sampling period is unknown.

Headwaters of the Upper Jordan River

The Jordan River headwaters contain high-quality water along their entire course.[110] Sampling of water from the Dan and Banias Springs between 2002 and 2004 showed a mean salinity of 343 µS/cm and 397 µS/cm as Electrical Conductivity (EC) respectively. [111] The three upper tributaries (Hasbani, Banias and Dan Rivers) also have low salinity values ranging from 310 to 420 µS/cm as shown in Table 10. While low salinity values are maintained until the confluence of the headwaters, agricultural activities in the Dan and Hasbani sub-basins are likely to expose the rivers to contamination from agricultural runoff. In particular, the Hasbani sub-basin is threatened by several types of pollution, including domestic wastewater and olive oil production residues.[112]

As it flows south, the Upper Jordan River passes through the Hula Valley (Box 8) and discharges into Lake Tiberias. The intensive agricultural activities in this region clearly impact water quality, with a noticeable increase in salinity values to 610 µS/cm at the inlet to Lake Tiberias (Table 10).[113]

Lake Tiberias

The water of Lake Tiberias has significantly higher salinity values than the Upper Jordan River (Table 10). In addition to an increase in salinity due to high evaporation rates,[114] higher salinity values are mainly a result of the presence of chloride-rich saline springs close to the lake shore and on the lake floor, which discharge an estimated 40 MCM/yr into the lake.[115] Prior to 1964, the chloride (Cl^-) content of Lake Tiberias reached 400 mg/L, and the high salinity of lake water damaged crops.[116] However, the construction of the Salinity Diversion Channel (SDC) in 1967 as part of Israel's National Water Carrier project allowed for the diversion of saline water from springs on the western and north-western side of the lake[117] to the Lower Jordan River. That has led to the removal of about 70,000 tons/yr of salt from Lake Tiberias and the transferral of 15-20 MCM/yr of water to the Lower Jordan River at the Alumot Dam location.[118] As a result of the diversion, the chloride content of the lake was reduced to 236 mg/L in 2006,[119] making it suitable for use as drinking water.[120]

Apart from natural factors, anthropogenic activities in the basin have direct impacts on the lake's water quality. The Tiberias watershed area is mainly used for agriculture, including aquaculture, but tourism and recreation have also grown over recent decades, leading to an increase in pollution from agricultural, industrial and domestic sources.[121] In addition, the drainage of the Hula Valley marshlands in the 1950s (Box 8) caused a rise in nutrient content in the lake and a bloom of potentially toxic cyanobacteria. It is estimated that more than 50% of the nutrient inputs into Lake Tiberias originate from the Hula Valley and surroundings.[122] Water-level fluctuations in the lake are also an issue of concern, threatening the stability of the basin's ecosystem.

Yarmouk

In terms of salinity, the Yarmouk River is characterized by good-quality water in comparison to the Lower Jordan River, with an average chloride and TDS content of 134 mg/L and 749 mg/L respectively (2001-2002).[123] Recent salinity values at the Wahdah Dam show the same range of values. The intensive agricultural activities in the dam's catchment area have, however, resulted in high levels of Total Phosphorus (TP) and Total Nitrogen (TN) at the dam site, as well as frequent algal blooms caused by agricultural runoff and wastewater flowing into the reservoir.[124]

Heavy metals have been detected in the water of springs in the Yarmouk Basin.[125] Sediment samples taken along the river also displayed high heavy metal content, which can be attributed to agricultural activities as well as the presence of a treatment plant, a landfill site and small industries in the basin area.[126]

King Abdullah Canal

The canal is mainly fed by water from the Yarmouk River and various sources along the Jordan River, including the water conveyed from Lake Tiberias, the Mukheibeh Wells and water from wadis and dams along the canal in Jordan (Wadi Arab, Wadi Ziqleb and the King Talal Dam).[127]

Polluted water in the Jordan Valley, Jordan, 2008. Source: Eileen Maternowski.

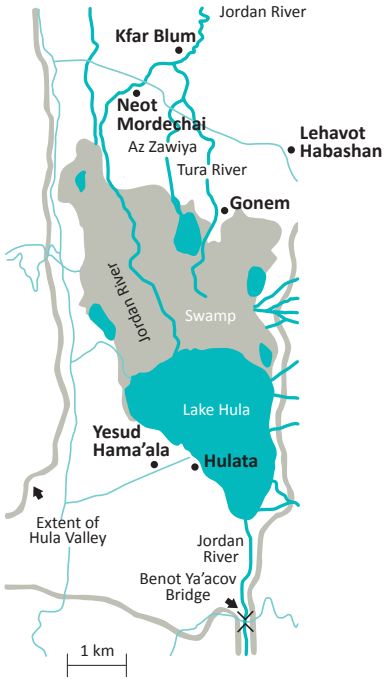
BOX 9

The Hula Valley Drainage Project

Located to the north of Lake Tiberias in current-day Israel, the Hula Valley used to be a 6,000 ha wetland area that included Lake Hula (1,200-1,400 ha) and featured unique fauna and flora.[a] In a bid to expand the agricultural lands in the area, eradicate malaria and reduce evaporative water losses, Israel drained the lake and surrounding marshes in the 1950s.[b] However, in the following decades it became clear that the drainage project had a severe ecological impact, causing wind and water erosion, underground peat fires, loss of endemic species and the release of increased nutrient loads into Lake Tiberias.[c] Israel attempted to restore the heavily damaged ecosystem in 1994 with the Hula Restoration Project, which re-flooded part of the former wetland and created the shallow Lake Agmon.[d] This lake is currently an eco-tourism area and serves as a zone for storage and reuse of agricultural drainage waters.[e] Analysis of water samples in the first three years after the new system was put in place indicated high nutrient levels with a gradual increase in eutrophication over the years.[f] Most of the water that flows into Lake Tiberias passes through the Hula Valley, and its low quality obviously harms water quality in the lake.[g]

(a) Hambright and Zohary, 1998.
(b) Ibid. A small portion of the original swamps (350 ha) was left inundated and became an Israeli nature reserve in 1964.
(c) Ibid. Large amounts of nitrates and sulphates were washed into Lake Tiberias during the rainy season as a result of decomposing peats.
(d) Tsipris and Meron, 1998; Hambright and Zohary, 1998.
(e) Hambright et al., 2000.
(f) Hambright et al., 1998.
(g) Gophen, 2000.

Figure 28. Lake Hula before drainage in the late 1950s



Source: Compiled by ESCWA-BGR based on Hambright and Zohary, 1998.

Lake Hula, Israel, 2008. Source: Itamar Grinberg.

In terms of salinity, EC values along the canal lie between 894 and 2,601 µS/cm, with values increasing from north to south.[128] The gradual increase can be attributed to the inflow of saline water along the course of the canal, specifically from the tunnel which conveys saline water from Lake Tiberias and the inflow of the Zarqa River (see Figure 27).[129]

Apart from its effects on water salinity, the high nutrient load of the water flowing into KAC from various sources causes serious problems of eutrophication. The most upstream discharge point of these compounds is the Yarmouk River (see Figure 27, Tunnel from Yarmouk sampling location), with mean nitrate (NO_3-N) and TP concentrations of 1.6 mg/L and 0.21 mg/L respectively. In addition, water from the King Talal Dam on the Zarqa River contains high nutrient loads as measured at the Mahdi sampling station, where the mean nitrate level is 9.5 mg/L. Similarly, the mean TP level at this site is 1.73 mg/L, an eight-fold increase compared to the first sampling site.[130] The planned rehabilitation of the Khirbet As-Samra Wastewater Treatment Plant located upstream of the King Talal Reservoir is expected to improve the water quality of the Zarqa River and, as a result, water quality in KAC.[131]

The eutrophication of KAC water first became a problem in 1998, when the unpleasant odour of the drinking water in the Greater Amman area gave rise to public concern.

Table 10. **Mean salinity values of the Upper Jordan River and Yarmouk River**

STATION	TDS (mg/L)	EC (µS/cm)	Cl (mg/L)	YEAR	SOURCE
Hasbani River	..	391	..	2006 (March)	Barinova and Nevo, 2010.
	287	410	25	2009 (Jan-Apr)	
Dan Spring	230-320	..	..	1996-2000	Gur et al., 2003.
	..	343	..	2002-2004	Brielmann, 2008.
Dan River	..	336	..	2006 (March)	Barinova and Nevo, 2010.
	244	340	14	2009 (Jan-Apr)	
Banias Spring	247-408	..	..	1996-2000	Gur et al., 2003.
	..	397	..	2002-2004	Brielmann, 2008.
Banias River	..	389	..	2006 (March)	Barinova and Nevo, 2010.
	297	420	15	2009 (Jan-Apr)	
Confluence of upper tributaries	..	371	..	2006 (March)	Barinova and Nevo, 2010.
	240	340	13	2009 (Jan-Apr)	
Jordan River at the inlet to Lake Tiberias	..	406	..	2006 (March)	Barinova and Nevo, 2010.
	431	610	25.2	2009 (Jan-Apr)	
Lake Tiberias	..	..	≤400	Pre-1964	Hambright et al., 2000.
	..	..	204-221	1980-1985	Hambright et al., 2000.
	..	..	300	Mid-1990s-2002	Siebert et al., 2009.
	..	..	250	2003-2004	
	..	..	236	2006	Kiperwas, 2011.
	..	1,081	..	2006	Ministry of Water and Irrigation in Jordan, 2002b.
Yarmouk River	571-901	..	..	1996	Howari and Banat, 2002.
	749	..	134	2001-2002	Farber et al., 2004.
	580	906	..	..	Ministry of Water and Irrigation in Jordan, 2002b[a].
Yarmouk Springs[b]	347-1,234	..	..	2006	Batayneh, 2011.
Wahdah Dam	541	845	..	1997-2002	Ministry of Water and Irrigation in Jordan, 2002b.
	..	704-717	143	2010	Al-Taani, 2011.

Source: Compiled by ESCWA-BGR.
Notes:
- The international TDS and EC guideline for irrigation of salt-sensitive crops is limited at <450 mg/L and <700 µS/cm respectively (FAO, 1994). This differs from the Jordanian guideline, which is set at <1,700 µS/cm (JVA and GTZ, 2006).
- The Cl guideline for irrigation varies according to crop tolerance and ranges from 106 to 960 mg/L (FAO, 1994).
- For drinking water, the Cl standard (<250 mg/L) is only taste-based and no health-based guideline is proposed (WHO, 2003).
For further information on the different water quality parameters and their respective guidelines, see 'Overview & Methodology: Surface Water' chapter.
(a) No specific date is mentioned for these salinity figures. In the document they appear as "According to the long-term monitoring data from the Jordan Valley Authority".
(b) Sampling of 36 major springs in the Yarmouk Basin.

Investigations revealed that dense algal growth in KAC, together with insufficiently treated water at the Zai Treatment Plant were the cause of the foul smell.[132] While treatment efficiency and KAC water quality monitoring programmes were subsequently improved,[133] algal blooms are still reported along the canal, which means there is a continued risk to public health.[134]

Lower Jordan

There is a significant deterioration in water quality from the Upper to the Lower Jordan River. High salinity levels and pollution indicate that the ecosystem in the Lower Jordan Basin is under threat and that the river's water is unsuitable for use in any sector.[135]

Water quality along the stretch of the river is particularly threatened by rising salinity levels caused by the dramatic reduction of freshwater inputs and the transferral of saline spring water from Lake Tiberias to the Lower Jordan River.[136] Water quality in the northernmost part of the Lower Jordan River is significantly modified downstream of the Alumot Dam (at around 1.5 km from Lake Tiberias) as effluent from SDC and agricultural and municipal sewage from Israel[137] is channelled into the river at this point.[138] This results in a sharp increase in chloride (Figure 27), TP and Biochemical Oxygen

Table 11. **Mean salinity values of the Lower Jordan River at different stations**

STATION	TDS (mg/L)	EC (µS/cm)	Cl (mg/L)	YEAR	SOURCE
Al Majami Bridge	3,823 [3,132-4,386]	5,986 [4,900-6,900]	..	2001-2008	Ministry of Water and Irrigation in Jordan, 2010.
	4,149	6,500	..	2009	
	..	..	1,968	2009	FoEME, 2010.
Sheikh Hussein Bridge	3,429 [3,093-3,706]	5,371 [4,800-5,800]	..	2001-2008	Ministry of Water and Irrigation in Jordan, 2010.
	3,494	5,500	..	2009	
	..	..	1,727	2009	FoEME, 2010.
	..	6,254 [5,800-6,754]	1,668 [1,482-1,846]	2010	RSS, 2010.
Damya Bridge	3,048 [1,717-3,813]	5,806 [5,649-5,960]	..	2001-2004	Ministry of Water and Irrigation in Jordan, 2010.
	..	10,360	2,553	2009	FoEME, 2010.
Zor Cha'cha'a	5,228 [5,074-5,382]	8,170 [7,930-8,410]	..	2001-2002	Ministry of Water and Irrigation in Jordan, 2010.
	6,582 [5,523-8,495]	10,283 [8,630-13,270]	..	2006-2008	Ministry of Water and Irrigation in Jordan, 2010.
	8,252	12,890	3,494 [1,698-5,138]	2009	
	..	9,930 [8,170-11,800]	2,703 [2,148-3,335]	2010	RSS, 2010.
King Hussein (Allenby) Bridge	5,907 [4,290-7,932]	9,230 [6,700-12,400]	..	2001-2008	Ministry of Water and Irrigation in Jordan, 2010.
	7,222	11,300	..	2009	
	..	..	3,074	2009	FoEME, 2010.
	..	10,105 [8,145-11,880]	2,762 [2,149-3,278]	2010	RSS, 2010.
King Abdullah Bridge	..	..	400	1925	Farber et al., 2005.
	..	..	Up to 5,400	2005[a]	
	..	16,435	..	2009	FoEME, 2010.

Source: Compiled by ESCWA-BGR.
Notes:
- Sampling stations are displayed from north to south.
- Data from Ministry of Water and Irrigation in Jordan, 2010 does not include mean salinity values for 2003.
- The international TDS and EC guideline for irrigation of salt-sensitive crops is limited at <450 mg/L and <700 µS/cm respectively (FAO, 1994). This differs from the Jordanian guideline, which is set at <1,700 µS/cm (JVA and GTZ, 2006).
- The Cl guideline for irrigation varies according to crop tolerance and ranges from 106 to 960 mg/L (FAO, 1994).
- For drinking water, the Cl standard (<250 mg/L) is only taste-based and no health-based guideline is proposed (WHO, 2003).
For further information on the different water quality parameters and their respective guidelines, see 'Overview & Methodology: Surface Water' chapter.
(a) No precise date is provided. The author refers only to "nowadays".

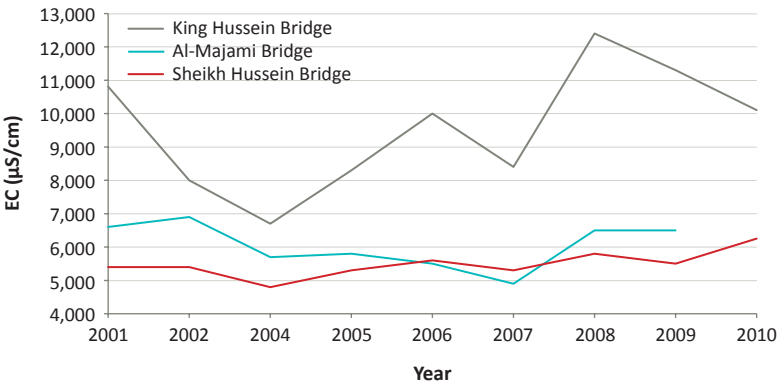
The King Abdullah Canal, Jordan, 2007. Source: Mark Haering.

Demand (BOD) levels. BOD values registered in 2009 showed a sharp increase from 1 mg/L upstream of the dam to 12 mg/L after the dam site. A similar exponential rise in TP was observed, with an increase from 0.3 mg/L before the dam to six times that amount downstream of the dam.[139]

Salinity levels increase progressively along the course of the Lower Jordan River,[140] with EC values of 6,500 µS/cm registered in 2009 at the Majami Bridge station and 16,435 µS/cm at the King Abdullah Bridge, the southernmost sampling station along the river (Table 11).[141] Available data on salinity variations in the last decade shows that no significant change has taken place during this period (Figure 29). However, sources suggest that there was a clear increase in salinity over the 20th century. For instance, historical data from 1925 indicates that the chloride concentration at the King Abdullah Bridge station was around 400 mg/L, while today it can reach up to 5,400 mg/L.[142]

The Lower Jordan River is also affected by extremely high levels of organic pollution, posing a risk to public health. This is of particular concern at the baptism sites on both banks of the river in Israel and Jordan, where observant

Figure 29. **Mean annual Electrical Conductivity (EC) values of the Lower Jordan River (2001-2010)**



Source: Compiled by ESCWA-BGR based on Ministry of Water and Irrigation in Jordan, 2010; RSS, 2010.

Christians immerse themselves in the water as part of religious rituals.[143] Moreover, the Lower Jordan River has suffered a 50% loss in biodiversity[144] as the inflow of saline water from side wadis, drainage water from fishponds, untreated sewage water, saline springs and agricultural return flows has increased over the years.[145] The deterioration of water quality in the Lower Jordan Basin severely restricts water use,[146] with serious long-term implications for the ecosystem.

Agreements, Cooperation & Outlook

Riparian cooperation on water resources management in the Jordan River basin is tragically entwined with the regional conflict. Despite a range of multilateral initiatives to reach a basin-wide agreement on water resources allocation,[147] riparian countries have still not reached a consensus. The 1991 Madrid Conference sought to initiate a regional peace process and find a comprehensive solution to the Arab-Israeli conflict. The meeting paved the way for a series of bilateral and multilateral negotiations on various issues, including shared water resources in the region. Lebanon and Syria refused to take part in the multilateral meetings before tangible progress was made on the Israeli-Lebanese and Israeli-Syrian bilateral level.

Today, there are a number of bilateral agreements between riparian countries in the basin (Table 12), which can be divided into two categories: agreements between Jordan and Syria on the Yarmouk River without any third-party involvement, and agreements negotiated in the aftermath of the Madrid Conference (peace treaty between Israel and Jordan and the Oslo Accords).

AGREEMENTS: JORDAN & SYRIA

From the late 1940s, the three Yarmouk riparians, Israel, Jordan and Syria, have held strong and often conflicting positions on water allocation in the basin. In 1953, Jordan and Syria signed an agreement on the use of the Yarmouk River, which outlined the construction of a dam near Maqarin in Syria to provide irrigation water to Jordan and electrical power to both countries.[148]

The agreement does not specify volumetric water allocations to the two countries, but instead states that Syria has the right to use all the water of the river and its tributaries entering the river upstream of the dam site, excluding the water necessary to supply the future dam.[149] Jordan is accorded the right to use the overflow from the reservoir and a quarter of the output from the joint generating station at Maqarin. According to the agreement, the electricity generated at Addasiya is to be divided on a 75%-25% basis between Syria and Jordan.[150] It also establishes a Joint Syrian-Jordanian Commission to oversee the implementation of

Table 12. Water agreements in the Jordan River basin

YEAR	NAME	SIGNIFICANCE	SIGNATORIES
1920	Franco-British Convention	Article 8 states that the signatories will undertake joint examination of the Upper Jordan and Yarmouk for the production of hydroelectric power.	Great Britain (Israel, Jordan, Palestine), France (Lebanon, Syria)
1923	Exchange of notes constituting an agreement between the British and French Governments	The agreement focuses on water rights.	Great Britain (Israel, Jordan, Palestine), France (Lebanon, Syria)
1926	Agreement I of Good Neighbourly Relations Concluded Between the British and French Governments	Article III focuses on water rights.	Great Britain (Israel, Jordan, Palestine), France (Lebanon, Syria)
1953	Agreement between the Republic of Syria and the Hashemite Kingdom of Jordan Concerning the Utilization of the Yarmouk Waters	Cooperative use and management of the Yarmouk River, including construction of the Wahdah Dam.	Jordan, Syria
1987	Agreement Concerning the Utilization of the Yarmouk Waters	Cooperative use and management of the Yarmouk River, including construction of the Wahdah Dam.	Jordan, Syria
1994	Treaty of Peace between the State of Israel and the Hashemite Kingdom of Jordan	Annex II outlines the principles of cooperative use and management on the Yarmouk River and the Jordan River.	Israel, Jordan
1995	Israeli-Palestinian Interim Agreement on the West Bank and the Gaza Strip	Annex III, Article 40 comprises the interim arrangement for water management in the West Bank and Gaza Strip.	Israel, Palestine (PLO)

Source: Compiled by ESCWA-BGR based on Oregon State University, 2010.

works, which comprises three members from each country.[151]

While the agreement remained in place for 34 years, neither the dam nor the hydropower facility was constructed during this period due to the unstable political relationship between Jordan and Syria and conflicts with Israel.[152] The two countries returned to the negotiation table in 1987, when they narrowed down the scope of the agreement with regards to the dam (now called the Unity or Wahdah Dam) and the reservoir at Maqarin. The new agreement differs in that it (1) outlines the construction of a smaller dam, reflecting the gradual depletion of available water resources in the Yarmouk Basin, (2) alters the approach to dispute resolution from an arbitration mechanism to a mechanism of intergovernmental mediation and (3) authorizes Syria to implement and use 25 dams on the Yarmouk and its tributary rivers and wadis.[153] The Wahdah Dam began to receive water in 2006 and was completed in early 2009.[154]

AGREEMENTS: ISRAEL & PALESTINE

Officially referred to as the Declaration of Principles on Interim Self-Government Arrangements (DOP), the 1993 Oslo Accords between Israel and the Palestine Liberation

BOX 10

The Johnston Plan

The equitable sharing of water resources in the increasingly densely populated and water-scarce Jordan River basin has been problematic for more than a century. In the first half of the 20th century, the United States, Israel, Arab countries and the international community put forward a number of basin development plans (Table 6), which outlined different approaches to water allocation and management in the Jordan River basin.

Following the 1948 war between Arab states and Israel, the United States attempted to develop a scheme to guarantee the availability of irrigation water for all populations sharing the Jordan River, including Palestinian refugees.[a]
US Ambassador Eric Johnston subsequently developed such a scheme following a series of visits to the region between 1953 and 1955. While it was never implemented, the Johnston Plan[b] continues to be the most authoritative scheme and still forms the basis for discussions over water allocation in the basin. It is also often referred to as a base for a "tacit" understanding among riparian countries.[c]

The plan assumes a total annual water availability of 1,503 MCM in the basin and allocates 616 MCM to Israel, 720 MCM to Jordan, 35 MCM to Lebanon and 132 MCM to Syria[d] (Table 6). While all riparians accepted the plan on a technical level,[e] it failed politically after the Council of the League Arab States voted against its ratification in October 1955, arguing that it constituted a formal recognition of the state of Israel. Israel also had its reservations towards the plan as politicians feared it would set a precedent and encourage Arab states to make claims to water resources from the Upper Jordan River.[f]

(a) Phillips et al., 2007.
(b) The Johnston Plan dated September 1955 is the only full version of the Jordan Valley Plan.
(c) See Jägerskog, 2003; Kliot, 1994.
(d) Several authors state that Israel's allocation is 394 MCM/yr or 400 MCM/yr. However, Phillips et al., 2007 underline that this figure does not include the local flows that Johnston included in the allocation. They argue that "The confusion of previous authors in relation to this figure was generated by the omission of a specific flow for Israel within the Johnston Plan itself." (p. 34).
(e) Phillips et al., 2007.
(f) Lowi, 1993, p. 193.

Wadi Shihab, a tributary of the Yarmouk River in Dera'a Governorate, Syria, 2009. Source: Adel Samara.

Organization (PLO) were the result of extensive negotiations in the aftermath of the Madrid Conference. They were followed in 1995 by the Israeli-Palestinian Interim Agreement on the West Bank and the Gaza Strip or Oslo II, which addresses the topic of water in Article 40 of the Protocol on Civil Affairs (annex 3). In Israel, this agreement is widely seen as a turning point that shifted responsibility for the Palestinian water sector to the Palestinian Authority. Yet in practice the interim agreement did not change the scope of Israeli control.[155]

The Interim Agreement includes provisions for both parties to establish a permanent Joint Water Committee for the interim period. This body is charged with regulating water resources use in the West Bank.

AGREEMENTS: ISRAEL & JORDAN

In the framework of the Madrid Conference, Israel and Jordan concluded the Treaty of Peace between the State of Israel and the Hashemite Kingdom of Jordan in October 1994. Annex II of the treaty deals with shared water resources, detailing water allocation, storage, water quality and protection, groundwater in Wadi Araba and the establishment of a Joint Water Committee.[156]

The agreement specifies that Israel is to receive an annual 25 MCM (12 MCM in summer, 13 MCM in winter)[157] from the Yarmouk River, while Jordan is to receive the rest of the flow.[158] The two countries also agreed that Israel can abstract an additional 20 MCM/yr from the Yarmouk River in winter, and in exchange transfers 20 MCM/yr of Jordan River water to Jordan in summertime.[159] In addition, Jordan is entitled to an annual 10 MCM of desalinated water from saline springs diverted to the Lower Jordan River. However, the treaty does not specify the exact amount of water to be supplied to Jordan.[160]

Besides ambiguities in the text,[161] several provisions have not been implemented as outlined in the agreement,[162] placing pressure on Israeli-Jordanian cooperation in the domain of water.

COOPERATION: JORDAN & SYRIA

In accordance with the 1987 bilateral agreement, Jordan and Syria established the Jordanian-Syrian Yarmouk River Basin Higher Committee. Representatives from the Jordan Valley Authority and the Syrian Ministry of Irrigation meet regularly to discuss issues of common interest, such as flood water storage in Syrian dams and the Wahdah Dam, the prevention of illegal agricultural activities and the control of unregulated groundwater pumping.

BOX 11 Division of the West Bank into Three Administrative Sectors

Following the Oslo Accords, the West Bank was divided into three administrative sectors, and most of the Jordan Valley – the area with the most fertile lands in the Palestinian part of the basin – was placed under Israeli control and administration (Area C, which covers about 60% of the West Bank). The land along the western banks of the Jordan River was declared "closed military areas". The only water resources in the Jordan River basin that Palestinians can use are inflows to the Jordan River and precipitation falling in the part of the basin that is controlled and administered by the Palestinian Authority (Area A). Even in this area, however, Israel can exercise its veto power over any water-related project. As a result, Palestinian project proposals for water development and maintenance regularly encounter years of delay or are rejected entirely.[a]

(a) UN-OCHA, 2012b.

In 2009, the two countries commissioned a joint study to evaluate the quantity and quality of water resources in the Yarmouk Basin, identify the causes of their depletion, and propose ways of protecting the basin from pollution and arbitrary pumping.[163] Furthermore, the parties agreed to establish six water monitoring stations on the Yarmouk to measure water inflows upstream of the Wahdah Dam, with three stations in Jordan (Wadi Glaed, Wadi Shallala, Wadi Zizoun) and three in Syria (Wadi Raqqad, Wadi Allan, Wadi Harir).

COOPERATION: ISRAEL & PALESTINE

In accordance with the Interim Agreement, the parties established in 1994 the Joint Water Committee (JWC), which comprises an equal number of representatives from Israel and the Palestinian Authority. It is charged with overseeing water resources management in the West Bank, excluding Gaza and the Jordan River.[164] Hailed as a success story for Israeli-Palestinian cooperation, the committee's work had limited impact.[165] Thus while it was set up to make all decisions in consensus, it lacks a mechanism to settle disputes. This has allowed Israel to veto Palestinian requests to drill new wells and obtain the additional water resources stipulated in the agreement.[166] As a result, JWC has been criticized as a means of "dressing up domination as cooperation".[167]

The Israeli minister of environment and the Palestinian minister of water conceded in December 2011[168] that JWC is ineffective. While they disagreed on how this could be remedied, they both called for the re-examination of the committee's structure and operational mechanism.[169]

COOPERATION: ISRAEL & JORDAN

The Israeli-Jordanian Joint Water Committee (JWC) was established to implement the treaty

between Israel and Jordan and facilitate joint development cooperation in the basin. The committee is made up of three high-ranking government officials from each state[170] and members communicate directly in regular meetings. Committee meetings are reportedly professional, but not always free of disputes. Decisions are made unanimously and at the end of each meeting minutes are compiled and submitted to the respective governments. Members are said to focus on technical issues in order to avoid discussion of sensitive political issues.[171]

The agreement mandates the committee to undertake monitoring inspections, but in practice it depends largely on the permission of member states to visit specific locations. In addition to the weak monitoring powers, JWC lacks a proper conflict-resolution mechanism. In case a dispute erupts but fails to be resolved in the committee, it can therefore negatively impact interstate relations.[172]

OUTLOOK

The Jordan River basin is comparatively small in an international context, yet it has a unique cultural and historical significance. The basin has been extensively studied and discussed, attracting scholars from various disciplines, diplomats, politicians, development workers and the media to analyse the dispute over water allocation in the basin and, more recently, the worsening environmental degradation. However, numerous failed attempts to reach a basin-wide agreement over water-sharing indicate that a resolution of the over-arching political conflict is prerequisite.

Shared water management in the Jordan River basin forms the subject of numerous regional and international studies and projects, including several initiatives to promote cooperation between all or some of the basin riparians.[173] While some projects include all riparians, other projects neglect upstream basin riparians and focus on infrastructure projects in order to address the severe water shortage in the region. The political conflict in the region and the ongoing Israeli occupation continues to stand in the way of a basin-wide agreement on water but also hampers many attempts to encourage cooperation over and a common understanding of the sustainable development and management of shared resources in the basin, including the preservation of the basin's natural wealth.

Lake Hula, Israel, 2008. Source: Itamar Grinberg.

A number of other points are important when considering the future of the Jordan River basin:

The data available for this study does not allow for a clear statement on changing precipitation patterns in the basin area. The perceived increase in low rainfall years over recent decades may impact surface runoff, the level of dam reservoirs and the recharge of aquifer systems. However, the role of intensive water use in the basin may outweigh any effect caused by climatic changes.

Demographic development in the Jordan River Basin has resulted in an intensification of land (development of housing, roads and other topographic changes) and water resources use (construction of dams and rainwater harvesting systems, excessive well drilling) in Israel, Jordan and Syria and has dramatically reduced transboundary flow. This situation is unlikely to change in the near future. On the contrary, Lebanon will eventually develop its southern districts, while Palestine plans to implement projects such as the West Ghor Canal. The current strive in Syria and refugee spillover to Jordan and Lebanon are putting further pressure on water resources in the Jordan River Basin.

Finally, as the pressure on water resources in the basin continues to increase and its ecosystem is threatened, it is clear that the strengthening of monitoring programmes and the exchange of data would allow for more sustainable region-wide water resources management.

Notes

1. The Dead Sea basin includes the Jordan River basin and catchments of wadis that discharge directly into Dead Sea from the east and west in addition to Wadi Araba to the south. The Dead Sea Basin is shared between six countries: Israel, Jordan, Lebanon, Palestine and Syria, with a minor part of the basin in Egypt.
2. Rouyer, 2000.
3. The Arabic name of the Dan is Liddan.
4. Basin area was estimated from a digital elevation model (HydroSHEDS) similar to Lehner et al., 2008.
5. Zeitoun et al., 2012.
6. Ibid. For the purpose of this Inventory the length of the Upper Jordan River has been calculated at 38 km from the confluence of the headwaters to the outlet at Lake Tiberias.
7. Institute for Veterinary Public Health, 2011; WorldClim, 2011.
8. Jordan Meteorological Department, 1999.
9. Precipitation data collected at high elevations in the basin show impressive records of 1,600-2,400 mm (Brielmann, 2008).
10. Beaumont in Kliot, 1994.
11. Zeitoun et al., 2012.
12. Known as Snir in Israel.
13. Known as Hermon in Israel.
14. The Hasbani River has another perennial tributary, the Ajoun (also known as Brighit), which also originates in Lebanon and has a basin area of 51 km^2. The area for all three sub-basins was estimated from a digital elevation model (HydroSHEDS) similar to Lehner et al., 2008 and may therefore contradict national basin estimates as in the case of the Hasbani Basin which is stated at 600 km^2 (Ministry of Energy and Water in Lebanon, 2011).
15. Zeitoun et al., 2012; Brielmann, 2008.
16. Brielmann, 2008.
17. Rimmer and Salingar, 2006.
18. Brielmann, 2008.
19. Klingbeil, 2012.
20. Both discharge records exhibit almost identical dynamics expressed by a CV of around 0.4.
21. These differences can also be a result of errors in discharge measurements. According to Sauer and Meyer, 1992, standard errors for discharge measurements can range from 2% under ideal conditions to about 20% when conditions are poor and shortcut methods are used.
22. Menzel et al., 2011.
23. See Chap. 21 for more information on the groundwater basin.
24. Errors in discharge measurements for these two stations are expected to be significant.
25. Courcier et al., 2005; FoEME, 2011 calculates the historic flow of the Yarmouk at 470 MCM. Kliot, 1994 estimates Yarmouk flow at 450-475 MCM, while Libiszewski, 1995, and Burdon, 1954 state that the Yarmouk contributes 450-500 MCM to the basin.
26. Extreme floods in 2003 disabled measurement facilities at Addasiya. Discharge in this year was estimated to be much higher than that of 1963 (Regner, 2012).
27. See Table 7 for an overview of dams in the basin.
28. Estimates range between 450 and 500 MCM (see Courcier et al., 2005; FoEME, 2011; Kliot, 1994).
29. See section on Water Resources Management and Chap. 21 for more information.
30. FoEME, 2011 reports that the level of Lake Tiberias has dropped below -211 m asl since 2006, which is the artificial level of the riverbed. This means that even when the dam was open, no water could flow out of the lake. Instead it had to be pumped from the lake to pass the Degania Dam.
31. During the monitoring period 1979-1999, a CV record of 1.07 was observed, indicating strong flow variability.
32. FoEME, 2010.
33. Courcier et al., 2005.
34. Courcier et al., 2005; FoEME, 2011 calculates the historic flow of the Yarmouk at 470 MCM. Kliot, 1994 estimates Yarmouk flow at 450-475 MCM, while Libiszewski, 1995, and Burdon, 1954 state that the Yarmouk contributes 450-500 MCM to the basin.
35. Anisfeld and Shub, 2009; Courcier et al., 2005; Al-Weshah, 2000 (1,400 MCM); Hof, 1998; Klein, 1998.
36. Courcier et al., 2005.
37. Ministry of Water and Irrigation in Jordan, 2011.
38. FoEME, 2011 states 20-30 MCM in 2009, Al-Weshah, 2000 states 175 MCM, Courcier et al., 2005 states about 275 MCM for 2000, while Klein, 1998 estimated 220-250 MCM during the 1980s.
39. Lowi, 1993.
40. Courcier et al., 2005.
41. In the case of Israel and Jordan in the early 1950s mainly for the absorption of immigrants and refugees (Lowi, 1993).
42. For more information on the region's hydropolitical history and the impact of the Six-Day War on water resources management see Feitelson, 2000; Lowi, 1993; Zeitoun and Warner, 2006.
43. Venot et al., 2006.
44. FAO, 2009, p. 85.
45. FoEME, 2010.
46. From 1996 onwards, water shortages have shifted the balance in favour of municipal use (e.g. in the eastern Jordan Valley, the agricultural sector uses treated wastewater).
47. Sofer, 1999, p. 217. "It must be noted that the region was much less developed than the rest of Lebanon before the occupation in 1978, particularly in terms of public infrastructure such as drinking water networks, sewerage collection and disposal networks and irrigation systems" (Comair, 2005, p. 14).
48. Israel's 1978 invasion of Lebanon is known as the 'Operation Litani'. It triggered the South Lebanon Conflict (Zeitoun et al., 2012).
49. Maternowski, 2006, p. 50.
50. Zeitoun et al., 2012, p. 51.
51. Republic of Lebanon, 2002.
52. The exact number quoted is 6.88 MCM/yr although no specific year is mentioned (Comair, 2005, p. 18; Comair, 2009, p. 255).
53. Rough estimate. Zeitoun et al., 2012.
54. The numbers include data from the 1999 agricultural census for three districts that lie in the Hasbani Basin: Hasbaya, Marjeoun and Rachaya (Ministry of Agriculture in Lebanon and FAO, 2005).

55. Supplementary irrigation can be defined as the addition of small amounts of water to essentially rain-fed crops in order to improve and stabilize yields when rainfall fails to provide sufficient moisture for normal plant growth.
56. Merheb, 2010.
57. Zeitoun et al., 2012, p. 55.
58. Kliot, 1994, p. 209.
59. Hof, 1998.
60. El-Nasser in Courcier et al., 2005.
61. See section on Agreements, Cooperation & Outlook below for more information.
62. Also known as the Maqarin Dam.
63. See table annexed to the agreement (The Syrian Arab Republic and Jordan, 1987). Of the 25 dams listed in the agreement, 22 have been constructed to date, with a total capacity of 145.7 MCM.
64. Ministry of Irrigation in the Syrian Arab Republic, 2006.
65. Syria considers two additional dams to be part of the Yarmouk Basin: Al Zalf and Jabal al Arab, which have a storage capacity of 9.6 MCM and 19.5 MCM respectively. As they are located outside the Yarmouk Basin as delineated in this Inventory, these two dams are not included in the total capacity.
66. Kolars, 1992, p. 110.
67. See section on Agreements, Cooperation & Outlook below for more information on the Syrian-Jordanian agreement.
68. Kliot, 1994, p. 212.
69. Ministry of Irrigation in the Syrian Arab Republic, 2012.
70. Ministry of Irrigation in the Syrian Arab Republic, 2012. Varelo-Ortega and Sagardoy, 2003 states similar values for 1999/2000 for the irrigated area in the Yarmouk Basin.
71. FAO, 2009, p. 85.
72. According to PASSIA, 2002, Israel diverts 75% of the Jordan River before it reaches the West Bank.
73. Courcier et al., 2005, p. 2.
74. OECD, 2010.
75. Including the sub-districts Golan, Lake Tiberias and Zefat.
76. FAO, 2012.
77. Courcier et al., 2005 suggest that 100 MCM were used annually (in 2000) for irrigated agriculture in the north/Lake Tiberias region.
78. According to an assumed water application rate of approximately 10,000 m^3/ha/yr.
79. OECD, 2010. However, more recently this water has been supplemented by application of treated wastewater.
80. FAO, 2012.
81. The Jordan River basin is the most water-rich area in Jordan, supplying 80% of the country's water resources (see Courcier et al., 2005).
82. Also known as the Greater Yarmouk Project.
83. Murakami, 1995, p. 297.
84. Originally East Ghor Canal.
85. Murakami, 1995.
86. The Mukheibeh Wells are an important groundwater resource situated to the north of the Jordan Valley, representing an annual flow of 25 MCM (Grawitz, 1998).
87. Ammary, 2007.
88. Venot et al., 2005.
89. Ministry of Water and Irrigation in Jordan, 2011.
90. Courcier et al., 2005.
91. Ibid.
92. Ministry of Water and Irrigation in Jordan, 2009 (figures for 2007). Other sources state that the agricultural sector in Jordan consumes 70% of water resources (Venot, 2004.)
93. Venot, 2004. The Jordanian highlands extend from the north of the country to the south and separate the Jordan Valley from the eastern desert plains.
94. Molle et al., 2008.
95. Ministry of Water and Irrigation in Jordan, 2009.
96. Venot, 2004.
97. Ministry of Water and Irrigation in Jordan, 2009.
98. Molle et al., 2008.
99. JVA, 2011, p. 43-44. These sources include the Yarmouk River, Mukheibeh Wells, Zarqa River, and the following wadis: Hisban, Jurum, Kafrin, Kufrinjah, Rajib, Ziqlab and other small wadis in the northern part of the Jordan Valley.
100. See also Ministry of Water and Irrigation in Jordan, 2002a and JVA, 2011.
101. Zeitoun et al., 2012, p. 30.
102. PWA, 2012.
103. Kliot, 1994, p. 217.
104. PWA, 2012.
105. Ibid.
106. UN-OCHA, 2012a.
107. Ibid; Amnesty International, 2009; Shuval and Dweik, 2007, p. 22.
108. PWA, 2012.
109. FoEME, 2010.
110. Murakami, 1995.
111. Brielmann, 2008.
112. Zeitoun et al., 2012.
113. Barinova and Nevo, 2010.
114. Shafir and Alpert, 2011 reported that evaporation from Lake Tiberias, measured by pan-evaporation, has increased by 20%-25% over the past four decades.
115. Siebert et al., 2009; FoEME, 2011.
116. Hambright et al., 2000.
117. Markel, 2005; Farber et al., 2005. Primarily the Tabgha Springs and Tiberias Hot Springs.
118. Farber et al., 2005.
119. Kiperwas, 2011. The highest chlorinity level after the construction of SDC was 300 mg/L during the drought period from the mid-1990s to 2002 (Siebert et al., 2009).
120. FAO, 2009; Farber et al., 2004; FoEME, 2010.
121. Hambright et al., 2000; Markel, 2005.
122. Rom, 1999 in Gophen et al., 2003.
123. Farber et al., 2004.
124. Al-Taani, 2011; Ministry of Water and Irrigation in Jordan, 2002b.
125. Batayneh, 2011.
126. Batayneh, 2010; Abu-Rukah and Ghrefat, 2001.
127. Alkhoury et al., 2010.
128. RSS, 2010.
129. Ibid; Farber et al., 2004.
130. RSS, 2010.
131. Al-Wer, 2009; Al-Momani, 2011.

132. Melkawi and Shiyyab, 2003.
133. Ministry of Water and Irrigation in Jordan, 2002b.
134. Alkhoury et al., 2010.
135. John Hopkins University Global Water Program Magazine, 2010.
136. FoEME, 2010.
137. Referred to as "Bitaniya sewage" from the Bitaniya wastewater treatment plant.
138. Barinova et al., 2010; Farber et al., 2005.
139. FoEME, 2010.
140. Ibid.
141. Ministry of Water and Irrigation in Jordan, 2010. It is suggested that shallow groundwater discharge buffers river quality and reduces salinity in the northern part of the Lower Jordan River (Farber et al., 2005).
142. Farber et al., 2005.
143. FoEME, 2010; The Huffington Post, 2010.
144. FoEME, 2010. Mainly resulting from the loss of fast-flow habitats and floods as well as high water salinity.
145. Farber et al., 2004, Barel-Cohen et al., 2006.
146. RSS, 2010.
147. See section on Water Resources Management above for detailed information on the plans.
148. Jordan was the driving force behind the agreement and was motivated by its ambition to build a dam on the Yarmouk – a structure discussed in the various development plans that preceded the Johnston Plan. See Hof, 1998.
149. See The Syrian Arab Republic and Jordan, 1953, Article 8a.
150. Ibid., Article 8b and 8c.
151. Ibid., Article 10.
152. Hof, 1998.
153. The Syrian Arab Republic and Jordan, 1987; Hof, 1998.
154. Al-Taani, 2011.
155. Zeitoun, 2008.
156. The State of Israel and the Hashemite Kingdom of Jordan, 1994, Article 6 and Annex 2.
157. The summer is from 15 May to 15 October, and the winter is from 16 October to 14 May.
158. The State of Israel and the Hashemite Kingdom of Jordan, 1994, Annex 2, Article 1, Item1.
159. Ibid., items 1 and 2.
160. Dombrowsky, 2003.
161. Fischhendler, 2008.
162. Haddadin, 2006.
163. Jordan Times, 2009.
164. Israel and the PLO, 1995.
165. Rouyer, 2000.
166. Zeitoun, 2008; UN-OCHA, 2012b.
167. Selby, 2003. Similarly Amnesty International, 2009 refers to JWC as a pretence of cooperation.
168. The discussion took place as part of the panel "Cross-Border Waters and Regional Sustainability" moderated by Gidon Bromberg, Israeli Director of Friends of the Earth Middle East. The Palestinians have suspended their side of JWC since September 2011, arguing that the committee is unable to address any water-related issue. A number of sub-committees are still active but the main decision-making body is not working.
169. According to Bromberg's conclusion of the meeting. See EMWIS, 2012.
170. The secretary-general of the Jordanian Ministry of Water and Irrigation and Jordan Valley Authority and the Israeli director of the Water Demand Management Division are responsible for the daily work of JWC. The Jordanian minister of Water and Irrigation and Israeli water commissioner periodically attend JWC meetings and oversee the institution. See Zawahri, 2010.
171. Zawahri, 2010.
172. For instance, the 1997 desalination dispute and the 1999 drought required emergency meetings between the state leaders of Jordan and Israel. See Zawahri, 2010 for more detailed information on these cases.
173. Kramer, 2008 reports on water cooperation initiatives in the basin. In addition, there is the Arab Jordan River Basin Initiative, which was promoted through the American University of Beirut in 2009, and the Red Sea-Dead Sea Conduit Project.

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Chapter 7

Orontes River Basin

Orontes River Basin

EXECUTIVE SUMMARY

Also known as the Assi River, the Orontes is the only perennial river in Western Asia that flows north from Lebanon to Syria and Turkey and drains west into the Mediterranean Sea. Its flow regime shows typical winter peak flows due to increased precipitation, and summer low flows maintained exclusively by groundwater discharge.

The river is mainly used for irrigation purposes with several agricultural projects planned in the three riparian countries. Water quality at the headwaters is generally good, but deteriorates in the middle and lower reaches of the river due to agricultural, urban and industrial activities.

There is no basin-wide agreement between the three riparians, but there are several bilateral agreements in place on issues such as water allocation (Lebanon-Syria) and the joint construction of infrastructure (Syria-Turkey). Orontes Basin politics are heavily influenced by the status of Turkish-Syrian relations in general, and discussions over the sharing of the Euphrates River in particular.

BASIN FACTS

RIPARIAN COUNTRIES	Lebanon, Syria, Turkey
BASIN AREA SHARES	Lebanon 8% Syria 67% Turkey 25%
BASIN AREA	26,530 km^2
RIVER LENGTH	404 km
MEAN ANNUAL FLOW VOLUME	1.2 BCM
MAIN DAMS	9 (max. storage capacity 939 MCM)
PROJECTED IRRIGATED AREA	~300,000 ha
BASIN POPULATION	5.86 million

The Dardara Falls on the Orontes River, Lebanon, 2009. Source: Andreas Renck.

MAIN AGREEMENTS

LEBANON - SYRIA	1994 – Agreement on the Distribution of Orontes River Water Originating in Lebanese Territory, which specifies water allocation between the two countries.
SYRIA - TURKEY	2009 – Memorandum of Understanding concerning the construction of the joint Orontes River Friendship Dam.

KEY CONCERNS

WATER QUANTITY

The Orontes River is under intensive use in all three riparian countries, mainly for agricultural purposes. The implementation of additional irrigation projects will place further pressure on the resource. While Lebanon and Syria have agreed on water allocation issues, Turkey and Syria have not. There is no agreement between the three riparians.

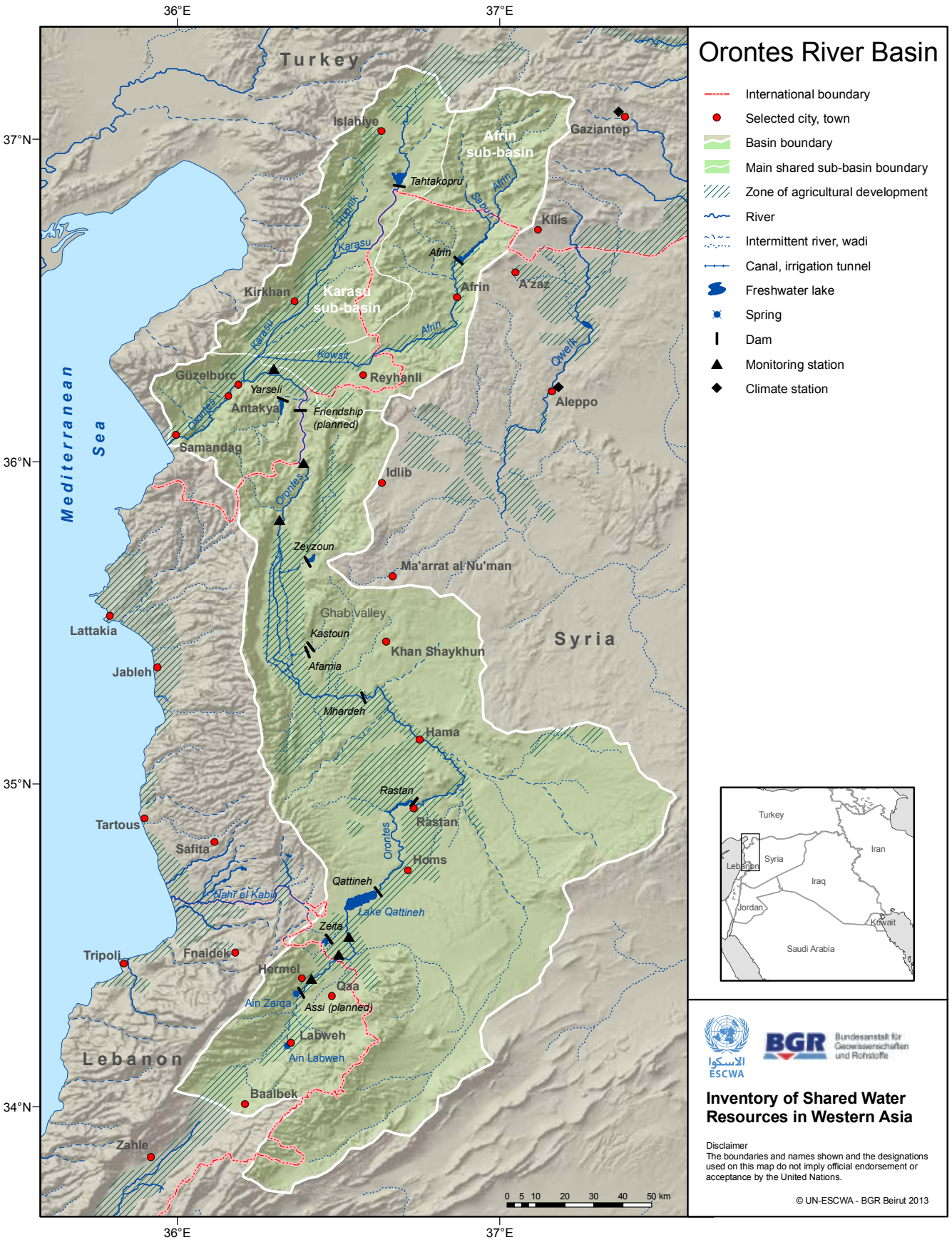
WATER QUALITY

In its middle and lower reaches, the Orontes is heavily polluted with untreated effluents that are directly discharged into the riverbed. Water quality issues have not been addressed in the cooperation context.

TERRITORIAL

Syria and Turkey have not resolved the question of the disputed coastal province of Hatay (Iskenderun) through which the Orontes exits to the Mediterranean Sea.

OVERVIEW MAP



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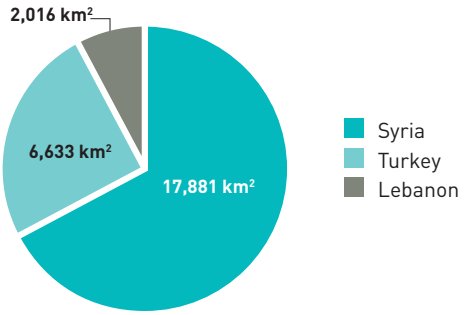
Geography

The Orontes River[1] originates in Lebanon and flows through Syria and Turkey before discharging into the Mediterranean Sea. The Orontes has two tributaries which are shared between Turkey and Syria: the Karasu and the Afrin. The latter originates in Turkey, passes through Syria and discharges into the Orontes in the disputed Hatay region in Turkey.

The Orontes Basin area is estimated at 26,530 km^2, of which 25% is located in Turkey, 67% in Syria and 8% in Lebanon.[2]

Figure 1. **Distribution of the Orontes Basin area**



Source: Compiled by ESCWA-BGR.

RIVER COURSE

The Orontes River forms the main artery in the Orontes Basin, which consists of several sub-basins. The river has a total length of 404 km, of which 38 km lie in Lebanon,[3] 280 km in Syria, 27 km along the Syrian-Turkish border, and 59 km in Turkey. It is the only river in Western Asia that flows to the north and drains to the west into the Mediterranean Sea. The Orontes River originates in Lebanon, not far from the city of Baalbek in the Bekaa Valley. It rises from the karstic Labweh Spring and flows north, entering Syria to the north-east of Hermel, where it flows through an area of intensive irrigation with a network of drainage canals for agricultural use. Farther downstream, the Orontes broadens into the dammed Lake Qattineh,[4] and then crosses the wide Homs Plain. The river passes the cities of Homs and Hama before turning west across the fertile Ghab Valley over a distance of 40 km. The Orontes is mainly canalized in this reach.[5] Before the river reaches Turkey in the province of Hatay, it meanders through Syria and subsequently forms the Syrian-Turkish border for almost 25 km. In Turkey, the river turns south-west and is joined by two tributaries, the Karasu and the Afrin,[6] before finally reaching Antakya and discharging into the Mediterranean Sea near Samandag.

The Rebel River

The Orontes is also known as the Assi in Arabic, which means "rebel". This is because unlike most rivers in the region, it flows from south to north before draining into the Mediterranean to the west.

MAIN SHARED TRIBUTARIES - THE AFRIN & KARASU SUB-BASINS

The Afrin River, which is shared by Syria and Turkey, is a major tributary to the Orontes. The river originates on the southern slopes of the Kartal Mountains in Turkey,[7] crosses the border into Syria and passes through the city of Afrin. In the past, the Afrin naturally discharged into Lake Amik. Today the river is drained through the artificial Nahr al Kowsit channel and redirected towards the Orontes River. Infrastructure on the river includes the Afrin Dam in Syria, which was constructed in 1997 with a capacity of 190 MCM.[8] The Afrin River has a total length of 131 km, including 54 km in Syria.

An estimated 60 MCM/yr of the Afrin flow originates in Syria,[9] but most of the flow volume (approx. 250 MCM/yr) originates in Hatay Province in Turkey.[10]

The Karasu is the second main tributary of the Orontes River. With a total length of 120 km, the river rises in Turkey and subsequently forms a small part of the Syrian-Turkish border. It discharges into the Orontes River at the confluence with the Afrin River north of Antakya (see Overview Map). The annual flow volume of the Karasu is approximately 40 MCM/yr.[11]

SUB-BASIN FACTS

RIVER	AFRIN	KARASU
BASIN AREA SHARES	Syria 43% Turkey 57%	Syria 3% Turkey 97%
BASIN AREA	3,920 km^2	2,952 km^2
RIVER LENGTH	131 km	120 km
MEAN ANNUAL FLOW VOLUME	60 MCM	40 MCM
DAMS	Afrin Dam	Karasu Dam
PROJECTED IRRIGATED AREA	28,000 ha (downstream of the dam)	..

BOX 1

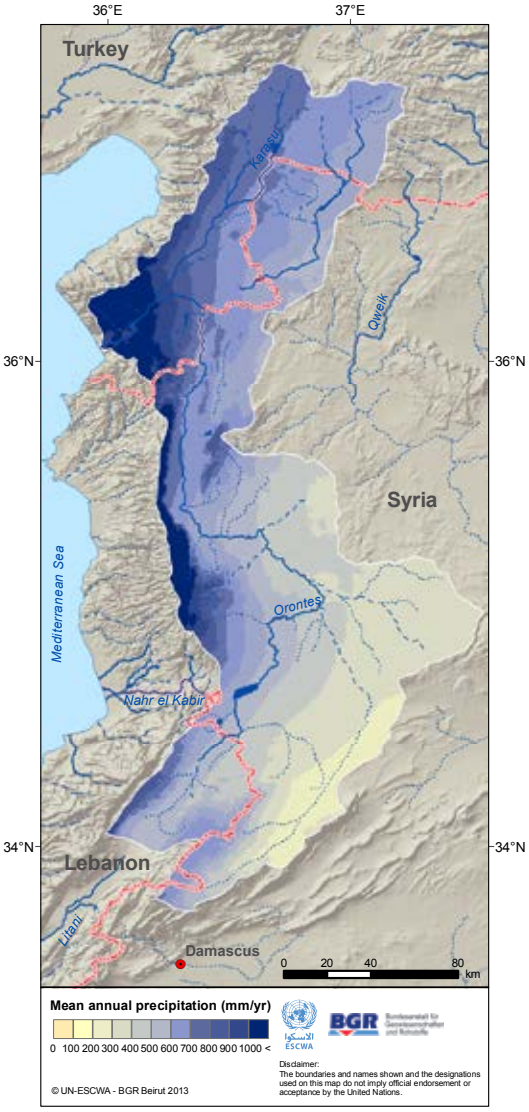
Lake of Antioch or Lake Amik

Before it was drained, the Lake of Antioch or Lake Amik was a large freshwater lake within the Orontes Basin in Hatay Province. Draining and land reclamation around the lake began in the 1940s, specifically for cotton production and to eradicate malaria. In the second half of the 1960s, the State Hydraulic Works (DSI) in Turkey initiated a major drainage project, channelling the lake's tributaries, the Karasu and the Afrin, as well as other rivers, directly to the Orontes River. By the 1970s Lake Amik had completely disappeared and its bed was being used as farmland in what is now known as the Amik Plain. Today, Hatay Airport is located on land that once lay at the bottom of the lake.

CLIMATE

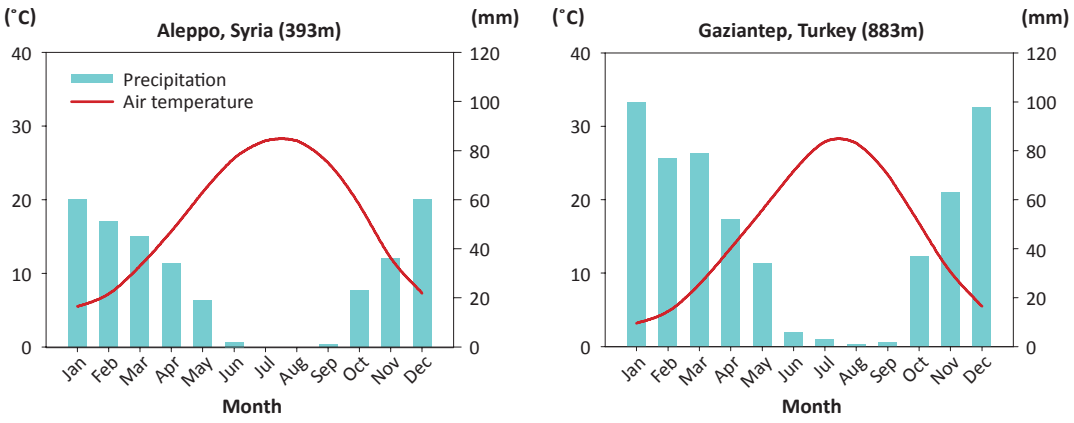
The climate in the Orontes Basin is characterized by Mediterranean winter precipitation (snow on higher ground and rain elsewhere), which decreases in intensity and quantity as one travels inland from the Mediterranean coastal plain (Figure 2). Precipitation in the basin ranges from around 300 mm/yr (the mean annual rainfall at Aleppo, Syria, is 332 mm) to around 800 mm/yr,[12] with highs in December and January and lows in June and July (Figure 3). Average annual basin precipitation is estimated at 644 mm.[13] Summers are dry and hot. The mean annual air temperature on the coast is around 20°C (measured at Tripoli, Lebanon), decreasing to 17.2°C (measured at Aleppo, Syria) further east.

Figure 2. Mean annual precipitation in the Orontes Basin



Source: Compiled by ESCWA-BGR based on data provided by WorldClim, 2011.

Figure 3. Climate diagrams for Aleppo, Syria, to the east, and Gaziantep, Turkey, to the north-east of the Orontes Basin



Source: Compiled by ESCWA-BGR based on data provided by WorldClim, 2011; Climate Diagrams, 2009; Phytosociological Research Center, 2009.

POPULATION

Estimates show that the Orontes Basin has a population of almost 5.7 million. In Lebanon, the population living in the basin is estimated at 381,000 people.[14] The area of the basin situated in Syria comprises 4.2 million inhabitants,[15] while more than 1 million people live in the area of the basin that lies in Turkey.

Table 1. **Estimated basin population**

RIPARIAN COUNTRY	COUNTRY POPULATION (MILLIONS)	ESTIMATED POPULATION IN THE BASIN		SOURCE
		MILLIONS	AS PERCENTAGE OF TOTAL BASIN POPULATION	
Lebanon	3.75	0.38	7	LOCALIBAN, 2009.
Syria	20.9	4.2	74	Ministry of Irrigation in the Syrian Arab Republic, 2010.
Turkey	73.7	1.1	19	Turkstat, 2010.
Total		5.68		

Source: Compiled by ESCWA-BGR.

The Ghab Valley, Syria, 2009. Source: Adel Samara.

Hydrological Characteristics

The sources of the Orontes River are karstic springs that lie at an altitude of 690 m in the Bekaa Valley in Lebanon. The river is mainly fed by groundwater (groundwater contributes up to 90% to stream-flow). Groundwater recharge depends on the snow cover in Mount Lebanon and the Anti-Lebanon Mountains.[16] Generally, the Orontes Basin receives 400 to 500 mm of rain annually, which is characteristic of the Mediterranean climate. In Syria, small streams and springs originating in the Coastal Mountains to the west and Zawiyeh Mountains to the east contribute to the Orontes river flow. Additional water sources originate in the Ghab Valley.[17] In Turkey, the Orontes River receives input from its two northern tributaries, the Afrin and the Karasu.

ANNUAL DISCHARGE VARIABILITY

The mean annual flow volume for the whole Orontes Basin including both the Afrin and Karasu tributaries is estimated at about 1,200 MCM. The mean annual flow volume for the period between 1931 and 2011 was 410 MCM at Hermel, Lebanon. At Darkosh at the Syrian-Turkish border, the mean annual flow volume was 949 MCM/yr between 1964 and 2011 (Table 2). The Darkosh records show a minimal, though statistically significant, negative trend (Figure 4). From Darkosh onwards, if not before, the Orontes can be considered a regulated river.

The mean annual discharge at Hermel is 13 m^3/s and farther downstream at Darkosh it is 30.1 m^3/s. Despite data gaps, the latter shows a quite regular variability,[18] with drier and wetter periods compared to the mean, and no extreme drought or flood periods (Figure 4).

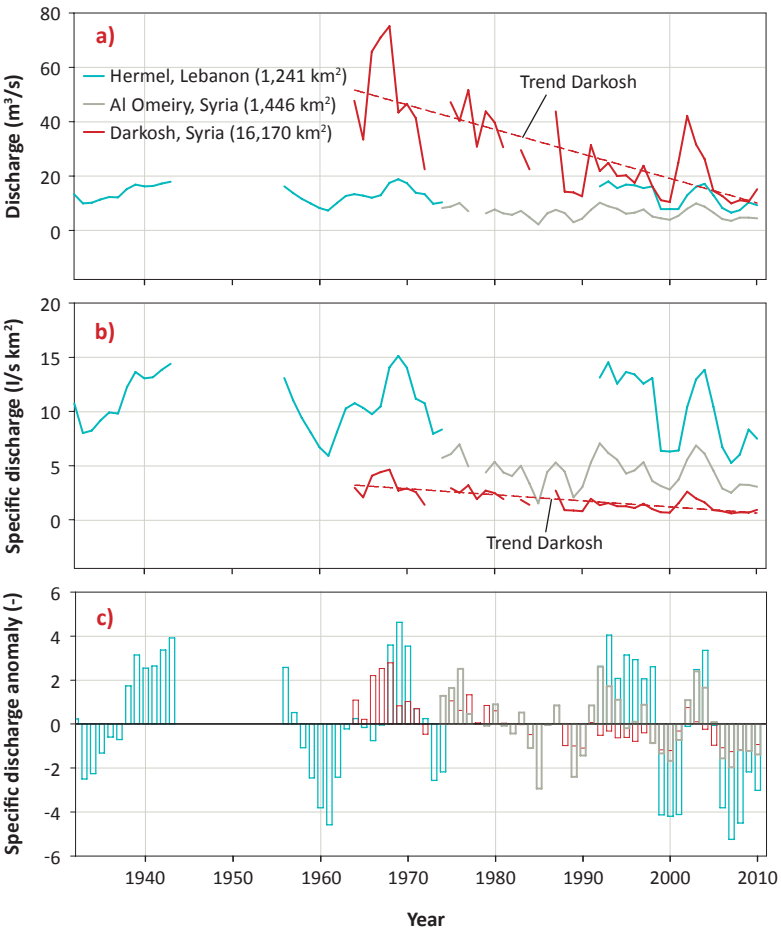
Available data for Al Omeiry station close to the Lebanese-Syrian border north-east of Hermel show a mean annual discharge of 6.4 m^3/s.[19] The difference in flow volume between Hermel and Al Omeiry (410 MCM/yr and 202 MCM/yr respectively) indicates that there is significant water abstraction from the Orontes River in this region, possibly for irrigation purposes.

Table 2. **Summary of annual flow volume statistics for the Orontes River (1931-2011)**

STATION (DRAINAGE AREA, km^2)	PERIOD	MEAN (MCM)	MINIMUM (MCM)	MAXIMUM (MCM)	CV[a] (-)
Hermel, Lebanon (1,241)	1931-2011	410	200	590	0.27
Al Omeiry, Syria (1,446)	1974-2011	202	70	310	0.32
Darkosh, Syria (16,170)	1964-2011	949	320	2,360	0.56

Source: Compiled by ESCWA-BGR based on GRDC, 2011; Ministry of Irrigation in the Syrian Arab Republic, 2012; Ministry of Energy and Water in Lebanon, 2011.
(a) Coefficient of Variation. For information on definition and calculation of the CV see 'Overview & Methodology: Surface Water' chapter.

Figure 4. **a) Mean annual discharge, b) specific mean annual discharge and c) discharge anomaly time series of the Orontes (1931-2011)**

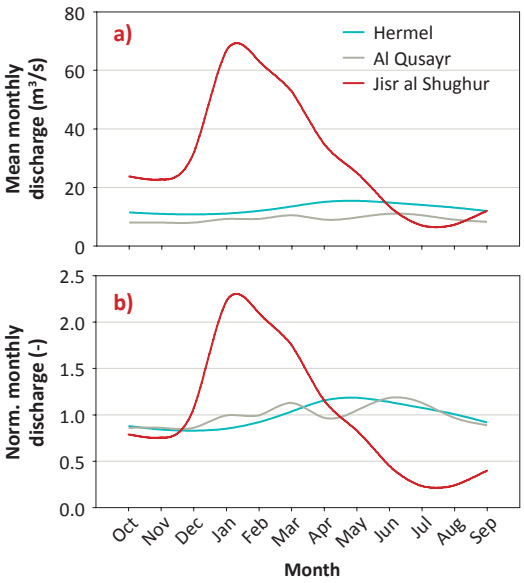


Source: Compiled by ESCWA-BGR based on data provided by GRDC, 2011; Ministry of Irrigation in the Syrian Arab Republic, 2012; Ministry of Energy and Water in Lebanon, 2011.

FLOW REGIME

Figure 5 shows the mean Orontes river flow regime at different gauging stations with increasing basin area (normalized monthly discharge). Generally, the downstream station Jisr al Shughur (15,130 km^2) exhibits a high-flow season from December to May and a low-flow season from June to November. The Orontes river regime cannot be considered entirely natural due to regulation on the main river stem by canals and dams, but it retains certain natural seasonal characteristics. The increased discharge during the high-flow period is typically generated by increased rainfall throughout the Mediterranean rainy winter season and by snowmelt originating in the mountainous basin areas during spring. The river flow regime is maintained entirely by groundwater discharge during the dry summer months as indicated by the upstream gauging stations at Hermel (1,241 km^2) and Al Qusayr (1,890 km^2), similar to a groundwater flow regime without pronounced seasonal variations.

Figure 5. **Mean monthly flow regime of the Orontes River at different gauging stations (1931-2011)**



Source: Compiled by ESCWA-BGR based on data provided by GRDC, 2011; Ministry of Irrigation in the Syrian Arab Republic, 2012; Ministry of Energy and Water in Lebanon, 2011.

GROUNDWATER

The largest contributor to Orontes river flow is the Ain Zarqa Spring in Lebanon with a mean flow of between 11[20] and 13.6 m^3/s.[21] The long-term average discharge at the Hermel station (13 m^3/s) just downstream from the Ain Zarqa Spring in Lebanon confirms these values.

Table 3 presents the mean annual discharge of some of the main springs in the Syrian part of the basin.

The annual amount of groundwater recharge in the Syrian part of the Orontes Basin is estimated at 1,607 MCM, of which 1,134 MCM discharges as spring flow and the remaining 473 MCM is stored in aquifers and eventually withdrawn from wells for irrigation and water supply.[22]

Ain Zarqa Spring, the source of the Orontes, Lebanon, 2009. Source: Andreas Renck.

Table 3. **Mean flow rate of the main springs in the Orontes Basin in Syria**

SPRING	FLOW RATE (m^3/s)											
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Ain al-Zarqa[a]	5.41	6.02	5.41	6.02	...	...	...	...	4.12	4.94	4.94	5.10
Ain Bared	1.10	2.50	1.21	1.04	1.49	2.78	5.18	4.07	1.56	1.19	0.69	0.82
Ain Fowar	0.07	0.01	0.43	0.41	0.81	1.29	2.02	1.6	1.53	0.77	0.31	0.39

Source: Compiled by ESCWA-BGR based on Central Bureau of Statistics in the Syrian Arab Republic, 2010.
(a) The Ain al-Zarqa Spring in Syria is located near the city of Idlib and should not be confused with the Ain Zarqa Spring in the Lebanese part of the basin.

Water Resources Management

All three riparian countries use the water resources in the Orontes Basin for agricultural, domestic and, to a lesser extent, industrial purposes. However, Syria and Turkey have dominated water resource use in the basin with various development plans to increase irrigated surface area. In 2009, FAO estimated total irrigated area in the basin at 300,000-350,000 ha, of which 58% lies in Syria, 36% in Turkey and 6% in Lebanon.[23] The annual water withdrawal for agriculture in the whole basin is estimated at about 2,800 MCM.[24]

The basin's sustainability is threatened by heavy exploitation of water resources and economic expansion, particularly in Syria and Turkey. This has resulted in the lowering of the water table, depletion of water storage in underground reservoirs and considerable reduction in spring yield.

Table 4. Main constructed and planned dams in the Orontes Basin

COUNTRY	NAME	COMPLETION YEAR	CAPACITY (MCM)	PURPOSE[a]	BACKGROUND INFORMATION
Lebanon	Assi Dam	Under construction	27 (Phase I) 37 (Phase II)	WS, I, HP	A Chinese contractor started construction of the diversion dam (Phase I) in 2005. Israel bombed the construction site during the 2006 Lebanon War.
Syria	Rastan	1960	228	I	Reservoir surface area: 21 km^2 Irrigated area: 59,841 ha
	Mhardeh	1960	50	I	Reservoir surface area: 4.5 km^2 Irrigated area: 72,000 ha
	Qattineh	1976	200	I	Reservoir surface area: 60 km^2 Irrigated area: 22,000 ha
	Kastoun	1992	27	I	Reservoir surface area: 3 km^2 Irrigated area: 3,000 ha
	Zeyzoun	1995	71	I	The dam is located at a bypass canal to the Orontes. In 2002, it ruptured and collapsed resulting in civilian casualties, and damage to villages in Syria and cultivated land in Turkey.[b] The dam has since been repaired.
	Afamia	1997	27.5	I	Reservoir surface area: 1.8 km^2 Irrigated area: 5,470 ha
	Zeita (Bassel al Assad)	2003	80	WS	This dam is partly supplied by a canal that crosses the Lebanese-Syrian border.
Turkey	Tahtakopru	1975	200		Reservoir surface area: 24.3 km^2
	Yarseli - Beyazcay River	1989	55	I	Reservoir surface area: 4 km^2
	Reyhanli Dam	Construction began in 2010	..	I	-
Turkey & Syria	Orontes River Friendship Dam	Construction began in 2011.	110	I, HP, FC	Syria and Turkey agreed under a 2009 bilateral agreement to undertake the joint Orontes River Friendship Dam project on the Syrian-Turkish border. 40 MCM of the dam's capacity will be used to prevent flooding, while the rest is destined for energy production and irrigation.

Source: Compiled by ESCWA-BGR based on Central Bureau of Statistics in the Syrian Arab Republic, 2008; General Directorate of State Hydraulic Works in Turkey, 2011; Ministry of Local Administration and Environment in the Syrian Arab Republic, 2003; Ministry of Energy and Water in Lebanon, 2011; Ministry of Irrigation in the Syrian Arab Republic, 2011.
(a) Water Supply (WS), Irrigation (I), Hydropower (HP) and Flood Control (FC).
(b) BBC News Middle East, 2002.

DEVELOPMENT & USE: LEBANON

At present, the use of the Orontes in Lebanon is limited to small-scale farming, fish farms and tourism. Total water use is estimated at 21 MCM/yr, of which around 23% is used for domestic purposes, and the rest for irrigation.[25] Official figures estimate irrigated areas in the Lebanese part of the basin at 1,703 ha. Most of this land is irrigated by wells.[26] It is likely, however, that these figures only refer to the perennial northern section of the Orontes River downstream of the Ain Zarqa Spring, which has also been the focus of Lebanese-Syrian cooperation. FAO estimates of irrigated area in the Lebanese part of the Orontes Basin are much higher (18,000-21,000 ha),[27] possibly because they refer to the entire topographic catchment, including the agricultural areas around Labweh, Al Ain, Ras Baalbek and El Qaa.

The Lebanese Ministry of Energy and Water has plans to increase the exploitation of water resources in the basin. One of the projects under consideration is the Assi scheme, planned following consultations with the Syrian Government and aimed at developing water use for irrigation, domestic use and power generation in the regions of Baalbek and Hermel.[28] The project is divided into two phases: the first phase includes a diversion dam with a storage capacity of 27 MCM near the Ain Zarqa Spring, three pumping stations and a network for the irrigation of around 3,000 ha. A second phase aims to construct a 37 MCM capacity dam upstream of the Hermel Bridge (Table 4), with several pumping stations and a network for the irrigation of 3,800 ha, as well as a hydroelectric power plant providing approximately 50 MW of electricity per day. Altogether, the proposed irrigation schemes comprise a new irrigated area of 6,800 ha in the Hermel and Al Qaa area of the basin.[29]

BOX 2 Progress Made on the Assi Project in Lebanon

The Assi Project was officially launched in 2004, with a Chinese contractor starting construction with a local partner in 2005. Phase 1 of the project was already well underway when Israel bombed the construction site during the 2006 Lebanon War. As the Lebanese Higher Relief Council was slow to provide compensation for losses suffered, the contractor demanded a renegotiation of the contract before resuming work. This has resulted in a dispute within the Ministry of Energy and Water about whether to cancel the contract and issue a new invitation to tender or to meet the current contractor's demands. The Lebanese Council of Ministers formed a special committee in 2011 to resolve this issue.

Source: Ministry of Energy and Water in Lebanon, 2011.

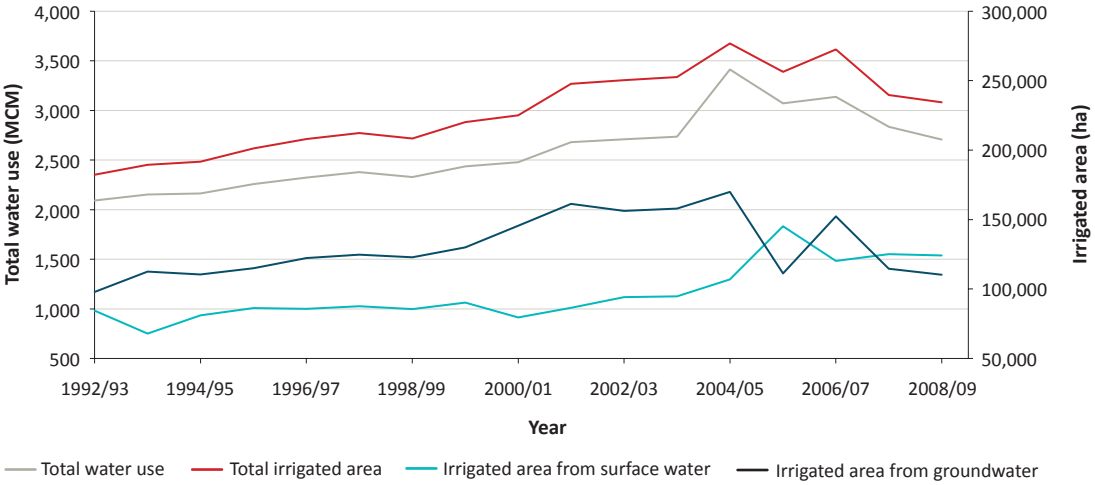
DEVELOPMENT & USE: SYRIA

Since the early 1950s, Syria has intensively developed water resources in the Orontes Basin. In terms of water use, the Orontes River constitutes the second most important river in Syria after the Euphrates, providing 20% of the country's total estimated water use volume.[30]

According to official data, total annual water use in the Orontes Basin has increased from around 2,000 MCM in 1992 and temporarily exceeded 3,000 MCM in 2004-2005 (Figure 6). Average annual use for the period from 1992 to 2009 was around 2,582 MCM.[31] Agriculture is the largest water user, consuming about 1,977 MCM annually (77% of total water use), followed by domestic water use at 9% and industry at 8% (Figure 7).

Both groundwater and surface water are heavily exploited in the Orontes Basin in Syria, and

Figure 6. Evolution of total water use and irrigated areas in the Orontes Basin in Syria (1992-2009)



Source: Compiled by ESCWA-BGR based on data provided by Ministry of Irrigation in the Syrian Arab Republic, 2012.

average annual groundwater use for irrigation (1,111 MCM or 56%) exceeded surface water use (886 MCM or 44%) during the period between 1992 and 2009.

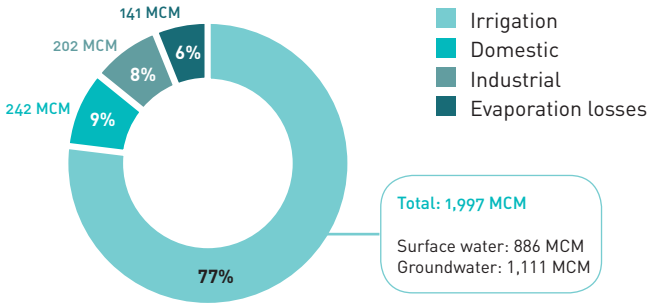
In order to increase irrigation capacity, Syria has over the years built more than 40 dams in the basin. The total reservoir capacity of all dams in the basin reached about 950 MCM in 2006.[32] A number of these dams, such as the Rastan, Qattineh, Zeita and Mhardeh Dams, have a large reservoir capacity (Table 4). The Zeita Dam near the Lebanese-Syrian border is partly supplied with water diverted from the main stream of the Orontes in Lebanon through the left-bank Zeita Canal. Both this canal and the right-bank Jawsiyeh Canal are also used for direct irrigation of downstream Syrian lands. The two canals are located between the Hermel and Al Omeiry monitoring stations. Diversions through these canals may partly explain the decrease in long-term average annual discharge (approx. 200 MCM/yr) between upstream Hermel and downstream Al Omeiry.

Two main agricultural areas in Syria are supplied with water from the Orontes: the region between Homs and Hama, and the Ghab, a large, formerly swampy valley. The latter was systematically drained from 1950 onward to reclaim land for irrigated agriculture. The Ghab project included the expansion and deepening of the Orontes riverbed, and the construction of dams for flow regulation and irrigation water. An area of about 70,000 ha is irrigated as part of the project, which consumes around 330 MCM/yr of reservoir water and another 150 MCM/yr of groundwater.[33] The region between Homs and Hama is partly supplied from Lake Qattineh via the Homs-Hama canal, which provides water to an area of about 23,000 ha. However, as the reservoir does not meet demand, it is supplemented by groundwater wells, which irrigate another 20,000 ha in this part of the basin.[34]

The total irrigated area in the Orontes Basin in Syria has increased from approximately 200,000 ha in 1992 and temporarily exceeded 250,000 ha in 2004-2008 (Figure 6). In the first half of the data period, irrigation with groundwater clearly dominated, but irrigation with surface water has gained momentum since 2004, possibly due to the construction of dams and other irrigation infrastructure or because of stricter regulation of groundwater abstractions. On average, an area of about 97,000 ha (43%) is irrigated by surface water, and 130,000 ha (57%) by groundwater (Figure 8).

Municipal and industrial use of the river is low due to water quality issues caused by untreated effluents into the Orontes River. These sectors

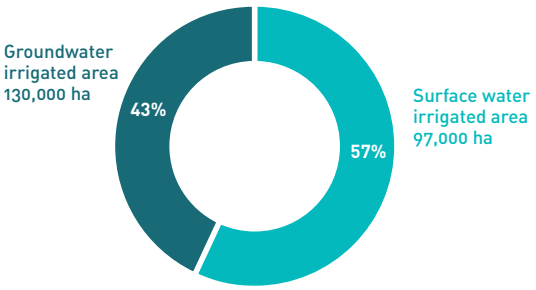
Figure 7. Mean water use across sectors in the Orontes Basin in Syria (1992-2009)



Source: Compiled by ESCWA-BGR based on data provided by Ministry of Irrigation in the Syrian Arab Republic, 2012.

Lake Qattineh near Homs, Syria, 2009. Source: Adel Samara.

Figure 8. Irrigated area in the Orontes Basin in Syria (1992-2009), by source



Average total irrigated area: 227,000 ha

Source: Compiled by ESCWA-BGR based on data from the Ministry of Irrigation in the Syrian Arab Republic, 2012.

are mainly supplied by groundwater, which is overexploited following the intensive drilling of wells.[35] Based on data presented in Figure 7, average total annual groundwater use in the Orontes Basin can be estimated at 1,466 MCM[36] and surface water use at 1,115 MCM.[37]

The intensification of water use in the Orontes Basin in Syria has raised the question of long-term sustainability. For example, the average annual discharge of more than 20 springs in the Ghab Valley dropped from approximately 18 m^3/s between 1965 and 1971 to 4.2 m^3/s in 1995-1996.[38] Water tables in some parts of the western Orontes Basin have dropped as much as 57 m in 10 years.[39]

DEVELOPMENT & USE: TURKEY

The most important dams in the Turkish part of the Orontes Basin are the Yarseli and Tahtakopru Dams, which are both located on tributaries of the Orontes (Table 4). The Tahtakopru Dam was built in 1975 on the Karasu River and has a maximum capacity of 200 MCM, with a reservoir area of 24.3 km^2.

In recent years, a dozen new water resource development projects have been planned and implemented in the Turkish part of the Orontes Basin. These projects are designed to regulate the flow of the river and its tributaries for irrigation and flood protection purposes. They also aim to provide water for domestic use and for the generation of electricity.[40] Once completed, the projects will irrigate an area of almost 100,000 ha, produce 180 GWh/yr of electricity and provide 37 MCM/yr of potable water.[41]

In 2004, Turkey proposed the construction of a joint dam on the Orontes River in Syria to generate power and provide irrigation water to both countries. Five years later, in December 2009, Turkey and Syria signed a memorandum of understanding regarding construction of the Friendship Dam on the Orontes River. The two countries agreed to split the costs of the dam, which will benefit both riparians by protecting land and settlements from floods and droughts. It will also irrigate 13,334 ha of farmland[42] and generate almost 16 GWh/yr of electricity.[43] The construction of the Orontes River Friendship Dam started in February 2011. It is unclear if construction is ongoing in view of the unrest in Syria which began in March 2011.

WATER QUALITY & ENVIRONMENTAL ISSUES

The quality of surface and groundwater in the basin varies, mainly according to the level of agricultural activity. While the quality of the Orontes headwaters is generally good, it deteriorates in the middle and lower reaches of the river due to agricultural, urban and industrial activities.[44] Increasing water pollution in these parts of the river is partly due to eutrophication, a process through which a large influx of nutrients causes excessive growth of algae.[45]

In 2000, levels of major ions and trace metals found in the river in Lebanon mostly reflected the basin's natural conditions. However, increases in nutrient concentrations and heavy metals were attributed to increased agricultural runoff and urbanization in the basin.[46]

In Syria, the Orontes Basin is considered one of the country's most disturbed hydrological ecosystems.[47] In addition to agriculture, there is intensive industrial activity in the basin and industrial wastewater is discharged into the river with limited or no treatment.[48] Industries mainly include cement and steel factories, a sugar processing plant, a fertilizer plant, a thermal power plant and an oil refinery.[49] Moreover, water quality is threatened by domestic wastewater discharge in many parts of the basin.[50] In places where the river is used for domestic needs and irrigation, epidemics such as typhoid, dysentery and cholera have

The Orontes in Hama, Syria, 2009. Source: Adel Samara.

Table 5. Mean Biochemical Oxygen Demand (BOD) and nutrients in the Orontes River in Syria (2010-2011)

		BOD (mg/L)	PO_4-P (mg/L)	NO_3-N (mg/L)
Station	Al Omeiry	0.14	0.05	1.48
	Lake Qattineh outlet	9.78	1.05	1.43
Total range		0-16.2	0.003-2.71	0.68-4.52
Guideline[a]		3-6 (for fisheries and aquatic life)	0.1	0.2

Source: Compiled by ESCWA-BGR based on Ministry of Irrigation in the Syrian Arab Republic, 2012.
(a) For further information on the different water quality parameters and their respective guidelines, see 'Overview & Methodology: Surface Water' chapter.

been observed.[51] According to the Ministry of Irrigation in Syria, analysis of water samples of phosphate, nitrate and Biochemical Oxygen Demand (BOD) since 1995 indicate that concentrations exceed permissible limits. The downstream part of the river (after Lake Qattineh) is particularly affected, while the upper part of the Orontes in Syria (up to Al Omeiry) has acceptable water quality.[52] Samples from 2010 and 2011 showed elevated nitrate concentrations even at the Al Omeiry station (Table 5).[53]

Moreover, sediment samples from the river have shown high concentrations of heavy metals (Table 6).[54] These were also detected in soil samples taken in the Orontes Basin, outlining significant differences between soil irrigated by Orontes River water and soil irrigated by groundwater alone: the former contained extremely high levels of arsenic (Ar), chromium (Cr), cobalt (Co) and nickel (Ni) throughout the river course. This contamination can be attributed to sewage sludge and use of phosphate fertilizers in the basin.[55]

In Turkey, the draining of Lake Amik (Box 1) caused severe environmental damage, flooding and droughts, and the productivity of reclaimed and irrigated land has decreased due to increased soil salinity.[56]

Overall, the most critical parameters of water quality in the Turkish part of the basin are phosphate levels and salinity. High concentrations of phosphate were found, especially around the city of Antakya, possibly as a result of untreated sewage sludge discharged into the river.[57] Agriculture and aquatic life are threatened by the high salinity of surface water, with a mean Electrical Conductivity (EC) value of 1,100 µS/cm for the period from 1995 to 2002.[58] In the lower part of the basin, drainage and groundwater also present high levels of salinity (Table 7).[59]

Heavy metal concentrations in the Turkish part of the Orontes Basin are generally low.[60] However, at the specific sampling site of Güzelburç (about 5 km from Antakya), cadmium (Cd) levels exceeded the allowed concentrations for drinking and irrigation water, and lead (Pb) levels were higher than the acceptable limits for drinking water. This sampling site is polluted by a number of industrial waste sources, sewage water and domestic waste, in addition to irrigation effluents.[61]

Table 6. Concentrations of heavy metals in sediment samples in the Orontes River in Syria in 2010

PARAMETER	MEAN CONCENTRATION (ppm)	GUIDELINE[a] (ppm)
Cr	91.8 (38.8-168)	80
Cu	160 (31.8-335)	65
Ni	129 (35.1-228)	21
Pb	25.4 (8-63.2)	50
Zn	310 (64.1-598)	200

Source: Compiled by ESCWA-BGR based on Hajj and Ismail, 2011.
Notes: Samples were taken from 11 sites along the Orontes River in Syria. The values in brackets refer to the range.
(a) Based on Sediment Quality Guidelines of the National Oceanographic and Atmospheric Administration (NOAA) in Hajj and Ismail, 2011.

Table 7. Mean Electrical Conductivity (EC) values of the Orontes River in Turkey (2002-2003)

	IN DRAINAGE WATERS	IN SHALLOW GROUNDWATER	GUIDELINE FOR IRRIGATION
EC (µS/cm)	1,210	1,290	<700
Range	640-1,740	390-2,220	

Source: Compiled by ESCWA-BGR based on Odemis et al., 2006.

Agreements, Cooperation & Outlook

AGREEMENTS

There are a number of bilateral agreements in place on the Orontes River, although none include all three riparians, Lebanon, Syria and Turkey.

Formal cooperation between Turkey and Syria dates back to 1939 when the two countries signed the Final Protocol to Determine the Syria-Hatay Border Delimitation. The agreement determined that the water of the Orontes, Karasu and Afrin Rivers are to be equitably shared in places where the rivers constitute the border between Syria and Turkey.

Negotiations over the Orontes between Lebanon and Syria date back to the 1940s. Formal cooperation started in 1972 when the two riparians signed a bilateral agreement concerning water use in the river basin.[62] However, this agreement never came into force due to the political situation in the two countries. Subsequently, Lebanon and Syria signed and ratified the Fraternity, Cooperation and Coordination Treaty in 1991, establishing the formal basis for cooperation between the two countries in the domain of water and other sectors.[63] The Lebanese-Syrian Joint Committee for Shared Water was established under this treaty, with representatives from the Lebanese Ministry of Energy and Water and the Syrian Ministry of Irrigation. In September 1994, the two countries signed a second agreement specific to the Orontes, building on the 1972 agreement. It acknowledged that the waters of the river are shared and stated that the parties agree to divide the resource. Accordingly, the Agreement on the Distribution of Orontes River Water Originating in Lebanese Territory accorded Lebanon an annual share of 80 MCM of water, while the remaining 323 MCM was allocated to Syria,[64] provided that the river's resources within Lebanon reached 400 MCM/yr or more.[65] However, the terms of the agreement were deemed unfavourable to Lebanon, and an annex added in 1997 identified four sub-basins and a main spring[66] which were to be excluded from Lebanon's 80 MCM/yr share.[67] In addition, it was agreed that all water extracted from

Table 8. **Water agreements on the Orontes River**

YEAR	NAME	SIGNIFICANCE	SIGNATORIES
1939	Final Protocol to Determine the Syria-Hatay Border Delimitation	The protocol specifies where the waters of the Orontes, Karasu and Afrin Rivers constitute the border between Syria and Turkey. Although water use in the basin is not specified, the protocol states that water is to be utilized in an equitable manner.	Syria, Turkey
1972	Agreement on Water Use	First bilateral agreement on water use in the Orontes Basin.	Lebanon, Syria
1991	Fraternity, Cooperation and Coordination Treaty	The treaty provides the formal basis for cooperation between the two countries in the domain of water and other sectors. Several joint entities were established, including the Lebanese-Syrian Joint Committee for Shared Water.	Lebanon, Syria
1994	Agreement on the Distribution of the Orontes River Water Originating in Lebanese Territory	The agreement states that the signatories consider the water resources of the Orontes as common waters. It specifies that, based on an annual discharge rate of approximately 400 MCM, Lebanon is to receive 80 MCM with the remainder allocated to Syria.	Lebanon, Syria
1997	Annex to the Agreement on the Distribution of Orontes River Water Originating in Lebanese Territory	The annex identifies four sub-basins and a main spring, which are to be excluded from Lebanon's annual share as agreed in the 1994 agreement.	Lebanon, Syria
2001	Amendment to the Agreement on the Distribution of Orontes River Water Originating in Lebanese Territory	This amendment allows Lebanon to establish infrastructures on the river.	Lebanon, Syria
2009	Turkish-Syrian Strategic Cooperation Council Agreement	At the High-Level Strategic Cooperation Council Meeting, the two countries agreed that water would be a focus point for cooperation with specific emphasis on improvements to water quality, the construction of water pumping stations and joint dams, as well as the development of joint water policies. During the meeting, Syria and Turkey signed a memorandum of understanding related to the construction of the joint Friendship Dam.	Syria, Turkey

Source: Compiled by ESCWA-BGR based by Scheumann et al., 2011; Comair, 2009.

The Afrin Dam, Syria, 2009. Source: Andreas Renck.

the river near the Hermel Bridge and sources such as rainfall, springs and groundwater are considered part of the Lebanese share. Conversely, Lebanon would not implement any projects that could limit the river's flow.[68] The original 1994 agreement was further amended in 2001 in order to allow Lebanon to construct a dam on the Orontes.

COOPERATION

Prior to the eruption of the Syrian crisis in March 2011, Turkish-Syrian ties had improved, as evidenced by the number of agreements the two countries signed and joint projects they initiated between 2006 and 2010.

Before this rapprochement, however, Turkey and Syria had disagreed about various aspects of water use in the Orontes Basin. Often these disputes were influenced by the two countries' position on the Euphrates River (Chap. 1).[69] When Syria complained about Turkey's construction of dams on the Euphrates and claimed Turkey was not releasing sufficient water from its dams, Turkey invoked Syrian use of the Orontes River. This made negotiations more complicated. When negotiations over the Euphrates between Iraq, Syria and Turkey were initiated in the early 1980s, Turkey insisted on including the shared waters of the Orontes, while Syria at the time refused to discuss Orontes water with Turkey. The Syrian refusal was motivated by its claim to the province of Hatay. It argued that the Orontes was a national river that only flowed within Syrian territory before draining into the Mediterranean Sea (Box 3).[70]

BOX 3

The Province of Hatay

Situated on the north-eastern Mediterranean shore at the foot of the Taurus Mountains, the province of Hatay[a] is the downstream riparian of the Orontes River. Historically, both Turks and Arabs have populated this land and sovereignty over the territory has changed several times, with the province even enjoying a brief stint as an autonomous republic. In 1939, the province of Hatay was incorporated into Turkey de facto, although Syria has never officially recognized the move. Both countries continue to use Hatay as a negotiating card in their discussions over international water rights.

(a) Also known as Iskenderun.

Syrian-Turkish dialogue improved in the 1990s and resulted in an economic rapprochement in the form of a 2004 Free Trade Agreement, which also defines and recognizes state boundaries.

Cooperative ties between Lebanon and Syria over the Orontes are strong. A special joint committee for the Orontes River was created under the Lebanese-Syrian Joint Committee for Shared Water, which is the central entity

through which both countries cooperate over issues related to shared water resources. The membership of the Orontes River Joint Committee is drawn from both countries. The Committee comprises two sub-committees. The River Protection and Environmental Preservation Sub-Committee is responsible for coordinating and supervising issues related to river hydrology, river pollution and river infringements. The Sub-Committee for the Expropriation of Lands in the Vicinity of the Zeita Canals (Figure 9) addresses issues related to lands that straddle the Lebanese-Syrian border in the vicinity of the Zeita Dam.[71] The parties have agreed that Syria is to compensate landowners for work related to the canals on Lebanese territory, while Lebanon is to enlist its local authorities to enforce the rule of law and prevent damage to the infrastructure of the canals. Members of the sub-committees usually hold monthly meetings in Lebanon or Syria to discuss issues related to the basin, and exchange hydrological data and results of water quality analysis. The members also specify joint measures in order to tackle problems such as violations and infringements along the river's course, as well as river pollution from sewage and fisheries.[72]

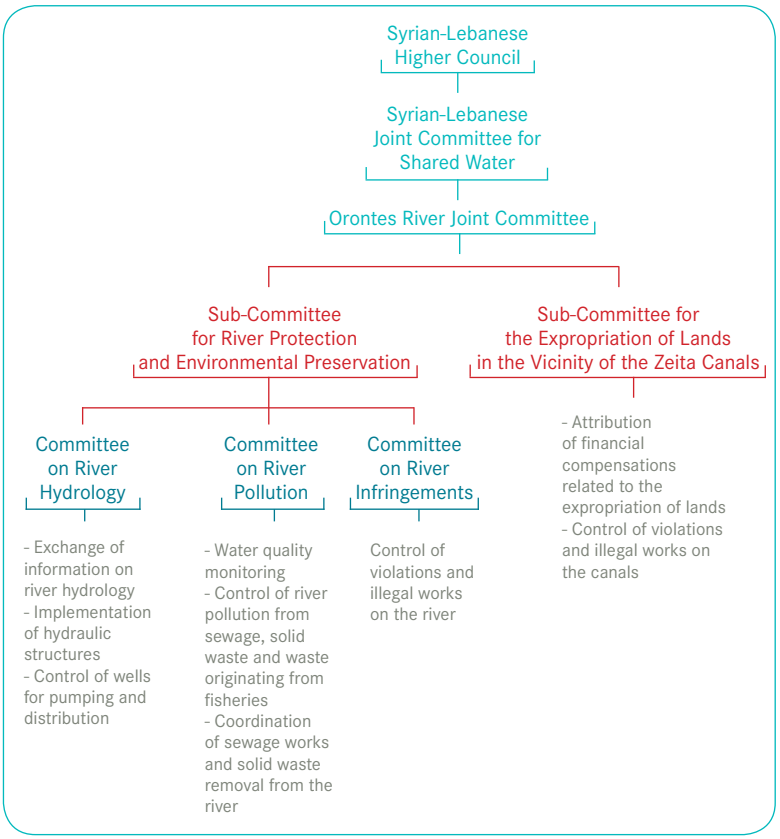
OUTLOOK

During the improvement of bilateral relations, Syria and Turkey launched a joint dam project on the Orontes River in Syria. In 2009, both countries signed a memorandum of understanding for the construction of the Syrian-Turkish Orontes River Friendship Dam to provide water for irrigation and hydropower. Construction on the dam started in February 2011.

In Lebanon, the Orontes River is likely to be further exploited in the coming years. For instance, the newly developed National Water Sector Strategy lists the surface storage potential of the Assi Dam in the supply-and-demand forecasts.[73]

Lebanon and Syria have solicited international donors for assistance in water supply management and hydrological monitoring, and various projects have been launched. However, with the ongoing crisis in Syria since March 2011 it is likely that most projects involving Lebanon or Turkey with Syria are currently on hold.

Figure 9. **Organizational structure and roles of the Orontes River joint sub-committees**



Source: Compiled by ESCWA-BGR based on data provided by Ministry of Energy and Water in Lebanon, 2011.

Notes

1. Also known as Nahr al Assi.
2. The basin area was delineated based on topography and stream network (Lehner et al., 2008). FAO, 2009, p. 77, states that the basin covers a surface area of 24,660 km^2 of which almost 70% lies in Syria, 23% in Turkey and 8% in Lebanon. Kloosterman and Vermooten, 2008, p. 7, state that the drainage catchment has a surface area of 21,666 km^2, while the Strategic Foresight Group, 2011, p. 102, gives a figure of 21,634 km^2.
3. Measured at the Labweh Spring.
4. Lake Qattineh, also referred to as Lake Homs, is about 15 km from the city of Homs. It is mainly used for irrigation and industry.
5. According to UN-ESCWA et al., 1996, p. 160, the canals are not large enough, which causes frequent overflowing during flood periods.
6. At this point, the Afrin joins the Orontes in the form of a canal.
7. UN-ESCWA et al., 1996, p. 160.
8. Ministry of Irrigation in the Syrian Arab Republic, 2009.
9. Kolars, 1992.
10. Ibid.
11. Fakioglu in Scheumann et al., 2011, p. 303.
12. World Bank, 2001, p. 2.
13. FAO, 2009.
14. LOCALIBAN, 2009. The Lebanese part of the basin comprises the districts of Baalbek and Hermel in Bekaa Governorate.
15. Ministry of Irrigation in the Syrian Arab Republic, 2010; Syrian Dutch Water Cooperation and Ministry of Irrigation in the Syrian Arab Republic, 2008.
16. UN-ESCWA et al., 1996, p. 160.
17. Sofer, 1999.
18. Coefficient of Variation = 0.2.
19. Ministry of Irrigation in the Syrian Arab Republic, 2012.
20. Wolfart, 1967.
21. UNDP, 1970.
22. FAO, 2009.
23. FAO, 2009, p. 80.
24. Ibid.
25. Ministry of Energy and Water in Lebanon, 2002.
26. Ibid.
27. Based on percentages presented by FAO, 2009, p. 80.
28. During the Syrian-Lebanese Higher Council meeting in March 2001.
29. JICA et al., 2003.
30. World Bank, 2001, p. 11.
31. Ministry of Irrigation in the Syrian Arab Republic, 2012.
32. Ministry of Irrigation in the Syrian Arab Republic, 2006.
33. Shapland, 1997, p. 145.
34. Kibaroglu et al., 2005, p. 68.
35. World Bank, 2001; Kloosterman and Vermooten, 2008.
36. This total is composed of the following parameters: groundwater use for irrigation added to an assumed 80% groundwater share in domestic and industrial water use. Kibaroglu et al., 2005, p. 70, estimate that the annual amount of groundwater used for irrigation, domestic water supply and industry in the basin exceeds 1,500 MCM.
37. This total is calculated as follows: surface water use for irrigation + full attribution of evaporation losses + an assumed 20% surface water share in domestic and industrial water use. The resulting value is far lower than the total river water use estimate of 1,721 MCM/yr in IPTRID-FAO, 2006.
38. IPTRID-FAO, 2006.
39. This refers to the period 1990-1999 as stated in FAO, 2003, p. 342.
40. Kibaroglu et al., 2005, p. 70.
41. Ibid.
42. EMWIS, 2011.
43. Hurriyet Daily News, 2010.
44. FAO, 2009.
45. Davie, 2003 in Varol et al., 2011.
46. Saad et al., 2004.
47. Syrian Dutch Water Cooperation and Ministry of Irrigation in the Syrian Arab Republic, 2008, p. 22.
48. Ministry of Irrigation in the Syrian Arab Republic, 2012.
49. Hajj and Ismail, 2011; Kassem et al., 2004.
50. Syrian Dutch Water Cooperation and Ministry of Irrigation in the Syrian Arab Republic, 2008, p. 21.
51. Scheumann et al., 2011.
52. Ministry of Local Administration and Environment in the Syrian Arab Republic, 2003, p. 23; Ministry of Irrigation in the Syrian Arab Republic, 2012.
53. Ministry of Irrigation in the Syrian Arab Republic, 2012.
54. Hajj and Ismail, 2011. Samples were taken in 2010.
55. Kassem et al., 2004.
56. Shapland, 1997; Caliskan, 2008.
57. Agca and Odemis, 2009.
58. Odemis et al., 2006; Agca and Odemis, 2009. The guideline for irrigation water is set at less than 700 µS/cm based on FAO, 1994.
59. Odemis et al., 2006.
60. Agca and Odemis, 2009. Samples were taken in 2004-2005.
61. Yilmaz and Dogan, 2008. Samples were taken in 2003-2004.
62. Sofer, 1999.
63. Syrian-Lebanese Higher Council, 1991.
64. The agreement is based on an assumed total annual discharge of 403 MCM in the Orontes Basin.
65. Syrian-Lebanese Higher Council, 1994, Article 3.
66. The four basins are Yammouneh, Marjhine, Jabal al Homr and Orgosh; the spring is the Labweh Spring.
67. Comair, 2009.
68. Syrian-Lebanese Higher Council, 1997.
69. Shapland, 1997.
70. Kibaroglu et al., 2005, p. 70.
71. Ministry of Energy and Water in Lebanon, 2011.
72. Syrian-Lebanese Higher Council, 2011.
73. Ministry of Energy and Water in Lebanon, 2012.

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Chapter 8

Nahr El Kabir Basin

Nahr El Kabir Basin

EXECUTIVE SUMMARY

The Nahr el Kabir rises from numerous springs in Syria and in the Lebanon Mountain range. It runs a westerly course forming a natural border between northern Lebanon and Syria. The Nahr el Kabir maintains most of its natural seasonal characteristics as water regulation is limited on the main river stem and in the runoff generation area in Lebanon and Syria.

Environmental degradation is a major issue in the basin: the river is severely polluted by widespread discharge of untreated sewage and uncontrolled solid waste disposal. Other threats include recurrent floods and the spread of water hyacinth along the whole river course. The two countries cooperate on the basis of a 2002 water-sharing agreement, with several joint technical sub-committees tackling various issues related to the watershed.

Overlooking the Bqaiaa Plain near the village of Chadra, Lebanon, 2010. Source: Eileen Maternowski.

BASIN FACTS

RIPARIAN COUNTRIES	Lebanon, Syria
BASIN AREA SHARES	Lebanon 26% Syria 74%
BASIN AREA	954 km^2
RIVER LENGTH	77.8 km
MEAN ANNUAL FLOW VOLUME	377 MCM
DAMS	3 (max. storage capacity 75 MCM)
PROJECTED IRRIGATED AREA	~23,000 ha
BASIN POPULATION	530,000

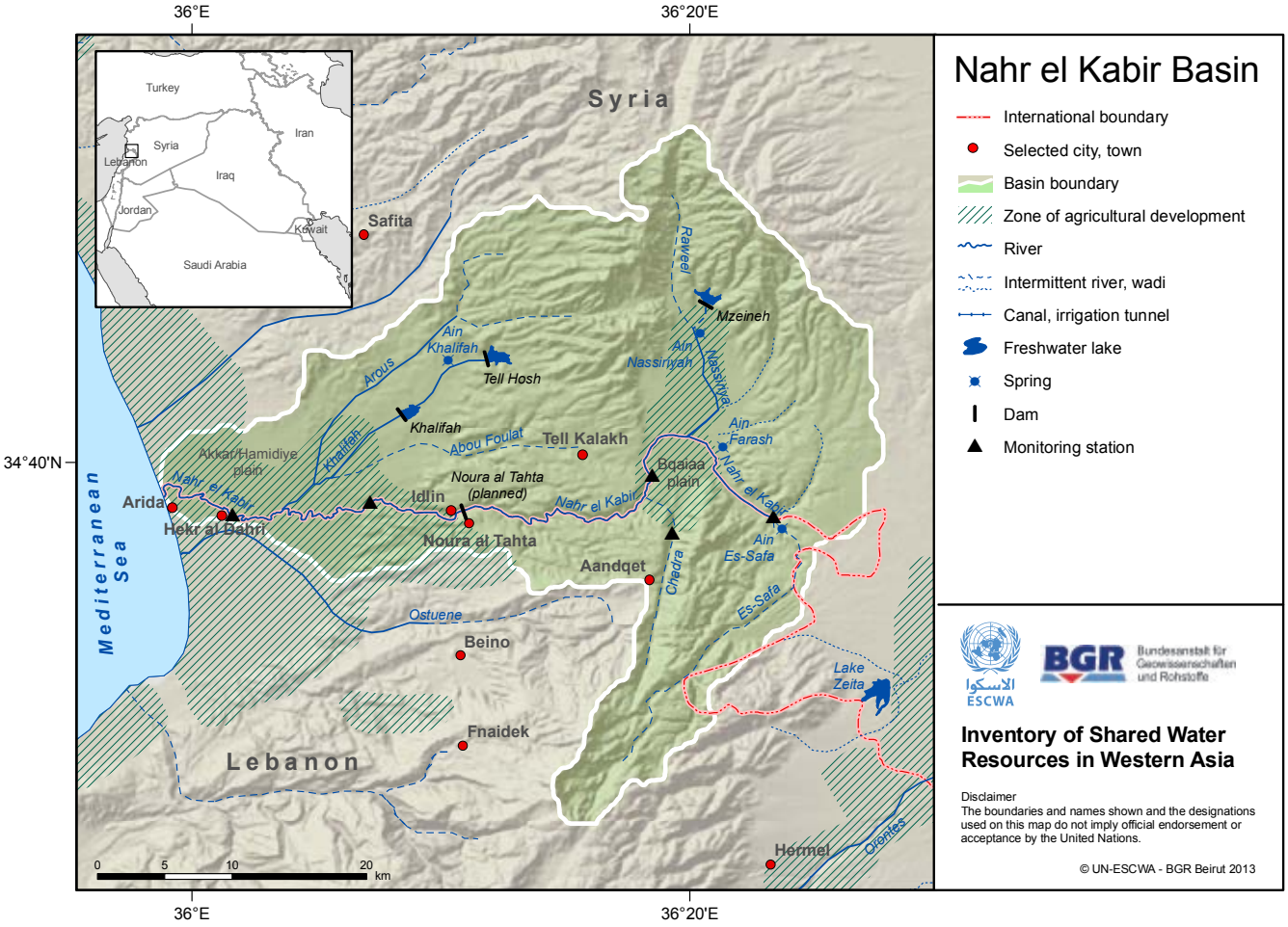
MAIN AGREEMENTS

LEBANON - SYRIA	2002 – Agreement between Lebanon and Syria to share the water of the Nahr el Kabir and build a joint dam on the main stem.

KEY CONCERNS

WATER QUALITY
The Nahr el Kabir is severely polluted. The absence of sound agricultural practices, the uncontrolled discharge of untreated wastewater and the random disposal of solid waste by both riparians has led to widespread environmental degradation and poses a serious threat to public health. Concerns over water quality are not addressed in the Syrian-Lebanese water agreement.

OVERVIEW MAP


36°E
36°20'E
34°40'N
Turkey
Iran
Syria
Lebanon
Iraq
Jordan
Kuwait
Saudi Arabia
Syria
Lebanon
Mediterranean Sea
Safita
Mzeineh
Ain Khalifah
Tell Hosh
Arous
Khalifah
Abou Foulat
Tell Kalakh
Akkar/Hamidiye plain
Nahr el Kabir
Arida
Hekr al Bahri
Noura al Tahta (planned)
Idlin
Noura al Tahta
Bqaiaa plain
Aandqet
Ain Es-Safa
Es-Safa
Ostuene
Beino
Fnaidek
Lake Zeita
Hermel
Orontes
0 5 10 20 km
Nahr el Kabir
Nassiriyah
Ain Farash
Qrayda
Nahr el Kabir
Nahr el Kabir
Nahr el Kabir

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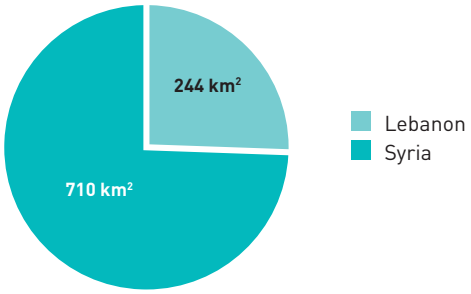
Geography

The Nahr el Kabir is a shared river that forms the north-south border between Lebanon and Syria. The basin covers 954 km², of which 26% lie in Lebanon and 74% lie in Syria (Figure 1). Generally, the basin is divided into four geomorphological zones: the mountain region in the upper catchment shared between Lebanon and Syria, the intra-mountainous cross-border Bqaiaa Plain, the central plateau/gorge area running along the border, and the coastal cross-border Akkar/Hamidiye Plain.[1]

Figure 1. **Distribution of the Nahr el Kabir Basin area**



Source: Compiled by ESCWA-BGR.

RIVER COURSE

As a coastal Mediterranean river, the Nahr el Kabir flows from east to west over an approximate distance of 52 km if the Ain Es-Safa Spring is considered the source, or 78 km if the Es-Safa tributary is included (see Overview Map). The river forms the international border between the Akkar region in Lebanon and the Syrian governorate of Tartous over much of its course.[2]

The river rises from numerous karstic springs and wadis (including the springs Ain Nassiriya, Ain Farash, Ain Es-Safa and Ain Khalifah) in the northern part of the Lebanon Mountain range.[3] Upon reaching the intra-mountainous Bqaiaa Plain, the Nahr el Kabir turns westward and traverses a basaltic central plateau where it forms steep gorges. It then meanders through the extensive alluvial flatlands of the coastal Akkar/Hamidiye Plain and discharges into the Mediterranean Sea near the Lebanese town of Arida.

Several tributaries discharge into the Nahr el Kabir on both sides of its course, including the Wadi al Atchane, the Nassiriya (formed by the confluence of the Raweel and the Mzeineh) and the Arous on the Syrian side. On the Lebanese side, the main tributaries are the Wadi Khaled, Es-Safa and Chadra. The Lebanese mountain Qarnat Araba constitutes the highest point of the catchment with an altitude of 2,215 m asl.[4]

The Great Southern River

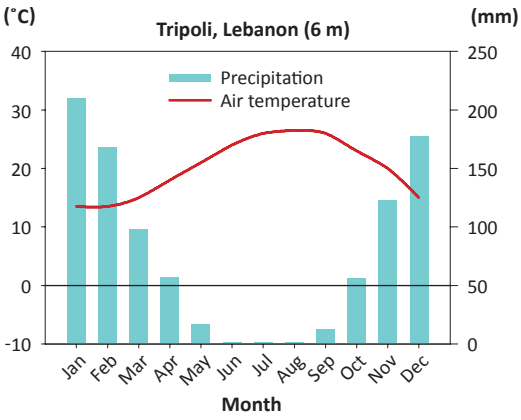
The name Nahr el Kabir al Janoubi means Great Southern River. Known as Eleutherus in ancient times, the river is mentioned in the Bible. It is also referred to as Nahr al Kebeer, Nahr el Kebir or simply the Kebir.

CLIMATE

The climate in the Nahr el Kabir Basin is characterized by Mediterranean winter precipitation with increasing intensity and quantity from the coastal plain towards the mountainous areas and dry, hot summers.[5] The mean annual air temperature measured in Tripoli, Lebanon to the south of the basin is 20°C (Figure 2).

Mean annual precipitation in the whole basin ranged from 600 to 1,000 mm[6] from 2001 to 2006 (Table 1).[7] It is estimated that 40%-50% of precipitation is lost to evapotranspiration and 30% contributes to river runoff.[8] Other sources estimate the mean annual basin precipitation at about 854 mm,[9] but observed data suggests a complex spatial pattern of precipitation throughout the basin, most likely caused by the intricate micro-climate[10] induced by the Homs Gap.[11]

Figure 2. **Climate diagram for Tripoli, Lebanon, to the south of the Nahr el Kabir Basin**



Source: Compiled by ESCWA-BGR based on data provided by WorldClim, 2011; Climate Diagrams, 2009; Phytosociological Research Center, 2009.

Table 1. Mean annual precipitation data from meteorological stations in the basin in Lebanon since 2000

STATION, ELEVATION (m asl)	PRECIPITATION (mm/yr)						
	2001	2002	2003	2004	2005	2006	MEAN[a] (2001-2006)
Al Qliaat (5)	907	1,002	896	698	876	879	876 (99)
Al Qubayat (540)	963	775	776	867	1,006	987	895 (105)
Halba (119)	980	767	670	770	605	910	783 (141)
Al Aabde (40)	988	904	961	768	814	768	867 (97)
Al Minia (10)	976	990	889	769	876	755	875 (99)
Sir Edenyeh (915)	1,003	956	894	869	991	934	941 (53)

Source: Compiled by ESCWA-BGR based on data provided by NCRS and UN-ESCWA, 2002.
(a) Standard deviations in parentheses.

POPULATION

The basin has an estimated total population of 530,000. Settlements, which range from 200 to 5,500 inhabitants, are made up of mixed urban and rural communities.[12] About 19% of the basin population lives in the area of the basin in Lebanon, while about 81% of the basin population lives in Syria.

Bridge over the Nahr el Kabir near Hekr al Dahri, Lebanon, 2010. Source: Andreas Renck.

Table 2. Estimated basin population

RIPARIAN COUNTRY	COUNTRY POPULATION (MILLIONS)	ESTIMATED POPULATION IN THE BASIN		SOURCE
		THOUSANDS	AS PERCENTAGE OF TOTAL BASIN POPULATION	
Lebanon	4.5	100	19	Central Administration of Statistics in Lebanon, 2011.[a]
Syria	20.9	430	81	Central Bureau of Statistics in the Syrian Arab Republic, 2005.[b]
Total		530		

Source: Compiled by ESCWA-BGR.
(a) The population estimate for the area of the basin that lies in Lebanon is based on a 2007 study.
(b) The population estimate for the area of the basin that lies in Syria is based on a 2010 estimate and includes populations living in the Syrian governorates of Tartous and Homs.

Hydrological Characteristics

ANNUAL DISCHARGE VARIABILITY

The annual flow volume of the Nahr el Kabir has been measured since 1955 (Table 3). At the outlet monitoring station near Hekr al Dahri, mean annual flow volume is estimated at approximately 377 MCM (1969-2011). Farther upstream at the Arida monitoring station in the Bqaiaa Plain it is 180 MCM (1955-2011). In the Syrian-Lebanese agreement, the mean annual flow volume at Noura al Tahta, where a dam is planned, is estimated at 150 MCM.[13] In the small Chadra tributary, a mean annual flow volume of about 9.3 MCM was measured during the period from 1966 to 2011.

Figure 3 shows river discharge data from the gauging stations near Hekr al Dahri and the upstream station of Arida in the Bqaiaa Plain over the period from 1955 to 2011. Both station records show a large gap in the 1970s and 1980s, when most of the hydrometric network was abandoned in Lebanon. In terms of discharge anomalies (Figure 3c), a major wet period in 2002 is the most noteworthy compared with the overall mean, and values from recent years lie below the average.

FLOW REGIME

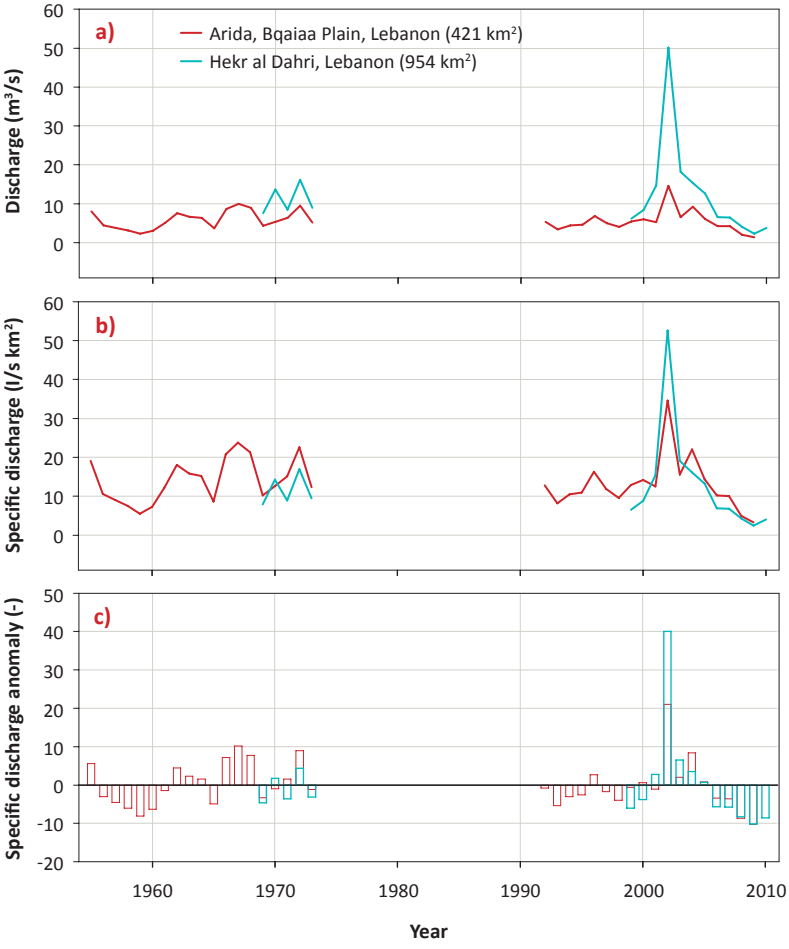
Figure 4 shows the mean flow regime of the Nahr el Kabir, with a high-flow season from November to May and a low-flow season from June to October. Minimum flow is generally reached in August/September. The river regime cannot be considered entirely natural, but as flow regulation is limited on the river's main stem and in the runoff generation area in both Syria and Lebanon (only three smaller dams are operational), the river maintains most of its natural seasonal characteristics. The increased discharge during the high-flow period is typically generated by increased rainfall throughout the rainy Mediterranean winter season and also by snow-melt that flows from the mountains to the basin area in springtime. The river's flow regime is maintained entirely by groundwater discharge during the dry summer months, as indicated by the groundwater flow regime of the Ain Es-Safa Spring shown in Figure 4. Furthermore, peak spring discharge caused by maximum groundwater recharge rates occurs in March and peak river discharge caused by surface runoff occurs in February.

Table 3. **Summary of annual flow volume statistics for the Nahr el Kabir in Lebanon (1955-2011)**

STATION (DRAINAGE AREA, km²)	PERIOD	MEAN (MCM)	MINIMUM (MCM)	MAXIMUM (MCM)	CV[a] (-)
Hekr al Dahri (954)	1969-1974, 1999-2011	377	73	1,578	0.91
Arida, Bqaiaa Plain (421)	1955-1974, 1992-2009	180	43	458	0.45
Chadra (..)	1966-1974, 1991-2011	9.3	1.7	23.5	0.61

Source: Compiled by ESCWA-BGR based on Ministry of Energy and Water in Lebanon, 2011.
(a) Coefficient of Variation. For information on definition and calculation of the CV see 'Overview & Methodology: Surface Water' chapter.

Figure 3. **a) Mean annual discharge, b) specific mean annual discharge and c) discharge anomaly time series of the Nahr el Kabir (1955-2011)**



Source: Compiled by ESCWA-BGR based on data provided by the Ministry of Energy and Water in Lebanon, 2011.

GROUNDWATER

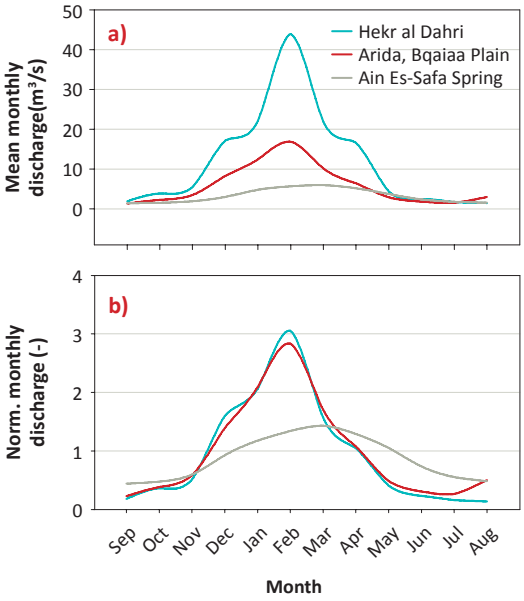
Groundwater significantly contributes to river runoff of the Nahr el Kabir.[14] About 70 perennial springs[15] ensure that the river's main channel maintains a continuous flow, even during the dry summer months. The springs' discharge depends on groundwater recharge from precipitation and snow-melt in the upper catchment zone, which mainly occurs towards the end of the rainy season in winter and spring. The bedrock in the basin is highly fractured and has good aquifer properties.[16] The mean annual flow rates of the Ain Farash, Ain Nassiriya, Ain Khalifah and Ain Es-Safa Springs are shown in Table 4. The mean annual flow volume of the Ain Es-Safa Spring for the period of record from 1969 to 2011 is 39.2 MCM.

Geological setting

The aquifers in the Nahr el Kabir Basin were formed through complex tectonic events related to the opening of the Red Sea, and subsequently the Dead Sea. The Yammouneh Fault, which belongs to the Dead Sea Transform Fault (DSTF) System, separates the elevated catchment zones to the east from the Bqaiaa and Akkar/Hamidiye Plains to the west.[17]

The headwaters of the Lebanese basin area feature a complex sedimentary aquifer system. The central part of the Nahr el Kabir Basin is a gorge carved from a volcanic aquifer system, composed of an upper basalt aquifer that is hydraulically connected to the overlying alluvial sediments, and a lower aquifer separated by a two-metre-thick aquitard clay layer. Finally, an alluvium aquifer system dominates both sides

Figure 4. **Mean monthly stream-flow and groundwater flow regime of the Nahr el Kabir and the Ain Es-Safa Spring (1955-2011)**



Source: Compiled by ESCWA-BGR based on data provided by the Ministry of Energy and Water in Lebanon, 2011.

of the basalt flow (i.e. in the coastal Akkar/Hamidiye Plain and the interior Bqaiaa Plain).[18] Groundwater recharge areas in the basin are difficult to identify, but empirical observations of different geological settings or subunits indicate their presence. For example, despite the steep slopes in the Chadra area, the Chadra has not shown a significant discharge response to intense rain events. The Chadra sub-basin thus appears to be one of the main regional groundwater[19] recharge areas, most likely due to the major fault system.[20]

Table 4. **Mean flow rate of main springs in the Nahr el Kabir Basin**

SPRING	FLOW RATE (m³/s)										
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	AVERAGE (2000-2009)
Ain Farash	..	..	0.58	0.33	0.57	1.33	1.33	..	0.75	0.75	0.81
Ain Nassiriya	..	..	0.43	0.92	0.81	2.45	2.45	..	0.69	0.69	1.21
Ain Khalifah	..	..	0.37	0.31	0.36	1.09	0.34	0.64	0.38	0.33	0.48
Ain Es-Safa[a]	0.71	0.79	1.66	2.62	2.19	2.19	..	..	..	0.54	1.53

Source: Compiled by ESCWA-BGR based on Central Bureau of Statistics in the Syrian Arab Republic, 2010; Ministry of Energy and Water in Lebanon, 2011.
(a) Available flow data for Ain Es-Safa Spring covers the period 1969-2010 and suggests an average flow rate of 1.4 m³/s.

Water Resources Management

Despite increasing socio-economic activity along the main service road between Lebanon and Syria, the Akkar region in the Nahr el Kabir Basin remains one of the poorest Lebanese districts. This has increased pressure on natural resources in the basin.[21] The main source of income is traditional agricultural production, which depends on irrigation in the lowland areas during summer. As a result, a dense network of irrigation and drainage canals has been constructed in the coastal and inner plains.

BOX 1

The Noura al Tahta Dam

In 1963, a joint Lebanese-Syrian commission undertook studies to identify potential dam sites on the Nahr el Kabir. In the 1970s, the construction of a dam and reservoir at Noura al Tahta in the river's gorge area was proposed as part of a larger development programme for the impoverished Akkar/Hamidiye region.[a] The reservoir was to capture surplus water in winter for agricultural use in the coastal region during the dry summer months, while at the same time controlling flooding in the coastal plain.[b] Later, based on the 2002 bilateral agreement concerning the division of the Nahr el Kabir waters, Lebanon and Syria agreed to build a shared dam with a capacity of 70 MCM at Noura al Tahta/Idlin. This will allow for the irrigation of 10,000 ha on both sides of the river,[c] and provide water for domestic and industrial use.

(a) Preliminary studies were carried out by the Food and Agricultural Organization in collaboration with the Lebanese government between 1969 and 1972 within the framework of the FAO Hydro-Agricultural Development Project for North Lebanon (FAO, 1991).
(b) UNESCO, 2004.
(c) UN-ESCWA, 2006.

DEVELOPMENT & USE: LEBANON

In Lebanon, water in the basin is mainly used for domestic purposes and for irrigation. To date, there are no dams in the Lebanese part of the basin.

There are two main irrigation schemes in the area: the Bqaiaa Plain (990 ha) and the Machta Hassan/ Machta Hammoud/ Chadra lands (730 ha).[22] Construction of the planned Noura al Tahta Dam would support the irrigation of another 4,959 ha in the Akkar Plain in Lebanon and higher surrounding zones, of which 3,500 ha will be reclaimed agricultural lands.[23]

DEVELOPMENT & USE: SYRIA

Syria started constructing dams in the Nahr el Kabir Basin in the 1980s. To date three main dams have been built with a total capacity of 75 MCM (Table 5). The dams irrigate the Bqaiaa Plain and the coastal region through three main irrigation schemes: the Tell Hosh and Khalifah Dams provide water for 6,820 ha and 700 ha of farmland respectively, while water from the Mzeineh Dam irrigates 4,000 ha.[24]

A pumping station planned at the Ain Farash Spring will deliver 0.25 m^3/s of water to irrigate 319 ha in the Bqaiaa Plain. Water from this spring will also be used to supply the Tell Hosh Dam through a planned diversion canal.[25] In addition, a groundwater irrigation scheme in place since 2000 supplies 2,138 ha through the exploitation of 92 wells with a total yield

Table 5. Constructed and planned dams in the Nahr el Kabir Basin in Syria

NAME	COMPLETION YEAR	CAPACITY (MCM)	PURPOSE[a]	BACKGROUND INFORMATION
Khalifah	1985	3.5	I	Irrigation of 700 ha.
Tell Hosh	1999	52.0	I	Irrigation of 6,820 ha. Water originates from the Farash Spring and the Raweel and Khalifah Rivers.
Mzeineh	2003	19.2	I	Located on the Mzeineh River. Irrigation of 4,000 ha. The dam will be supplied with 14 MCM from the Raweel River through a water diversion canal.
Idlin-Noura al Tahta	planned	70.0	I, FC	Joint Lebanese-Syrian project. Irrigation of 10,000 ha on both sides of the border. It will also be used for flood management and for domestic and industrial water supply.

Source: Compiled by ESCWA-BGR based on Ministry of Irrigation in the Syrian Arab Republic, 2011; Syrian Economic News, 2010; Al-Thawra, 2011; E-Homs, 2011.
(a) Irrigation (I) and Flood Control (FC).

Table 6. **Mean salinity, nutrients, bacteria and heavy metals in the Nahr el Kabir Basin (2001-2002)**

		SALINITY (µS/cm)	NUTRIENTS (mg/L)			COLIFORM BACTERIA (cfu/100 ml)		HEAVY METALS (ppm)	
		EC	Po_4-P	NO_3-N	NO_2-N	Total coliform	Faecal coliform	Cr	Ni
Region	Upper Kabir	470	8.02	0.58	0.03	173,609	18,684	1,150	375
	Bqaiaa Plain	520	15.82	0.04	0.05	64,056	29,489	702	459
	Chadra	510	15.05	0.03	0.02	39,756	18,177	513	562
	Coastal plain	670	17.64	0.08	0.08	37,500	19,924	686	515
Total range		10-680	0.05-31.4	0-15.6	0-0.15	0-26,999,800	0-1,890,000	443-1,150	306-640
Guidelines[a]		<700 (irrigation)	0.1	0.2	In the order of 0.001	0 (drinking water) 1000 (irrigation) 10,000 (bathing)		120 (world average)[b]	80 (world average)[b]

Source: Compiled by ESCWA-BGR based on Hassan et al., 2005; IDRC, 2003; Thomas et al., 2005.
Note: Salinity values, nutrients and bacterial concentrations were analysed from water samples in 2001-2002. Heavy metals were analysed from sediment samples in 2001.
(a) For further information on the different water quality parameters and their respective guidelines, see 'Overview & Methodology: Surface Water' chapter.
(b) World average values are based on Chapman, in IDRC, 2003, p. 28.

of 20 MCM/yr.[26] The total irrigated area in the Syrian part of the Nahr el Kabir Basin is estimated at about 13,660 ha.

WATER QUALITY & ENVIRONMENTAL ISSUES

Water quality is a serious issue in the basin. The absence of sound agricultural practices, the uncontrolled discharge of untreated wastewater and the random disposal of solid waste from both riparians cause widespread environmental degradation and pose a severe threat to public health.[27]

Sampling and analysis of water and sediments in the watershed[28] in 2001-2002 showed high levels of nitrate-nitrogen (NO_3-N) and in particular extremely high levels of phosphates (PO_4-P) and nitrite (NO_2-N) (Table 6).[29] Nutrient pollution results from settlements in the basin that discharge sewage and solid waste directly into the river or dispose of it nearby. Agricultural fertilizers are another source of nutrient pollution.[30] In addition, counts of coliform bacteria from sewage waste exceed international guidelines whether for drinking, irrigation or bathing.[31]

While salinity is not an issue of concern, in the upstream area, Electrical Conductivity (EC) values of the river water increase towards the coastal plain as a result of intensive irrigation practices.[32] DDT parent compound was found in the river sediments at higher levels than its residual compound DDE, indicating that this banned substance was still being used as an insecticide in 2001-2002 in agricultural areas in the watershed.[33] High levels of the heavy metals chromium (Cr) and nickel (Ni) were also found in sediments, indicating anthropogenic enrichment that can be attributed to small-scale leather tanning and metal plating industries in the watershed.[34] Other pollutants from point sources were found including seasonal residues and waste from olive presses in Syria and traces of oil products from fuel tanks in Lebanon.[35]
The wide-ranging pollution in the basin poses a risk to groundwater, particularly to the shallow aquifers[36] in the Bqaiaa and Akkar/Hamidiye Plains, which are currently being tapped by wells. Nutrients and coliform bacteria were detected in certain springs, indicating that contamination through localized upstream land use practices may already have reached the aquifer.[37] In these coastal plains, the aquifer lies 15-20 m below the surface in the border area.[38]

Apart from severe pollution, flooding is a recurrent issue in the basin, causing losses to farmers and damage along the Nahr el Kabir on both sides of the border.[39] In 1979, floods destroyed the iron bridge in the village of Arida and in 2003 the river flooded villages, destroying several houses, damaging crops and causing the loss of livestock.[40] As a result, Lebanon built a two-metre-high flood wall over a distance of 4.5 km in the Bqaiaa Plain, starting at the Ain Farash Spring.[41] In Syria, the construction of dams has somewhat reduced flood risks. By contrast, regularly occurring flash floods in the Lebanese part of the basin continue to cause significant damage to the agricultural sector, especially in the deprived Akkar region.[42]

Another environmental problem that appeared more recently is the spread of the invasive water hyacinth (*Eichhornia sp.*), known as 'Zahret el Nil' in Arabic. It was first discovered in the basin in 2006, clogging the irrigation canals of the Arous river in Syria. Subsequently, it quickly spread to the Nahr el Kabir, clogging waterways throughout the river course and spreading

over a distance of 13 km.[43] It is not known how this non-native aquatic weed was introduced in Syria.[44] The damage caused is considerable since it can double its population in two weeks and it rises to a height of up to one metre above the water surface, blocking sunlight to and oxygenation of aquatic organisms and disturbing river flow. It is therefore considered a potential cause of flooding. The plant also creates a prime habitat for mosquitoes, which are potential vectors of disease in the basin. Both riparian countries have attempted to use excavators to remove the plant from the river and thus control its spread. However, despite continuous joint efforts to control it, the nutrient-rich discharge of agricultural runoff and sewage waste into the Nahr el Kabir has favoured the survival of this invasive plant.

The invasive water hyacinth, which is clogging water channels in the basin, 2009. Source: Ministry of Energy and Water in Lebanon.

Agreements, Cooperation & Outlook

AGREEMENTS

The Fraternity, Cooperation and Coordination Treaty signed and ratified by Lebanon and Syria in 1991 provides the formal basis for cooperation in the domain of water and in other sectors. Several joint entities were established in the same year to supervise the implementation of the treaty's provisions and agreements.[45] This includes the Lebanese-Syrian Joint Committee for Shared Water, in which the Lebanese Ministry of Energy and Water and the Syrian Ministry of Irrigation are represented.

In April 2002, after an eight-year negotiation process,[46] both countries agreed to share the water of the Nahr el Kabir. The agreement draws on the United Nations Convention on the Law of Non-Navigational Uses of International Watercourses,[47] to which both countries are signatories. The agreement is centred on the joint construction of a multi-purpose dam near Noura al Tahta with a planned storage capacity of 70 MCM that will provide water mainly for irrigation and domestic use. According to the agreement, water allocation follows each riparian country's share in the catchment area that drains to the dam location (representing a total area of 591 km^2).[48] Thus Lebanon and Syria respectively receive 40% and 60% of the river's total annual yield (Article 3 of the agreement). The origin of the water, i.e. the respective contribution of each basin riparian to river flow is not taken into account. The amount of water used upstream of the dam (within the limit of the respective allocation proportions) is to be deducted from the riparian countries' share of stored water (article 12). Costs of dam construction and engineering studies are to be equally divided between both countries (Article 10).[49]

Both countries consider the agreement as a model for bilateral cooperation over shared water resources in the Arab region. According to Annex 3 of the agreement, the joint committee is to prepare an annual programme for water use in the basin. However, these annual programmes have yet to be drafted, pending construction of the dam, which have not yet started.

BOX 2

Progress on the Joint Noura al Tahta Dam Project

The Lebanese Ministry of Energy and Water invited international tenders for the study and design of the dam in December 2003. In November 2004, the contract was pre-awarded to a Swiss-Lebanese consortium, pending approval by the Syrian and Lebanese governments. The Lebanese Council of Ministers only approved the contract in February 2006, and due to administrative delays and the prevailing political situation in both countries during that period, the necessary funds were not made available. When the two sides resumed discussions on the dam in 2009, the cost of the project had increased substantially. After several meetings of the joint committee in 2009 and 2010, the parties agreed to prepare a new call for tenders. This was done in January 2011 and resulted in the selection of the same Swiss-Lebanese consortium in June 2011. This was subsequently approved by the Lebanese and Syrian governments. Both parties released funds in August 2011, allowing for the feasibility study to be launched. Subsequent events in Syria have delayed the study.

Source: Ministry of Energy and Water in Lebanon, 2011.

COOPERATION

The Lebanese-Syrian Joint Committee for Shared Water is the central entity through which the two countries cooperate over issues related to shared water resources. The membership of the special joint committee for the Nahr el Kabir is drawn from both countries. The committee comprises two subcommittees. The Sub-Committee for the Control of Water Hyacinth

The Nahr el Kabir near the river mouth at Arida, Lebanon, 2010. Source: Andreas Renck.

was created in 2009 with the aim of assessing and controlling the spread of this invasive plant. The Sub-Committee for River Protection and Environmental Preservation is responsible for coordinating and supervising issues related to river hydrology, river pollution and river infringements (Figure 5).

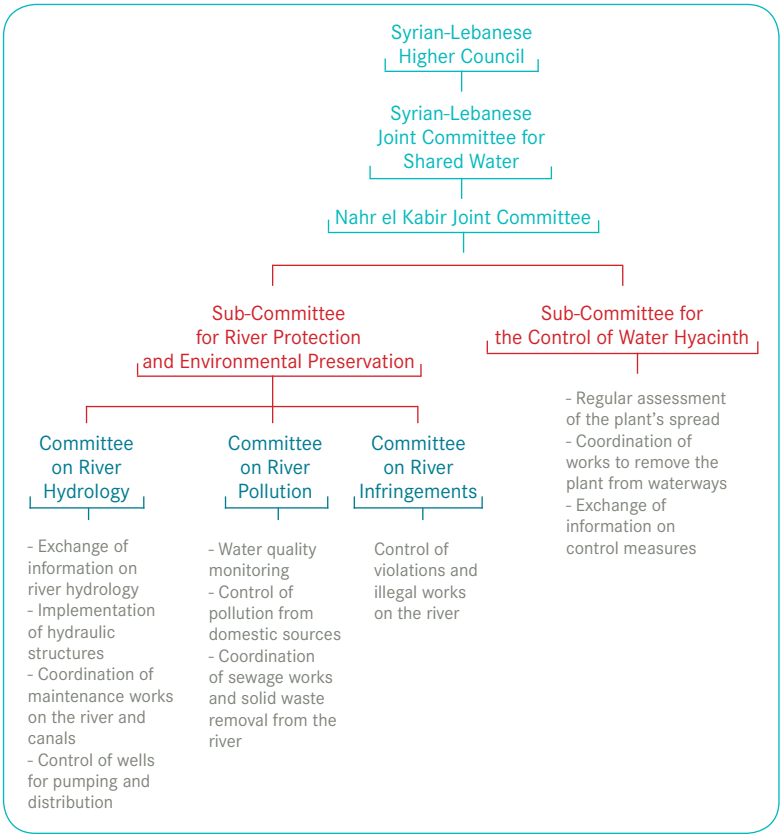
Members of the sub-committees usually hold monthly meetings in Lebanon or Syria to exchange data, discuss issues related to the basin and specify joint measures in order to tackle problems such as illegal acts and violations along the river course and river pollution.[50]

OUTLOOK

The quality of both surface and groundwater in the Nahr el Kabir watershed is rapidly deteriorating due to uncontrolled disposal of untreated domestic sewage, animal waste and solid waste, and unsustainable agricultural practices. To date, joint government efforts to tackle water pollution, floods and illegal activities in the watershed have only offered temporary solutions to recurrent problems. An overall joint plan for the integrated and sustainable management of the basin's natural resources is still lacking.

Plans for the construction of new wastewater treatment plants in the watershed are under preparation for the region of Al Bireh/Mounjez in Lebanon[51] and Tartous Governorate in Syria.[52] Both countries have solicited international donors for assistance in water supply management and hydrological monitoring, and various projects were launched. However, with the ongoing crisis in Syria since March 2011, it is likely that some of these projects are currently on hold.

Figure 5. **Organizational structure and roles of the Nahr el Kabir joint sub-committees**



Source: Compiled by ESCWA-BGR based on Ministry of Energy and Water in Lebanon, 2011.

Notes

1. IDRC, 2003; UN-ESCWA and BGR, 2009, p. 8.
2. UN-ESCWA, 2006; Khawlie et al., 2005.
3. Comair, 2009, p. 210; Ministry of Irrigation in the Syrian Arab Republic, 2011; Ministry of Irrigation in the Syrian Arab Republic, 2010, p. 149.
4. UNESCO, 2004; Comair, 2009.
5. UNESCO, 2004; UN-ESCWA and BGR, 2010.
6. Lebanese Ministry of Public Works in Shaban et al., 2005.
7. NCRS and UN-ESCWA, 2002; Shaban et al., 2005; IDRC, 2003.
8. Khawlie et al., 2005; IDRC, 2003, p. 17.
9. Shaban et al., 2005, p. 94.
10. UN-ESCWA and BGR, 2010, p. 17, 23.
11. The Homs Gap is a large north-east/south-west strike-slip fault, which separates the Coastal Mountains in Syria from the Lebanon and Anti-Lebanon Mountains.
12. IDRC, 2003.
13. Syrian-Lebanese Higher Council, 2002.
14. IDRC, 2003.
15. Shaban et al., 2005, p. 95.
16. UNESCO, 2004, p. 3.
17. UN-ESCWA and BGR, 2010, p. 17.
18. UNESCO, 2004, p. 2, 3.
19. UN-ESCWA and BGR, 2010, p. 17.
20. The Yammouneh Fault, which belongs to the Dead Sea Transform Fault System (DSTF) (UNESCO, 2004, p. 2).
21. IDRC, 2003.
22. Hreiche, 2009, p. 15, 24.
23. Ministry of Energy and Water in Lebanon, 2000.
24. Ministry of Irrigation in the Syrian Arab Republic, 2006; World Bank, 2001.
25. Ministry of Irrigation in the Syrian Arab Republic, 2011; Al-Thawra, 2011.
26. World Bank, 2001, p. 96; Syrian Economic News, 2010.
27. IDRC, 2003; Syrian-Lebanese Higher Council, 2011.
28. The study was conducted by IDRC, 2003. Samples were taken from both riparians.
29. IDRC, 2003.
30. Hassan et al., 2005.
31. IDRC, 2003, p. 44.
32. IDRC, 2003.
33. Ibid. Banned in 1972, DDT (dichlorodiphenyltrichloroethane) was commonly used as a pesticide and can persist in the environment for many years. It is toxic to a wide range of animals, insects and aquatic organisms. It can also accumulate in the food chain and is considered a human carcinogen (US-EPA, 2011).
34. Thomas et al., 2005; IDRC, 2003.
35. Syrian-Lebanese Higher Council, 2004.
36. The Upper Basalt Alluvium Aquifer System.
37. IDRC, 2003.
38. IDRC, 2003; UNESCO, 2004.
39. UN-ESCWA, 2006.
40. Lebanese Army Magazine, 2003.
41. Ministry of Energy and Water in Lebanon, 2011.
42. Al-Diyar, 2011; Sada Akkar, 2010.
43. SANA, 2010; Tishreen, 2009.
44. The water hyacinth was brought from its native home in South America to various countries as an ornamental plant. It was introduced to the United States of America in the 1980s and to Africa in the 1950s, where it spread to the Congo, the Nile and Lake Victoria (Columbia University, 2003).
45. Syrian-Lebanese Higher Council, 1991.
46. UN-ESCWA, 2006, p. 15.
47. Comair, 2003.
48. The respective riparian shares are allocated based on the following surface areas: 360 km^2 of the total area in Syria (63%), and 231 km^2 in Lebanon (37%) (Ministry of Energy and Water in Lebanon, 2011; Ministry of Irrigation in the Syrian Arab Republic, 2011).
49. Syrian-Lebanese Higher Council, 2002.
50. Ministry of Energy and Water in Lebanon, 2011.
51. Tidière, 2009, p. 7, 27; Council for Development and Reconstruction in Lebanon, 2011.
52. Syrian-Lebanese Higher Council, 2011.

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Chapter 9

Qweik River Basin

Qweik River Basin

EXECUTIVE SUMMARY

The Qweik River rises in Turkey and discharges in Syria, forming a closed drainage basin. Before the 1950s, the Qweik was the main source of freshwater for the city of Aleppo. However, the river and tributary springs have today run dry as a result of rising demand in Aleppo, the regulation of the river, and the over-exploitation of groundwater resources.

The Qweik currently flows partly intermittently before reaching Aleppo, after which it becomes a permanent carrier of wastewater generated from households and industries in the city.

Water from the Qweik has been used intensively for irrigation around Aleppo, posing a serious threat to public health and the environment. Syria initiated a project in 2006 to supply the river with freshwater from the Euphrates. Additional projects to construct wastewater treatment facilities are planned.

The Qweik River in Aleppo, Syria, 2012. Source: Harout Minassian.

BASIN FACTS

RIPARIAN COUNTRIES	Syria, Turkey
BASIN AREA SHARES	Syria 88% Turkey 12%
BASIN AREA	6,941 km^2
RIVER LENGTH	167 km
MEAN ANNUAL FLOW VOLUME	82 MCM
DAMS	3
PROJECTED IRRIGATED AREA	..
BASIN POPULATION	~5.5 million

MAIN AGREEMENTS

SYRIA – TURKEY (FRENCH MANDATE)	1921 – Franklin-Bouillon Agreement in which reference is made to the rule of equitable utilization and the importance of ensuring water supply to the city of Aleppo.

KEY CONCERNS

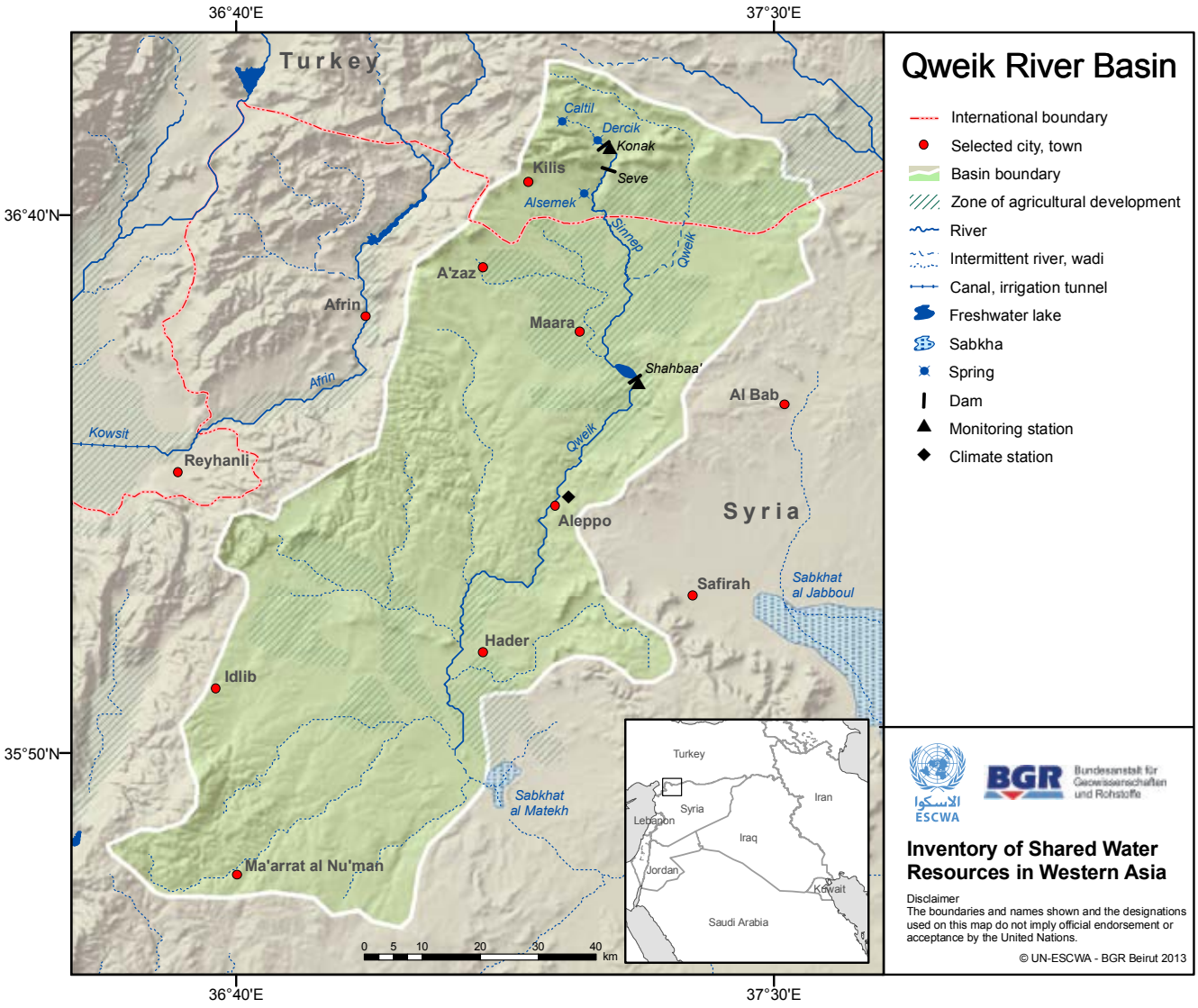
WATER QUANTITY

Water diversions and groundwater over-abstraction in the basin have caused most springs to dry up, turning the Qweik into an intermittent river in its upper reaches.

WATER QUALITY

The Qweik carries a mix of domestic-industrial, treated-untreated wastewater that has been used for irrigation since the 1980s, presenting potential risks of crop contamination. The geological setting of the basin also makes groundwater resources particularly vulnerable to contamination from agricultural drainage.

OVERVIEW MAP



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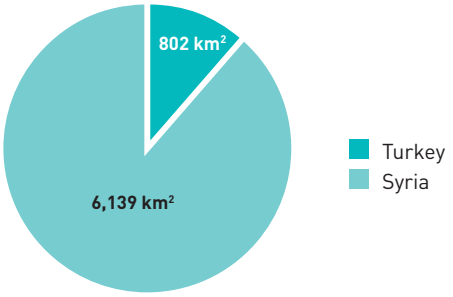
Geography

The Qweik River[1] is a closed[2] drainage basin shared between Turkey and Syria. The river originates in Turkey, and is joined by the Sinnep after the Syrian-Turkish border. It then flows further southward, discharging into the Sabkhat[3] al Matekh south of the city of Aleppo.

The Qweik Basin area is 6,941 km², of which 12% is located in Turkey (Figure 1). The main part of the basin is situated in northern Syria (88%).[4]

Figure 1. **Distribution of the Qweik Basin area**



Source: Compiled by ESCWA-BGR.

RIVER COURSE

The 167 km-long Qweik River originates in the Taurus Mountains in Turkey. It flows through Syria for 144 km and crosses the Turkish province of Kilis and the Syrian governorate of Aleppo, where it discharges into the Sabkhat al Matekh between the Syrian cities of Hader and Idlib (see Overview Map).

The Qweik Basin forms part of a larger closed basin called the Aleppo Basin.[5] The Qweik Basin borders on the Jabboul Basin to the east and the Orontes Basin to the west.

The Qweik is fed by several springs in Turkey including the Caltil, Dercik and Alsemek Springs, as well as other intermittent springs. One of its tributaries is the Sinnep stream.

CLIMATE

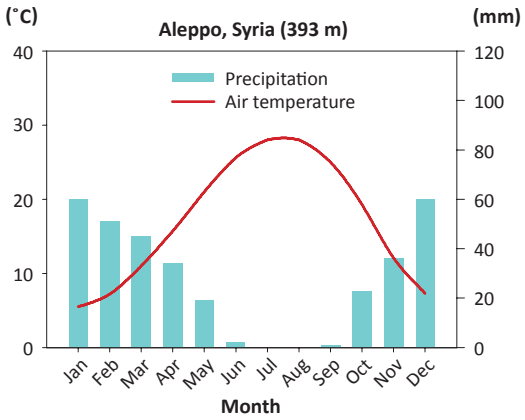
The climate in the Qweik Basin is moderately dry to dry, with more rain than in the south-east (predominantly Mediterranean climate with continental influence). Mean annual air temperature is around 20°C (Figure 2).

A Region of Orchards

Many place names in the Qweik catchment around Aleppo feature the word 'boustan' (orchard). Names such as Boustan Basha, Boustan Sheikh Taha, Boustan Qasr and Boustan Kleib testify to the region's rich agricultural heritage.

Winters are cool and wet with high levels of humidity; summer lasts from June to September with maximum temperatures of around 30°C. Mean annual precipitation is estimated between 250 and 500 mm (Table 1).[6]

Figure 2. **Climate diagram for Aleppo, Syria, in the Qweik Basin**



Source: Compiled by ESCWA-BGR based on data provided by WorldClim, 2011; Climate Diagrams, 2009; Phytosociological Research Center, 2009.

Table 1. **Basin areas and mean annual precipitation estimates**

BASIN	AREA (km²)	MEAN ANNUAL PRECIPITATION		SOURCE
		mm/yr	MCM/yr	
Qweik (Syrian part)	6,130	370	2,300	Wolfart, 1966.
Al Bab (Sabkhat al Jabboul)	4,800	250	1,200	
Qweik (Syrian part)	..	400-450	2,200	Selkhozpromexport, 1979.
Al Bab (Sabkhat al Jabboul)	..	300	1,200	
Qweik (Syrian part)	..	340	2,100	JICA, 1997.

Source: Compiled by ESCWA-BGR.

POPULATION

The Qweik Basin area has a population of about 5.5 million, including the densely populated city of Aleppo, which constitutes about 75% of the basin area's total population and is the main urban centre.[7] Over the last 60 years, Aleppo's population has grown dramatically from 320,000 in 1950 to about 2.2 million in 2004, a sevenfold increase.[8] Outside of Aleppo, the Qweik Basin is characterized as rural and agricultural.

Table 2. **Estimated basin population**

RIPARIAN COUNTRY	COUNTRY POPULATION (MILLIONS)	ESTIMATED POPULATION IN THE BASIN		SOURCE
		MILLIONS	AS PERCENTAGE OF TOTAL BASIN POPULATION	
Turkey	73.7	0.12	2.2	Turkstat, 2010.[a]
Syria	20.9	5.42	97.8	Central Bureau of Statistics in the Syrian Arab Republic, 2005.[b]
Total		5.53		

Source: Compiled by ESCWA-BGR.
(a) The population estimate for the area of the basin that lies in Turkey is based on a 2010 census and includes the population living in the Turkish province of Kilis.
(b) The population figure for the area of the basin that lies in Syria is based on a 2010 estimate and includes populations living in the Syrian governorates of Aleppo, Idlib and Hama, including cities such as Aleppo, Maara and Hader.

The city of Aleppo, Syria, 2010. Source: Bernard Gagnon.

Hydrological Characteristics

DISCHARGE AND FLOW REGIME

Continuous time series of discharge along the Qweik River were not available. Data collected for the period from 1958 to 2009 from different literature sources (Table 3) was insufficient for a conclusive hydrological analysis, due to data gaps, lack of information on location[9] and incompatible data sets.

The overall literature review suggests that until the early 1980s the mean discharge of the Qweik River and tributaries near the Syrian-Turkish border was in the range of 2-5 m^3/s (approx. 60-160 MCM/yr) with an average of around 3 m^3/s (approx. 95 MCM/yr).[10]

Water diversion and dam projects in upstream Turkey and Syria, paired with an intensification of irrigation from 1975 onward (but possibly also much earlier), are likely to have strongly impacted river flow at the border and in Aleppo, a city which used to rely on the Qweik for its water supply. As a result of abstractions and drought periods, the Qweik has reportedly dried up completely before Aleppo[11] as have many of the springs contributing to river flow in Syria.[12] In the 1980s, average discharge fell to 0.3 m^3/s (9.5 MCM/yr).

At the same time, the rapid urban growth of Aleppo has led to a rise in wastewater discharge into the Qweik, increasing flow rates downstream of the city. As Aleppo no longer extracts water from the Qweik River for domestic use and imports most of its drinking water supply from the Euphrates Basin,[14] the Qweik River has once again become a perennial river downstream of Aleppo due to wastewater discharges into the river.[15] Measurements carried out on 14 April 2004 estimated the river's upstream discharge at 2-3 m^3/s (lined canal section), and downstream discharge south of Aleppo at 5-6 m^3/s (Wdaihy gauge).

Table 3. **Summary of annual flow volume statistics for the Qweik River (1958-2009)**

YEAR	MEAN (m^3/s)	MEAN (MCM/yr)	MAXIMUM (m^3/s)	MINIMUM (m^3/s)	SOURCE
1958	2.5	78.8	60	—	Central Bureau of Statistics in the Syrian Arab Republic, 1958-2000.
1963	2.5	78.8	60	—	
1967	2.5	78.8	60	—	
1970	2	63.1	70	—	
1973	5	157.7	60	—	
1980	2.79	87.9	..	..	Kolars and Mitchell, 1991.
1982	0.3	9.5	7.8	—	Central Bureau of Statistics in the Syrian Arab Republic, 1958-2000.
1986	0.3	9.5	7.8	—	
1987	0.3	9.5	7.8	—	
1988	5	157.7	60	—	
1995	1.3	40.9	3.5	0.6	
1996	4.6	145.1	9.9	2.4	
1997-2000	3.4	107.2	..	..	
2002	1.7	53.6	2.2	1.1	Central Bureau of Statistics in the Syrian Arab Republic, 2003-2010.
2003	1.5	47.3	4.2	0.8	
2004	2.4	75.7	4.4	0.8	
2005	2	63.1	2.6	1.7	
2006	4.6	145.1	5.6	3.9	
2007	3.5	113.4	5.3	3	
2009	5.13	161.8	8.08	3.62	

Source: Compiled by ESCWA-BGR.

Since 2009, water from the Euphrates River has been diverted to the Qweik through an extension of the Maskaneh irrigation canal. Flow rates downstream of the insertion point will therefore not be comparable to historic values.

Downstream from Aleppo, the entire surface water flow (including effluents) is used for irrigation purposes.[16]

GROUNDWATER

Several springs in Turkey contribute to the flow of the Qweik River, including the Caltil, Dercik and Alsemek Springs (see Overview Map). There are also several seasonal springs on the Syrian side of the border, some of which used to be perennial. It can be assumed that groundwater is the main source of base flow in the Qweik River.

Together with the catchments of the Afrin, Sajour and Al Bab Rivers, the Qweik Basin overlies the wider Aleppo groundwater sub-basin.[17] In 1976, the Qweik Basin still had a positive groundwater balance.[18] However, 20 years later the deficit had reached 100 MCM/yr or 37%, as intensive agricultural development in the Aleppo sub-basin led to widespread over-exploitation of groundwater (Table 4).[19] Consequently, groundwater levels have dropped by 1-2 m/yr in many parts of the basin, and even up to 5 m/yr in certain places.[20]

Table 4. Groundwater balance in the Qweik Basin

STUDY PERIOD	AREA (km^2)	GROUNDWATER (MCM/yr)				SOURCE
		INPUT[a]	OUTPUT[b]	ABSTRACTION	BALANCE	
1976	5,190	252	242	200	+10	Selkhozpromexport,1979.
1993-1996	6,333	273	373	373	-100	JICA, 1997.

Source: Compiled by ESCWA-BGR based on Ministry of Irrigation in the Syrian Arab Republic, 2004.
(a) Lateral inflow + Recharge through precipitation + Irrigation return flow.
(b) Lateral outflow + Spring discharge + Base flow (river) + Abstraction.

Water Resources Management

Before the 1950s, the Qweik River was the main source of water for the city of Aleppo.[21] However, the regulation of the river (construction of dams, channels and diversions) and the over-exploitation of groundwater resources have resulted in the river and its tributary springs running seasonally dry.[22]

Today, the Qweik River is partly used for irrigation purposes, posing potential health hazards to consumers of cultivated vegetables that have been irrigated by polluted Qweik water.[23]

DEVELOPMENT & USE: TURKEY

The areas adjacent to the river on the Turkish side of the border are used for agriculture. Several water diversion and land irrigation projects have been implemented since the 1970s. There are also two dams on the Qweik: the Seve Dam and the Konak Dam. Both dams were constructed for irrigation purposes (Table 5).

DEVELOPMENT & USE: SYRIA

The Qweik River in Syria serves domestic, industrial and agricultural purposes. However, its use patterns have changed in recent decades.

Historically, the Qweik was Aleppo's main source of water, but the city's exponential growth over the last 60 years has severely affected the flow of the river, reducing it to a trickle of concentrated wastewater.[24] In a bid to address this worsening problem, the Syrian Ministry of Irrigation explored various options and launched a project in 2006 that included the construction of a canal that brings Euphrates water from Lake Assad to the Qweik River.[25] This canal receives 4 m^3/s of water from the Al Babeeri pumping station which distributes a total of 90 m^3/s of water from Lake Assad to various irrigation schemes. The Qweik River has thus been restored in Aleppo, with water filling the riverbed since 2009. While the bulk of water is released into the river to improve its quality, 1 m^3/s is used in the Sheikh Najjar industrial area which houses local businesses and light manufacturing.[26]

The water of the Qweik has also been used to supply a fruit canning industry at Idlib, two cement plants, a glass factory and a sugar plant.[27]

Large-scale irrigation in the Qweik Basin started around 1960 when the Syrian Government constructed the Shahbaa Dam close to the village of Maara. Ever since, the dam has supported part of the area's irrigation needs and domestic supply to adjacent villages. It is also used for flood control purposes (Table 5). In addition, a total area of 20,814 ha is irrigated in the Qweik Valley. In summer, 43% of this area is irrigated using 133 MCM of surface water; in winter, 31% of the area is irrigated using 26 MCM.[28] However, as the riverbed has also become a wastewater drainage channel, water quality has deteriorated, making it unsuitable for agricultural use.

WATER QUALITY & ENVIRONMENTAL ISSUES

Formerly a source of freshwater, the Qweik River currently acts as a carrier of wastewater generated in the city of Aleppo and its suburbs.[29] Water pollution is obvious both upstream and downstream of Aleppo, with households

Table 5. Dams in the Qweik Basin

COUNTRY	NAME	COMPLETION YEAR	CAPACITY (MCM)	PURPOSE[a]	BACKGROUND INFORMATION
Turkey	Konak (Goleti)	2006	..	I	-
	Seve	2005	..	I	Located on the Sinnep, a tributary of the Qweik.
Syria	Shahbaa	1968	12	FC, I	The dam is only operational during flood periods.

Source: Compiled by ESCWA-BGR based on General Directorate of State Hydraulic Works in Turkey, 2009; Radwan, 2006; Ministry of Irrigation in the Syrian Arab Republic, 2011; BGR and ACSAD, 1984.
(a) Irrigation (I) and Flood Control (FC).

and industries along the Qweik River directly discharging wastewater and untreated industrial waste into the river.[30] In addition, the Aleppo wastewater treatment plant that was built in 2002 discharges insufficiently treated effluents into the river.[31] The river thus carries a mix of domestic-industrial, treated-untreated wastewater that has been used for irrigation for over 25 years.[32] During the agricultural growing period, all sewage water is used for crop irrigation, amounting to 142-164 MCM/yr. In winter, the water is routed to Sabkhat al Matekh, where it evaporates or infiltrates into the subsurface.[33]

Water quality tests on the Qweik River in peri-urban Aleppo in 2009-2010 have shown extremely high levels of Total Phosphorus (TP), Total Nitrogen (TN), Biochemical Oxygen Demand (BOD) and faecal coliform bacteria, as well as a salinity (Electrical Conductivity) value exceeding the international guidelines for irrigation (Table 6).[34] Moreover, they also revealed high concentrations of heavy metals in the water, especially chromium (Cr) stemming from Aleppo's tannery industries.[35] This has resulted in crop contamination:[36] according to estimates, an area of about 20,000 ha around the city is irrigated with insufficiently treated wastewater.[37] The new canal that was completed in 2009 diverts Euphrates River water to the Qweik River in order to improve its quality during the summer months (mid-April until end of August).[38]

The contamination of the Qweik River also poses a risk to groundwater resources, as it runs along a geological fracture zone with high permeability. Pollutants contained in the wastewater are therefore likely to be leached to the groundwater through excess irrigation water from areas where insufficiently treated effluents are used, and where irrigation drainage systems are missing.[39]

Table 6. Mean salinity, nutrients and biological indicators in the Qweik River (2009-2010)

	SALINITY	NUTRIENTS		BIOLOGICAL INDICATORS	
	EC (µS/cm)	TP (mg/L)	TN (mg/L)	BOD (mg/L)	Faecal coliform (cfu/100ml)
Mean	..	7.2	38	182	..
Range	1,000-1,500	5-12	22-54	..	1,600,000-10,900,000
Guidelines[a]	<700 (irrigation)	0.075	2-6	3-6	0 (drinking water) 1,000 (irrigation) 10,000 (bathing)

Source: Compiled by ESCWA-BGR based on Sato et al., 2010; Sato et al., 2012.
(a) For further information on the different water quality parameters and their respective guidelines, see 'Overview & Methodology: Surface Water' chapter.

Agreements, Cooperation & Outlook

AGREEMENTS

There is no basin-wide agreement in place for the Qweik River, and the riparian countries have not addressed the water resources in the basin in any bilateral talks in recent years.

The last agreement was concluded in 1921 between Turkey (under the Turkish revolutionaries) and Syria (under the French Mandate) when the Qweik River had a much higher flow rate. The Franklin-Bouillon Agreement (Ankara Treaty)[40] states that the water of the Qweik is to be shared between Syria – especially to meet Aleppo's water needs – and Turkey, in such a way that is satisfactory to both parties. Further, it stipulates that if either party wishes to build any structure for use of the river, there should be an agreement to ensure the rights of both states.

COOPERATION

There is currently no cooperation between Syria and Turkey on the Qweik River.

OUTLOOK

Since 2009, the flow of the once-dry Qweik River has been restored in Aleppo, with water flowing through the city. Moreover, there are plans to construct several wastewater treatment plants in the basin in order to improve water quality and re-establish the possibility of recreational activities along the river.[41] However, with the ongoing crisis in Syria since March 2011 it is likely that most projects are currently on hold. Moreover, it can assumed that water infrastructure in the greater Aleppo area has been damaged.[42]

The Qweik in Aleppo, Syria, 2012. Source: Harout Minassian.

Notes

1. In Turkey, the river is referred to as the Balik River, which should not be confused with the Syrian Balikh, a tributary of the Euphrates. See The Institute of Mineral Research and Exploration of Turkey, 1962; Kolars and Mitchell, 1991, p. 111.
2. A closed (endorheic) basin does not naturally drain into the sea.
3. Sabkha is the Arabic word for salt-pan or clay flat.
4. Basin area was delineated based on topography and stream network (Lehner et al., 2008).
5. According to Wolfart, 1966, only the eastern part (ca. 4,000 km^2) of the Qweik catchment belongs hydrogeologically to the Aleppo sub-basin.
6. Wolfart, 1966; JICA, 1997.
7. Central Bureau of Statistics in the Syrian Arab Republic, 2005; Turkstat, 2010.
8. Central Bureau of Statistics in the Syrian Arab Republic, 2005.
9. It is, for example, unclear whether data is from locations upstream or downstream of Aleppo.
10. Kolars and Mitchell, 1991, p. 110-111. Radwan, 2006, speaks of a historic flow of approx. 3.1 m^3/s.
11. Kolars and Mitchell, 1991.
12. Ministry of Irrigation in the Syrian Arab Republic, 2004.
13. Radwan, 2006.
14. About 220 MCM/yr are imported from the Euphrates River, which is more than twice the 'natural' flow of the Qweik itself. According to Ministry of Irrigation in the Syrian Arab Republic, 2004, drinking water production for Aleppo was 625,000 m^3/d, of which around 8% is consumed outside Aleppo (and most likely outside the Qweik Basin). The water purification plant situated on the Qweik River has a capacity of approx. 200 MCM/yr. Due to technical problems, current actual capacity is only 127 MCM/yr.
15. Ministry of Irrigation in the Syrian Arab Republic, 2004.
16. Ibid.
17. Ministry of Irrigation in the Syrian Arab Republic, 2004, p. 83. The Al Bab or Al Dahab was a perennial endorheic river discharging south-east of Aleppo into Sabkhat al Jabboul before 1950. Today the river no longer flows perennially because of groundwater over-abstraction.
18. Selkhozpromexport, 1979.
19. JICA, 1997.
20. Ministry of Irrigation in the Syrian Arab Republic, 2004.
21. Kolars and Mitchell, 1991.
22. General Directorate of State Hydraulic Works in Turkey, 2010; ICARDA and IWMI, 2008.
23. Ministry of Irrigation in the Syrian Arab Republic, 2004.
24. Kolars and Mitchell, 1991; ICARDA and IWMI, 2008.
25. Ministry of Irrigation in the Syrian Arab Republic, 2010.
26. Ibid.
27. Kolars and Mitchell, 1991, p. 110.
28. Luijendijk, 2003.
29. ICARDA and IWMI, 2008.
30. Sato et al., 2012; Ministry of Irrigation in the Syrian Arab Republic, 2004.
31. Effluents discharged to the Qweik are generally untreated or treated with preliminary measures. Ministry of Irrigation in the Syrian Arab Republic, 2004.
32. Sato et al., 2010; Sato et al., 2011; Sato et al., 2012.
33. Ministry of Irrigation in the Syrian Arab Republic, 2004.
34. Sato et al., 2010; Sato et al., 2012.
35. Sato et al., 2010; Ministry of Irrigation in the Syrian Arab Republic, 2004; Sato et al., 2011. Chromium levels exceeded FAO water quality guidelines for irrigation.
36. ICARDA and IWMI, 2008; Ministry of Irrigation in the Syrian Arab Republic, 2004.
37. Ministry of Irrigation in the Syrian Arab Republic, 2004; Sato et al., 2012.
38. Ministry of Irrigation in the Syrian Arab Republic, 2010; ICARDA and IWMI, 2008; Sato et al., 2012.
39. Martin, 1999.
40. Hirsch, 1956.
41. Ministry of Irrigation in the Syrian Arab Republic, 2010.
42. The Epoch Times, 2012.

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PART II

GROUNDWATER

OVERVIEW & METHODOLOGY:

GROUNDWATER

Part II of the Inventory provides a comprehensive overview of shared (transboundary)[1] aquifer systems in Western Asia. This chapter defines the terminology used in the groundwater chapters and presents the methodology and approaches that helped identify, delineate, characterize and describe the shared aquifer systems in the region.[2] Each aquifer system is then categorized and briefly described. Finally, the structure of the groundwater chapters and the parameters used to characterize the aquifers and aquifer systems are outlined.

Definition of Terminology

On 11 December 2008, the United Nations General Assembly adopted resolution 63/124[3] on the Draft Articles on the law of transboundary aquifers in response to growing international concern about the use and protection of shared groundwater resources. The terminology used in the Inventory is based on the definitions used in that resolution and in the International Hydrogeology Glossary published by the United Nations Educational Scientific and Cultural Organization (UNESCO). The following key terms are widely used in the Inventory's groundwater chapters:

Aquifer: A permeable water-bearing geological formation underlain by a less permeable layer plus the water contained in its saturated zone. This implies that an aquifer could encompass part or parts of a formation. An aquifer also includes the unsaturated part of the permeable formation, although the description of hydraulic parameters such as transmissivity and storativity refer to the saturated part of the aquifer.

BOX 1

Data Availability and Implications

As explained in 'Introduction to the Inventory', information for the chapters was collected from various sources. Data and information on (shared) aquifer systems available to the public is often outdated, obsolete, contradictory or of different nature and scale. Some information, especially recent data on large aquifer systems that cross the political borders of several countries, is classified in national databases and unpublished reports to which the ESCWA-BGR team did not have access. The Inventory's Country Consultation process and consultation with experts produced only a limited amount of new data. This has affected the breadth and scope of the Inventory, especially in the area of water use and abstraction where the literature provides limited information.

The descriptions and findings contained in the Inventory should therefore be understood as the best possible approximation, based on the information available to the ESCWA-BGR team and in view of the overview character and regional scale of this desk study. The aim is to provide a starting point for future technical deliberations on shared aquifer systems in Western Asia among riparian countries and within the expert community. Rigorous scientific referencing and comprehensive bibliographies in each chapter aim to facilitate a continued debate.

Wadi Rum, Jordan, 2010. Source: Anouk Pappers.

Aquifer system: A series of two or more aquifers that are hydraulically connected. Aquifer systems are defined by continuity and characteristics rather than by the origin of the aquifer material. They may therefore be made up of several lithologies and stratigraphic units.[4]

Shared aquifer/Shared aquifer system: An aquifer or aquifer system that extends across political borders. The terms transboundary aquifer/transboundary aquifer system are commonly used synonyms.

Aquitard: A formation of semi-pervious rock that can store water. It can also transmit enough water to be significant in the regional migration of groundwater, but not enough water to supply individual wells. It retards but does not totally prevent the flow of water to or from an adjacent aquifer.

Aquiclude: A saturated bed, formation or group of formations which yield inappreciable quantities of water to drains, wells, springs and seeps.

Groundwater basin: A physiographic unit made up of one large aquifer or several connected or interrelated aquifers. The water in a groundwater basin flows to a common outlet and is delimited by a groundwater divide.

Other terms and concepts used in the Inventory are explained throughout the chapter.

Disi area, Jordan, 2009. Source: Andreas Renck.

Identifying Shared Aquifer Systems

Unlike rivers, which are visible linear features in the landscape, aquifers are three-dimensional structures hidden underground. This complicates the research process for the compilation of a groundwater inventory: a solid interpretation requires a wide spectrum of geological information, including geo-tectonics, geological structures, lithostratigraphy, geochemical and isotope data and groundwater dynamics. As a result, exact aquifer boundaries are often unknown and therefore not well defined. This is also the case in Western Asia, where regional hydrogeological specificities pose additional challenges to the identification and delineation of aquifer systems.

For instance, many of the region's major groundwater resources are located in deep geological strata and cover extensive areas, especially in the Arabian Peninsula. The massive water reserves contained in these aquifer systems have limited renewability (see section on Key Parameters below), and may form part of complex and partially inter-connected series of mainly confined aquiferous formations. The spatial extent and water-bearing characteristics of many of these formations are not well known. These deep aquifers are usually characterized by regional rather than local flow patterns and exhibit low natural flow gradients. Significant flow alteration may have occurred at local to sub-regional levels due to sustained abstraction and groundwater drawdown (Figure 1).

Moreover, not all parts of these aquifer systems can be considered exploitable due to poor water quality, technological limitations or inadequate saturation level. Riparian countries often do not recognize non-exploitable aquifers such as those with very high salinity levels.

The task of identifying distinct groundwater basins and defining them as groundwater management "units" at either a national or regional scale is challenging. In practice the definition of such a unit is scale-dependent, and differs in individual studies (i.e. using groundwater models) based on assumptions of boundary conditions or hydraulic connections for example. The question of hydraulic connectivity and how it affects the vertical and lateral definition of a shared resource is crucial in this context. Moreover, it is closely related to the concept of the aquifer system and the groundwater basin.

BOX 2

The Umm er Radhuma-Dammam as an Example of a Large Aquifer System in the Arabian Peninsula

The Umm er Radhuma-Dammam is the most extensive aquifer system in the Arabian Peninsula, covering a distance of 2,200 km from south-eastern Iraq to the coastal areas of Oman and Yemen (Map 2), and extending into eight Arab countries. The main geological aquiferous formations of the aquifer system (Umm er Radhuma, Dammam and Rus) vary in thickness, sequence and water-bearing characteristics but exhibit hydraulic continuity in several locations across the peninsula. Locally, the three formations exhibit significant lateral variations in lithology. For example, the Rus may be aquiferous in places while acting as an aquitard in others. Similarly, certain riparian countries no longer consider the Dammam an aquifer because the progressive decline of the water table (e.g. in Bahrain) or its hydraulic connectivity to sabkhas in desert areas (e.g. in Oman) mean that it is no longer exploitable.

Moreover, there may be a hydraulic connection to other formations, constituting an extensive and complex aquifer system equivalent to half the length of the Mediterranean Sea. While such an interpretation of a shared aquifer system may be of scientific value, it offers little guidance to the groundwater manager tasked with assessing or developing the resource across the aquifer area. In practice, groundwater abstraction from the Damman Formation in Iraq does not affect the status, dynamics or productivity of this aquifer system or any connected formation in Yemen and vice versa. This is why the Umm er Radhuma-Dammam Aquifer System has been divided into several sections for the purpose of this Inventory (see Chap. 14-16).

The region's specific hydrogeological setting gives rise to large sedimentary basins with extensive aquifer systems characterized by very low to low renewability, low flow gradients and confined conditions. Thus, an all-inclusive approach could lead to the delineation of vast and/or heterogeneous aquifer systems, in which hydraulic connectivity represents a theoretical construct that is of little practical relevance (Box 2).[5]

THE PROCESS

The process of identifying, delineating and describing shared aquifer systems in the Inventory can be broken down into the following steps:

1. Identifying shared aquifers in the literature

The first step was to list known shared groundwater resources in the study area and to gather information[6] to allow for further hydrogeological interpretation and delineation.[7] Based on the results of initial screening, additional research was carried out on shared or potentially shared aquifers using regional and national geological and hydrogeological maps,

geological cross-sections, stratigraphy tables, journal articles and studies.[8] The resulting list included a brief characterization of the identified shared aquifers and a corresponding bibliography.

2. Verifying shared aquifers vs. shared aquifer systems

This step aimed to ascertain whether water-bearing geological formations that extend across the region's political borders constitute shared aquifers or shared aquifer systems. The examination of vertical and lateral hydraulic linkages between shared aquifers and aquifer layers (often individual water-bearing geological formations) led to a better understanding of hydrogeological units in the area. Sets of interconnected aquifers or aquifer layers were combined into aquifer systems if the vertical and lateral hydraulic conditions allowed water flow between and across formations. Given the complexity of the region's hydrogeology and the general lack of data and information, this step was based to some extent on logical reasoning. In case of doubt, an exclusive rather than an inclusive approach was preferred; the significance of hydraulic connections and the interpretation of hydrogeological data in this Inventory remain open to discussion.

3. Dealing with issues of scale

During this step, the findings of previous steps were reassessed from a transboundary perspective in order to focus research and interpretation, and refine the delineation of shared aquifers and aquifer systems.

Many of the large aquifers and aquifer systems in the Arabian Peninsula extend into areas that are far removed from country borders and therefore not relevant from a transboundary perspective (see Chap. 12-13). Moreover, the hydraulic setting and groundwater dynamics at the extremities of such large regional aquifer systems may vary significantly. Structural features or groundwater divides may create different hydrogeological sections in the aquifer system. Extensive aquifer systems were therefore geographically divided into sub-units, which are referred to as sections. Sections that are relevant from a transboundary perspective are covered in separate chapters in the Inventory (see Chap. 14-16).

By contrast, the geology and structure in the folded and faulted zones of the Anti-Lebanon and the Taurus-Zagros Mountain ranges are highly complex. The aquiferous formations in these areas consist of small units that cross political borders in several places and generally discharge through springs. This makes it difficult to determine their hydraulic relationship and/or delineate their geographical extent across political boundaries. These units are grouped together in two chapters (Anti-Lebanon and Taurus-Zagros), without specifying whether they constitute aquifers or aquifer systems. These chapters follow a different structure, with a description of the overall hydrogeological framework conditions and the main aquifer formations. Where applicable, more detailed information is provided on individual, smaller groundwater basins.

Research for the Inventory also revealed that among the hundreds of wadis in the region some extend beyond political borders and are situated above an aquiferous formation or formations. These shared alluvial aquifers are a source of freshwater at shallow depth and replenish the underlying shared aquifer system. A brief description of the main shared alluvial aquifers is featured in box texts that are included in relevant chapters, as is the case for Wadi Najran in Chapter 11.

4. Approximating aquifer system boundaries

This step served to refine the delineation of each section of the shared aquifers and aquifer systems where necessary. In principle, it would have been preferable to delineate aquifers and aquifer systems on the basis of groundwater flow systems. However, the lack of available data and issues of scale meant that this was not always feasible. As regional groundwater divides were not available in many cases, groundwater flow information was used to approximate aquifer system boundaries.

Boundaries of hydrological basins that had been delineated in previous studies on the basis of surface water drainage were taken into account. However, the Inventory went beyond these boundaries in order to describe the aquifer system(s) that normally extend outside the basin. Structural features such as faults, graben structures, anticlines or synclines, which usually control groundwater flow, were then used to approximate groundwater boundaries where possible. In such cases, the main title of relevant chapters reflects the names of the aquifer system formations; the previous basin name (e.g. Wadi Sirhan Basin) still features as a subtitle.

If there was no previous basin name and the aquifer system is divided into different sections for the purpose of the Inventory, the main title reflects the names of the aquifer system formations and the subtitle refers to the geographical location name(s) of the sections (e.g. Sakaka-Rutba).

These approximations should be understood as a basis for further discussion rather than an absolute delineation. All area figures provided in fact sheets and chapter texts refer to this approximated delineation, except where otherwise specified.

5. Description of shared aquifer systems

During this final step, each of the shared aquifer systems, sections or basins was characterized with respect to hydrogeology, groundwater use, agreements and cooperation and each aspect was described within a standardized chapter template. Suitability for groundwater development, which is referred to as "exploitability" in the Inventory (see 'Key Parameters' below), was also analysed. The results of this analysis were used to further refine the section and/or basin delineation by excluding non-exploitable parts of the aquifer.

The Inventory team had intended to classify the aquifer systems featured in the Inventory, given that no such classification currently exists for the Western Asia region. There are a number of ways of classifying aquifers and aquifer systems using information on geological/geotectonic setting, lithology, age, importance based on total exploitable volume, importance based on population dependent on the resource or a combination of categories.[9] However, as the Inventory is descriptive and not evaluative, and as information on shared groundwater units in the region was limited, no such classification has been made. Moreover, due to the lack of data some shared aquifer systems in the region have not been covered in individual chapters (see below).

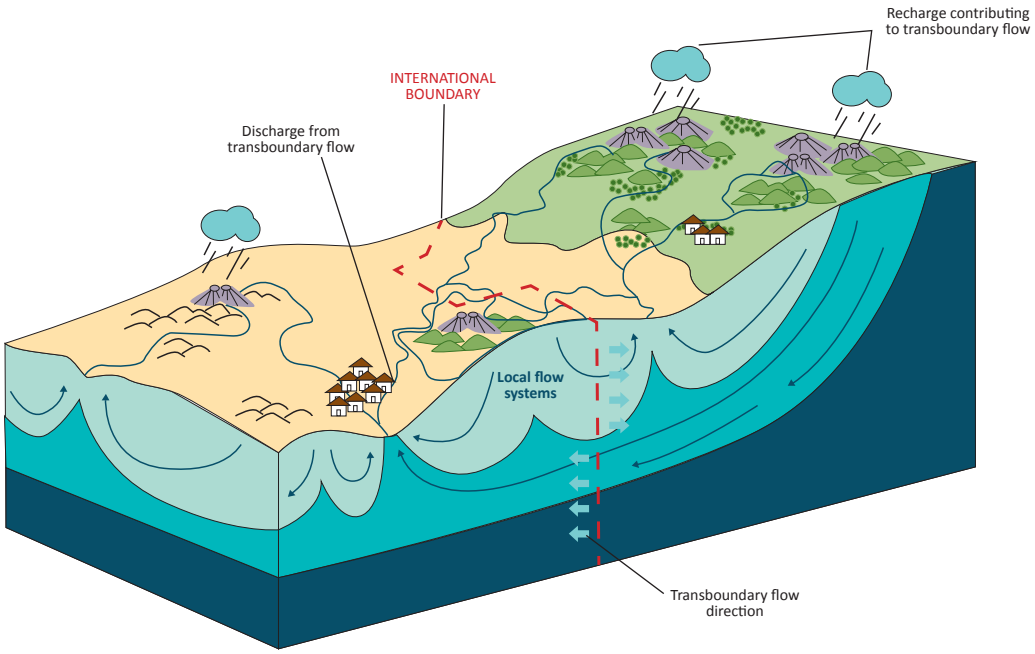
NOMENCLATURE

As shared aquifer systems in Western Asia have not been systematically delineated before, the systems do not have established names. Commonly used nomenclature could include locally known geological/geographical names, age and lithology. The nomenclature used in the Inventory is based on geological, hydrogeological and geographical information and aims to be descriptive. The name of most aquifer systems is based on the local name that riparian countries use to designate the main water-bearing formations based on lithology and age. The 'Basin Facts' table at the beginning of each chapter lists alternative names, which may also be based on lithology and/or age. Extensive aquifer systems that are divided into different sections or basins are generally designated through geographical names for the purpose of this Inventory. For instance, the Umm er Radhuma-Dammam Aquifer System (South) is situated in the Rub' al Khali Desert, which is an integrated part of Saudi Arabia and extends to Oman, UAE, and Yemen; however, reference to Rub' al Khali is meant to specify the geographical area where this section of the aquifer system is situated, but does not serve as an alternative name for the aquifer system itself.

In most cases, the nomenclature is determined as follows: Local name of the formation/age/lithology (Location): Geographic references.

However, some of the smaller aquifer systems are not divided into basins or sections and have the same name in all riparian countries.

Figure 1. Schematic diagram of a shared aquifer and its flow directions



Source: Redrawn by ESCWA-BGR based on Puri and Arnold, 2002.

Overview of Shared Aquifer Systems

The Inventory identifies 22 aquifer systems of which 17 are covered in separate chapters. These aquifer systems are located across the three Western Asia sub-regions: the Arabian Peninsula, the Mashrek and Mesopotamia (including Taurus-Zagros). Box 3 describes the regional geology of these areas. Table 1 lists the region's shared aquifer systems according to geological age: the Paleozoic, Mesozoic and Cenozoic eras.

Table 1. Shared aquifer systems in Western Asia based on geological age

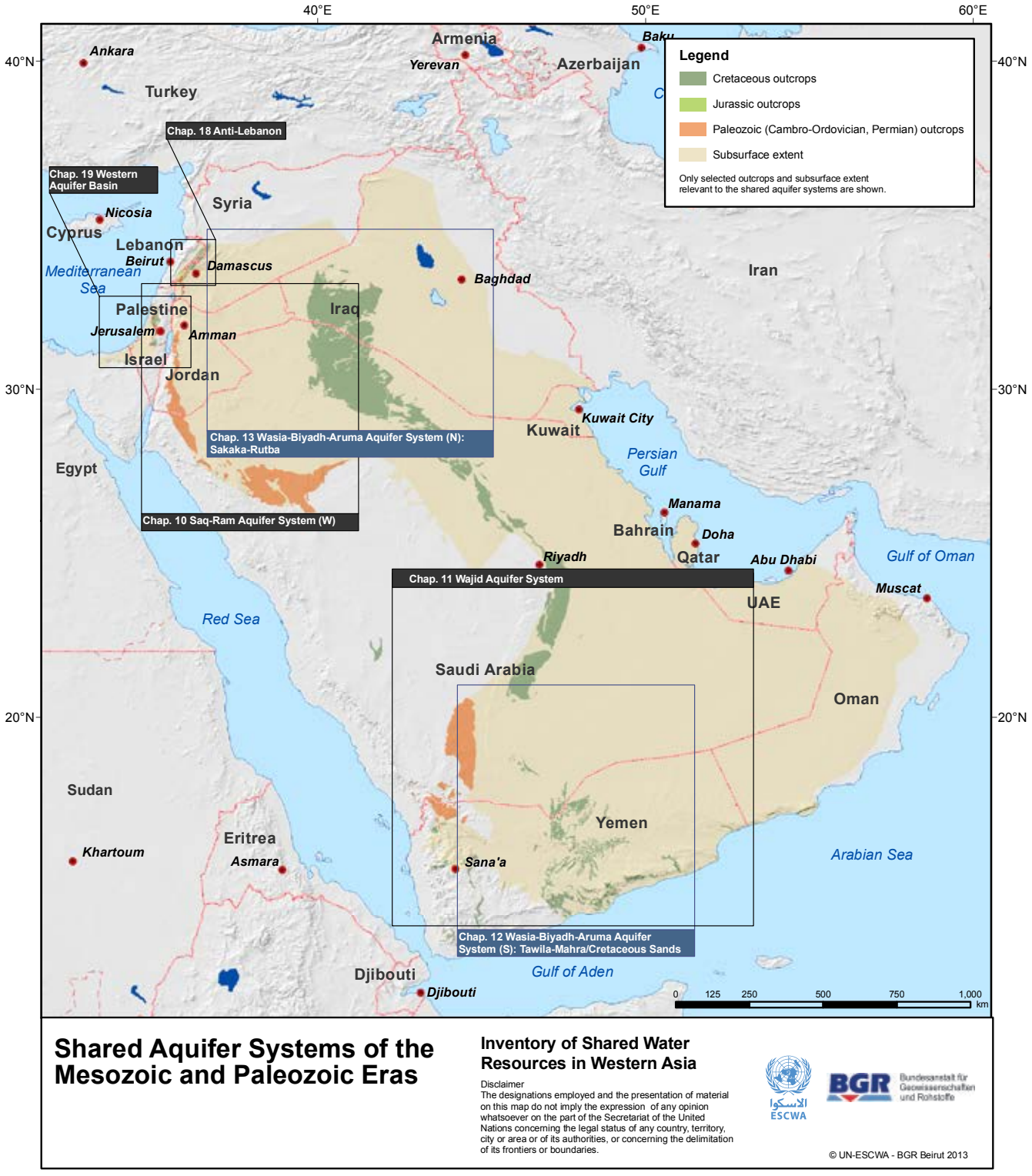
ERA	SHARED AQUIFER SYSTEM	CHAPTER	RIPARIAN COUNTRIES	ROCK TYPE	
Cenozoic	Umm er Radhuma-Dammam Aquifer System (North): Widyan-Salman	16	Iraq, Kuwait, Saudi Arabia	Fractured/karstic	Non-Renewable
	Umm er Radhuma-Dammam Aquifer System (Centre): Gulf	15	Bahrain, Qatar, Saudi Arabia	Fractured/karstic	
	Umm er Radhuma-Dammam Aquifer System (South): Rub' al Khali	14	Oman, Saudi Arabia, United Arab Emirates, Yemen	Fractured/karstic	
	Neogene Aquifer System (South-East), Dibdibba-Kuwait Group: Dibdibba Delta Basin	26	Iraq, Kuwait, Saudi Arabia	Fractured/karstic	
	Neogene Aquifer System (North-West), Upper and Lower Fars: Jezira Basin	25	Iraq, Syria	Mixed	Renewable
	Tawil-Quaternary Aquifer System: Wadi Sirhan Basin	17	Jordan, Saudi Arabia	Porous	
	Central Hammad Basin[a]	-	Jordan, Syria	Fractured/karstic	
	Basalt Aquifer System (South): Azraq-Dhuleil Basin	22	Jordan, Syria	Mixed	
	Basalt Aquifer System (West): Yarmouk Basin	21	Jordan, Syria	Mixed	
	Coastal Aquifer Basin	20	Egypt, Israel, Palestine	Porous	
	Eastern Aquifer Basin[a]	-	Israel, Palestine	Fractured/karstic	
	North-Eastern Aquifer Basin[a]	-	Israel, Palestine	Fractured/karstic	
	Jezira Tertiary Limestone Aquifer System	24	Syria, Turkey	Fractured/karstic	
	Western Galilee Basin[a]	-	Israel, Lebanon	Fractured/karstic	
	Taurus-Zagros[b]	23	Iran, Iraq, Turkey	Fractured/karstic	
Mesozoic	Anti-Lebanon[b]	18	Lebanon, Syria	Fractured/karstic	
	Western Aquifer Basin	19	Egypt, Israel, Palestine	Fractured/karstic	
	Wasia-Biyadh-Aruma Aquifer System (North): Sakaka-Rutba	13	Iraq, Saudi Arabia	Porous	Non-Renewable
	Wasia-Biyadh-Aruma Aquifer System (South): Tawila-Mahra/Cretaceous Sands	12	Saudi Arabia, Yemen	Porous	
	Ga'ara Aquifer System[a]	-	Iraq, Jordan, Saudi Arabia, Syria	Mixed	
Paleozoic	Saq-Ram Aquifer System (West)	10	Jordan, Saudi Arabia	Porous	
	Wajid Aquifer System	11	Saudi Arabia, Yemen	Porous	

Source: Compiled by ESCWA-BGR.
(a) These aquifer systems are not covered in stand-alone chapters.
(b) Aquifers in faulted and folded tectonic areas have been classified as one group. However, in practice they may represent more than one aquifer system.

PALEOZOIC AQUIFER SYSTEMS

Paleozoic aquifer systems are sandstone aquifers with very low to low renewability that only occur in the Arabian Peninsula (Map 1). The Saq-Ram Aquifer System (West), which is shared by Jordan and Saudi Arabia, is known as Ram, Rum, Disi or Disi-Mudawwara in Jordan and Saq or Saq-Tabuk in Saudi Arabia. It consists of several formations of Cambro-Ordovician age (see Chap. 10). The deposition of the formation comprising the Wajid Aquifer System (see Chap. 11), which is located in Saudi Arabia and Yemen, occured from the Cambro-Ordovician to the

Map 1. Overview Map of Mesozoic and Paleozoic shared aquifer systems in Western Asia



Source: Compiled by ESCWA-BGR.

Permian age. As a result, only its lower part, known as the Dibsiyah Formation, is correlatable with the Saq-Ram Aquifer System (West).

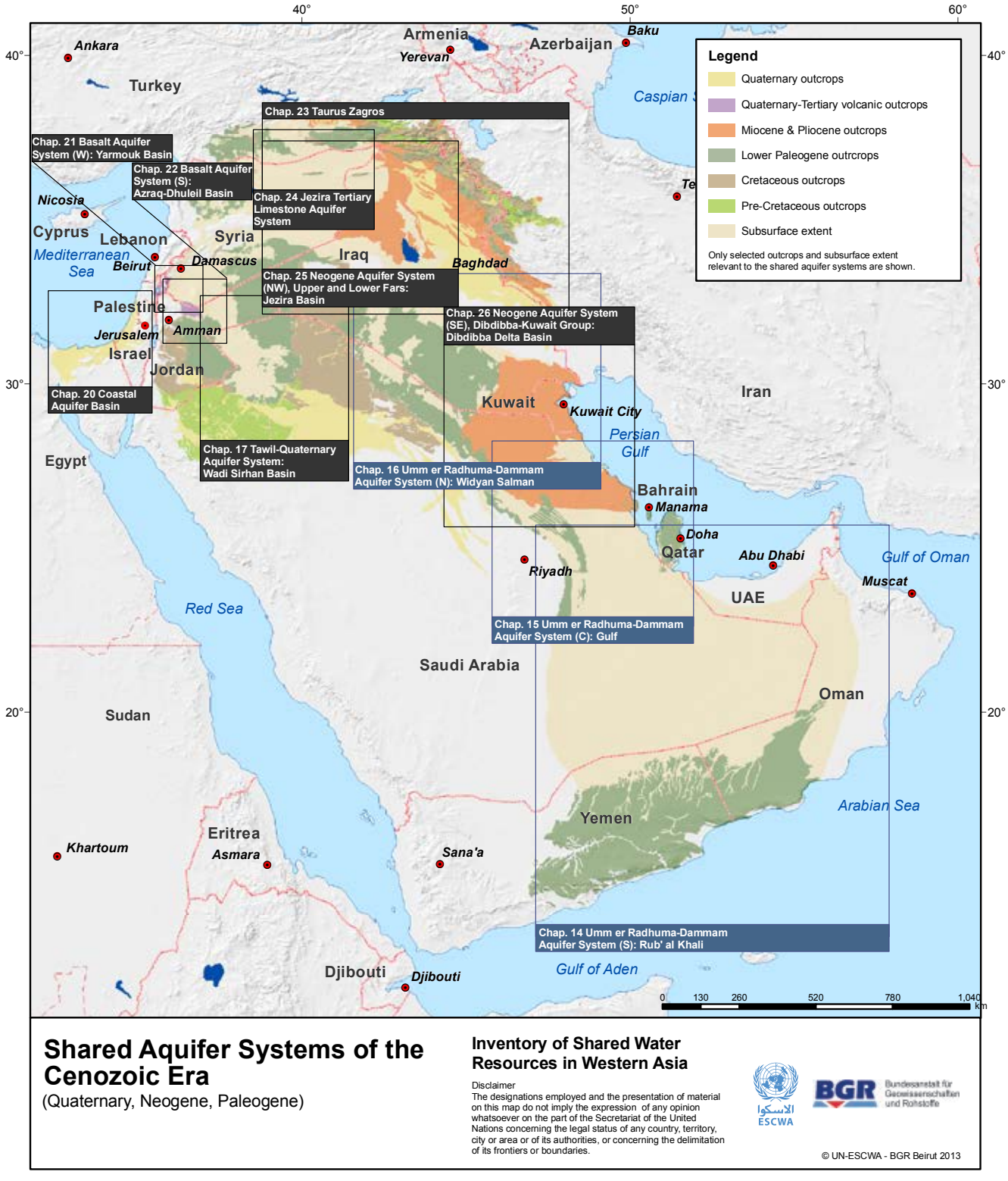
MESOZOIC AQUIFER SYSTEMS

Mesozoic aquifer systems are common throughout Western Asia (Map 1) and consist primarily of Cretaceous deposits.

In the Arabian Peninsula, the Wasia-Biyadh-Aruma Aquifer System consists mainly of sandstone and some carbonates with low renewability. It is divided into two shared sections:

In the north, the Sakaka-Rutba, shared by Iraq and Saudi Arabia and formed by the extension of the Wasia Formation (known as

Map 2. Overview Map of Cenozoic shared aquifer systems in Western Asia



Shared Aquifer Systems of the Cenozoic Era
(Quaternary, Neogene, Paleogene)

Inventory of Shared Water Resources in Western Asia

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Source: Compiled by ESCWA-BGR.

Sakaka) and the overlying Aruma Formation. The Biyadh Formation does not extend this far (see Chap. 13).

In the south, the Tawila-Mahra/Cretaceous Sands is shared by Saudi Arabia and Yemen. In this section, the Biyadh and Wasia Formations grade together with the Aruma Formation to form a thick sandstone unit known as the Cretaceous Sands in Saudi Arabia and Tawila-Mahra in Yemen, which correlate stratigraphically (see Chap. 12).

In the Mashrek, the dominant and most productive aquifers are the carbonate rocks ranging in age from Upper Cretaceous to Jurassic. They extend along the mountain chains and include the Anti-Lebanon, which is shared by Lebanon and Syria (see Chap. 18), and the Western Aquifer Basin, which stretches through parts of Egypt, Israel and Palestine (West Bank) (see Chap. 19).

The Taurus-Zagros (see also Map 2) is situated in Iran, Iraq and Turkey. It is made up of a limestone-dolomite sequence that covers large areas, mainly in the northern Taurus-Zagros Mountains. This group of aquifers also includes the Eocene-age Pila Spi Formation (see Chap. 23).

CENOZOIC AQUIFER SYSTEMS

Cenozoic aquifer systems are found across the region. They display significant differences in hydrogeological characteristics and geographical extent (Map 2).

As the most extensive aquifer system in the region, the Umm er Radhuma-Dammam extends across most of the length of the Arabian Peninsula. This system generally consists of three Paleogene (Paleocene-Eocene) carbonate formations: the Umm er Radhuma, the Rus and the Dammam. The Umm er Radhuma is the principal aquifer with the widest extent, while the Rus is the least important. The aquifer system is divided into three shared sections: the north-eastern section or Widyan-Salman (see Chap. 16) is shared by Iraq, Kuwait and Saudi Arabia; the eastern section or Gulf (see Chap. 15) is located in Bahrain, Qatar and Saudi Arabia; and the southern section or Rub' al Khali (see Chap. 14) extends across parts of Oman, Saudi Arabia, the United Arab Emirates and Yemen.

Another large aquifer system, composed of clastic Neogene formations, extends across most of the northern Arabian Platform. It is divided into two shared sections: the south-eastern section or Dibdibba Delta Basin (see Chap. 26) shared by Iraq, Kuwait and Saudi Arabia; and the north-western section or Jezira Basin[10] (see Chap. 25), which extends across parts of Iraq, Syria and Turkey and consists of Upper to Middle Miocene strata (gypsum, limestone and mudstone).

Other Cenozoic aquifer systems in the region are significantly smaller and/or highly complex. North-west of the three Umm er Radhuma-Dammam sections, the Paleogene deposits extend to the Hammad Plateau area where they are hydraulically connected with unconsolidated Neogene-Quaternary deposits or underlie

The Qandil Mountains, Iraq, 2010. Source: Stefan Jürgensen.

these deposits at greater depth. This is the case of the Tawil-Quaternary Aquifer System (see Chap. 17), which is shared by Jordan and Saudi Arabia. The Eocene- to Holocene-age clastic formations of the Coastal Aquifer Basin (see Chap. 20) are situated along the Mediterranean coast. This basin is shared by Egypt, Israel and Palestine (Gaza Strip). The Jezira Tertiary Limestone Aquifer System (see Chap. 24) that is situated in Syria and Turkey is of Middle Miocene age. Located in parts of Jordan and Syria, the Basalt Aquifer Systems in the Azraq-Dhuleil and Yarmouk Basins (see Chap. 21, 22) are completely different. They consist of complex volcanic sequences of Neogene-Quaternary age and older sedimentary formations (carbonates) of Upper Cretaceous age.

AQUIFER SYSTEMS NOT COVERED IN INDIVIDUAL BASIN CHAPTERS

A number of shared aquifer systems in the region have not been covered as stand-alone chapters in the Inventory for the following reasons:

(a) Insufficient data made it impossible to describe potentially shared aquifer systems (e.g. in the area between the city of Aleppo in Syria and Turkey), and certain transboundary linkages may not yet have been discovered.

(b) The scale of the Inventory was too large to allow for the description of local aquifer systems (e.g. the Western Galilee Basin and the North-Eastern Aquifer Basin) or aquifer systems that are only shared to a minor extent by some riparian countries (e.g. the Eastern Aquifer Basin)

(c) Certain larger aquifer systems change facies and are no longer considered aquifers (e.g Ga'ara Aquifer System)

(d) The system is not based on hydrogeological boundaries but on geographical basins including a number of different flow systems (e.g. Central Hammad Basin).

Table 2 lists the lithology and location of aquifers/aquifer systems/basins that have not been covered in individual basin chapters in the Inventory.

Table 2. **Lithology and location of shared aquifers not covered in individual basin chapters**

NAME	LITHOLOGY	RIPARIAN COUNTRIES
Central Hammad Basin	Basalt, carbonates and marl	Jordan, Syria
Eastern Aquifer Basin	Limestone	Israel, Palestine
Ga'ara Aquifer System	Sandstones/ carbonates	Iraq, Jordan, Saudi Arabia, Syria
North-Eastern Aquifer Basin	Predominantly limestone	Israel, Palestine
Western Galilee Basin	Limestone and dolomite	Israel, Lebanon

Source: Compiled by ESCWA-BGR.

Information in the Basin/Aquifer System Chapters

The Inventory identifies and characterizes shared aquifer systems in Western Asia, describing basic hydrogeology and groundwater use, environmental aspects, as well as agreements and cooperation projects between riparian countries. Each groundwater basin chapter follows the standard structure outlined in Table 3 and provides information on all relevant keywords, to the extent possible. As applied in the methodology, the information on hydrogeology is covered in two sub-headings, the first focusing on the characteristics of the rock bearing the water, and the second examining the status and dynamics of the groundwater.

Table 3. Chapter structure

HEADING	CONTENT
Summary	Executive summary, Basin facts.
Introduction	Location, Area, Climate, Population, Other aquifers in the area, Information sources.
Hydrogeology - Aquifer Characteristics	Aquifer configuration (geometry, depth, outcrop areas, subsurface extent), Stratigraphy, Aquifer thickness, Aquifer type (confined/unconfined) and Aquifer parameters (transmissivity, storativity).
Hydrogeology - Groundwater	Recharge, Flow regime (water levels, gradients, flow direction), Storage, Discharge (springs, vertical leakage), Water quality, Exploitability.
Groundwater Use	Groundwater abstraction and use (timeline of development, areas and sector of use, abstraction volumes), Groundwater quality issues (return flows, salinization, pollution), Sustainability issues (trends, over-abstraction).
Agreements, Cooperation & Outlook	Agreements (treaties, Memoranda of Understanding, ongoing negotiations), Cooperation (timeline, form, mechanism, issues of conflict), Outlook (main management issues, opportunities).

Source: Compiled by ESCWA-BGR.

KEY PARAMETERS

This section provides further detail on some of the parameters used to characterize aquifer formations, groundwater resources and groundwater use in the groundwater chapters.

Recharge and renewability

Renewability describes the rate of replenishment of the aquifer system through present-day recharge water. Present-day groundwater recharge is primarily dependent on the volume and timing of precipitation. Very limited recharge occurs if precipitation is below 75 mm/yr; direct recharge takes place when precipitation exceeds 350 mm/yr[11] (see 'Overview: Shared Water Resources in Western Asia', Figure 3). Indirect recharge through wadi beds is therefore often more important than direct recharge through soil infiltration in arid regions. While direct quantification of recharge is often hindered by a lack of hydrological and meteorological field data, indirect methods like isotopic signature, groundwater dating and sometimes chloride mass balance[12] in the groundwater can provide an insight into present recharge rates. In general, recharge via infiltration can only occur in the unconfined part of the aquifer system, while the confined part can only receive inflow through vertical or horizontal leakage.
For the purpose of the Inventory, renewability is categorized according to the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP)[13] into very low (0-2 mm/yr), low (2-20 mm/yr), medium (20-100 mm/yr) and high (>100 mm/yr). The Western Asia region is predominantly subjected to very low/low recharge rates of 0-20 mm/yr, though medium recharge does occur in mountainous areas such as the Taurus-Zagros and Anti Lebanon Mountain ranges.[14] Regardless of how they are used, aquifers that receive only limited recharge are vulnerable to groundwater mining.

Rock type

Rock type describes the aquiferous formations in terms of their water-bearing openings (i.e. primary voids vs. secondary fissures). All rock types exist in Western Asia:

Porous aquifer systems are dominated by primary voids (pores).They are mainly sandstones and alluvial sediments along river or wadi channels and in the foothill areas of the Arabian Peninsula.

Fissured/karstic aquifer systems are dominated by fractures and karstic features, resulting in high flow anisotropy. These are mainly carbonate rocks occurring in the eastern part of the Arabian Peninsula and in mountainous areas in the Mashrek and Taurus-Zagros regions.

Mixed pore/fissure aquifer systems contain mixed pores and fissures. Different types of rocks occur in relatively unstable areas in which sedimentation is interrupted by magmatic activities and/or volcanic events, mainly in the northern part of the region.

Table 1 above provides information on the rock types found in each of the identified shared aquifers and aquifer systems.

Aquifer type

The aquifer type indicates whether an aquifer that forms part of an aquifer system is unconfined, confined or semi-confined. In general, larger aquifer systems exhibit unconfined conditions at and around the outcrop areas and become more confined as the depth of the aquifer increases. Shallow aquifers are commonly unconfined and deep aquifers are confined. Unconfined aquifers have high storativity[15] as they release the stored water by draining the voids. The resulting drop in the water table is limited to a localized area. By contrast, confined aquifers have a low storativity and release water stored through matrix expansion and water compressibility. Hence, a change in piezometric head can be transmitted over a much larger distance, as it does not involve the physical movement of water molecules but is only a transmission of pressure. This is also relevant in the context of shared water management as the impact of abstraction in one country is potentially much greater in confined aquifers than in unconfined settings.

Exploitability

Exploitability is used to assess whether groundwater stored in an aquifer system is viable for use, based on water quality, technical feasibility and economic viability.

The presence of groundwater in an aquifer system does not necessarily imply that it can be readily abstracted and used. Economic viability and technical feasibility determine whether or not these resources are exploitable. Moreover, resources that are exploitable now may not be exploitable in the future if water tables continue to decline and groundwater quality deteriorates as a result.

Three parameters were used to determine the exploitability of aquifer systems in Western Asia: depth to top of aquifer, depth to water level[16] and water quality. The parameters were used as criteria to delineate exploitable areas within the identified aquifer systems, as explained below.

Depth to top of aquifer: Researchers who have worked in the region have applied a maximum depth to top of aquifer of 2,000 m.[17] The Inventory has adopted the same criterion and applied it to the upper formation of the geological units that constitute an aquifer system. The Middle East Geological Map Series (MEG maps) were used to determine the depth to the top of these formations.[18] For formations not covered in the MEG maps (Neogene and Paleogene), the top of the underlying Cretaceous formations is considered the lowest level at which they can be tapped. For example, if the top of the Cretaceous is less than 2,000 m bgl, then the exploitation of any younger aquifer overlying the Cretaceous is not considered limited by drilling depth.

Depth to water level: Some regional studies apply a maximum depth to water level of 250-300 m.[19] The Inventory sets the limit at 250 m, using the most recent data available from official sources wherever possible.

Water quality: Groundwater with a salinity of less than 2,000 mg/L TDS is usually desirable for exploitability. However, this type of water is rare in large parts of the region, particularly in the extensive shared aquifer systems of the Arabian Peninsula. Moreover, as the water is used in combination with desalination or to grow highly salt-tolerant crops such as date palms, brackish groundwater is also considered an exploitable resource. Hence, the Inventory applies a salinity level of 10,000 mg/L TDS as a limiting factor for the exploitability of aquifer systems.

In addition to the three parameters mentioned above, transmissivity[20] has been used in two cases (Umm er Radhuma-Dammam Aquifer System south and central sections) where the Umm er Radhuma Formation is discontinuous and/or unsaturated and can therefore not sustain production of economically viable water through well extraction.

Unfortunately, in many cases the information required to assess exploitability does not cover the whole aquifer system. Therefore, any reference to the extent and volume of the exploitable resource should be considered as an estimate.

Groundwater abstraction and use

Little is published on groundwater abstraction in the study region. In most Western Asia

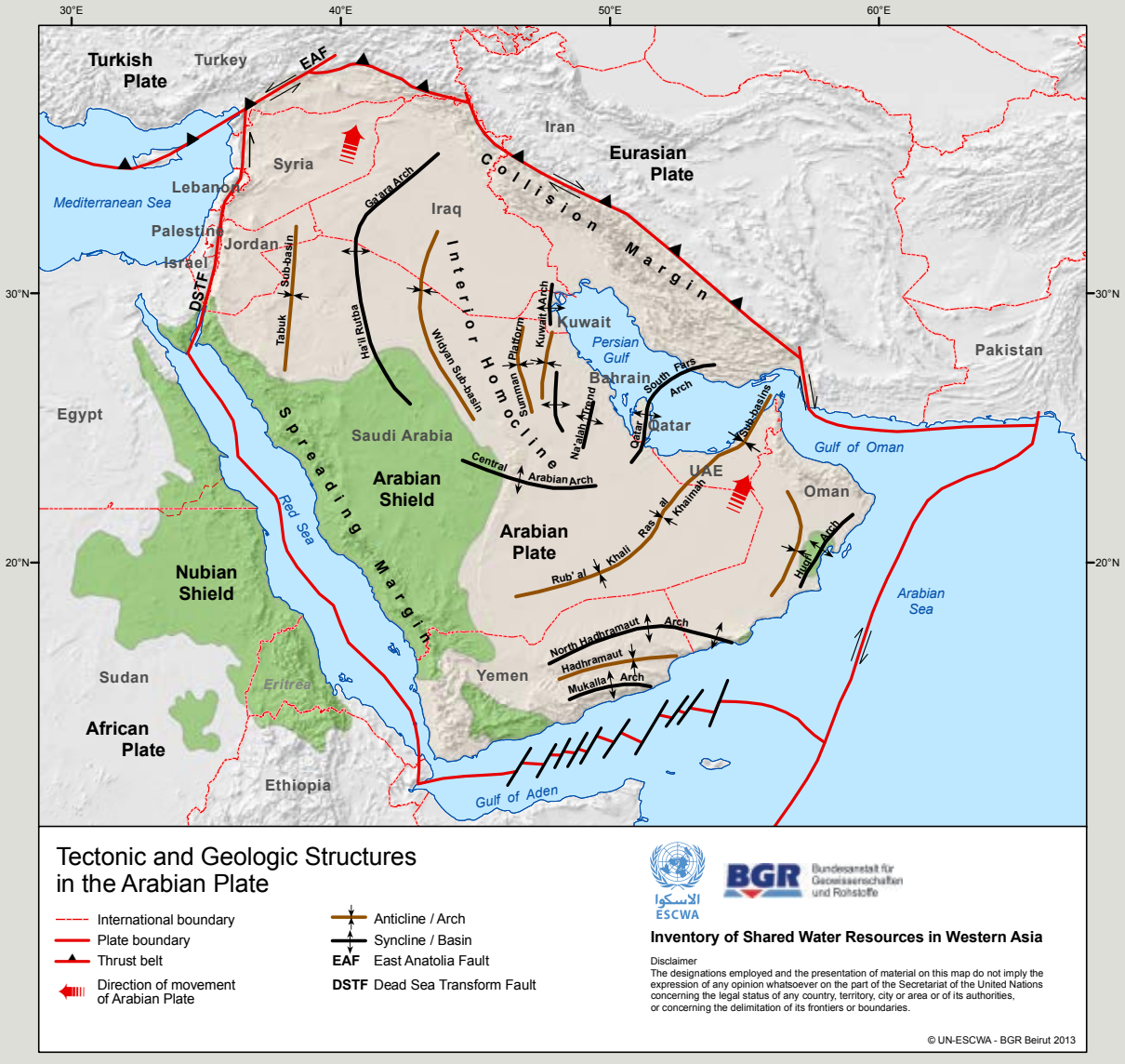
countries, groundwater abstraction is not measured and governmental data sets are usually approximations based on remote sensing, groundwater modelling studies and/or extrapolations from surveys. Official data on groundwater abstraction was only sporadically made available for the Inventory. Given that agriculture is by far the largest water consumer in the region, official agricultural statistics were sometimes used to provide historical context and highlight trends and the scale of irrigation and groundwater development. In arid desert areas in particular, there is a direct link between groundwater abstraction and agricultural development, as in the Tabuk, Al Jawf or Wajid areas in Saudi Arabia, where agricultural areas can easily be identified and rely entirely on groundwater irrigation due to the low annual precipitation rates. However, as agricultural statistics are usually based on administrative units, they could not always be precisely matched with the extent of agricultural areas within the identified aquifer systems. In this case, agricultural data only shows an overall trend for the administrative unit.

The most relevant agricultural parameters used in the Inventory are total crop area (which is practically equivalent to irrigated areas in dry areas) and yields and/or area of individual crops and/or crop groups (i.e. perennial and seasonal; cereals, fruits and vegetables).

BOX 3 Geological Setting

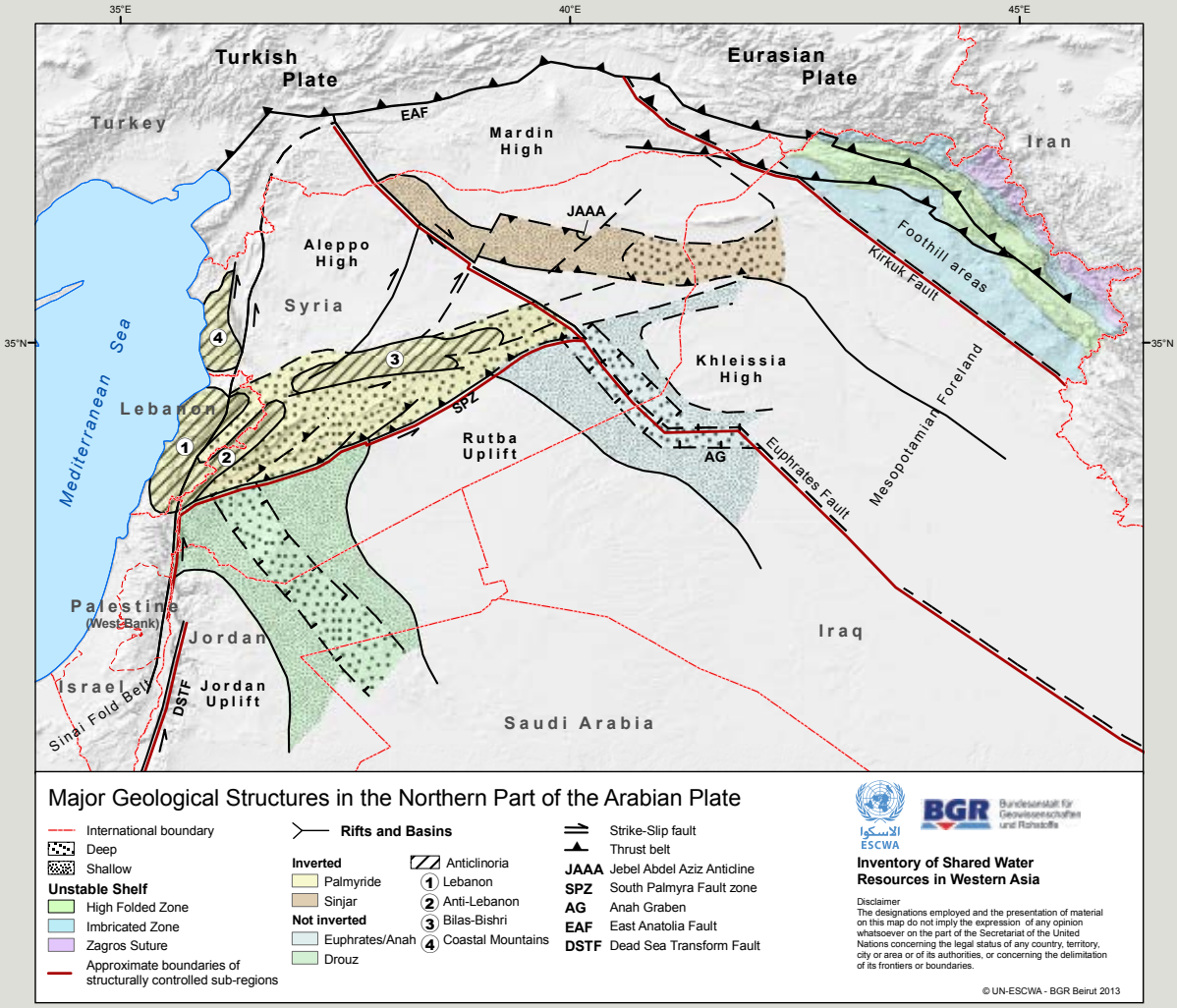
Geologically, the Western Asia region extends across the Arabian Plate, which has been moving incrementally from the African Plate to the north and north-east, where it collides with the Turkish and Eurasian Plates (Figure 2). This collision along the northern boundaries of the plate has led to the development of different tectonic zones and geological structures.

Figure 2. Tectonic and geologic structures in the Arabian Plate



Source: Compiled by ESCWA-BGR based on Edgell, 2006; Vincent, 2008.

Figure 3. Major geological structures in the northern part of the Arabian Plate



Source: Compiled by ESCWA-BGR based on Kazmin, 2002.

The southern boundaries of the Arabian Plate are passive margins, while the northern boundaries are active margins with lateral movements[21] and/or compression forces[22] (Figure 3). As a result, the sedimentation of thick deposits in the northern part was interrupted and the deposits were folded, compressed, metamorphosed, subsided, uplifted, laterally displaced and/or inverted in three main tectonic phases (Late Carboniferous-Early Triassic, Late Permian-Early Cretaceous and Paleogene).[23] The region is now dominated by rift-related structures like troughs and grabens, as well as high folded mountains[24] and tectonic forces (e.g. strike-slip transformations) which are still active today.

In addition to these geological and structural factors, the northern areas are influenced by the Siberian Anticyclone/Mediterranean regime and receive significantly higher precipitation than the southern areas. Based on this, four main sub-regions can be distinguished:

a) The **Arabian Peninsula**, which extends from the Palmyride Mountains in the north to the Indian Ocean in the south and from the Jordan Uplift in the west to the Rutba High in the east. The peninsula has been tectonically reasonably stable since the Pre-Cambrian era[25] and the Arabian Shelf in the eastern part provided the depositional basin (thickness: ≤7,500 m) for extensive sedimentary strata (continental and marine deposits, punctuated by evaporitic events) from the Paleozoic to the Neogene eras. Since they form large regional aquifer systems,[26] these sediments were only subjected to minor folding and faulting along extensive anticlines and arches, and the lithological character is maintained over large areas. The Arabian Shield (Pre-Cambrian Rocks, Basement) that covers the western part of the Arabian Peninsula has seen some uplifting.[27] It is characterized by local fissured aquifers that do not provide extensive flow into neighbouring countries. Hence, it is not covered in the Inventory. Chapters 10 to 17 cover the shared aquifer systems in the Arabian Peninsula.

b) The **Mashrek** extends west of the Dead Sea Rift and the South Palmyra Fault zone to the Mediterranean Sea, incorporating Israel, Lebanon, Palestine, the Sinai Peninsula, large parts of Syria and small parts of southern Turkey. The mountainous areas are characterized by high precipitation falling on extremely well-exposed and highly karstified carbonate rocks of Early Jurassic to Late Cenozoic era (e.g. Anti-Lebanon). Many of these fissured and complex aquifers supply springs that sustain important river systems. The low-lying coastal areas, on the other hand, are more arid and are characterized by Cenozoic porous aquifer systems. Chapters 18 to 22 address the shared aquifer systems in the Mashrek.

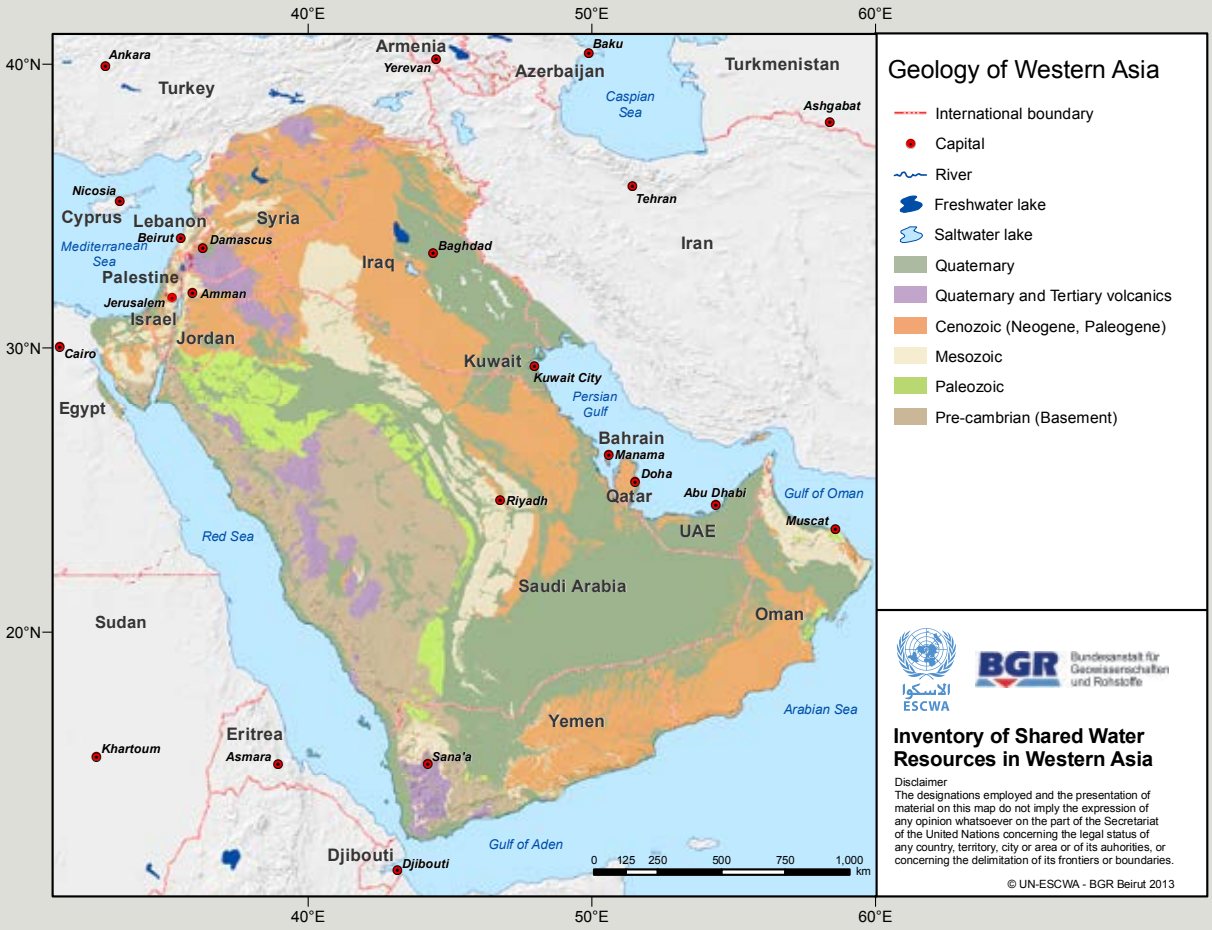
c) The **Mesopotamian Plain** is bounded by two major faults, the Euphrates Boundary Fault and the Kirkuk Fault (Figure 3). It has formed a depositional basin since the Neogene time. The basin extends across Iraq into Syria and Turkey and is characterized by Cenozoic clastic sedimentary aquifer systems. The shared aquifer systems in Mesopotamia are discussed in Chapters 24 to 26.

d) The **Taurus-Zagros** extends north-east of the Kirkuk Fault from Iran through Iraq into Turkey. This highly folded and faulted region features elevated areas made up of karstified Tertiary and older carbonates with many springs discharging good-quality water, and younger clastics that form isolated to semi-isolated aquifer systems (Chap. 23).

In conclusion, tectonic forces and structural settings have created significant differences in the geological and hydrogeological features of the main part of the plate (Arabian Peninsula) and the northern part.

Figure 4 shows that the western part the Arabian Plate, which is tectonically more stable, exposes Pre-Cambrian-age rocks, whereas the geological formations in the eastern part are younger. The youngest sediments, including volcanic outcrops, are exposed in the northern part of the Arabian Platform, in the highly faulted and tectonically active area.

Figure 4. Geological map of the Arabian Plate



Source: Compiled by ESCWA-BGR based on USGS, 2004.

Notes

1. The terms "transboundary" and "shared" are used interchangeably in the Inventory. See 'Overview: Introduction to the Inventory', Box 1 for more information.
2. Only shared aquifer systems on the Arabian Plate (i.e. the western part of Western Asia) feature in the Inventory; those on the African Plate are not addressed. See 'Overview: Shared Water Resources in Western Asia' for more information.
3. This resolution is based on the draft articles of the law of transboundary aquifers prepared by the International Law Commission (United Nations General Assembly, 2008).
4. An aquifer system may include aquitards and confining beds (UNESCO, 1978).
5. Direct transboundary impacts may involve measurable physical flow of water or the propagation of groundwater pressure changes across boundaries as well as the induction of water quality changes through spreading of pollutants via mass flow or diffusion, or other chemical alterations such as upconing of saltwater, seawater intrusion etc.
6. Initial data collection was based on existing regional compilations including ACSAD, 1983; Khoury and Droubi, 1990; UN-ESCWA, 1990; UN-ESCWA and BGR, 1999 and Alsharhan et al. 2001.
7. Previous investigations (e.g. ACSAD-UNESCO, 1988) have used the geographical extent of specific geological formations to delineate aquifers across the Western Asia region.
8. Ministry of Agriculture and Water in Saudi Arabia, 1984; ACSAD and UNESCO, 1988; Van der Gun and Ahmed, 1995; Edgell, 1997; Jassim and Goff, 2006 among others.
9. Van der Gun, 2008 describes a hierarchical system (region – province – aquifer/aquifer system) that is considered useful for collecting information on global groundwater regions.
10. Also known as Fatha-Injana Aquifer System.
11. Lloyd, 1997.
12. Allison et al., 1994.
13. Struckmeier and Richts, 2008.
14. In most cases, recharge estimates in mm/yr were not available. Instead, estimates were based on models for individual sub-areas and estimates from isotope studies, among others. Category designations were therefore somewhat arbitrary.
15. Storativity or the storage coefficient is a physical property that characterizes the capacity of an aquifer to release groundwater. It is defined as the volume of water released per unit change of hydraulic (pressure) head. Storativity is a dimensionless quantity, and ranges between 0 and the effective porosity of the aquifer. In confined aquifers, storativity is usually much less than 0.01. There are various other related parameters to characterize aquifer storage properties, such as specific storage, specific yield or specific capacity (Freeze and Cherry, 1979).
16. E.g. Abunayyan Trading Corporation and BRGM, 2008.
17. Ibid.
18. Christian, 2000.
19. E.g. Abunayyan Trading Corporation and BRGM, 2008.
20. The rate at which groundwater flows through an aquifer and is dependent on the hydraulic conductivity and the saturated thickness of the aquifer.
21. Brew et al., 1999.
22. Jassim and Goff, 2006.
23. Ibid.
24. Ibid.
25. Powers et al., 1966.
26. Alsharhan et al., 2001.
27. Ibid.

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Chapter 10

Saq-Ram Aquifer System (West)

Saq-Ram Aquifer System (West)

EXECUTIVE SUMMARY

The Saq-Ram Aquifer System (West) extends on the surface from northern Saudi Arabia into Jordan. At present, it is exploited from the Tabuk Plain in Saudi Arabia to Wadi Rum in Jordan, in an area delineated in this Inventory as the Tabuk-Mudawwara-Disi area.

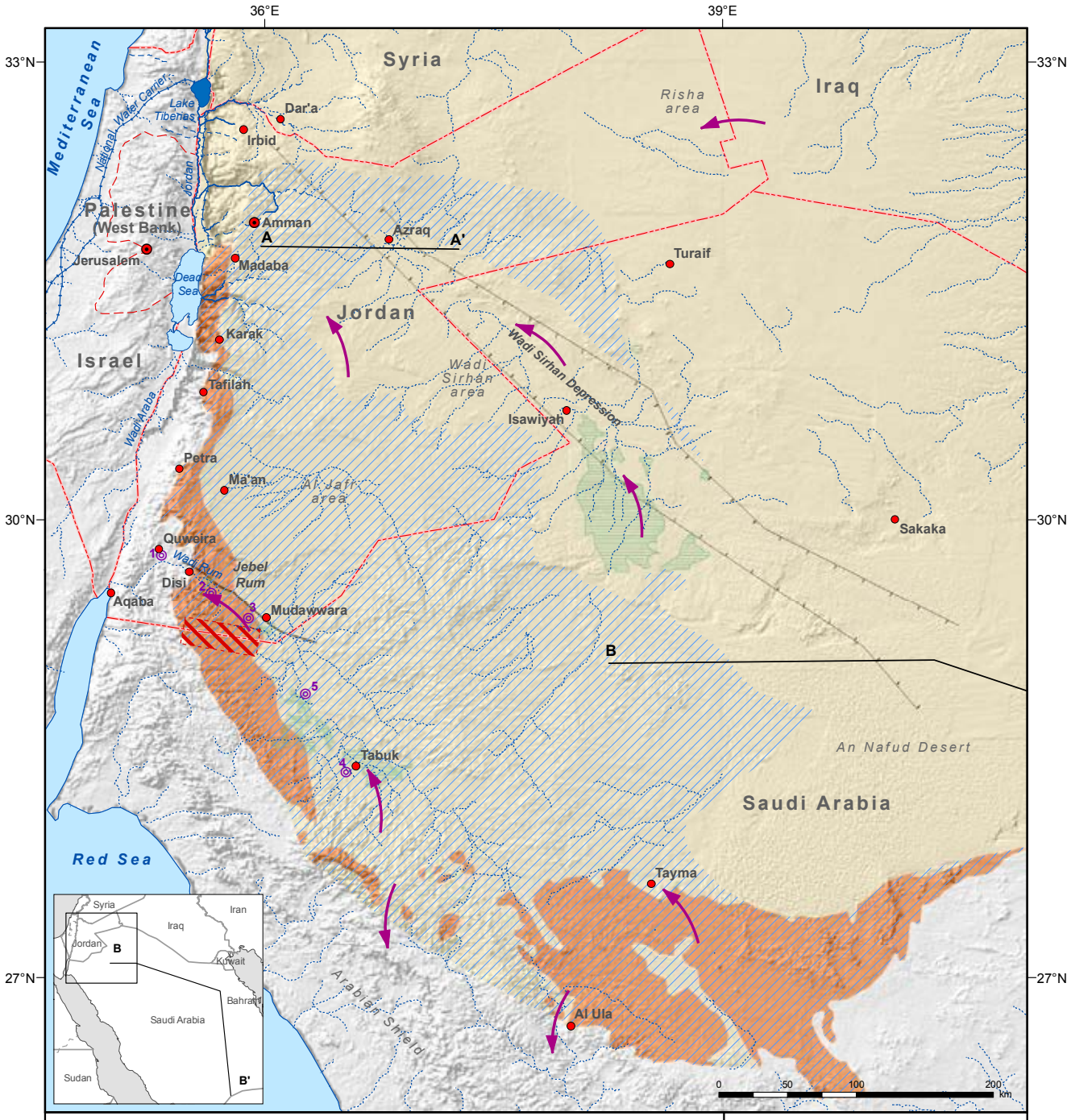
In Jordan, where the aquifer system is known as the Ram Group, it is widely exposed in the southern desert and is present in the subsurface throughout most of the country. Current abstraction in the Mudawwara-Disi area (Jordan) is 60 MCM/yr although higher values of 70-80 MCM/yr were reported in 2008.

In Saudi Arabia south of the Jordanian border (Tabuk area), the Saq lies directly on the Basement and dips gradually towards the north/north-east under less permeable formations. Groundwater abstraction in the Tabuk area has increased drastically from about 29 MCM/yr in 1983 to between 1,050-1,700 MCM/yr in 2004, mostly in the agricultural sector, while recharge remains at 3-10 MCM/yr. The heavy mining of the aquifer system has resulted in water level drops of up to 32 m/yr in the late 1980s in Saudi Arabia. There are indications that the exploitable part of the resource may be exhausted within 30-40 years, unless abstraction can be controlled on both sides of the border.

BASIN FACTS

RIPARIAN COUNTRIES	Jordan, Saudi Arabia
ALTERNATIVE NAMES	Disi, Disi Mudawwara, Ram, Rum, Saq, Saq-Tabuk
RENEWABILITY	Low (2-20 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Weak
ROCK TYPE	Porous
AQUIFER TYPE	Unconfined in shallow layers; confined or leaky in deeper layers
EXTENT	308,000 km^2
AGE	Paleozoic (Cambro-Ordovician)
LITHOLOGY	Sandstones
THICKNESS	250-700 m Eastern Jordan: ≥1,000 m Risha Area: 500 m
AVERAGE ANNUAL ABSTRACTION	Jordan: 90 MCM Saudi Arabia: >1,000 MCM
STORAGE	Jordan: 4-10 BCM Saudi Arabia: ~740 BCM
WATER QUALITY	Fresh (mostly <1,000 mg/L TDS)
WATER USE	Mainly agricultural. A rise in municipal and industrial use is expected.
AGREEMENTS	-
SUSTAINABILITY	Overexploitation due to agricultural development. Possible health risk due to high natural radioactivity (Ra).

OVERVIEW MAP



Saq-Ram Aquifer System (West)

- Capital
- Selected city, town
- International boundary
- Armistice Demarcation Line
- River
- Intermittent river, wadi
- Canal
- Freshwater lake
- Dike
- A A' Approximate location of geological cross-section
- Graben
- Saq-Ram outcrop
- Approximate subsurface extent of the aquifer formations
- Approximate extent of exploitable area
- Zone of agricultural development (selection)
- No drilling zone
- Direction of groundwater flow
- Water supply well fields
  - 1 Quweira
  - 2 Dubaydib
  - 3 Mudawwara
  - 4 Tabuk
  - 5 Uyanah

ESCWA

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

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The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

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Introduction

LOCATION

The Saq Sandstones in Saudi Arabia are separated by the vast aeolian Nafud Desert and can be divided into the eastern Qassim-Ha'il region[1] with natural groundwater flow towards the north-east, and the western Tabuk-Tayma region where the flow direction is generally northward.[2]

The lithostratigraphy of the Saq in the Tabuk-Tayma region has many similarities with the Ram[3] Sandstones in Jordan.[4] In this Inventory, the term Saq-Ram Aquifer System refers to the Cambro-Ordovician Sandstones, which extend from the Tabuk-Tayma region to the northern borders of Jordan and Saudi Arabia and beyond.[5] The aquifer system occurs along the eastern margins of the Arabian Shield where its outcrops can be seen on the surface, extending from central Saudi Arabia to the Dead Sea in western Jordan (see Overview Map).

AREA

The Ram Sandstones are found across the whole of Jordan (both in the subsurface and as outcrops), except in the Wadi Araba area. The Saq Sandstones cover a large part of Saudi Arabia from the Qassim area to the northern borders of the country (see 'Overview and Methodology: Groundwater' chapter, Map 1). The Saq-Ram Sandstones cover a total area of approximately 560,000 km^2, of which 82,000 km^2 are situated in Jordan and 478,000 km^2 in Saudi Arabia.[6] The shared part of the Saq-Ram Aquifer System (West) as delineated in this Inventory covers an area of approximately 308,000 km^2.

The Tabuk-Mudawwara-Disi area stretches from the Tabuk Plain in Saudi Arabia to the Wadi Rum Desert in Jordan, between the localities of Disi, Mudawwara and Jafr. This area is surrounded on two sides by aquifer outcrops which form spectacular mountains and high cliffs that rise to an altitude of about 800 m in the south[7] to 1,750 m near Jebel Rum in Jordan.[8] The Tabuk Plain is covered by gravel, resting directly on the sandstones, while further north in Wadi Rum the terrain changes to broad sand-covered valley floors.

CLIMATE

The aquifer system stretches across an arid terrain where mean annual temperature ranges between 20°C and 24°C. Mean annual precipitation over the entire area is estimated at 50-100 mm but reaches up to 365 mm around Karak.[9] The area along the southern border of Jordan commonly receives less than 50 mm/yr. Potential evaporation reaches more than 3,500 mm/yr[10] and actual evaporation is greater than 90% of all precipitation.[11]

POPULATION

The total population presently living in the Tabuk-Mudawwara area is less than 750,000 of which over 500,000 are in Tabuk Province in Saudi Arabia[12] and about 250,000 in Jordan (133,000 in Aqaba Governorate and about 116,000 in Ma'an Governorate). When the water conveyance system from the Disi-Mudawarra area to Amman (population of more than 2.3 million) is completed, more than 3.5 million people will depend on this aquifer system.[13]

OTHER AQUIFERS IN THE AREA

Other aquifer systems in the area include the Tawil-Sharawra, the Jubah-Jawf (Paleozoic) and the Secondary-Tertiary-Quaternary,[14] which consists of Upper Cretaceous to Quaternary Formations/Sediments and is exploited in Iraq, Jordan and Saudi Arabia.

INFORMATION SOURCES

The riparian countries did not focus on transboundary areas of the aquifer system until the 1980s and studies from the 1980s and 1990s cover the Saq in Saudi Arabia or the Ram (Disi)-Kurnub in Jordan. It is only in recent years that groundwater studies have become more focused on the Tabuk-Mudawwara-Disi area as a potential shared aquifer system. This chapter uses data from these studies and relevant regional data. Delineation of the Overview Map was based on several references from both riparian countries.[15]

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

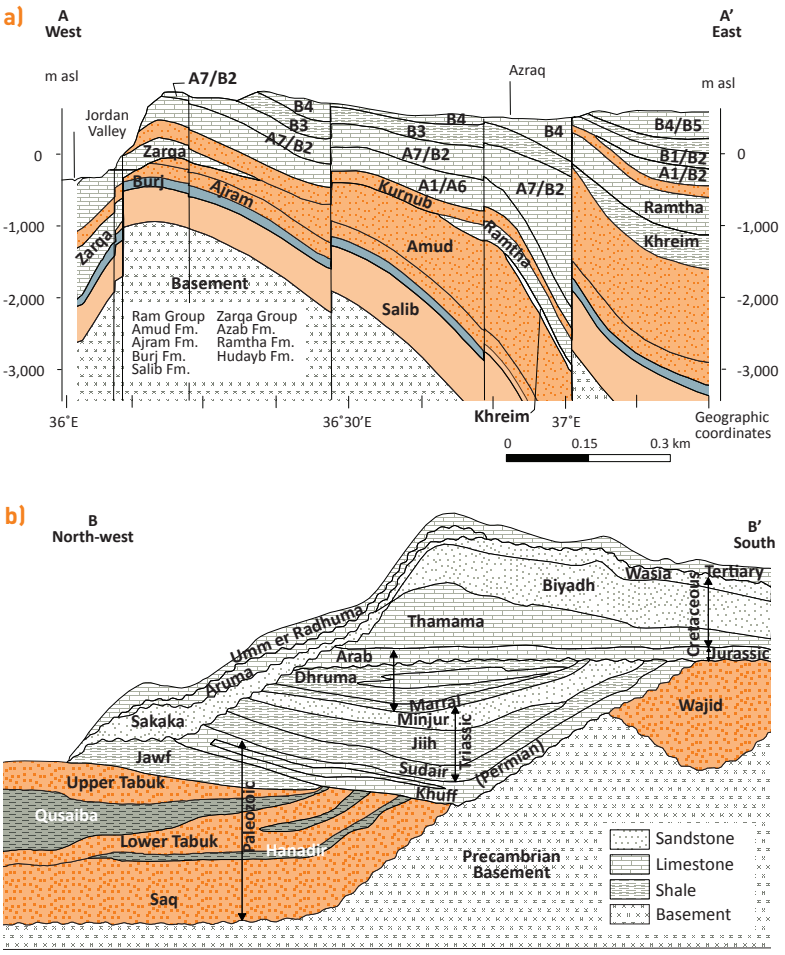
In Saudi Arabia, the Saq lies directly on the crystalline Basement (Figure 1b) and dips gradually towards the north and north-east under less permeable formations (see Chap. 13, Figure 2). During the 1980s the water level of the Saq was higher than that of the Kahfah Aquifer[16] and the Saq was being tapped in conjunction with the overlying Lower (Kahfah) and Middle (Quwarah) Tabuk[17] Sandstones in the Tabuk area. The situation has since then changed in this area and the Saq water table is currently at a lower elevation.[18] Further east and south, the Saq is separated from the overlying sandstones by the Hanadir Shale as shown in Figure 1a. South of the town of Tabuk and as far as the town of Al Ula, young basalts lie above the Saq outcrop.

Figure 1a shows the continuation of the Saq northward to Jordan. Here the sandstones of the Ram Group rest on the peneplaned Basement beneath the Khreim (equivalent to Qassim) east of Wadi Sirhan, whereas the Khreim/Qassim is in direct contact with the Kurnub Aquifer further west. The sandstones are widely exposed in the southern desert and are present at depth throughout Jordan except for the outcrop areas of the Basement in the extreme south-west. In general, the base of the group dips in north to north-easterly directions.[19] The group is confined by the Khreim and younger formations,[20] in the eastern and northern part of the country (Figure 1a). The lowest point of the base of the Ram Aquifer is located near Turaif in Saudi Arabia.[21]

STRATIGRAPHY

The Saq-Ram Sandstones constitute several beds that change in composition from continental and fluviatile at the bottom (Cambrian Period) to fluviatile, deltaic and coastal members further up (Early Ordovician Period).[22] These formations have been given different names over the years.[23]
Table 1 presents a correlation of the Saq-Ram Formations, citing the most recent names used in official studies from Jordan and Saudi Arabia.

Figure 1. a) Geological cross-section of subsurface stratigraphy of the Ram Aquifer System and overlying formations, b) position of the Saq Aquifer System in relation to major aquifer systems in Saudi Arabia



Source: Modified by ESCWA-BGR based on (a) Margane et al., 2002; (b) Alsharhan et al., 2001.
Note: The figure shows how the Saq Aquifer merges with the Lower Tabuk Aquifer and dips below the Qusaiba Shale as it extends northward towards Jordan. See Overview Map and index map for locations.

AQUIFER THICKNESS

In Jordan, the Saq-Ram Aquifer System thickens from the outcrop areas towards the Jafr and Sirhan Basins in the north-east. Average thickness is about 1,000 m, but increases to about 1,900 m in Jafr, over 2,250 m in the southern part of Wadi Sirhan,[24] and more than 2,500 m in the Risha area near the Iraqi border.[25] In the Tabuk area, the thickness of a typical profile of the Saq is 800 m and reaches more than 1,000 m in some places, but thicknesses of 250 to 500 m are also common.[26]

Table 1. Nomenclature and correlation of the Saq-Ram Aquifer System (West) (aquifer-aquitard) in Jordan and Saudi Arabia

JORDAN			SAUDI ARABIA		
PERIOD	UNITS (GROUP)	SUB-UNITS (FORMATION)	PERIOD	UNITS (GROUP)	SUB-UNITS (FORMATION)
Silurian	Khreim[a] (aquitard)	Sahl as Suwwan, Umm Tarifa, Trebeel, Batra and Alna.	Ordovician	Qassim (aquitard)	Handir, Ra'an-Quwarah, Zarqa-Sara-Hawban.
Cambro-Ordovician	Ram (aquifer)	Amud: sandstone.	Cambro-Ordovician	Saq (aquifer)	Saq: sandstone.
		Ajram: sandstone.			
		Burj: siltstone, dolomite, limestone, sandstone.			Burj:[b] limestone.
		Salib: arkosic sandstone, conglomerate.			Siq-Quweira: sandstone.

Source: Abunayyan Trading Corporation and BRGM, 2008; Barthelemy et al., 2010; Margane et al., 2002; Teimeh et al., 1990.
(a) In western Jordan, the Khreim disappears and the Ram is in contact with the Kurnub Sandstones.
(b) Found only at great depths without any surface exposures (Abunayyan Trading Corporation and BRGM, 2008).

AQUIFER TYPE

In general, the Saq-Ram Aquifer System (West) is unconfined in the outcrop areas and their surroundings and becomes a confined or leaky[27] aquifer towards the north and north-east as the sandstones dip below the rocks of the Khreim Group or the Permian to Jurassic Sequence (aquitards)[28] in Jordan and the Qusaiba-Hanadir Shales (aquitards)[29] in Saudi Arabia (Figure 1).

AQUIFER PARAMETERS

A large variation in hydraulic parameters is expected between confined and unconfined areas and towards the northern and north-eastern areas where the aquifer base reaches greater depths. This variation is reflected in the results of individual studies on the Saq[30] and the Ram.[31] Table 2 summarizes the results of a number of comprehensive studies that focused on the shared part of the aquifer.

Transmissivity values vary over a wide range for the entire aquifer system. However, it is clear that the values for the confined/leaky part are higher than those for the unconfined part. Storativity/storage coefficient values show relatively less variation.

The region of Al Ula, Saudi Arabia, 2012. Source: Amru Essam.

Table 2. Hydraulic parameters of the Saq-Ram Aquifer System (West)

AREA	TRANSMISSIVITY (m^2/s)	STORATIVITY	SOURCE
Tayma-Tabuk	$2.2x10^{-3}$-$6.5x10^{-3}$ AVG:[a] $4.5x10^{-3}$ (unconfined) $5.8x10^{-3}$-$4.3x10^{-2}$ AVG: $2.6x10^{-2}$ (confined)	$1.0x10^{-2}$-$4.0x10^{-2}$ (unconfined) $1.0x10^{-4}$-$2.0x10^{-3}$ (confined)	BRGM and CNABRL, 1985.
Tabuk-Mudawwara	$1.1x10^{-3}$-$1.7x10^{-3}$ $3.9x10^{-3}$ (Disi Basin) $1.4x10^{-2}$ (Jafr Basin)	$1.0x10^{-3}$-$5.0x10^{-3}$	Haiste Kirkpatrick International and Scott Wilson Kirkpatrick, 1995.
Tabuk-Mudawwara	$3.4x10^{-3}$ (unconfined) >$1.1x10^{-2}$ (confined)	..	Hydrogeological Services International (1990) as cited in Barthelemy et al., 2010.
Jordan	AVG: $8x10^{-3}$	$1x10^{-2}$-$3x10^{-2}$	Barthelemy et al., 2010.

Source: Compiled by ESCWA-BGR.
(a) AVG refers to average values.

Hydrogeology - Groundwater

RECHARGE

Potential sources of present-day recharge to the Saq-Ram Sandstones include:

- Runoff from the Basement in the south-west directly passing over outcrops of the permeable sandstones.
- Infiltration of runoff through wadi beds.
- Infiltration of rain falling directly on the sandstones, sand dunes or through overlying soils.
- Infiltration of excess irrigation water (locally, mainly in outcrop areas).

The occurrence of recharge to the Saq and Ram Sandstones in southern Jordan and north-western Saudi Arabia during previous pluvial periods is inferred from isotopic data, which suggests the recharge took place 10,000-30,000 years ago.[32] Combining isotopic data with field observations in wells along a regional flow line from the Quweira area to the Saudi border near Mudawwara indicated that the oldest waters are now emerging from deep wells in the Jordan Valley.[33] A field survey from 2002 also concluded that modern recharge is negligible (0.03 mm/yr) in areas with no outcrops and where rainfall is less than 75 mm/yr. However, present-day recharge to the sandstones occurs as evidenced by recharge mounds north/north-west of Amman[34] and the Wadi Araba Escarpment.[35] In such areas, recharge has been shown to increase with elevation from 3 to 11 mm/yr.[36] For the Saq, an average annual recharge of 2.5 mm was estimated for the Saq outcrops.[37]

FLOW REGIME

Until the 1980s, groundwater flow was directed northwards, starting from the Tayma-Tabuk area in Saudi Arabia, crossing the southern desert in Jordan, passing the Jafr Basin and converging across the Azraq Basin to the natural discharge zone, the low-lying Dead Sea.[38] There is no discharge to the north-east as the formation is too deep there, but one model showed flow from the Tabuk-Tayma area towards Wadi Sirhan[39] while other models simulated a flow from Wadi Sirhan westwards to the Dead Sea.[40] Modelled groundwater table contours of the Ram Sandstone Aquifer also indicate an inflow across the southern and eastern border from

Wadi Rum, Jordan, 2008. Source: Eileen Maternowski.

Saudi Arabia into Jordan.[41] Net flow calculations for the aquifer system indicated that downward leakage from overlying aquifers might take place[42] and might have increased due to the formation of cones of depression.[43] Depth to the water table varies from around 150 m near the outcrops and in Wadi Sirhan to over 400 m in central Jordan.[44] Increased abstraction since the 1980s has changed the general pattern of groundwater flow, with a significant effect in the Tabuk area, where substantial volumes of water are abstracted for agriculture purposes (see below). This has produced a very large and deep cone of depression, locally diverting the natural north-easterly groundwater flow direction,[45] reducing the assumed natural flow across the border to Jordan (140 MCM/yr) to negligible amounts.[46]

Near the border, the Kharawi basaltic dike forms a natural hydraulic barrier impounding the groundwater so that the flow is deflected in a south-easterly direction towards Saudi Arabia[47] or north-westerly direction towards the Wadi Araba.[48] Some 100 km south of Tabuk, flow is directed outward to the Shield areas. Further south-east, the Al Ula Valley also drains the Saq Aquifer to the Arabian Shield.[49]

Wadi Rum, Jordan, 2010. Source: Andreas Renck.

STORAGE

Saudi Arabia estimates the total volume of groundwater proven-reserve (storage) throughout the Saq Aquifer at 65 BCM, without specifying how much of this reserve is in the Tabuk area that falls within the Saq-Ram shared system.[50] Other investigations in Saudi Arabia state that with continued pumping at the current rate of 5,515 MCM/yr from the Saq and 1,050 MCM/yr in the Tabuk area, the exploitable reserve will drop from currently 75% to 38% between 2005 and 2055.[51] Available groundwater reserves in the Saq in the Tabuk area were estimated at 43 BCM in 1985, of which about 20 BCM is in the unconfined part, compared with 220 BCM in the Qassim area.[52]

In Jordan, estimates of available water reserve commonly range between 4 and 10 BCM with a maximum of 40 BCM.[53] Only $1x10^{-1}$MCM lies in the unconfined part of the aquifer, mainly within the southern desert zone.[54]

DISCHARGE

The main discharge zone for the aquifer system is the Dead Sea area where the Ram and Kurnub Groups form a combined aquifer complex. Groundwater level contour maps of the sandstones indicate a groundwater inflow from Saudi Arabia into Jordan of about 50 MCM in the Mudawwara-Disi area. Inflow increases to 140 MCM in the Dead Sea area due to additional inflow from the Kurnub.[55]

Natural discharge occurs in the form of springs and base flow in the deeply incised wadis that discharge into the Dead Sea. The occurrence of springs is restricted to areas along the eastern side of the Jordan Rift Valley, where average rainfall is around 150-200 mm/yr. Of a total annual spring discharge of 27 MCM in southern Jordan, 10 MCM (37%) is from the Ram Group.[56] These springs feed the wadis along the central and southern part of the Dead Sea (mainly Wadi Ibn Hammad, Wadi Karak, Wadi Feifa). Base flow in these wadis was estimated at around 25 MCM, with wide fluctuations from year to year.[57] While this could be due to a significant variation in annual recharge, it also indicates that in many cases direct runoff and base flow have not been separated properly. Base flow may therefore be even lower (see Chap. 17).[58]

Groundwater discharge also occurs in the Wadi Sirhan Depression and its northern extension into the Azraq Graben, as well as in the Shield areas as inferred from the flow lines (see Overview Map). Further discharge emanates from springs in valleys draining towards the Red Sea.[59] However, no data was available from these areas.

WATER QUALITY

The quality of water in the Saq-Ram Aquifer System (West) is generally good with Total Dissolved Solids (TDS) levels between 1,000 and 1,200 mg/L,[60] and dominated by calcium (Ca^{2+}) and bicarbonate (HCO_3^-). Salinity increases northwards along the flow path, from freshwater (200-400 mg/L TDS) in the Mudawwara-Disi area, to slightly brackish (1,000-3,000 mg/L) at the Dead Sea, where thermal springs are common. This salinity increase is most likely due to downward leakage from the overlying formations that contain highly saline waters (up to 35,000 mg/L), and the dissolution of evaporites contained in the aquifer.[61] In Saudi Arabia, salinity levels are slightly elevated in unconfined areas.[62] The chemistry of abstracted water in both the confined and unconfined areas appears to be largely unchanged over several years of operation.[63] Elevated concentrations of boron (B^{3+}) (>$5x10^{-1}$ mg/L) and selenium (Se^{4+}) (>$1x10^{-2}$ mg/L) have been detected in Saudi Arabia in about 37% and 26% of samples respectively.[64] Elevated concentrations of nitrate (NO_3^-) (25% of samples >50 mg/L) are mostly found in wells that tap unconfined aquifers at a depth of less than 150 m. However, contamination of confined aquifers through the wells themselves has also been observed.[65]

The occurrence of natural radionuclides is common in Cambro-Ordovician Sandstones, and their presence in groundwater within the Ram and overlying Khreim Group in Jordan and Saudi Arabia has been reported.[66] Radioactive elements might originate from the Basement, shale layers, phosphate-bearing formations[67] and cementing material in the sandstones such as iron (Fe^{2+}) and manganese (Mn^{2+}) oxides with other trace metal oxides, including those of uranium (U).[68] In general, a decrease in pH enhanced the dissolution of uranium and radium (Ra) from the matrix and thermal springs in the Dead Sea area, discharging waters that contain elevated concentrations of carbone dioxide (CO_2), hydrogen sulfide (H_2S) and radon (Rn) gases.[69] Radioactivity appears to be increasing as the water level declines, most probably due to an increase in vertical leakage from less permeable layers that contain higher concentrations of radioactive minerals.[70] The highest concentrations of radium isotopes in groundwater have been reported in confined areas,[71] which can be explained by the fact that the isotopes are most mobile under reducing conditions. Such groundwater might pose a risk to human health when threshold values for drinking water are exceeded.[72]

EXPLOITABILITY

The following criteria were used to delineate the exploitable areas of this aquifer system:

- **Depth to top of aquifer:** The depth to the top of the Cambro-Ordovician Formations generally increases from west to east. It is 2,000 m bgl in the vicinity of and inside the Wadi Sirhan Graben and in most areas east of the graben, except in the area of Azraq.[73] Hence drilling depth is a limiting factor to exploitability east of the Wadi Sirhan Depression, excluding the Azraq area.
- **Depth to water level:** Groundwater in the Tabuk area is around 200 m bgl.[74] Across the border, similar depths are found in the Mudawwara-Disi area and in the Azraq area where it can be as high as 62 m bgl.[75] Water level is therefore not a limiting factor.
- **Water quality:** The TDS of the groundwater is generally below 1,200 mg/L throughout the Saq-Ram Aquifer System (West)[76] and does not constitute any limitation to exploitability.

Based on the above, the Saq-Ram Aquifer System (West) is exploitable within a total area of 153,000 km^2 across the Jordanian-Saudi Arabian border as shown in the Overview Map.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

Jordan and Saudi Arabia started groundwater production from the Saq-Ram Aquifer System (West) in 1977 and 1983 respectively.[77]

In Jordan, groundwater abstraction from the Saq-Ram Aquifer System commenced at an average rate of 5.4 MCM/yr and the water was used for various purposes.[78] From 1981/82 onward, a total of 8-10 MCM/yr of groundwater was abstracted, mainly from a new well field for domestic use in the city of Aqaba. Abstraction increased to around 15 MCM/yr in 2001,[79] including municipal supplies for the village of Disi.

In 1982, a Jordanian farming corporation (Rum Farms) started exploiting the aquifer at a rate of 1.2 MCM/yr.[80] Abstractions for agricultural purposes rose quickly to reach 55 MCM in 2001, bringing total abstraction to 70 MCM.[81] Average annual abstraction from the Ram Aquifer oscillated between 70 and 80 MCM/yr until about 2008.[82] Abstraction was subsequently reduced to the current rate of 60 MCM/yr, of which 40 MCM/yr is for agricultural use, 15 MCM/yr for domestic use and the remaining 5 MCM/yr for industrial use.[83]

The following main farming corporations are currently licensed to operate in the Disi and Mudawwara areas in Jordan: Rum Company (5,000 ha), WAFA Farm (1,448 ha), ARICAT Farm (2,115 ha), Jordan Financing House Co. (1,481 ha) and GRAMCO Farm (1,638 ha), bringing the total licensed area to 11,676 ha.[84] An additional 11 MCM/yr are abstracted from the Lajjun area away from the border.[85] Further abstractions of about 100 MCM/yr are planned from the Dubaydib well field (Box 1 below).

The Jordanian Government announced plans to reduce groundwater abstraction for agricultural purposes after 2011, when its contract with the main agricultural companies expired,[86] thus stabilizing overall abstractions in Jordan.

Based on the above, the cumulative total abstraction from the Ram Group in the Disi and Mudawwara areas in Jordan between 1977 and 2011 is in the order of 1.7 BCM.[87]

Agriculture in the Disi-Mudawwara area, Jordan, 2009. Source: Andreas Renck.

In Saudi Arabia, the extensive Saq Aquifer is nationally very important and currently accounts for more than half of total nationwide groundwater withdrawals from major aquifer systems. Overall withdrawals from the entire Saq Aquifer were marginal until the 1960s but have risen sharply from approximately 890 MCM/yr in 1980 to 8,727 MCM/yr in 2005. Most of these withdrawals are from the Saq Aquifer itself (5,708 MCM or 65% in 2005). The remainder is abstracted from the overlying Tawil Aquifer (876 MCM or 10%) and the Secondary-Tertiary-Quaternary Aquifer Complex (1,388 MCM or 16%).[88]

More than 80% of all withdrawals from the Saq Aquifer take place in the eastern part (Qassim, Ha'il, Riyadh areas) at considerable distances from any national border. This Inventory focuses mainly on the western part of the Saq Aquifer, and more specifically on the Tabuk area which borders on the Mudawwara-Disi areas in Jordan. Practically all groundwater abstractions in the Tabuk area stem from the Saq Aquifer.[89] Significant abstraction also takes place in the northern Jawf area close to the Wadi Sirhan Graben. However these abstractions are mainly from other overlying aquifer systems (see Chap. 17).

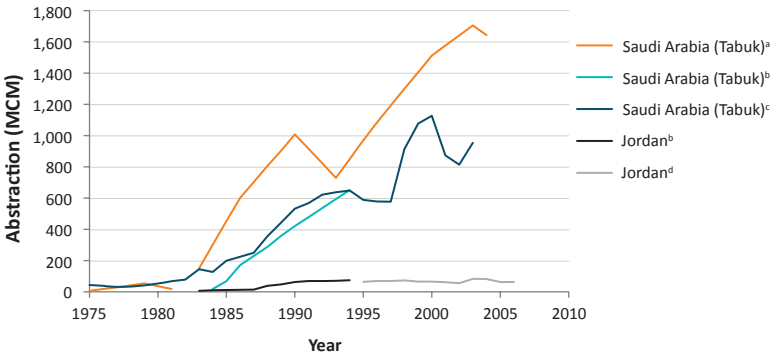
Total abstraction from the Tabuk area was limited until 1983 (less than 50 MCM/yr) but increased dramatically to between 1,053[90] and 1,700 MCM/yr[91] in 2004 (Figure 2).

According to an estimate from 2008, abstraction in the Tabuk area represented nearly 20% of total abstraction from the Saq Aquifer in Saudi Arabia (5,515 MCM/yr). An estimated 990 MCM/yr (94%) were used for irrigation and 63 MCM/yr (6%) for domestic and industrial water supply in the town of Tabuk and at the nearby Tabuk airbase.[92]

The main farming corporations in the Tabuk area include the TADCO Farms, which were established in 1986, and currently cover 35,000 ha[93] and the ASTRA Farms, which were established in 1979 and currently cover 3,200 ha. The latter company also owns the Rum Farms in Jordan[94] and a number of smaller concessions in Saudi Arabia.

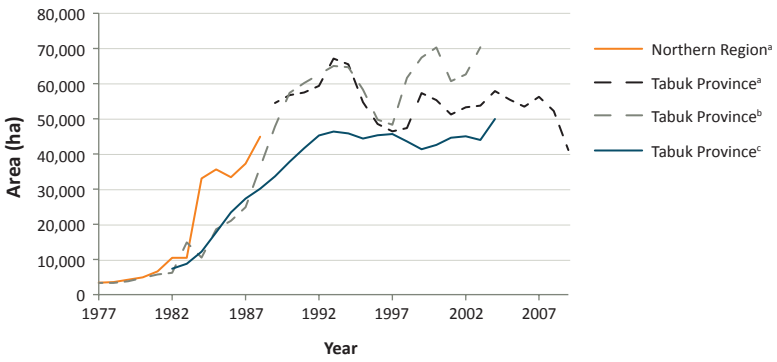
In 1995, lands irrigated by the aquifer system were estimated at 10,600 ha and 137,800 ha in the Mudawwara-Disi (Jordan) and Tabuk-Tayma (Saudi Arabia) areas respectively.[95] Official agricultural census data for Tabuk Province in Saudi Arabia[96] shows lower total crop area for the same year and indicates that total cropped area has remained stable since 1995 at around 50,000 ha. Similar results have been obtained from other remote sensing studies, as shown in Figure 3.

Figure 2. Historical abstraction from the Saq-Ram Aquifer System (West) (1975-2007)



Compiled by ESCWA-BGR based on sources below.
(a) Water Watch, 2006.
(b) Haiste Kirkpatrick International and Scott Wilson Kirkpatrick, 1995.
(c) Approximate numbers only. Data digitized from Abunayyan Trading Corporation and BRGM, 2008, p. 42, Figure 24.
(d) Data for the years 1995-2006 was taken from Barthelemy et al., 2010 by adding Mudawwara and Disi area abstractions.

Figure 3. Development of total crop area in the Tabuk region of Saudi Arabia (1977-2009)



Source: Compiled by ESCWA-BGR.
(a) Central Department of Statistics and Information in Saudi Arabia, 1977-2009.
(b) Water Watch, 2006.
(c) Abunayyan Trading Corporation and BRGM, 2008.

Despite the stabilization of the total cropped area, groundwater abstraction continued to increase after 1995 (Figure 2), possibly due to a shift towards increased summer cultivation and more water-intensive crops. According to the census, most of the irrigated crop area in the Tabuk region is used for temporary crops such as wheat, which covered 71% of the cropped area in 1989.

Wheat production declined sharply after 1993, from 187,553 tons in 1989 to 15,763 tons in 1998, covering just 11% of cropped area (Figure 4). This reduction came in the wake of the government's decision to cut fixed wheat commodity prices by 25% in 1994, as well as a number of other factors including a delay in payment to producers and fuel subsidy cuts, which increased groundwater pumping costs and hence overall production cost.[97]

Figure 4 shows a strong increase in the (summer) cultivation of fodder crops (mainly alfalfa), from 7% of total crop area in 1989 (total fodder production 30,111 tons) to over 45% in 1999 (329,040 tons). While these trends reversed again soon after, fodder production remained at higher levels than in the early 1990s.[98] These crops are often grown year-round and have higher water requirements of up to 3,900 mm compared to wheat, a winter crop which requires around 1,300 mm per cycle.[99] The agricultural policy changes outlined above may therefore have temporarily lowered wheat production, but did not lead to a decrease in water abstraction from the Saq Aquifer in the Tabuk area.

Based on the above figures, cumulative total abstraction from the Saq Aquifer in the Tabuk area of Saudi Arabia was roughly 32.2 BCM between 1977 and 2011.[100]

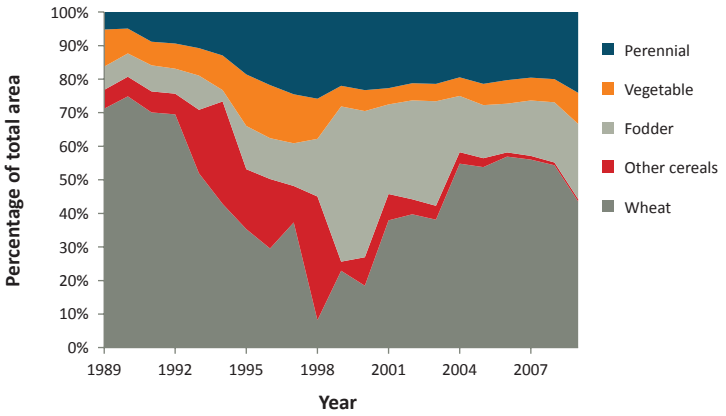
Effect of abstraction on water tables

Rising groundwater abstraction resulted in a drop in the water table in both countries from the mid-1980s onward. The average drop in water level in Jordan varied from 0.6 to 1.0 m/yr, with maximum declines of up to 5 m in some places between 1985 and 1989.[101] The water level continues to decline steadily (Figure 5). In Saudi Arabia, data from the TADCO wells indicates significant declines in the Tabuk area, with total water level drops of 100 m to 160 m from 1983 to 1988,[102] resulting in the reversal of the horizontal and vertical hydraulic gradient in some areas.[103] Currently most water levels range between 50 m bgl and 150 m bgl.[104] Continued abstraction from the Tabuk area could result in further head level decline in south-western Jordan, as the pressure changes in the confined system may be transferred over more than 100 km.[105] In principle, this also applies to abstraction in Jordan, but given that abstraction is significantly lower here than in the Tabuk area, there is less likely to be a far-reaching impact on the aquifer into Saudi Arabia.

GROUNDWATER QUALITY ISSUES

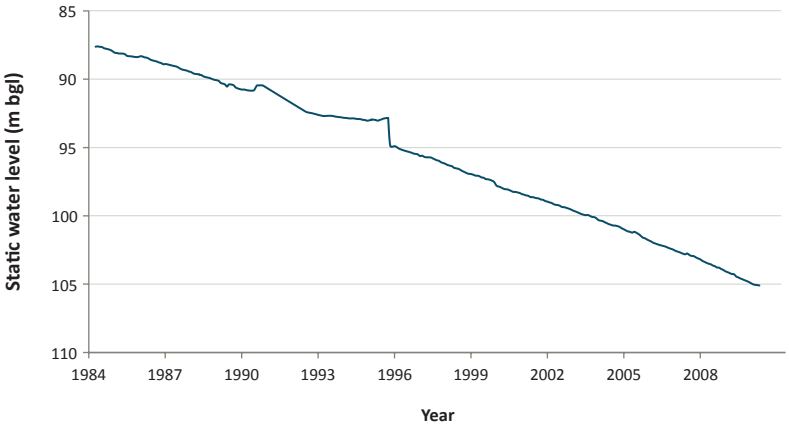
Groundwater in the Saq-Ram Sandstones is fresh and suitable for all purposes. However, there are indications that some problems may arise in the future. Natural sources of radioactivity[106] may affect the entire aquifer system in the long term and limit its use. Other potential sources that may affect water quality could develop locally as a result of heavy pumping. They include leakage of saline water from overlying shale formations, nitrate concentration from irrigation return flows, and upconing of saline and hypersaline formation waters in faulted and geothermal areas.[107]

Figure 4. Main crops in the Tabuk area as a percentage of total cultivated area (1989-2009)



Source: Compiled by ESCWA-BGR based on Central Department of Statistics and Information in Saudi Arabia, 1977-2009.

Figure 5. Groundwater decline in the Ram Aquifer in the South Wadi Araba Basin in Jordan (1984-2010)



Source: Compiled by ESCWA-BGR based on Ministry of Water and Irrigation in Jordan, 2010.
Note: Water level measured from ED1203L Q'A Abu Suwana Observation well.

Wadi Rum, Jordan, 2008. Source: Eileen Maternowski.

BOX 1

The Disi-Amman Water Conveyance Project

The Disi Water Conveyance Project is designed to supply the Jordanian capital Amman with 100 MCM/yr (273,973 m^3/d) for at least 25 years. The projected minimum winter flow is 80 MCM/yr (219,178 m^3/d) and maximum summer flow is expected at 120 MCM/yr (328,767 m^3/d). Water will be drawn from the Dubaydib well field in the Ram Aquifer and pumped over a distance of 325 km to Amman, providing water to the cities of Ma'an, Tafilah, Karak and Madaba on the way. Water travelling through the Disi Conveyor will take at least 20 days to cover the distance from Mudawwara in the south of Jordan to Madaba near Amman. Groundwater will be pumped from 64 production wells, with 55 wells yielding the required flow and the remaining nine serving as piezometric wells. While the actual difference in altitude between Disi and Amman is about 250 m, the water needs to be lifted by about 800 m in total, which will require an estimated 4 kW/m^3 of energy for vertical and horizontal pumping. The project's total energy requirement has been reported to be 50 MW, or 2% of Jordan's annual energy consumption.

Following the issuing of the tender in 2007, the project was awarded to GAMA Energy, a joint venture between GAMA Holding of Turkey and General Electric (GE) of the United States of America. The project, which is being built on a Build-Operate-Transfer basis over a 48-month period, has been described as the largest infrastructure project ever in Jordan, with a value of USD 1.2 billion. In 2007, the Jordanian Government was reported to have committed USD 200 million, while GAMA has invested USD 700 million.

Construction of the wells, the pipeline and the pumping stations was initiated in August 2008, but had to be suspended several times due to security issues. In January 2011, two employees were killed and four were heavily injured during a shooting incident, as local communities protested against the project's implementation. The project was again suspended for nearly two months in October 2011 after further shooting incidents in July and September. Since then, local police forces have been enlisted to patrol the project area.

In July 2012, government sources announced that 85% of the project had been completed and that experimental pumping would start in the fourth quarter of 2012 with 20-30 MCM of water reaching Amman by February 2013. The project is scheduled for completion in July 2013. The Disi Water Conveyance Project will satisfy about 40% of Jordan's annual water demand. The price of water will range between USD 0.95/m^3 and USD 1.40/m^3 depending on energy consumption prices.

Sources: Compiled by ESCWA-BGR based on Consolidated Consultants (Engineering and Environment), 2004; Venture, 2012; Jordan Times, 2012; Global Water Intelligence, 2007.

The Disi Water Conveyor, Jordan, 2012. Source: Eileen Maternowski.

SUSTAINABILITY ISSUES

A 1995 compilation of yield estimates for the Ram Aquifer gave a very wide range of results predicting aquifer depletion within the space of 23 to 200 years (Table 3). Based on the simulation of production scenarios, it was concluded that it is realistic for Jordan to abstract an additional 150 MCM/yr for public supply (to reach a total supply of 225 MCM/yr from the system) for a period of 40 years, while production in Saudi Arabia could increase to 977 MCM/yr by the end of this period.[108] In Saudi Arabia, it was concluded that 71% of the groundwater reserves in the Saq will have been used by 2055 and that it is only a matter of time before the exploitable groundwater resources in the Saq will be exhausted.[109] These projections suggest that the lifespan of the aquifer system may be limited to the first half of this century unless abstraction is reduced or technological innovation allows for the abstraction of additional reserves that cannot be accessed at present.

The simulated drawdown for the new Dubaydib well field is about 2 m/yr and the dynamic drawdown may reach 100 m in 25 years. This means that the water table depth may drop to approximately 350 m bgl, making the well field economically unviable.[110]

Table 3. Summary of Saq-Ram Aquifer System (West) yield estimates

SOURCE	QUANTITY FOR PRODUCTION (MCM/yr)	BACKGROUND INFORMATION
PRIDE, 1992.	128	Resource available for 23.5 years. Estimate based on the extent of the "Disi (surface) Basin".
UNDP,1990.	125	Yield for 50 years provided Tabuk constant at 250 MCM/yr. Restatement of Howard Humphreys, 1986. Tabuk area already pumping approx. 478.5 MCM/yr in 1990.
Thames Water, 1988.	50-70	Economic resource for Amman supply.
Howard Humphreys, 1986.	110	Reliable yield for 200 years. Model study alone, not based on drilling/testing in the confined area, or consideration of "leakage". Model boundaries not set relative to aquifer flow lines.

Source: Modified by ESCWA-BGR based on Haiste Kirkpatrick International and Scott Wilson Kirkpatrick, 1995.

Agreements, Cooperation & Outlook

AGREEMENTS

The riparian countries have to date not signed an official treaty, but the Jordanian Ministry of Water and Irrigation and the Saudi Arabian Ministry of Electricity and Water signed a memorandum of understanding (MoU) at the technical level in 2007. The agreement prohibits the drilling of new production wells and the expansion of agricultural activities within an area of 10 km along both sides of the border between the new Dibdib/Dubaydib and Tabuk well fields (indicated as 'no drilling zone' on the Overview Map). The MoU is non-binding as it does not constitute a treaty under international law.

COOPERATION

Based on the 2007 bilateral MoU, the two countries plan to enhance cooperation through monitoring and exchange of data.

OUTLOOK

In Jordan, continued unsustainable extractions for agricultural use in the Tabuk-Mudawwara-Disi area form the greatest threat to the aquifer system. The creation of new well fields in Dubaydib, Lajjun and east of the town of Azraq would place extra pressure on water resources. A modernized groundwater monitoring network that was installed in 2011[111] may help to assess the condition of the Ram Aquifer. In Saudi Arabia, the Ministry of Water and Electricity has suggested a reduction of up to 50% in agricultural water demand in the Tabuk area. This would not only increase the lifespan of the Saq Aquifer, but also reduce further radioactive contamination of the groundwater.[112] Previous studies that focused exclusively on the Jordanian or Saudi Arabian parts of the aquifer could provide a useful basis for future cooperation efforts. The establishment of a joint monitoring network on both sides of the border could verify and assess water level draw-downs across the border, and foster information exchange.

The region of Al Ula, Saudi Arabia, 2012. Source: Amru Essam.

Notes

1. More than 80% of all groundwater withdrawals from the Saq Aquifer take place in this part (Qassim, Ha'il, Riyadh areas), which is at a considerable distance from any national border and hence not considered in this Inventory.
2. BRGM and CNABRL, 1985; Abunayyan Trading Corporation and BRGM, 2008.
3. Disi, the old name for the sandstones, is not used anymore since it refers only to one formation within the Ram Group (Table 1).
4. Abunayyan Trading Corporation and BRGM, 2008.
5. The Cambro-Ordovician Sandstones extend to Iraq and Syria, where they are too deep and probably not exploitable. The description and area calculations in this chapter take the northern border of Jordan and Saudi Arabia as the limit of the aquifer system.
6. The Water Atlas of Saudi Arabia (Ministry of Agriculture and Water in Saudi Arabia, 1984) stated a total area of 225,000 km^2 for the whole Saq Aquifer extension (65,000 km^2 outcrops and approx. 160,000 km^2 subsurface), which is less than half of what has been calculated in this Inventory. Considering that the Inventory data is based on the Atlas Map, the discrepancy may stem from the fact that the original subsurface data was an estimate, while this Inventory based estimates on digitized data. The fact that a figure of 300,000 km^2 was reported for the Tabuk Basin alone (Edgell, 1997) appears to support the more recent findings.
7. Vincent, 2008.
8. Edgell, 2006.
9. Margane et al., 2002.
10. Margane, 2011.
11. Margane et al., 2002.
12. Including coastal areas that are not supplied with water from the Saq Aquifer.
13. Department of Statistics in Jordan, 2004.
14. Abunayyan Trading Corporation and BRGM, 2008.
15. Saudi Arabian Ministry of Agriculture and Water in Saudi Arabia, 1984; Haiste Kirkpatrick International and Scott Wilson Kirkpatrick, 1995; Christian, 2000; Abunayyan Trading Corporation and BRGM, 2008; and Barthelemy et al., 2010.
16. BRGM and CNABRL, 1985.
17. The term Tabuk Formation is gradually being replaced by the new term Qassim Formation. The names Kahfah and Quwarah are used informally for the sandstones in this formation (Abunayyan Trading Corporation and BRGM, 2008).
18. Abunayyan Trading Corporation and BRGM, 2008.
19. Hobler et al., 1991.
20. Margane et al., 2002.
21. Barthelemy et al., 2010.
22. BRGM and CNABRL, 1985.
23. Hobler et al., 1991; Andrews, 1991; Margane et al., 2002.
24. Hobler et al., 1991.
25. Margane et al., 2002.
26. Ministry of Agriculture and Water in Saudi Arabia, 1984; Sharaf and Hussein, 1996; Alsharhan et al., 2001.
27. Haiste Kirkpatrick International and Scott Wilson Kirkpatrick, 1995 report that, in contrast to previous descriptions, the aquifer behaves as a leaky system and not a simple confined one.
28. Margane et al., 2002; Barthelemy et al , 2010.
29. Abunayyan Trading Corporation and BRGM, 2008.
30. E.g. Ministry of Agriculture and Water in Saudi Arabia, 1984; Alsharhan et al., 2001; Tomaihy, 2007.
31. E.g. Margane et al., 2002; Hobler et al., 1991.
32. BGR et al., 1999.
33. Water Authority of Jordan, 2002.
34. Margane et al., 2002.
35. Haiste Kirkpatrick International and Scott Wilson Kirkpatrick, 1995.
36. Ibid.
37. Abunayyan Trading Corporation and BRGM, 2008.
38. Haiste Kirkpatrick International and Scott Wilson Kirkpatrick, 1995.
39. Abunayyan Trading Corporation and BRGM, 2008.
40. Barthelemy et al., 2010.
41. Hobler et al., 1991.
42. Ibid.
43. Abunayyan Trading Corporation and BRGM, 2008.
44. Barthelemy et al., 2010.
45. Abunayyan Trading Corporation and BRGM, 2008.
46. Barthelemy et al., 2010.
47. Hobler et al., 1991.
48. Barthelemy et al., 2010.
49. Abunayyan Trading Corporation and BRGM, 2008.
50. Ministry of Agriculture and Water in Saudi Arabia, 1984.
51. Abunayyan Trading Corporation and BRGM, 2008.
52. BRGM and CNABRL, 1985.
53. Ferragina and Greco, 2008.
54. Hydrogeological Services International, 1991.
55. Hobler et al., 1991; Barthelemy et al., 2010.
56. Hobler et al., 1991.
57. Ibid.
58. Margane et al., 2002.
59. Abunayyan Trading Corporation and BRGM, 2008.
60. Ibid.; Barthelemy et al., 2010.
61. Lloyd, 1969 cited in Barthelemy et al., 2010.
62. Abunayyan Trading Corporation and BRGM, 2008.
63. Hydrogeological Services International, 1991; Haiste Kirkpatrick International and Scott Wilson Kirkpatrick, 1995; Abunayyan Trading Corporation and BRGM, 2008.
64. Abunayyan Trading Corporation and BRGM, 2008.
65. Ibid.
66. Salameh and Rimawi, 1987; Abunayyan Trading Corporation and BRGM, 2008; Vengosh et al., 2009; Barthelemy et al., 2010.
67. Abunayyan Trading Corporation and BRGM, 2008.
68. Bender, 1968 cited in Salameh and Rimawi, 1987.
69. Salameh and Rimawi, 1987 [^{222}Rn = 1,700 to 30,000 pCi/L (picoCuries/L)].
70. Barthelemy et al., 2010; Abunayyan Trading Corporation and BRGM, 2008.
71. Vengosh et al., 2009 [^{228}Ra + ^{226}Ra = up to 4 Bq/L (becquerel/L)].

72. According to WHO, 2011, the guidance levels for drinking water are the following: ^{224}Ra = 1 Bq/L; ^{226}Ra = 1 Bq/L; ^{228}Ra = 0.1 Bq/L.
73. Abunayyan Trading Corporation and BRGM, 2008, Vol. 13; Christian, 2000.
74. Abunayyan Trading Corporation and BRGM, 2008, Vol. 1.
75. Barthelemy et al., 2010.
76. Ibid., Abunayyan Trading Corporation and BRGM, 2008, Vol. 1.
77. Abu-Ajamieh et al., 1988.
78. Ibid.
79. Barthelemy et al., 2010.
80. Haiste Kirkpatrick International and Scott Wilson Kirkpatrick, 1995.
81. Barthelemy et al., 2010.
82. Ferragina and Greco, 2008.
83. Ministry of Water and Irrigation in Jordan, 2011.
84. All numbers from Barthelemy et al., 2010.
85. Barthelemy et al., 2010.
86. Government of Jordan, 2010; Margane, 2011.
87. According to the data plotted in Figure 3 from Haiste Kirkpatrick International and Scott Wilson Kirkpatrick, 1995 and Barthelemy et al., 2010. An initial abstraction rate of 5.4 MCM/yr was assumed for the years 1977-1982, an average abstraction of 70 MCM/yr was assumed for the years 2007 to 2011.
88. All numbers in the paragraph from Abunayyan Trading Corporation and BRGM, 2008, pp. 20, 22, 40.
89. See Abunayyan Trading Corporation and BRGM, 2008, plate 4.
90. Abunayyan Trading Corporation and BRGM, 2008.
91. Water Watch, 2006. These figures were derived from remote sensing only and it is unclear whether the figures refer to the Tabuk area or to abstractions from the Saq Aquifer only.
92. Abunayyan Trading Corporation and BRGM, 2008.
93. TADCO, 2012.
94. ASTRA Food Company, 2012.
95. UN-ESCWA et al., 1996. Estimates based on landsat imageries.
96. The Tabuk-Tayma irrigated areas in Saudi Arabia lie almost entirely within the boundaries of Tabuk Province and constitute by far the largest agricultural areas in this province. In terms of geographical scope, census data for Tabuk Province is roughly comparable to estimates for the Tabuk-Tayma areas from other studies with regards to agricultural production and water use.
97. Al Sheikh, 2001, p. 307.
98. Fodder production represented around 16% of total cultivated area in 2004 and has since then continued to amount to 35%-40% of total yield of temporary crops (fodder production estimated at 145,000-200,000 tons/yr).
99. Water requirement according to Al Sheikh, 2001, p. 305, Table 14.4.
100. Based on estimated groundwater abstraction for the Tabuk area for the period 1977-2004 according to Water Watch, 2006; a constant abstraction of 1,400 MCM/yr was assumed for the period 2005-2011.
101. UN-ESCWA et al., 1996.
102. Ibid.
103. Abunayyan Trading Corporation and BRGM, 2008.
104. Ibid.
105. Barthelemy et al., 2010.
106. The occurrence of the radioactive elements (radionuclides) in the Saq-Ram Aquifer at levels higher than acceptable for human use has been reported by Al-Saud et al. 2011; Vengosh et al., 2009; Abunayan and BRGM, 2008; Salameh and Rimawi, 1987.
107. Abunayyan Trading Corporation and BRGM, 2008; Haiste Kirkpatrick International and Scott Wilson Kirkpatrick, 1995; Harza Group, 1996 as cited in Ferragina and Greco, 2008.
108. Haiste Kirkpatrick International and Scott Wilson Kirkpatrick, 1995.
109. Abunayyan Trading Corporation and BRGM, 2008.
110. Barthelemy et al., 2010.
111. This programme is being implemented by the ESCWA-BGR Cooperation.
112. Abunayyan Trading Corporation and BRGM, 2008.

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Chapter 11

Wajid Aquifer System

Wajid Aquifer System

EXECUTIVE SUMMARY

The Wajid Sandstones are made up of two permeable formations, the Upper and Lower Wajid Sandstones, which are separated by a less permeable shale formation. They are hydraulically connected over a long distance to constitute a regional aquifer system.

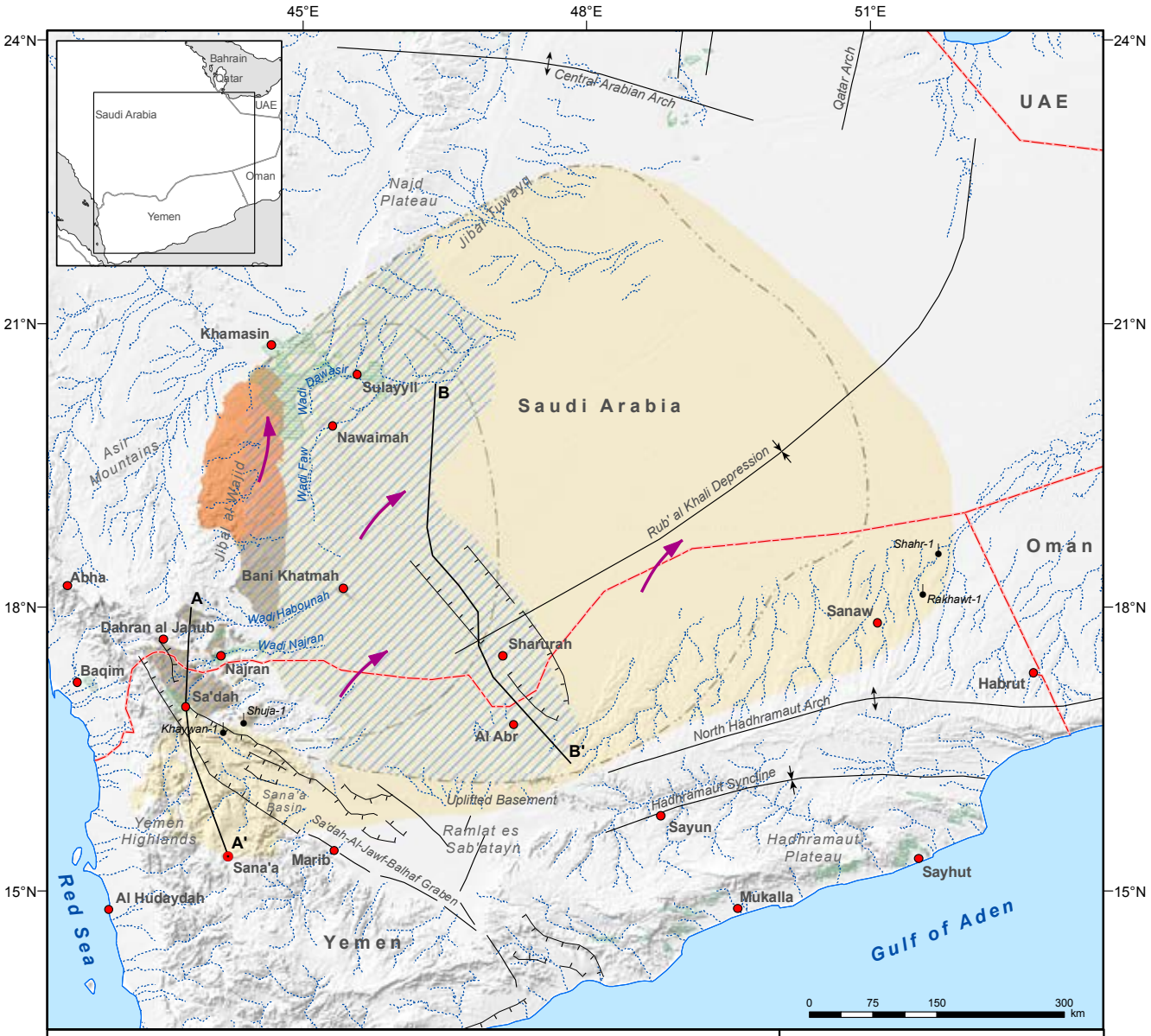
The Wajid Aquifer System extends across the border of Saudi Arabia and Yemen, from the Asir-Yemen Highlands to the Rub' al Khali Depression. In the subsurface, the aquifer system extends from the Wadi Najran area to the eastern areas of the Rub' al Khali and possibly to the Gulf coast. On the surface, the Upper Wajid is found mainly in the Sa'dah-Najran area while only the Lower Wajid is exposed in the Jibal al Wajid further north. The combined thickness of the Upper and Lower Wajid may be anywhere between 100 and 900 m in the areas where it is currently exploited.

The water level in the aquifer system has dropped at a rate of 3 m/yr for the past 20 to 30 years and as much as 6 m/yr in some areas around Wadi Dawasir-Sulayyil (Saudi Arabia) and Sa'dah (Yemen). Heavy abstraction for agricultural development in these areas has led to the exhaustion of the aquifer system in some areas, while other areas are threatened by exhaustion in the coming 10 to 15 years.

BASIN FACTS

RIPARIAN COUNTRIES	Saudi Arabia, Yemen
ALTERNATIVE NAMES	Bani Khatmah Formation
RENEWABILITY	Very low to low (0-20 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Weak
ROCK TYPE	Porous
AQUIFER TYPE	West: Unconfined East: Confined
EXTENT	~455,000 km^2
AGE	Paleozoic (Permian and older)
LITHOLOGY	Sandstones
THICKNESS	100-900 m (AVG: 300 m)
AVERAGE ANNUAL ABSTRACTION	Saudi Arabia: 2,260 MCM (2004) Yemen: ~100 MCM (2002)
STORAGE	Saudi Arabia: 30-225 BCM Yemen: 4-6 BCM
WATER QUALITY	Fresh to slightly brackish (700-1,000 mg/L TDS)
WATER USE	Predominantly agricultural; limited municipal and industrial
AGREEMENTS	-
SUSTAINABILITY	Water level decline and salinization due to overexploitation, resulting in partial exhaustion of the resource

OVERVIEW MAP



Wajid Aquifer System

- Capital
- Selected city, town
- International boundary
- Intermittent river, wadi
- Exploratory bore-hole
- Anticline
- Syncline
- Graben
- Lineaments
- Lower Wajid Sandstone outcrop
- Upper Wajid Sandstone outcrop
- Approximate subsurface extent of the aquifer formations
- Approximate boundary of exploitable area
- Zone of agricultural development
- Subsurface extent after Ministry of Agriculture and Water in Saudi Arabia, 1984
- Subsurface extent after Edgell, 1997
- Direction of groundwater flow
- A A' Approximate location of cross-section

ESCWA

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

Disclaimer
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

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Introduction

LOCATION

The Wajid Aquifer System is located at the edge of the crystalline Arabian Shield near the south-western tip of the Arabian Peninsula (see Overview Map). It extends across the border of Saudi Arabia and Yemen.

AREA

The Wajid Aquifer System extends over an area of more than 455,000 km^2 of which 26,300 km^2 is covered with outcrops. Around 307,000 km^2 is located in Saudi Arabia, and the remaining 146,000 km^2 is in Yemen. Recent data[1] from deep exploratory wells suggests that the aquifer system extends over a much larger area than previously estimated.[2] A recent study found that the subsurface extent of the sandstones reaches the eastern shores of the Arabian Peninsula.[3] The aquifer system is bounded by the Asir-Yemen Highlands to the west, the vast Rub' al Khali Desert to the east, the Ramlat es Sab'atayn Desert-Hadhramaut Plateau to the south, and the Najd Plateau to the north.

CLIMATE

In the south-western part of the Arabian Peninsula, where the Wajid Sandstones exist, rain can occur throughout the year, but happens mainly during spring and summer when the region comes under the influence of the Indian Ocean Monsoon system. While maximum annual rainfall levels of 200 mm have been registered, average annual rainfall is 50-100 mm,[4] with two rainy seasons: March-May and July-August. Temperatures vary according to elevation and season, from a minimum of 9°C in December-January to a maximum of 25°C in July in the western plateau areas[5] and about 44°C in August in the desert areas further east.[6] Annual evapo-transpiration was estimated at about 2,150 mm in the Sa'dah area.[7]

POPULATION

Most of the population living within the boundaries of this basin is concentrated in Sa'dah Governorate in Yemen and Najran Province in Saudi Arabia. Population figures for these two regions are not available, but previous estimates suggest a population of around 1.14 million, of which 450,000 live in Saudi Arabia[8] and 695,000 in Yemen.[9] About a third of this population lives in the cities of Sa'dah in Yemen and Najran in Saudi Arabia.

OTHER AQUIFERS IN THE AREA

Two other categories of aquifer systems occur in the area: the alluvial aquifer systems in the Wadi Najran Basin in the western part of the delineated area (Box 1), and the Wasia-Biyadh-Aruma Aquifer System (South) further east (see Chap. 12).

INFORMATION SOURCES

Official sources in both countries provided information on the hydrogeology of the aquifer system, though most of it was not recent. Other data and information on groundwater use was drawn from the literature. The Overview Map was delineated based on various local and regional references.[10]

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

The depositional basin of the Wajid Sandstones is divided by the north-west/south-east Sa'dah-Al Jawf-Balhaf Graben, which divides the system into a southern part along the western boundaries of the graben and a northern part along the eastern boundaries of the graben.

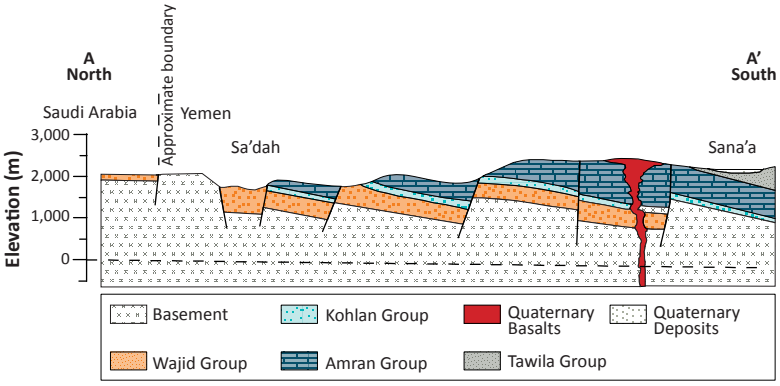
In the southern part and within the graben itself, the Wajid Sandstones occur only in the subsurface of the so-called Sana'a Basin. They were deposited mainly within separate small sub-basins between Sa'dah and Sana'a, which were formed by block faulting related to the opening of the Red Sea (Figure 1).[11] The location and configuration of these sub-basins suggest that the Wajid Sandstones cannot constitute shared systems in this part. Hence they are not considered in this report.

On the northern side of the graben, outcrops of the Wajid Sandstones are found along the edges of the Basement of the Shield. In the Wadi Najran area, the sandstones form a thin cover over the Basement but are partly removed in places where they have been cut by drainage.[12] In some areas, isolated outcrops form spectacular cliffed outliers.[13] Further east, the sandstones are found in the subsurface, dipping gently under Permo-Carboniferous and Mesozoic strata of the south-western Rub' al Khali Depression. Towards the south in the direction of the Northern Hadhramaut Arch, which is the structural boundary of the sedimentary basin, the thickness of the sandstones is reduced from about 900 m in Saudi Arabia to 350 m in Yemen. The depth to the top of the formation is reduced from about 1,650 to 600 m bgl (Figure 2).[14]

STRATIGRAPHY

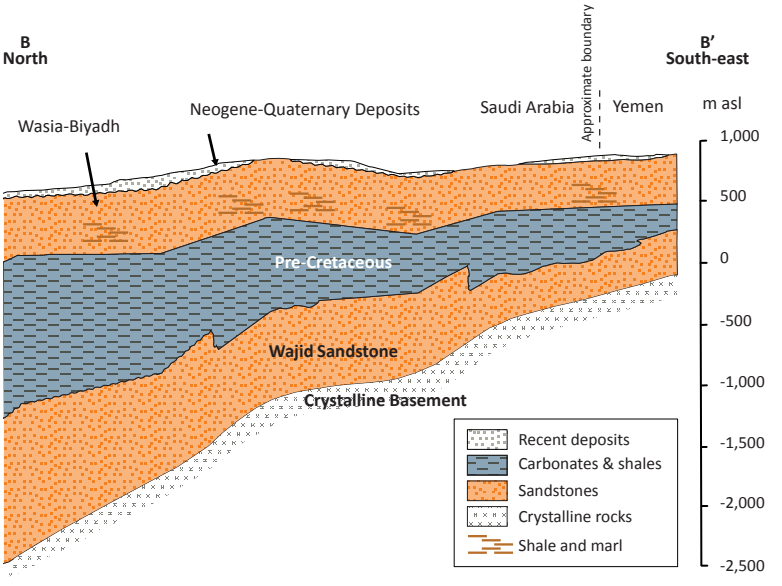
A comprehensive study has shown that the sandstones in the Dahran al Janub-Najran are coarse to conglomeratic with some siltstones near the top, which indicates that they were deposited in a braided-stream environment, while those in Jibal al Wajid are finer with no evidence of channelling, suggesting a shallow-marine environment.[15] Further studies[16] have shown that the Wajid Sandstones comprise an upper and a lower formation (see Overview Map). The Lower Wajid (in the Jibal al Wajid area) is restricted mainly to the Cambro-Ordovician Period while the Upper Wajid (in the Sa'dah-Najran-Bani Khatmah area) contains Late Permian fossils. In Saudi Arabia, a recent study has shown that the Wajid Sandstones represent two individual fractured aquifers in the subsurface separated by an aquitard. The lower aquifer (Lower Wajid) comprises two formations (Dibsiyah and Sanamah) and is effectively separated from the upper aquifer (Upper Wajid), which comprises the Khusayyan and Juwayl Formations, by the siltstones and shales of the Qusaiba Shale equivalent.[17]

Figure 1. Geological cross-section of the Wajid Sandstones in the Sa'dah-Sana'a area in Yemen



Source: Modified by ESCWA-BGR based on Van der Gun and Ahmed, 1995.

Figure 2. Geological cross-section of the Wajid Sandstones across the border of Saudi Arabia and Yemen



Source: Modified by ESCWA-BGR based on Edgell, 1997.

Figures 2 and 3 show the aquifer system's subsurface extension into Yemen. Exploratory bore-holes indicate that the Wajid Aquifer System extends at least into eastern Yemen.

AQUIFER THICKNESS

The thickness of the Wajid Sandstones generally increases away from the graben and the uplifted Basement in north and north-easterly directions. In the Sa'dah Plain in Yemen, where the sandstones have been largely removed by erosion, the sandstones have a thickness of around 100 m,[18] while thicknesses of around 600 m occur around the town of Sa'dah in downthrown blocks of the graben.[19] Further north in Saudi Arabia, a thickness range of 11 m (at 19°30' N and 44°00' E) to 365 m (at 19°43'N and 44°41'E) has been measured.[20] Available data indicates a thickness of up to 950 m[21] in the Rub' al Khali Depression, where both sandstone formations are preserved at depth (Figure 2 and 3).

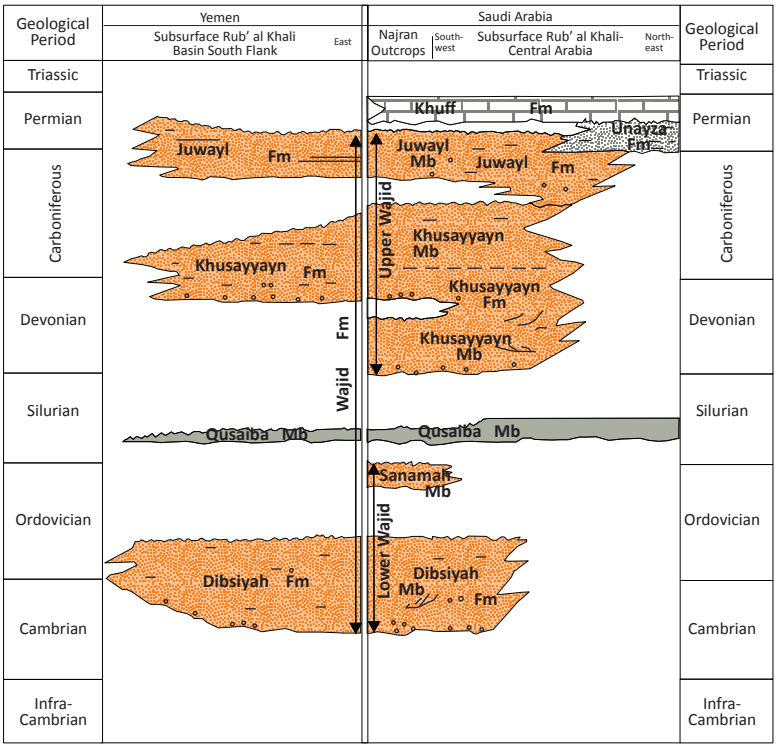
AQUIFER TYPE

The numerous outcrops around the town of Najran in Saudi Arabia form unconfined aquifer zones.[22] In the nearby Sa'dah area in Yemen, the sandstone aquifer is also mainly unconfined except in areas where it is overlain by relatively thick deposits of Jurassic (Amran) Limestone.[23] Further east in the Rub' al Khali, where the two sandstone formations are separated by shale, the Upper Wajid is unconfined, while the Lower Wajid acts as a confined aquifer over an area of 170,000 km^2 in Saudi Arabia.[24]

AQUIFER PARAMETERS

Data on the hydraulic parameters of the aquifer system is limited. Nevertheless, the transmissivity values obtained from the southern (Sa'dah) and northern (Dawasir) parts of the basin are remarkably similar, indicating that they most likely represent the same aquifer system. Field measurements in the Sa'dah area showed significant differences in transmissivity (Table 1), which reflect the variations in the hydraulic permeability and thickness.[25] Also the wide range of values for storativity reflects the variability of the confining pressure due to differences in lithology and thickness of both the aquifer and the overlying formations, particularly toward the south-eastern edge of the system.

Figure 3. Correlation of the lithostratigraphy of the Wajid Formations in Saudi Arabia and Yemen



Source: Redrawn by ESCWA-BGR based on Stup and Van Der Eem in Beydoun et al., 1998.

Table 1. Hydraulic parameters of the Wajid Aquifer System

TRANSMISSIVITY (m^2/s)	STORATIVITY			COMMENTS	SOURCE
	CONFINED	UNCONFINED	RANGE		
5.7x10^{-4}-2.1x10^{-2} AVG:[a] 1.5x10^{-2}	AVG: 4.0x10^{-2}	2.0x10^{-1}	2.0x10-4.0x10^{-4}	Values obtained mainly for the Wadi Dawasir area in 1965.	Ministry of Agriculture and Water in Saudi Arabia, 1984.
2.2x10^{-4}-8.1x10^{-3}	..	AVG: 7.5x10^{-2}	..	Values obtained for the Sa'dah Plain.	Van der Gun, 1985.
2.3x10^{-4}-4.6x10^{-3}	..	..	..	Values obtained mainly for the Sa'dah area in Yemen in the early 1990s.	Al-Sakkaf et al., 1999.
5.8x10^{-4}-8.1x10^{-2} AVG: 1.4x10^{-2}	..	..	..		Al Shami and Al-Dubby, 2004.

Source: Compiled by ESCWA-BGR.
(a) AVG refers to average values.

Hydrogeology - Groundwater

RECHARGE

Carbon-14 dating of groundwater in the Wajid Aquifer in Saudi Arabia shows that the water is more than 30,000 years old[26] and thus represents 'fossil water'.[27] Judging from isotope studies, groundwater from deep wells in the Wajid Sandstones in Wadi Dawasir is older than the groundwater in the Tuwayq Mountains, which was recharged after the last pluvial period.[28] Since rainfall in most of the basin is less than 200 mm/yr,[29] it is unlikely that significant recharge takes place in the northern (Wadi Dawasir) part of the basin. However, direct and indirect recharge has been reported in the southern Sa'dah-Najran area where average rainfall is 250-300 mm/yr. In Yemen, it is estimated that a total recharge (natural sources plus irrigation return) of 17.7 MCM/yr[30] occurs in this escarpment zone, which is equivalent to 7.9 mm/yr,[31] although lower (4.4 mm/yr,[32] 3.2 mm/yr[33]) values have been suggested. In Saudi Arabia a recharge of 114 to 240 MCM (equivalent to 4.4[34] to 19.2 mm/yr[35]) has been estimated.

FLOW REGIME

Groundwater flows from the recharge area in the south-west corner of the basin (Asir Mountains-Yemen Highlands) towards the north and north-east, where groundwater seeps into the alluvium of Wadi Dawasir[36] or sinks into the Rub' al Khali Depression. Groundwater flow across the political border has presumably been disrupted by the heavy abstraction in the Sa'dah-Najran area since the late 1970s. However, available data does not reveal the impact of this cone of depression on the groundwater dynamics of the aquifer system.

STORAGE

Table 2 indicates that the values obtained for groundwater storage in the Wajid Aquifer System in Saudi Arabia are very diverse. Official data states a much smaller storage volume, but also suggests that much of the water lies at great depth.[37] There is also a difference in the values reported by different sources.[38] The available groundwater reserve in the Sa'dah area is an order of magnitude lower than in Saudi Arabia. However, no data is available on the Rub' al Khali Basin, which has much larger storage at substantially greater depths.

Table 2. Groundwater reserves in the Wajid Aquifer System

COUNTRY	RESERVES (BCM)	COMMENTS	SOURCE
Saudi Arabia	30	Based mainly on data from the Wadi Dawasir area.	Ministry of Agriculture and Water in Saudi Arabia, 1984.
	225	Represents groundwater exploitable by lowering depth to water level to 300 m.	Al Alawi and Abdulrazzak, 1993.
	69 (1984) 40 (Estimated, 1996)	Based on data from the Ministry of Planning in Saudi Arabia.	Al Sheikh, 2000.
Yemen	5.7	Estimation takes into consideration the economic pumping lift of 150 m for irrigation purposes.	HWC, 1992 (cited in Al Shami and Al-Dubby, 2004).
	3.7	Based on data from Sa'dah area.	WikiADAPT, 2009.

Source: Compiled by ESCWA-BGR.
Note: The values for Saudi Arabia are assumed to cover the total area of the Wajid as delineated by Ministry of Agriculture and Water in Saudi Arabia, 1984 (see Overview Map), while the values from Yemen are for the much smaller area around Sa'dah, though none of the studies specifically mentions the area.

DISCHARGE

Up until about 1980, natural discharge from the sandstones occurred from springs (in the mountainous areas) or as base flow into wadi beds (in the desert plain further east and north-east). Many springs in the Sa'dah area were located near the contact with the underlying basement and were therefore considered an alternative to drilling.[39] In Saudi Arabia, natural discharge in the form of sabkhas occurs between Khamasin and Nawaimah (in Wadi Faw) and to the west of the Tuwayq Mountains along fractured zones extending between Wadi Dawasir and Wadi Faw.[40] Almost all base flows in Wadi Dawasir and Wadi Faw used to originate from groundwater discharge from the Wajid.[41] Flowing wells located to the east of Wadi Dawasir and towards the Rub' al Khali area used to discharge to the surface.[42] However, as the groundwater level have dropped significantly over the past 25-30 years due to heavy abstraction, most springs have dried up and the surface water/groundwater dynamics

have changed. In the Wadi Dawasir area, for example, an inversion of flow occurred, with the result that water from the Wadi Dawasir bed now infiltrates into the drained Wajid Aquifer.

WATER QUALITY

In Saudi Arabia, Total Dissolved Solids (TDS) of groundwater in the Wadi Dawasir ranges between 700 and 1,000 mg/L, although it can be as high as 3,000 mg/L.[43] The higher values are found west of Wadi Dawasir where the water level lies at 90-100 m bgl. In the confined areas towards the east (e.g. Sulayyil), water quality improves and TDS can be as low as 450 mg/L.[44] In Yemen, the average TDS calculated from 60 representative samples from the Sa'dah area was found to be 740 mg/L in 2004.[45] This represents an increase over average values measured in 1983 and 1992 of 124 mg/L and 67 mg/L respectively, and would signify a gradual increase in groundwater salinity over the years.

EXPLOITABILITY

Both depth to groundwater (approx. 100-150 m bgl) and water quality (≤1,000 mg/L TDS) are within the limits of the criteria selected for exploitability. Hence the depth to the top of the aquifer system is the limiting factor for exploitability here. Information from the Middle East Geological Map Series (MEG-Maps)[46] suggests that the eastern margin of the outcrops and the adjacent subsurface areas are exploitable with modern technology, in the area delineated in the Overview Map. Based on this information, the total exploitable area has been calculated at around 157,000 km^2, of which around 120,000 km^2 is in Saudi Arabia and the remaining 37,000 km^2 in Yemen.

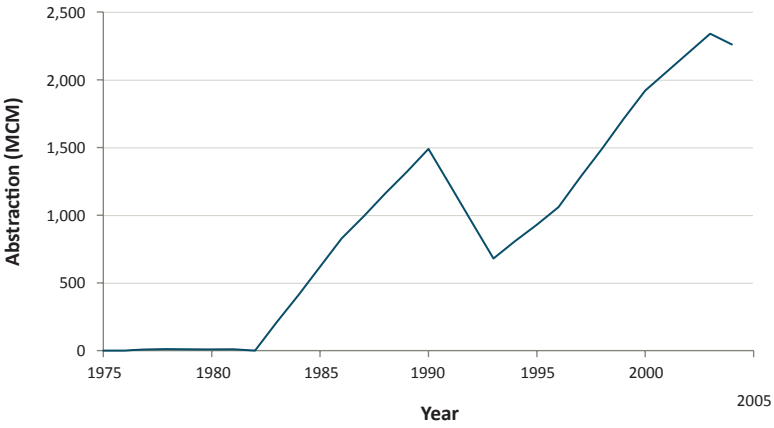
The Sarawat Mountains, Saudi Arabia, 2012. Source: Amru Essam.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

Exploitation of the Wajid in Saudi Arabia began with the development of Wadi Dawasir in 1965. In 1968, abstraction from the aquifer amounted to 11 MCM/yr, increasing gradually to 25 MCM/yr by 1977[47] and more rapidly throughout the 1980s and 1990s to reach 2,260 MCM/yr in 2004. In Yemen, exploitation of the aquifer system did not take off until 1978. Since then, there has been a sharp increase in groundwater abstraction.
The volume of groundwater abstracted in the Sa'dah Plain in 2002 was estimated at 98 MCM/yr.[48] The heaviest abstraction was and still is mainly in two areas: the Wadi Dawasir-Sulayyil area in Saudi Arabia and the Sa'dah-Baqim area in Yemen.

Figure 4. **Historical abstraction from the Wajid Aquifer System in Saudi Arabia (1975-2004)**



Source: Compiled by ESCWA-BGR based on Water Watch, 2006.

Wadi Dawasir-Sulayyil area (Saudi Arabia)

Water from the Wajid Aquifer System has mainly been used for agricultural development in the dry desert plains of the Wadi Dawasir-Sulayyil area, where large farms use centre-pivot irrigation systems to irrigate crops.[49] Throughout the 1980s and 1990s, wheat was the major crop but since then the agricultural pattern has changed. The volume of groundwater abstracted from the Wajid Aquifer increased steadily until 1990 when a significant drop occurred, most likely due to a reduction in wheat production. Wheat was mostly replaced by forage crops during the 1990s, and abstraction rose again (Figure 4) as fodder, unlike wheat, is harvested up to three times a year. Overall, abstraction increased from 210 MCM/yr in 1983 to 2,260 MCM/yr in 2004.[50] Cumulative abstraction for the period 1975-2004 was 29 BCM or 29 times what was predicted in 1984 (1,000 MCM).[51] The drop in abstraction in the early 1990s is most likely due to a decrease in global wheat prices, which was also reflected in other basins. Currently, wheat is the main winter crop and, together with fruit and vegetables (potatoes, tomatoes and watermelon), constitutes about 35% of the total annual crops. The remaining 65% is forage.[52]

When abstraction started, many of the wells in this area flowed and water levels were well above ground level. One of the bore-holes reportedly gushed with such a strong flow that water shot up about 30 m in the air and formed a large lake that attracted migratory birds to the area.[53] Many of these flowing wells discharged groundwater on the surface at a rate of up to 50 L/s.[54] Substantial abstraction has taken place since then, and as a result groundwater levels have dropped significantly. Judging from the normal practice of pipe-lowering as wells are deepened by farmers, it is estimated that the water level is dropping at an average rate of 3 m/yr and up to 6 m/yr in some areas. Currently the water level stands at around 150 m bgl.[55]

Sa'dah-Najran area (Saudi Arabia-Yemen)

Over the past 30 years, the use of the Wajid Sandstones and the overlying alluvium has been limited to the Sa'dah and Najran areas within the upper catchment of Wadi Najran. Water use in these areas has been limited to agricultural development and, to a much lesser extent, domestic water supply.

In the Najran area, most of the groundwater is pumped from the alluvium, although the deepening of wells over the years must have reached the Wajid in some areas. The Wadi Najran alluvial system is mainly linked to the Wajid Aquifer System through its recharge potential, although this potential may have been reduced over the years.

In Yemen, the Wajid Aquifer System is considered a poor to moderate aquifer rock, with the upper layers displaying a higher primary porosity.[56] Hence the response of the aquifer to increased abstraction is expected to change as water is pumped from deeper horizons with progressively less permeability, and storage is gradually depleted. In 1983, the average depth to groundwater was 20-40 m bgl and by 2002 it had

Table 3. Groundwater abstraction and changes in bore-hole characteristics in the Sa'dah Plain, Yemen

YEAR OF WELL INVENTORY	NO. OF BORE-HOLES IN WAJID	AVERAGE DEPTH TO WATER (m)	AVERAGE BORE-HOLE DEPTH (m)	AVERAGE DRAW-DOWN (m)	AVERAGE YIELD (L/s)	AVERAGE WELL ABSTRACTION (m^3/yr)	TOTAL ABSTRACTION (MCM)
1983	1,293	20-40	102	3	6.7	47,700	53
1992	2,285	60-80	174	4.5	3.3	34,300	80
2002	3,234	100	200	3.1	3	31,200	98

Source: Compiled by ESCWA-BGR based on Al Shami and Al-Dubby, 2004.

dropped to 100 m bgl. A decrease in the average well yield was observed during this period from 6.7 to 3.0 L/s and water levels are currently dropping at a rate of about 3 m/yr. Table 3 shows that abstraction almost doubled over the 20-year period between 1983 and 2002.

In the Sa'dah area, water abstracted from the Wajid is mostly consumed in the agricultural sector. Until the mid-1970s, agriculture in the catchment relied mainly on rainwater, spate flows and water harvesting. The cultivated lands were scattered along the wadi beds and in plain areas. Over the years, the use of groundwater for irrigation increased in the Sa'dah-Baqim area, giving farmers the flexibility to grow different crops throughout the year. As a result, pump irrigation spread widely in the area, with groundwater supplying 92% (74 MCM) of total requirements in 1992 and 97% (95 MCM) in 2002.[57] Domestic demand has increased progressively as the population in the Sa'dah area grew from 45,000 in 1975 to 53,000 in 1983 and 230,000 inhabitants in 2002. On the basis of an average daily consumption of 35-40 L/cap./d, it was estimated that the domestic sector consumed an annual amount of about 3 MCM in 2004.[58]

Vineyards in the area of Najran, Saudi Arabia, 2011. Source: Charles Roffey.

GROUNDWATER QUALITY ISSUES

National data from Yemen shows that groundwater remains suitable for drinking purposes in the Sa'dah Plain.[59] There are, however, two threats to groundwater quality: increased salinity and pollution. Salinity levels may rise as a result of the leaching of salts from irrigated fields and percolation through thin soils into the Upper Wajid Formation unit (agricultural return flows). Other sources of salinization include the overlying and/or outcropping sediments/formations such as the Akbara Shale and Amran Limestone. Irrigation return flow is also a potential source of pollution because of the continued percolation of pesticides and nutrients from fertilizers, domestic and industrial waste from petrol stations, etc.

Further east in the Wadi Dawasir-Sulayyil and Sharurah-Al Abr areas, groundwater salinity may increase due to the effect of evaporite deposits (Hith Anhydrite deposits of the Arab Formation in Saudi Arabia and Ramlat es Sab'atayn Formation in Yemen), which contain highly mineralized water; and the Wasia-Biyadh Formations that contain groundwater of variable salinity levels.

Groundwater in the Wajid Sandstones may contain significant amounts of radionuclides of natural origin, such as radon (Rn), which are potentially hazardous to human health.[60] This natural source of contamination constitutes a potential risk to water quality and is a major challenge to groundwater management due to its unpredictability.

SUSTAINABILITY ISSUES

The current heavy abstraction of groundwater reserves is leading to the rapid depletion of groundwater reserves in the aquifer system and it is only a matter of time before the proven reserve is exhausted. Furthermore, it is difficult to predict the lifetime of the aquifer because of significant discrepancies in the estimated reserves. Nevertheless, a number of studies have already predicted that the aquifer will soon be economically exhausted in certain areas. For the unconfined part, the Sa'dah Plain may be most threatened. Table 4 presents estimates for the exhaustion of the aquifer system in this area, which shows that the predicted exhaustion date

is progressively revised downward as abstraction progresses. Assessments indicate that it is a matter of 10 to 20 years before this aquifer is locally completely exhausted.

For the confined part, the Wadi Dawasir-Sulayyil area may be the most threatened. The results of early groundwater modelling indicated that the prevailing abstraction rates could be sustained only until 2011, beyond which the drop in groundwater level and water hydrostatic pressure was expected to become critical.[61] This would suggest that the Wajid is already in a critical condition in this area due to heavy pumping. If the discrepancy over the recharge rate is also taken into account, water level could be even lower. However, no data was available to verify the current status.

Table 4. Projected dates for the economic exhaustion of the Wajid Aquifer System in the Sa'dah Plain

YEAR OF STUDY	ESTIMATED EXHAUSTION (yr)	COMMENTS	SOURCE
1999	2032	Based on 1994 data.	Al-Sakkaf et al., 1999.
2002	2030	Based on 2002 data.	Techniplan, 2002 cited in Al Shami and Al-Dubby, 2004.
2009	2024	-	WikiADAPT, 2009.

Source: Compiled by ESCWA-BGR.

BOX 1

The Wadi Najran Basin

INTRODUCTION

The Wadi Najran Basin comprises the main Wadi Najran with its headwaters in the Yemen Highlands, and two smaller wadis (Habaunah and Idimah) that originate in the Asir Mountains in Saudi Arabia. The basin, as delineated in this Inventory (Figure 5), covers an area of 33,500 km^2, of which about 28,500 km^2 is in Saudi Arabia and 5,000 km^2 in Yemen.

SEDIMENTOLOGICAL PROPERTIES

The ground elevation in the basin ranges from 1,280 m to 2,900 m.[62] The wadi valleys are mainly cut into the Basement and, to a lesser extent, into the Wajid Sandstones.[63] Since probably the Late Pliocene-Early Pleistocene time, the wadis have carried the sediments from these rocks and deposited them around the edge of the Rub' al Khali Basin to form a large alluvial fan.[64] The valley depressions are filled with a thick gravel accumulation (approx. 30 m thick) covered by silty material that usually does not exceed 4 m in thickness.[65]

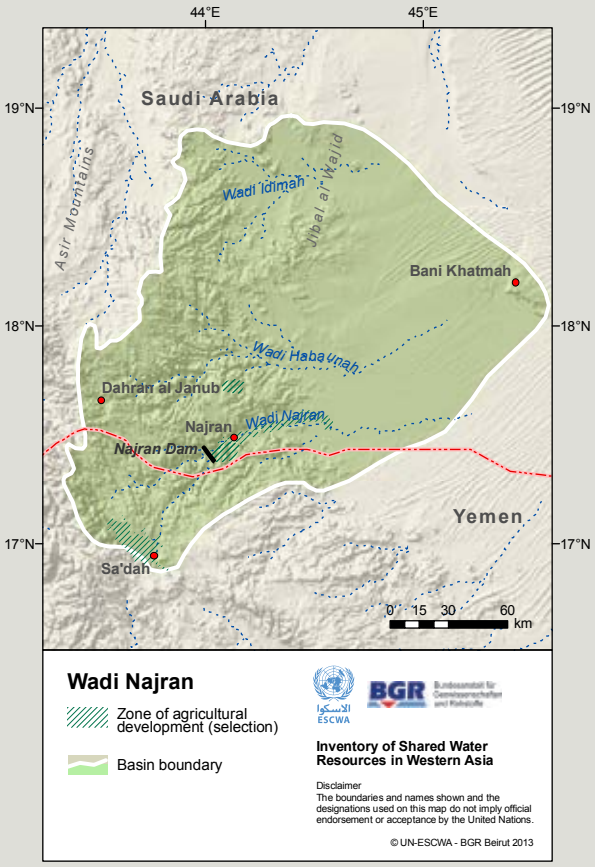
HYDROLOGICAL FEATURES

The three wadis in the basin join in an old drainage system that once extended north-eastward to connect with the Wadi Dawasir system during older wetter periods, probably between 17,000 and 36,000 years ago.[66] Today, the average annual rainfall ranges from 80 to 500 mm.[67] Storms, which can occur year-round and particularly following summer monsoon rains, usually generate high-intensity rainfall with short-lived associated runoff.[68] The Wadi Najran Basin is the second-largest runoff-producing area in the inland drainage system after Wadi Dawasir.[69] The annual runoff in the wadis has been assessed at 3.17 m^3/s in Wadi Najran, 0.95 m^3/s in Wadi Habaunah and 0.16 m^3/s in Wadi Idimah.[70]

HYDROGEOLOGICAL CHARACTERISTICS

The Wadi Najran Basin is a closed shallow basin, in which groundwater potential depends mainly on the unusually high transmissivity of the alluvial deposits in the basin.[71] Infiltration rates were found to be as high as 95% of total runoff over a 50 km reach.[72] Annual recharge in the wadi system is approximately 100 MCM.[73] Estimates show that 33,350 MCM was stored in this basin in the early 1980s.[74]

Figure 5. The Wadi Najran Basin



Source: Compiled by ESCWA-BGR based on Van der Gun, 1985; Haidar, 1984.

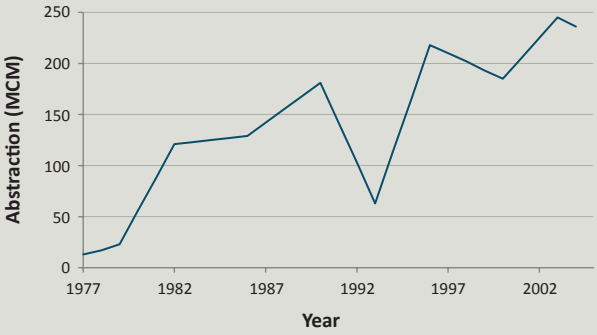
GROUNDWATER ABSTRACTION

In Yemen, many of the wells abstracting water from the Wajid Sandstones were actually drawing water from the overlying alluvial aquifer before depletion of this upper aquifer in several areas prompted the deepening of wells to reach the sandstones.[75] However, no abstraction data could be found during the course of this study. In Saudi Arabia, a total of 2,086 tube wells provided irrigation water to 3,145 farms in the Wadi Najran alluvial system in 1980, with a total annual abstraction of 255 MCM.[76] Most of these wells withdrew water from the alluvial deposits but some may have reached the bedrock, especially in the foothill zones where fractured rocks can be found at shallow depths. The total abstraction may have increased to about 475 MCM/yr since there were plans in 1980 to increase the number of tube wells to about 3,900.[77] However, in 2003, only about 250 MCM/yr was being abstracted,[78] which would suggest that actual abstraction may have been different than what had been planned (Figure 6). The alluvial aquifer system is also used for domestic purposes, mainly by the population of the city of Najran, which had an estimated population of around 265,000 people in 2004.[79] Already in the 1980s, the Wadi Najran alluvial aquifer system experienced a groundwater deficit of 150 MCM, which was expected to increase to 375 MCM in the following years.[80]

SUSTAINABILITY AND MANAGEMENT ASPECTS

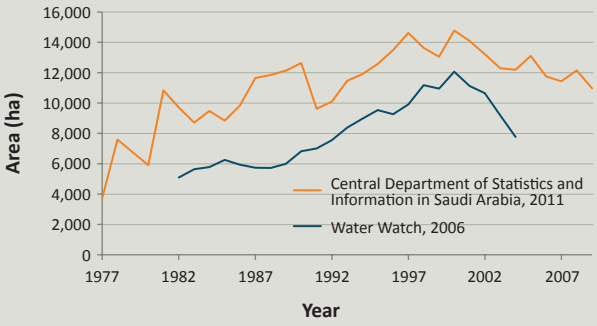
A 73 m-high dam with a storage capacity of 86 MCM was constructed in 1980 in a gorge where Wadi Najran cuts across the crystalline rocks of the basement. The dam was built to regulate water flow and ensure the supply of freshwater for irrigation throughout the year, and to recharge the alluvial aquifer.[81] Since this aquifer is usually in hydraulic connectivity with the lower aquifers (Wajid Sandstones and fractured basement), some of this recharge may eventually seep to the lower aquifers, particularly in areas where runoff occurs in fractured bedrock with thin alluvial cover.

Figure 6. Historical abstraction in Najran in Saudi Arabia (1977-2004)



Source: Compiled by ESCWA BGR based on Water Watch, 2006.
Note: The Water Watch, 2006 study does not explain whether these values are for Najran Province or only for Wadi Najran. However, as the total abstraction of 25 MCM was already reported in 1980 (Haidar, 1984 based on data from the Ministry of Agriculture and Water in Saudi Arabia, 1984), it is likely that values are for Wadi Najran.

Figure 7. Total cropped area in Najran Province in Saudi Arabia (1977-2009)



Source: Compiled by ESCWA-BGR.

Flax and vineyards in the area of Najran, Saudi Arabia, 2011. Source: Charles Roffey.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place for the Wajid Aquifer System which is shared between Saudi Arabia and Yemen.

COOPERATION

No information was available regarding cooperation between the riparian countries on the aquifer system. Yemen has underlined the need and its willingness to cooperate over the management of shared groundwater resources in the aquifer system, particularly with regards to reducing the risk of aquifer depletion.[82]

OUTLOOK

Western part (Najran-Sa'dah area): Further investigation would contribute to delineating and protecting recharge areas, and to estimating how much groundwater flows in the Wajid Sandstones across the political border.

Eastern part (Sharurah-Al Abr area): The availability of more field data would improve the knowledge base on the aquifer system. In particular, future work would need to clarify if and how the hydraulic properties of the Upper and Lower Wajid Sandstone units are different, how they are related, and how they might affect each other in response to abstraction in the future.

The region of Asir, Saudi Arabia, 2006. Source: Walter Callens.

Notes

1. Beydoun et al., 1998.
2. Ministry of Agriculture and Water in Saudi Arabia, 1984; Edgell, 1997.
3. Schubert et al., 2011.
4. Van der Gun and Ahmed, 1995.
5. National Water Resources Authority in Yemen, 2012.
6. Central Department of Statistics and Information in Saudi Arabia, 2011.
7. National Water Resources Authority in Yemen, 2012.
8. Central Department of Statistics and Information in Saudi Arabia, 2011.
9. Kruck and Thiele, 1983.
10. Ministry of Agriculture and Water in Saudi Arabia, 1984; Alsharhan et al., 1991; Edgell, 1997; Beydoun et al., 1998; and PSRCE, 2007.
11. Van der Gun and Ahmed, 1995; Beydoun et al., 1998.
12. Beydoun et al., 1998.
13. Edgell, 1997.
14. Ibid.
15. Dabbagh and Rogers cited in Alsharhan et al., 1991.
16. Alsharhan et al., 1991; Al Shami and Al-Dubby, 2004; Beydoun et al., 1998.
17. GTZ/DCo 2010, cited in Al-Ajmi et al., 2011.
18. Al Shami and Al-Dubby, 2004.
19. National Water Resources Authority in Yemen, 2012.
20. Powers et al., 1966.
21. Edgell, 1997.
22. Ibid.
23. Van der Gun, 1985.
24. Ibid.
25. National Water Resources Authority in Yemen, 2012.
26. Ministry of Agriculture and Water in Saudi Arabia, 1984.
27. Edgell, 1997.
28. Job et al. cited in BGR et al., 1999.
29. PSRCE, 2007.
30. High Water Council cited in Al Shami and Al-Dubby, 2004.
31. Assuming that recharge occurs mainly in the outcrop areas (2,250 km^2 in Yemen; 26,000 km^2 in Saudi Arabia).
32. Yominco/TNO, 1983 cited in Al Shami and Al-Dubby, 2004.
33. DHV, 1991 cited in Al Shami and Al-Dubby, 2004.
34. Ministry of Agriculture and Water in Saudi Arabia, 1984.
35. PSRCE, 2007.
36. Ministry of Agriculture and Water in Saudi Arabia, 1984.
37. Ibid.
38. Ibid; Al Sheikh, 2000.
39. Dreilbatt, 1982.
40. Othman et al., 1986.
41. UN-ESCWA, 1981.
42. Ministry of Agriculture and Water in Saudi Arabia, 1984.
43. Othman et al., 1986.
44. Edgell, 1997.
45. Al Shami and Al-Dubby, 2004.
46. Christian, 2000.
47. Ministry of Agriculture and Water in Saudi Arabia, 1984.
48. Al Shami and Al-Dubby, 2004.
49. See PSRCE, 2007, p. 139.
50. Water Watch, 2006.
51. Ministry of Agriculture and Water in Saudi Arabia, 1984.
52. Bashour, 2009.
53. Ibid.
54. Ministry of Agriculture and Water in Saudi Arabia, 1984.
55. Bashour, 2009.
56. HWC, 1992 cited in Al Shami and Al-Dubby, 2004.
57. Al Shami and Al-Dubby, 2004.
58. Ibid.
59. National Water Resources Authority in Yemen, 2011b.
60. Al-Saud et al., 2011.
61. Ministry of Agriculture and Water in Saudi Arabia, 1984.
62. Haidar, 1984.
63. Jado and Zotl, 1978.
64. Edgell, 2006.
65. Ibid.
66. Ibid.
67. Haidar, 1984.
68. Vincent, 2008.
69. Ministry of Agriculture and Water in Saudi Arabia, 1984.
70. Ibid.; Vincent, 2008.
71. Haidar, 1984.
72. Bennie and Partner, 1975 cited in Abdulrazzak, 1995.
73. Ibid., cited in Haidar, 1984.
74. Ministry of Agriculture and Water in Saudi Arabia, 1984.
75. Van der Gun, 1985.
76. Haidar, 1984.
77. Ibid.
78. Water Watch, 2006
79. Central Department of Statistics and Information in Saudi Arabia, 2004.
80. Haidar, 1984.
81. Ibid.
82. National Water Resources Authority in Yemen, 2011a.

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Chapter 12

Tawila-Mahra/Cretaceous Sands

Wasia-Biyadh-Aruma Aquifer System (South)

Wasia-Biyadh-Aruma Aquifer System (South)

Tawila-Mahra/Cretaceous Sands

EXECUTIVE SUMMARY

The Wasia-Biyadh Sandstones merge with the Aruma in the southern areas of Saudi Arabia to constitute the so-called Cretaceous Sands. These sandstones extend across the Rub' al Khali Depression into Yemen where stratigraphically correlatable sandstones exist (the so-called Tawila-Mahra Group), thus forming a transboundary aquifer system denoted here as the Wasia-Biyadh-Aruma Aquifer System (South).

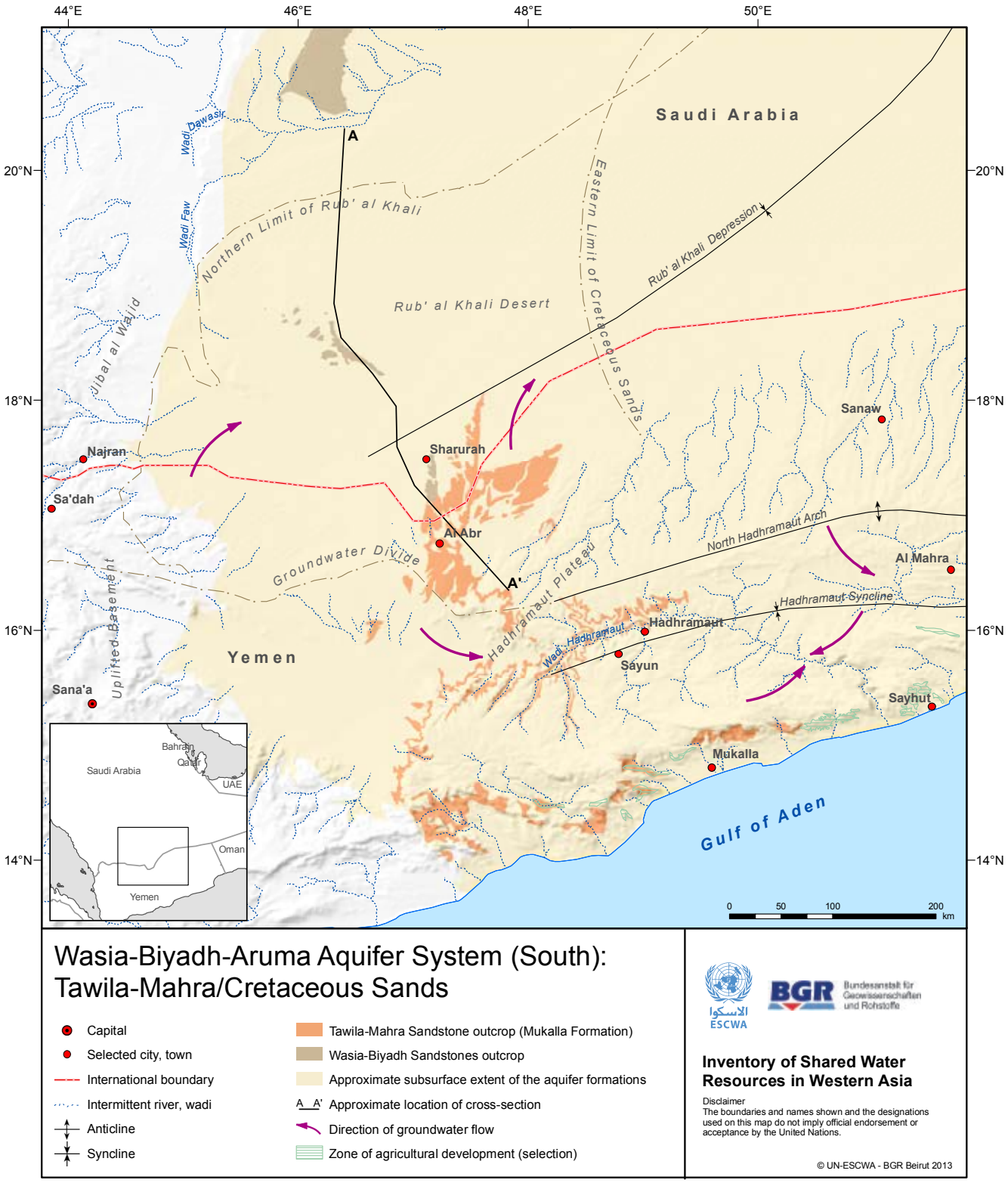
The maximum extraction potential from this aquifer system is estimated at around 500 BCM, making this one of the most promising groundwater reservoirs in the Arabian Peninsula. The aquifer system is hardly used at present due to the remote and harsh nature of the sparsely populated desert environment. Extraction only takes place in the area around the Sharurah/Al Abr border posts, where the sandstones appear at or near the surface, and nomadic populations use freshwater from shallow wells for drinking water supply. The presence of exploratory wells in the sandstones south of the delineated area indicates that freshwater is also found at depth.

This large reservoir of fresh groundwater is an important resource for the economic development of the Sharurah/Al Abr area in the future. It may also prove to be a source of water for more distant but rapidly developing urban areas that face growing water shortage such as Najran in Saudi Arabia and Sa'dah in Yemen.

BASIN FACTS

RIPARIAN COUNTRIES	Saudi Arabia, Yemen
ALTERNATIVE NAMES	Cretaceous Sands, Mahra Group, Tawila Group
RENEWABILITY	Very low (0-2 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Weak to medium
ROCK TYPE	Mixed
AQUIFER TYPE	West: Confined East: Unconfined
EXTENT	~157,000 km^2
AGE	Mesozoic (Cretaceous)
LITHOLOGY	Predominantly sandstones with some marls and siltstones
THICKNESS	100-200 m
AVERAGE ANNUAL ABSTRACTION	Unknown, but very limited
STORAGE	~500 BCM
WATER QUALITY	Fresh (400-800 mg/L TDS)
WATER USE	Water supply for desert nomads and the Sharurah/Al Abr border posts
AGREEMENTS	-
SUSTAINABILITY	-

OVERVIEW MAP



Wasia-Biyadh-Aruma Aquifer System (South): Tawila-Mahra/Cretaceous Sands

- Capital
- Selected city, town
- International boundary
- Intermittent river, wadi
- Anticline
- Syncline
- Tawila-Mahra Sandstone outcrop (Mukalla Formation)
- Wasia-Biyadh Sandstones outcrop
- Approximate subsurface extent of the aquifer formations
- A A' Approximate location of cross-section
- Direction of groundwater flow
- Zone of agricultural development (selection)

ESCWA

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

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The Wasia-Biyadh-Aruma Aquifer System in this Inventory

The Wasia, Biyadh and Aruma Formations extend across the Arabian Peninsula over a distance of about 2,400 km from north-eastern Iraq to the southern coast of the peninsula, with a width that varies between 350 km and 1,450 km and covering a total area of about 1,923,000 km^2 (see 'Overview and Methodology: Groundwater' chapter, Map 1).

The large geographical extent and the lithostratigraphic variations within the formations suggest that they can be divided into three sections, as described below:

- **In the northern section**, the Biyadh Formation disappears completely, while the Wasia (known in this area as the Sakaka)[1] forms an aquifer system with the overlying Aruma Formation that continues across the border into the Rutba area in Iraq. This section is presented in Wasia-Biyadh-Aruma Aquifer System (North) Sakaka-Rutba (see Chap. 13).[2]

- **In the southern section** near Wadi Dawasir, the sandstones of the Biyadh and Wasia grade together with the Aruma to form a thick sandstone unit, known as the Cretaceous Sands,[3] which extends to the Yemeni border. The stratigraphically correlatable sandstones across the border are known as the Tawila Group in Yemen (see current chapter).[4]

- **In the central section**, both the Wasia and Biyadh Formations are present and constitute one aquifer system inside Saudi Arabia, which may extend as far east as the western boundary of the Shu'aiba Formation. Beyond that, the two aquifers are separated by the well-developed dolomitic limestone of the Shu'aiba.[5] The Wasia Aquifer extends to Bahrain where it is currently not used due to high salinity and excessive depth. Hence, while the central section of the Wasia-Biyadh is a major aquifer system inside Saudi Arabia, it is not considered a shared aquifer.

The Bir Ali Crater with the Gulf of Aden in the background, Yemen, 2009. Source: Email4Mobile.

Introduction

LOCATION

The Wasia-Biyadh-Aruma Aquifer System (South) is located in the south-western part of the Rub' al Khali Depression, which has been described as the largest area of sand dune fields in the world, with some dunes reaching hundreds of metres in height.[5] The aquifer system extends across the Saudi-Yemeni border.

AREA

This chapter focuses only on the small area in the southern section of the aquifer system that is considered to be shared. The aquifer system was delineated on the basis of available information, resulting in an area of around 157,000 km^2, of which 52,000 km^2 lies in Yemen, and 105,000 km^2 in Saudi Arabia.

The Tawila-Mahra/Cretaceous Sands Formations occur in a largely inaccessible, arid and hyper-arid region, where the only sign of human settlement is in the Sharurah/Al Abr area. On the Yemeni side, the aquifer system is located in the north-eastern plateau zone, which descends gradually from the north of Wadi Hadhramaut to the southern reaches of the Rub' al Khali Desert.[6] The elevation is approximately 900 m on the edge of this desert, which also extends into Saudi Arabia.[7] In Saudi Arabia, the sandstones lie in extensive dune areas.

CLIMATE

The aquifer system lies within the Hadhramaut Plateau in Yemen, which is generally hot and dry with average annual rainfall below 100 mm and an annual Penman evapotranspiration of 2,000-3,500 mm.[8] There is a slight decrease in rainfall towards the northern Rub' al Khali areas, where the annual average may range between 40 and 80 mm.[9] Temperatures may rise to 50°C during the day, but decrease immediately after sunset.[10]

POPULATION

The area of the Wasia-Biyadh-Aruma Aquifer System is sparsely populated, with a population density of 0.1-1 inhab./km^2. No significant human settlements exist apart from the border post towns of Sharurah and Al Abr.[11]

OTHER AQUIFERS IN THE AREA

In the Sharurah/Al Abr area, the Wasia-Biyadh-Aruma Aquifer System (South) is overlain by Quaternary deposits. Further east, it is overlain by the Hadhramaut Group (Paleogene) Aquifer System (see Chap. 14). It is separated from the underlying Wajid Aquifer System (Cambro-Ordovician to Devonian-Permian, see Chap. 11), by a number of pre-Cretaceous Formations (Figure 1) of which the Middle to Lower Jurassic Formations (e.g. Kohlan Sandstones in Yemen) constitute local aquifers.

INFORMATION SOURCES

In the absence of specific data on the Cretaceous Sands in Saudi Arabia, this chapter draws on information from the Wasia-Biyadh (Central) area where relevant. For the area in Yemen, information is mainly drawn from a number of studies on the Mukalla Sandstone that were undertaken in the eastern part of the country, towards the border with Saudi Arabia and Oman. The Overview Map was delineated based on various local and regional references from both riparian countries.[12]

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

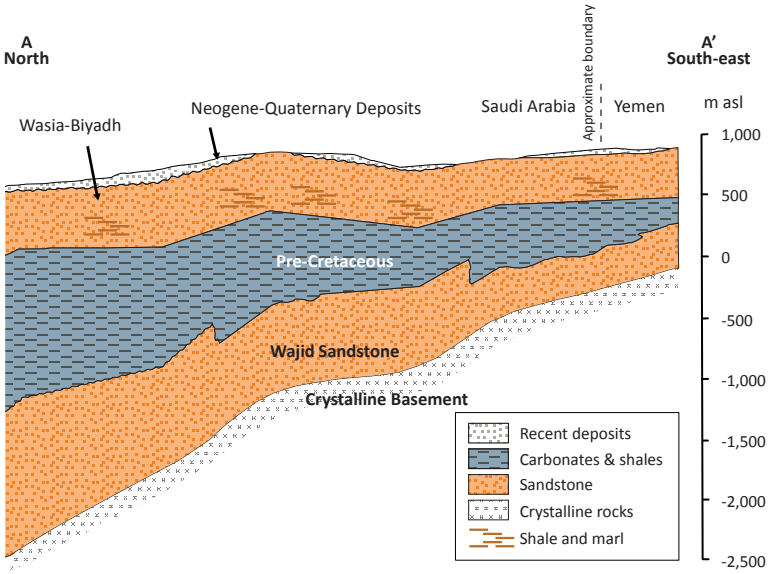
The aquifer system is bounded on four sides:

- In the east by the limit of the Cretaceous Sands.[13]
- In the west by the uplifted basement and Jibal Wajid (see Chap. 11).
- In the south by the North Hadhramaut Arch, which forms a groundwater divide.[14]
- In the north by the limit of the Rub' al Khali Depression.[15]

The Wasia-Biyadh-Aruma Aquifer System (South) is part of the Rub' al Khali structural depression that formed a depositional basin for Paleozoic and Mesozoic Formations. The basin stretches into north-eastern Yemen and is bounded by the Paleozoic North Hadhramaut Arch to the south. All Paleozoic and Mesozoic sedimentary sequences pinch out onto the North Hadhramaut Arch, which prevents the advance of Paleozoic transgressions further south.[16] In the northern part of the basin, the flank slopes gently but in a step-like manner and the sedimentary column thickness increases from about 2 km near the crest of the Hadhramaut Arch to over 4 km on the Saudi-Yemeni border. Accordingly, the formations dip in an east to north-easterly direction. A reactivation of the North Hadhramaut Arch probably occurred in the Paleocene. Both the Arch and the Rub' al Khali Depression reached their present form by the end of Eocene.[17] As a result, the Paleogene Hadhramaut Group (Umm er Radhuma-Dammam Aquifer System) forms an extensive and almost continuous cover overlying the Cretaceous Formations in the eastern part of Yemen.[18]

The main outcrops of the sandstones are found in Yemen, where they extend into Saudi Arabia along a fault. The sandstones also occur on the surface at the foot of Jibal al Wajid near the western margin of the Rub' al Khali Depression, in the form of isolated outcrops that are separated from the central Wasia-Biyadh outcrops. In the south-west, the sandstones may overlie the Precambrian Basement,[19] whereas further east they lie on top of the Paleozoic-Mesozoic Sequence (Figure 1).

Figure 1. Geological cross-section of the eastern Rub' al Khali showing the stratigraphic position of the Wasia-Biyadh Sandstones



Source: Modified by ESCWA-BGR based on Edgell, 1997.

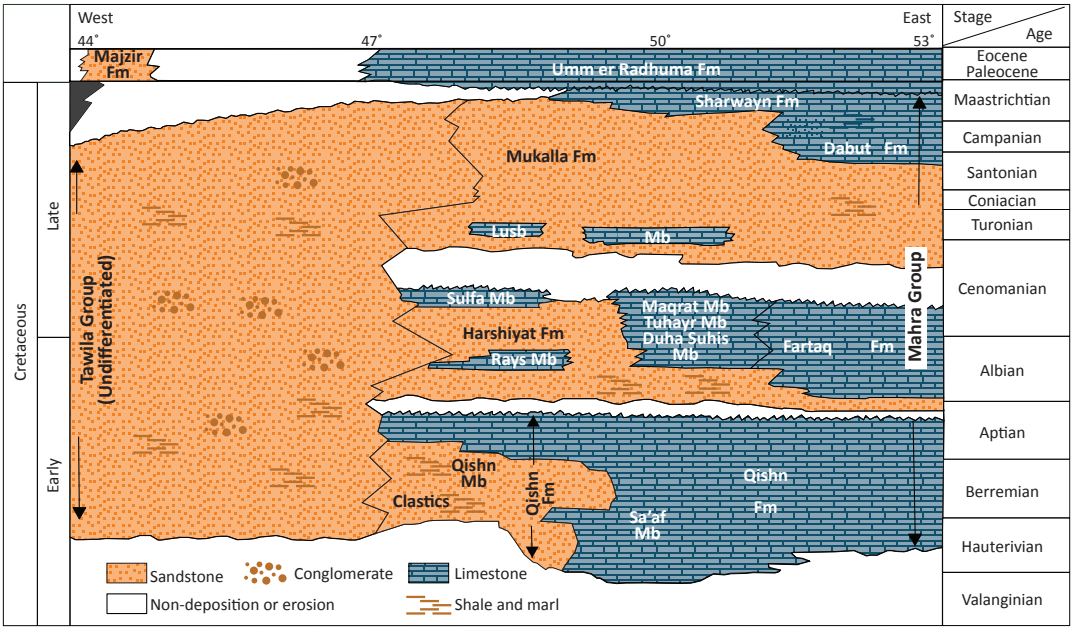
In the northern part of the study area, the sandstones are overlain by superficial deposits of Quaternary age.

STRATIGRAPHY

During the Cretaceous period, the marine advance into the region was from the east with a series of short transgressions followed by regressions, but marine conditions never covered the western areas where terrestrial, fluvial and fluvio-deltaic conditions prevailed.[20] Figure 1 highlights the lithostratigraphic similarity of the early to middle Cretaceous Formations in the eastern areas of Saudi Arabia and Yemen.

Figure 2 shows that in Yemen the zone of the main lateral interdigitation of the individual formations occurs roughly between longitudes 49°30' and 50°30'. West of longitude 47°, the Tawila Group is entirely made up of undifferentiated clastics,[21] which constitute the major aquifer in north-western Yemen. East of this longitude, the Mukalla Formation constitutes the main aquifer within the Mahra Group.

Figure 2. Lithostratigraphy of the Wasia-Biyadh-Aruma Aquifer System (South) in Yemen



Source: Modified by ESCWA-BGR based on Beydoun et al., 1998.

Similarly, only the lowest unit of the Wasia-Biyadh Formations (Khafji-Safaniyah) is water-bearing in the eastern areas of Saudi Arabia, compared with the central part where the sandstone deposition was much thicker (Figure 2) and continued until the Late Cretaceous epoch (sandstone unit of the Aruma Formation not shown in Figure 3).

AQUIFER THICKNESS

In Saudi Arabia, the Wasia Sandstone reaches a maximum thickness of 600 m in the Rub' al Khali[22] where a thickness of 1,000 m is not uncommon for the Cretaceous Sands east of Wadi Dawasir.[23] The Mukalla Sandstone also reaches a thickness of 1,000 m in Yemen, south of the North Hadhramaut Arch. In the North Hadhramaut Arch and its Rub' al Khali Depression flank, however, the thickness of the sandstone in the subsurface varies between 100 and 200 m.[24] This would suggest that the Cretaceous Sands are less thick in the border area than they are further to the north in Saudi Arabia, or to the south in Yemen.

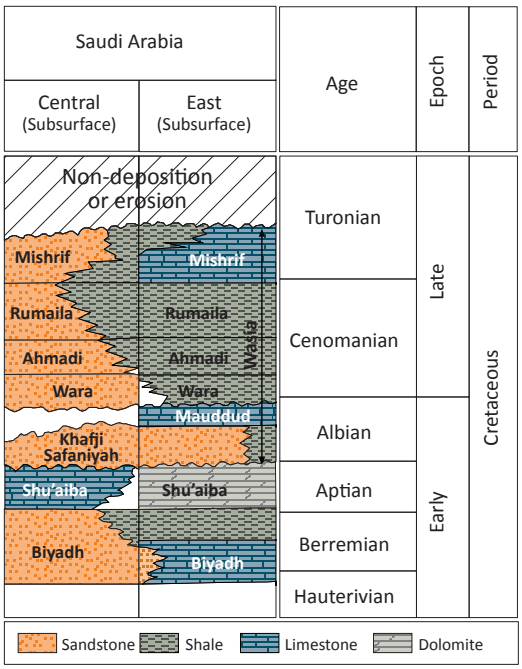
AQUIFER TYPE

Water table conditions are common, whereas some perched water is localized in areas where it is held above the clay layers.[25] In the eastern part of the basin, the sandstone is overlain by a thick sequence of Paleogene carbonate rocks, and the aquifer may be mostly confined in these areas.

AQUIFER PARAMETERS

A transmissivity range of 6.9×10^{-3} to 1.1×10^{-3} m^2/s has been recorded for five wells in the Mukalla Sandstone.[26] These values are within the range estimated by FAO for only a part of the Hadhramaut Valley (2.0×10^{-2} – 3.9×10^{-3} m^2/s).[27] No values could be found for storativity.

Figure 3. Lithostratigraphy of the Wasia-Biyadh-Aruma Aquifer System (South) in Saudi Arabia



Source: Modified by ESCWA-BGR based on Alsharhan and Nairn, 1997.

Hydrogeology - Groundwater

RECHARGE

Despite the very low rainfall, recharge to the Mukalla Sandstone reportedly occurs across the area.[28] Modern recharge could occur in the following manner:

- The areas along the Saudi border are covered by aeolian and alluvial sands which would quickly absorb the infrequent but intense rainfall and allow it to percolate into the sandstones, particularly near the outcrop areas where the alluvial cover is thin.
- A strong potential for structurally facilitated recharge occurs in the western and central areas, where the Mukalla Sandstone and the Umm er Radhuma Formation are exposed, because of the intensive structural dislocation and faulting within these rocks.
- The eastern part of the plateau that is covered by the practically impervious Jeza Formation[29] generates considerable runoff. This in turn infiltrates into the permeable Umm er Radhuma and Mukalla Formations, which are exposed in the deeply incised valleys, and into the Quaternary alluvial valley fill further north.[30]

The age of deep water in the Mukalla Sandstone was determined through carbon-14 dating at 8,000 years, which is relatively young compared to the deep water in the Umm er Radhuma Aquifer System (20,000 years). This young age together with the stable isotopic composition (^{18}O: -2.0 to -3.5‰) suggest that recent recharge water must be reaching the sandstones.[31] Similarly, the water in the Wasia-Biyadh Aquifer System was found to be 8,000 years old at the main outcrop near Al Kharj and 16,000 years down-dip in the Khurais area[32] (see 'Overview and Methodology: Groundwater' chapter, Map 1) for the central part of the aquifer system.

A summary[33] of several studies[34] undertaken in Saudi Arabia estimated recharge to the Wasia-Biyadh and Aruma System at 419 MCM/yr over an area of 47,500 km^2 (29,000 km^2 of Wasia-Biyadh outcrops and 18,500 km^2 of Aruma outcrops), which would be equivalent to 8.8 mm/yr for the outcrop areas.

A far lower rate for direct recharge through the Mukalla Sandstone outcrops (1.5 mm/yr) was found in the Hadhramaut Plateau south of the study area (see Overview Map).[35] These estimates (1.5 and 8.8 mm/yr) and the outcrop areas of the sandstones of the aquifer system as delineated here (8,660 km^2) would translate into a direct recharge volume of between 13 and 76 MCM. Indirect recharge is also likely to occur through runoff, particularly through the wadis descending from the uplifted basement areas where precipitation is higher. However, no estimates of this additional recharge were available.

FLOW REGIME

The Mukalla Sandstone dips in an easterly to north-easterly direction[36] and hence groundwater flows towards the Rub' al Khali and south-eastern Saudi Arabia.[37] Further north, groundwater in the Wasia-Biyadh Formations flows towards the Persian Gulf under the influence of a small but consistent hydraulic head.[38]

STORAGE

A 1986 study compiled data from previous studies and estimated the quantity of water in storage in the Wasia-Biyadh Aquifer System in Saudi Arabia between 120 and 290 BCM.[39] Since then, other studies have given a wide range of values for the same aquifer system.[40] Perhaps the most comprehensive study is that prepared by the British Arabian Advisory Company for the Ministry of Agriculture and Water in Saudi Arabia in 1980, in which both depth and water quality limitations were taken into consideration.[41] This study estimated that the total volume of water with acceptable quality (TDS = 2,000 ppm) that could be extracted from a depth of 300 m in this aquifer system was in the order of 500 BCM (the maximum depth currently possible with pumping technology existing at the time).[42]

The storage calculation of the Mukalla Sandstone,[43] which extends to the Gulf of Aden and covers around 200,000 km^2, was based on an assumed porosity of about 25%. However, such a high porosity is most likely not sustained

Between Mukalla and Bir Ali, Yemen, 2000. Source: Kebnekaise.

throughout this huge area. Even if such high values were sustained, they would not represent effective (drainable) porosity. Effective porosities of sandstones vary between 0.5% and 10%; in this case a value of 5% was used for the Mukalla Sandstone.[44] Assuming a regional drawdown of 200 m below the groundwater table and an effective porosity of 5%, total storage would be 2,000 BCM. If it is then assumed that at least 25% of this water lies within the boundaries of the Wasia-Biyadh-Aruma (South) Aquifer System – a very conservative figure – then the maximum extraction potential from the aquifer system in this basin would be roughly 500 BCM. This figure is identical to that estimated for the Wasia-Biyadh Aquifer System in Saudi Arabia as shown above.

DISCHARGE

There are no visible signs of discharge on the surface. Downward flow discharge into the Upper Wajid Sandstone could occur on the Yemeni side of the border where the Khuff Formation, which separates the two aquifer systems in Saudi Arabia, seems to disappear. However, there is no data to confirm or negate this.

WATER QUALITY

Groundwater from seven bore-holes drilled into the Mukalla Sandstone in the plateau area south of the North Hadhramaut Arch was found to be of excellent quality, with TDS values in the range of 406-833 mg/L and ionic compositions as follows:
$Ca > Mg > Na$ and $HCO_3 > SO_4 > Cl$.[45]

No information is available on groundwater quality north of the North Hadhramaut Arch, but TDS values are possibly similar.

EXPLOITABILITY

The top of the Cretaceous has an approximate maximum depth of 600 m bgl across the whole area shown in the Overview Map.[46] Information on observed depth to groundwater (100-200 m bgl) and water quality (TDS of ≤1,000 mg/L) was only available for the Yemeni part of the study area. As both parameters are within the limits of the criteria selected for exploitation (see 'Overview and Methodology: Groundwater' chapter), the entire delineated area can be considered exploitable, subject to accessibility and drilling/well stability in areas of thick sand dunes.

However, groundwater exploitation would probably present logistical and access issues at these depths, thus significantly increasing unit cost per volume of groundwater extracted. The area of exploitation could even extend beyond the mapped area if depth to water and TDS were not considered limiting factors. Recent data however suggests that one or both parameters may be limiting factors, since practically no exploitable area is shown beyond the eastern limit of the Cretaceous Sands.[47]

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

The water table in the sandstones is in the range of 100-200 m bgl, with the possible exception of wadi bed areas, where relatively shallow groundwater occurs.[48] The use of groundwater from the aquifer system is at present limited to insignificant quantities for the needs of small groups of nomadic populations.

GROUNDWATER QUALITY ISSUES

There are no quality issues related to use since there is very limited abstraction. However, water quality may be affected by natural elements in the future if water is abstracted on a larger scale. Sandstone formations may contain substantial amounts of disperse uranium (U) derived originally from granitic or related metamorphic host rocks.[49] This would suggest that the Tawila-Mahra/Cretaceous Sands, which lie in the vicinity of the Basement, may contain radionuclides that are potentially hazardous to human health. Groundwater quality in the aquifer system is further threatened by the infiltration of saline water from wadi beds. Possible future threats could also include pollution from the oil industry, as a growing number of exploratory oil wells are drilled in the Rub' al Khali.

SUSTAINABILITY ISSUES

The aquifer system is in a very remote and sparsely populated area where no sustainability issues are foreseen in the near future.

Wadi Doan, Yemen, 2000. Source: Kebnekaise.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place for the Wasia-Biyadh-Aruma Aquifer System (South) which is shared between Saudi Arabia and Yemen.

COOPERATION

No information was available regarding cooperation between the riparian countries on the aquifer system.

OUTLOOK

This is a 'virgin' aquifer system that has a potential for producing groundwater for many, perhaps hundreds, of years, if protected from pollution by the oil industry.

Mukalla, Yemen, 2000. Source: Kebnekaise.

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40. See Al Alawi and Abdulrazzak, 1993; Al Sheikh, 2000.
41. BAAC, 1980.
42. Al Alawi and Abdulrazzak, 1993.
43. Van der Gun and Ahmed, 1995, p. 57.
44. Komex International Inc., 1997, p. 154, 163; Domenico and Schwartz, 1990.
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Chapter 13

Sakaka-Rutba

Wasia-Biyadh-Aruma Aquifer System (North)

Wasia-Biyadh-Aruma Aquifer System (North)

Sakaka-Rutba

EXECUTIVE SUMMARY

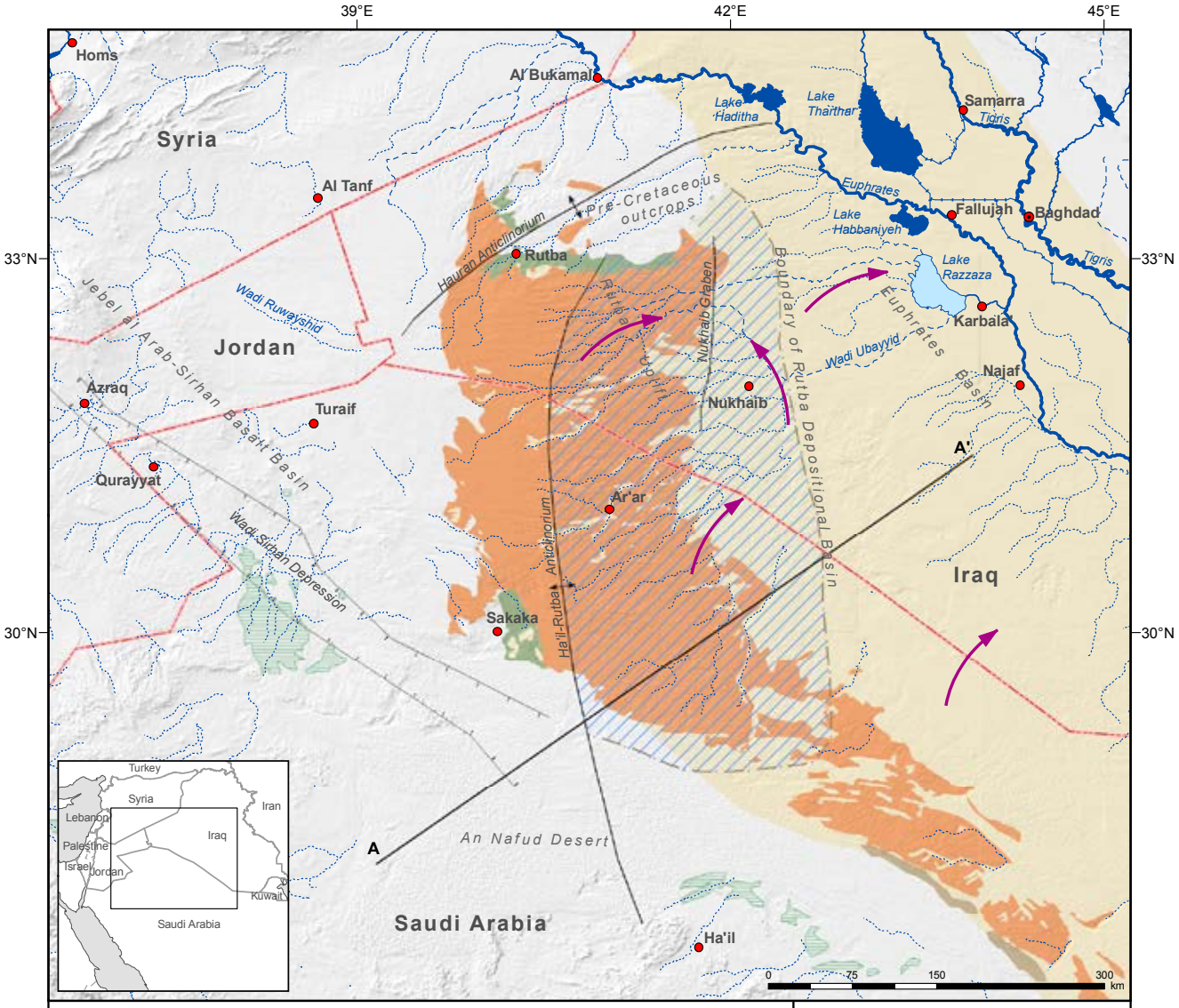
The Wasia-Biyadh-Aruma Aquifer System (North) lies on a high plain (400-800 m) that extends across the western Rutba High in Iraq and the Widyan Plain in Saudi Arabia. Also referred to as Sakaka-Rutba, the Wasia-Biyadh-Aruma Aquifer System (North) constitutes an important aquifer system in the area with freshwater flowing through six aquiferous units (Rutba-Ms'ad-Hartha-Tayarat in Iraq and Sakaka-Aruma in Saudi Arabia). Exploitation depth ranges between 200 and 400 m bgl.

The use of this aquifer system is currently limited due to its remoteness and the harsh environment in the area but the towns of Ar'ar and Sakaka in Saudi Arabia and Rutba in Iraq presumably rely on the aquifer system for their water supply. The Wasia-Biyadh-Aruma Aquifer System (North) is a promising aquifer system that could be used to encourage agricultural development in this pediment region, especially around the wadi areas where soils are fertile.

BASIN FACTS

RIPARIAN COUNTRIES	Iraq, Saudi Arabia
ALTERNATIVE NAMES	Iraq: Rutba-Ms'ad-Hartha-Tayarat Saudi Arabia: Wasia Group Sakaka-Aruma
RENEWABILITY	Very low to low (0-20 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Weak
ROCK TYPE	Mixed
AQUIFER TYPE	Unconfined at/near outcrop areas Confined further away
EXTENT	~112,000 km^2
AGE	Mesozoic (Middle to Late Cretaceous)
LITHOLOGY	Sandstones, locally calcareous or argillaceous
THICKNESS	Iraq: 250 m Saudi Arabia: 400 m
AVERAGE ANNUAL ABSTRACTION	≥ 30-35 MCM
STORAGE	..
WATER QUALITY	Fresh to slightly brackish (400-3,000 mg/L TDS)
WATER USE	Domestic and irrigation
AGREEMENTS	-
SUSTAINABILITY	-

OVERVIEW MAP



Wasia-Biyadh-Aruma Aquifer System (North): Sakaka-Rutba

- Capital
- Selected city, town
- International boundary
- River
- Intermittent river, wadi
- Canal
- Saltwater lake
- Freshwater lake
- A A' Geological cross-section
- Sakaka/Rutba-Ms'ad outcrop
- Aruma/Hartha-Tayarat-Digma outcrop
- Wasia-Biyadh outcrop
- Approximate subsurface extent of the aquifer formations
- Approximate extent of exploitable area
- Direction of groundwater flow
- Zone of agricultural development (selection)
- Graben
- Anticline

ESCWA

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

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The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

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The Wasia-Biyadh-Aruma Aquifer System in this Inventory

The Wasia, Biyadh and Aruma Formations extend across the Arabian Peninsula over a distance of about 2,400 km from north-eastern Iraq to the southern coast of the peninsula, with a width that varies between 350 km and 1,450 km and covering a total area of about 1,923,000 km^2 (see 'Overview and Methodology: Groundwater' chapter, Map 1).

The large geographical extent and the lithostratigraphic variations within the formations suggest that they can be divided into three sections, as described below:

- **In the northern section**, the Biyadh Formation disappears completely, while the Wasia (known in this area as the Sakaka)[1] forms an aquifer system with the overlying Aruma Formation that continues across the border into the Rutba area in Iraq (see current chapter).[2]

- **In the southern section** near Wadi Dawasir, the sandstones of the Biyadh and Wasia grade together with the Aruma to form a thick sandstone unit, known as the Cretaceous Sands,[3] which extends to the Yemeni border. The stratigraphically correlatable sandstones across the border are known as the Tawila Group in Yemen.[4] This section is presented in Wasia-Biyadh-Aruma Aquifer System (South) Tawila-Mahra/ Cretaceous Sands (see Chap. 12).

- **In the central section**, both the Wasia and Biyadh Formations are present and constitute one aquifer system inside Saudi Arabia, which may extend as far east as the western boundary of the Shu'aiba Formation. Beyond that, the two aquifers are separated by the well-developed dolomitic limestone of the Shu'aiba.[5] The Wasia Aquifer extends to Bahrain where it is currently not used due to high salinity and excessive depth. Hence, while the central section of the Wasia-Biyadh is a major aquifer system inside Saudi Arabia, it is not considered a shared aquifer.

The Tuwaiq Escarpment, An Nafud Desert, Saudi Arabia, 2006. Source: Marcel Baptiste.

Introduction

LOCATION

The Wasia-Biyadh-Aruma Aquifer System (North) lies beneath a high plain across the north-western border between Iraq and Saudi Arabia (the Widyan Plains-Rutba Uplift). The general location of the aquifer system is defined by the boundary of the Rutba depositional basin in the east, the Jebel al Arab-Sirhan Basalt Plateau in the west, the An Nafud Desert in the south, and the Pre-Cretaceous outcrops in the vicinity of the Hauran Anticlinorium, which limits the northern extension of the aquifer (See Overview Map).

AREA

This chapter focuses only on the small area in the northern section of the aquifer system that is considered to be shared. The aquifer system was delineated on the basis of available information, resulting in an area of around 112,000 km^2, of which 49,000 km^2 lies in Iraq and 63,000 km^2 in Saudi Arabia. This area extends along the arid western part of the Iraqi-Saudi border, which consists of a pediment plain (serir)[6] known as the Widyan[7] Plain in Saudi Arabia and the Western (Rutba) Desert in Iraq. South of the border, this high plain, which is between 400-800 m asl, dips gently north-eastwards with a gradient of 10-20 m/km from the great An Nafud Desert into south-central Iraq towards the Euphrates River at an elevation of 100-200 m asl.[8]

CLIMATE

The Western Desert along the Iraqi-Saudi border is characterized by low precipitation (50-100 mm/yr) and very high surface evaporation (2,500-3,000 mm/yr).[9] Precipitation is extremely variable in time and space, and may sometimes exceed 40 mm in 24 hours. The maximum daily recorded precipitation at some stations exceeds the total recorded amount during a whole dry year. Most precipitation occurs in the form of sudden downpours, which reduces evaporation rates and hence induces recharge.

Average temperatures in the Rutba district in Iraq drop to 2°C in winter and reach 38°C in summer.[10] In the Saudi part of the basin, temperatures range between 8°C in winter and 41°C in summer time.[11]

POPULATION

This aquifer system lies in one of the least populated areas in Western Asia with population densities ranging from 2-5 inhab./km^2 in Saudi Arabia to 6-25 inhab./km^2 in Iraq.[12] Total population within the delineated area is estimated at around 420,000 people. The three main towns are Rutba (55,000 inhabitants) in Iraq,[13] and Sakaka (197,000 inhabitants) and Ar'ar (165,000 inhabitants) in Saudi Arabia.[14] In addition, a few thousand nomads move freely across the borders and are mostly based in the Al Ruwayshid[15] area in Jordan.

OTHER AQUIFERS IN THE AREA

Fractured limestones and sandstones of Paleozoic to Mesozoic age (Muhaiwir, Mulussa, and Ga'ara Formations in Iraq; Jawf and Juba Formations in Saudi Arabia) are exploited in the northern and southern parts of this area respectively. These formations are exploited as local aquifers around the towns of Sakaka[16] and Rutba[17] but there is no information that suggests that they extend in between to constitute a shared aquifer system.

INFORMATION SOURCES

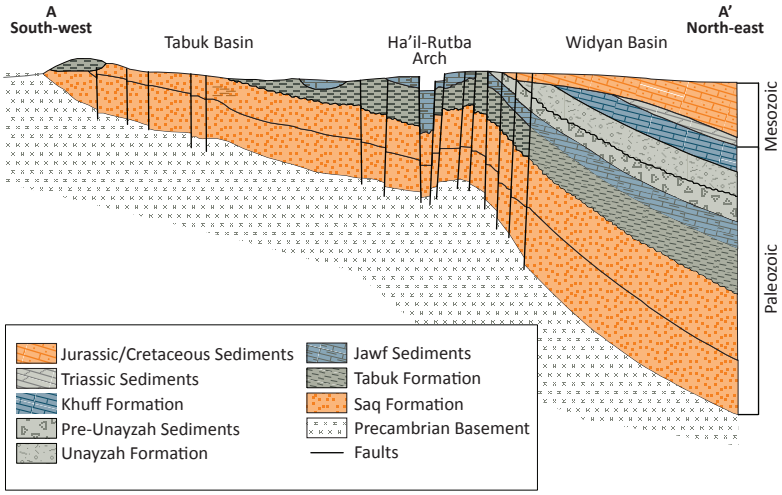
Most of the hydrogeological information used in this chapter comes from Iraq, while no recent sources were available in Saudi Arabia. Hardly any information is available on water use from the Wasia-Biyadh-Aruma Aquifer System (North). The Overview Map was delineated based on several references from both riparian countries.[18]

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

The northern section of the Wasia-Biyadh-Aruma Aquifer System stretches across the Widyan-Rutba Plateau. Geologically the Widyan-Rutba area developed as a depositional basin, and is distinct from the Tabuk Basin to the west, from which it is separated by the Ha'il-Rutba Arch and associated faults (Figure 1). The Ha'il-Rutba Arch is the longest arch in Western Asia, extending across the Arabian Peninsula from the northern border of Saudi Arabia into Iraq. It is covered by 4-6 km of Paleozoic-Mesozoic clastic sediments.[19] The arch was mainly formed during the Cretaceous-Early Tertiary due to the northward extension of the Ha'il Arch from northern Saudi Arabia into Iraq where it joined with the Rutba High.[20] North of the border, the Rutba area is part of a high carbonate plateau, which is separated from the low karstified Paleogene carbonate and gypsum to the east and south-east by a low depression filled with Pleistocene gravel. This is known as the Nukhaib Graben.[21] The Rutba High resulted from a huge uplift (known in Iraq as the Rutba Uplift) that was active between late Permian and Paleogene (Eocene) time.[22] Figure 1 shows that while the Jurassic/Cretaceous Formations, which include the Sakaka-Rutba Aquifers, constitute thin units in faulted areas, their thickness increases significantly towards the north where they are no longer confined within fault zones. Towards the east and west, the Wasia-Biyadh-Aruma (North) Aquifer System is overlain by up to 300 m of younger sediments of Paleogene and Neogene age (see Chap. 16), while in the north older pre-Cretaceous rocks crop out due to folding by the Hauran Anticlinorium.

Figure 1. Generalized lithostratigraphic cross-section of the Widyan and Tabuk Basins



Source: Redrawn by ESCWA-BGR based on Alsharhan and Nairn, 1997.

Table 1. Lithology of the formation units in the Wasia-Biyadh-Aruma Aquifer System (North)

COUNTRY	FORMATION	LITHOLOGY	COMMENTS	SOURCE
Saudi Arabia	Sakaka (Wasia)	Fine- to medium-grained, cross-bedded sandstone, siltstone, and shale.	Main aquifer; outcrops form a rough, maturely dissected plateau with scattered hills near the town of Sakaka.	Ministry of Agriculture and Water in Saudi Arabia, 1984.
	Aruma	Mainly shallow water limestone locally replaced by dolomites, with impure dolomite and shale occurring in the upper units.	Crops out for 1,600 km beyond the Sakaka-Rutba area across central Saudi Arabia, with outcrops decreasing in width from 200 km at the Iraqi-Saudi border to 20 km in the Rub'al Khali area.	
Iraq	Rutba	Fine- to coarse-grained, cross-bedded quartz sands, which are locally calcareous or argillaceous.	Main aquifer; equivalent to the Sakaka Sandstone of the Wasia Group; passes laterally into the Ms'ad Formation.	Jassim and Buday, 2006a.
	Ms'ad	Alternating siltstone, marl and sandstone with beds of limestone and dolomite.	Conformably overlies the Rutba Formation throughout its outcrop area and entirely replaces it 140 km east of the town of Rutba.	
	Hartha	Marl, dolomite and dolomitic limestone beds comprising stacked 10-15 m thick cycles of cross-bedded calcareous sand-stone.	Partly correlates with the Aruma Formation.	
	Tayarat	Rubbly, porous, chalky limestone, locally dolomitized and sandy.	Upper part of the formation in the western areas is replaced by the phosphatic Digma Formation.	

Source: Compiled by ESCWA-BGR.

STRATIGRAPHY

Table 1 gives a brief description of the formations that constitute the Wasia-Biyadh-Aruma Aquifer System (North). A lithostratigraphic correlation of the formations is shown in Figure 2.

AQUIFER THICKNESS

In Saudi Arabia, the Sakaka Formation is thickest near the town of Sakaka where the exposure is 285 m thick. The formation thins in the north-east towards Iraq, where a thickness of only 40 m has been recorded beneath the Trans-Arabian Pipeline (Tapline). The Aruma is also thickest just west of the town of Sakaka where it reaches a thickness of 145 m.[23] In Iraq, the Rutba Formation is 30-40 m thick near the town of Rutba and thins to the east due to its transition into the Ms'ad Formation.[24]
The thickness of the Ms'ad Formation varies from 45 m near Rutba to 97 m about 140 km east of the town. A thickness of 160 m has been recorded for the Hartha Formation about 40 km east of Rutba. South of the town of Rutba, however, its thickness is significantly reduced to 35 m compared to 48 m for the Tayarat Formation in the same area. The thickness of the Tayarat increases towards the east, reaching about 350 m near the town of Ansab.[25]

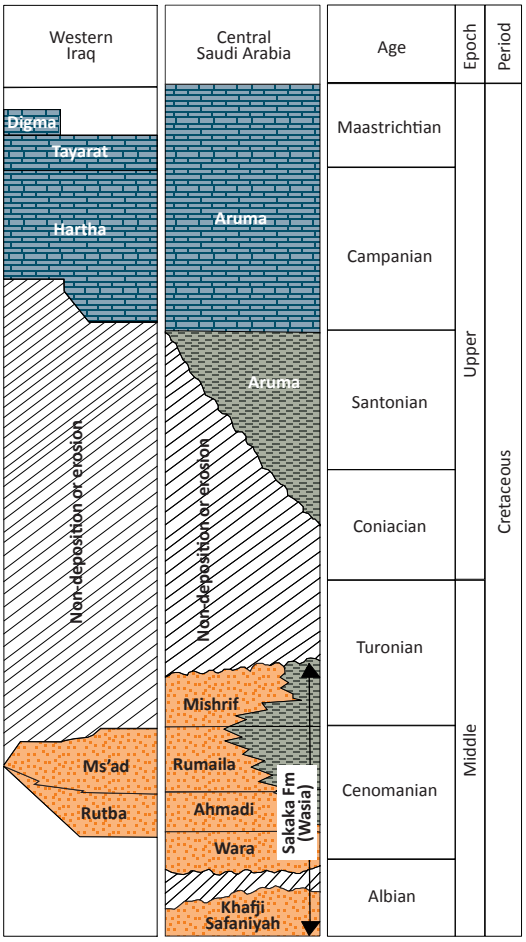
AQUIFER TYPE

In Saudi Arabia, unconfined conditions exist at or near the outcrop areas of the main aquifer units and flowing artesian conditions are found farther away.[26] Artesian conditions are related to the overlying fissured limestone of the Umm er Radhuma Formation and, in some areas, the Sakaka-Rutba Sandstones.[27] In Iraq, all formations within this aquifer system are predominantly confined.[28]

AQUIFER PARAMETERS

Data on the hydraulic parameters of this aquifer system is very scant. The limited information available from the Sakaka area (1978 data)[29] indicates that transmissivity of wells in the outcrop area ranges between $3x10^{-4}$ and $2.8x10^{-3}$ m^2/s, and the storage coefficient lies between $6.7x10^{-4}$ and $9.8x10^{-4}$. Transmissivity values in the Rutba area have been recorded for the Cretaceous and the underlying older rocks. Different studies obtained a range of $3.5x10^{-3}$ to $5.8x10^{-3}$ m^2/s and $2.8x10^{-3}$ to $6.9x10^{-3}$ m^2/s.[30] These values are similar to those obtained for the Sakaka area. However, transmissivity values of $4.0x10^{-2}$ to $1.0x10^{-1}$ m^2/s may be found in karstified areas.[31]

Figure 2. Lithostratigraphic correlation of the formations in the Wasia-Biyadh-Aruma Aquifer System (North)



Source: Redrawn by ESCWA-BGR based on Alsharhan and Nairn, 1997; Jassim and Buday, 2006b; Jassim and Buday, 2006a.

Hydrogeology - Groundwater

RECHARGE

Although the occurrence of direct replenishment of the aquifer system from rainfall would seem unlikely in this arid environment, several factors suggest that restricted quantities of recharge water may be reaching the aquifer system in localized areas within the basin, either directly from rainfall or indirectly via wadi beds and fractured zones:

- The occurrence of numerous faults and wadi systems would enhance the percolation of surface water, particularly Wadi Hauran along the Hauran Anticlinorium that is cut by several faults.
- The basin is a high carbonate plateau and the shallow formations overlying the main aquifer are mainly fractured carbonates with very high permeability that may allow for the percolation of surface water.[32]
- The presence of relatively shallow bicarbonate-dominated groundwater with low salinity (<1,000 mg/L) near the town of Rutba, which lies on the crest of the Hauran Anticlinorium, indicates that recharge takes place in this area.[33]
- Isotope data shows that many groundwater samples from the Rutba area contain tritium concentrations up to 70 TU, which means that present-day recharge water must be percolating into the aquifer system.[34]

Thus the aquifer system may presently be replenished with limited quantities of water. It is estimated that a total recharge of 242 MCM/yr takes place through the Hartha and Tayarat Formations.[35] No recharge data exists for the Rutba, but it is likely to be significantly less due to the very limited exposure of this formation. No information is available for the Saudi Arabian part of the aquifer system.

FLOW REGIME

In general, groundwater in the Wasia-Biyadh-Aruma Aquifer System (North) flows in a north-easterly direction towards its final outlet in the Gulf and the coastal plains. The Sakaka-Rutba area has not been subject to heavy abstraction that could influence this natural groundwater flow and, hence, the piezometric surface faithfully reflects morphology, which allows the groundwater to move across the border in a north-easterly direction. An exception occurs in the vicinity of the Nukhaib Graben where groundwater from the Rutba Uplift flows mostly towards the graben en route to its final discharge zone, the central depression in the Mesopotamian Plain.

In the Sakaka area, the depth to water increases northwards and in 1979 the static water level was 200 m bgl at the town of Sulaymaniya near the Iraqi border.[36] North of this, in the Rutba area across the border, the static water level was still 200 m bgl in 2006, which would indicate that groundwater levels have not changed significantly in about 25 years.[37] In the Nukhaib area to the east, the depth to water is less than 200 m bgl while in the Rutba area farther west it drops to 300 m bgl. The depth of exploitation bore-holes ranges between 200 and 400 m bgl. The relatively shallow groundwater in the Sakaka-Rutba Basin can most easily be tapped along the eastern margin of the basin.[38.]

STORAGE

It was estimated that the total volume of water with acceptable quality (TDS = 2,000 ppm) that can be extracted from a depth of 300 m in the Wasia-Biyadh Aquifer System in Saudi Arabia is in the order of 500 BCM.[39] The volume of groundwater stored in the Sakaka-Rutba area is expected to be significantly less than this figure, although no information could be found on either the volume of water in storage or how much of it is extractable.

DISCHARGE

The only evidence of natural discharge is in the Nukhaib Depression around the town of Nukhaib, with discharge following the main direction of faults in the area. Groundwater flowing into the depression from elevated areas forms an elongated north-west/south-east sabkha or mudflat upstream of Wadi Ubayyid. Otherwise the water stays underground until its final discharge zone, the central depression in the Mesopotamian Plain.

WATER QUALITY

In general, groundwater of acceptable quality can be found in the Sakaka-Aruma and younger rocks in the southern part of the basin as well as in underlying older formations that are preserved in the basin.[40] Groundwater in this section is fresh in the south (Sakaka area) and becomes slightly more brackish towards the north (Rutba area) as described below.

The Sakaka area

Based on 1978 data, groundwater in this sub-zone was found to have a TDS range of 400-1,800 mg/L.[41] The lowest salinity (TDS = 400-600 mg/L) was obtained from wells in the outcrop area of the Sakaka Formation around the town of Sakaka. Dominant cations and anions were shown to be sodium-calcium and chloride-sulphate respectively, and some of the water had an unusually high concentration of magnesium (Mg). Farther north, towards the Iraqi border (Ar'ar-Jalamid area) the TDS increases to 1,000-1,800 mg/L. This increase in salinity was observed in wells drawing water from the Aruma Formation. Water in these wells is calcium-sulphate type changing to sodium-sulphate with increasing mineralization.

The Rutba area

Groundwater in this area has a TDS range of <1,000-3,000 mg/L[42] although it may be over 4,000 mg/L in the Tayarat and Hartha Formations, especially in the southern part.[43] The lowest salinity values occur in the recharge areas around the towns of Rutba and Nukhaib. The groundwater is suitable for domestic use, irrigation and watering livestock.[44]

Recent data indicates that salinity may have increased across the aquifer system as shown below:[45]

- **Rutba Formation:** 1,000-6,000 mg/L TDS
- **Hartha Formation:** 1,500-5,500 mg/L TDS
- **Tayarat Formation:** 1,500-4,000 mg/L TDS

EXPLOITABILITY

West of the Ha'il-Rutba Arch, the productivity of the Cretaceous Formations is very limited and highly unpredictable[46] due mainly to facies change as the formations become phosphatic towards Jordan and marly or argillaceous farther north towards Syria.[47] Furthermore, this part lies mostly within the Central Hammad hydrogeological region, where groundwater is stagnant[48] and the Cretaceous Formations act as an aquitard.[49]

- **Depth to top of aquifer:** The depth of exploitation bore-holes (200-400 m bgl) is significantly less than 2,000 m.[50]
- **Depth to water level:** The depth to water was reported to be 200 m bgl (2006 data) in the area around the border; no data was available from other areas.[51]
- **Water quality:** TDS values of groundwater (<1,000-3,000 mg/L) are within the selected upper limit of 10,000 mg/L.[52]

Hence the aquifer system is exploitable mainly east of the Ha'il-Rutba Arch (see Overview Map), over an area that was estimated to be around 87,000 km^2, of which 35,000 km^2 lies in Iraq and 52,000 km^2 in Saudi Arabia.

Artificial lake near Dumat al-Jandal, Saudi Arabia, 2006. Source: Walter Callens.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

The main abstraction of groundwater probably occurs around the towns of Ar'ar and Sakaka in Saudi Arabia and Rutba in Iraq, where water is used for domestic and irrigation purposes. In addition, the aquifer system is the main water source for the nomadic populations and their livestock. In the central area of the aquifer system within Iraq, some 40 wells abstract 30-35 MCM/yr of water.[53]

No data is available on the total volume of water abstracted in the entire area. However, considering that 1,000 m^3/cap./yr is the recommended agricultural water requirement[54] and assuming that abstraction is halved due to the lack of adequate water infrastructure, water abstraction is estimated at 200-300 MCM/yr.

GROUNDWATER QUALITY ISSUES

There are no water quality issues, except for the possible increase of salinity with depth in the future, if wells are deepened to the pre-Cretaceous Formations underneath.

SUSTAINABILITY ISSUES

At present, there are no sustainability issues within the area of the aquifer system, and none are foreseen in the near future.

An Nafud Desert, Saudi Arabia, 2004. Source: Banco de Imágenes Geológicas.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place for the northern section of the Wasia-Biyadh-Aruma Aquifer System which is shared between Iraq and Saudi Arabia.

COOPERATION

No information was available regarding cooperation between the riparian countries on the aquifer system.

OUTLOOK

The Wasia-Biyadh-Aruma Aquifer System is a promising aquifer system that could be used to encourage agricultural development in this pediment region, especially around the wadi areas where soils are fertile.

The desert between Sakaka and Tayma, Saudi Arabia, 2006. Source: Walter Callens.

Notes

1. The name Sakaka Sandstone has previously been used for a Devonian Formation now called the Jubah Formation. The Sakaka Sandstone referred to in this chapter is part of the Cretaceous Wasia Group.
2. Christian, 2000. This aquifer system also extends to the Hammad regions of Syria and north-eastern Jordan where the equivalent formations (Ajlun and Belqa) act as an aquitard (Barthelemy et al., 2010) (A1/A6) or contain stagnant groundwater (BGR and ACSAD, 1984) with high salinity (Margane et al., 2002) (A1/B7). They will therefore not be considered in this chapter. Area calculations are made within the boundaries of Iraq and Saudi Arabia.
3. Ministry of Agriculture and Water in Saudi Arabia, 1984.
4. Van der Gun and Ahmed, 1995.
5. Othman et al., 1986.
6. The Arabic word "serir" literally means "bed", and is used to describe a flat plateau area.
7. The name Widyan (plural of wadi) reflects the fact that thousands of shallow wadi channels oriented down-dip are found on this pediment that is covered with desert pavements of cherry gravels (Vincent 2008).
8. Jassim and Buday, 2006b.
9. Krasny et al., 2006.
10. Central Organization for Statistics in Iraq, 2012.
11. Central Department of Statistics and Information in Saudi Arabia, 2011; El-Nesr et al., 2010.
12. CIESIN, 2010.
13. Central Organization for Statistics in Iraq, 2010.
14. Central Department of Statistics and Information in Saudi Arabia, 2004.
15. SIWI, 2000.
16. Abunayyan Trading Corporation and BRGM, 2008.
17. Krasny et al., 2006.
18. Ministry of Agriculture and Water in Saudi Arabia, 1984; Jassim and Buday, 2006b; Krasny et al., 2006; and Abunayyan Trading Corporation and BRGM, 2008.
19. Alsharhan and Nairn, 1997.
20. Powers et al., 1966.
21. Krasny et al., 2006.
22. Jassim and Goff, 2006.
23. Ministry of Agriculture and Water in Saudi Arabia, 1984.
24. Jassim and Buday, 2006a.
25. Jawad, 2011.
26. Ministry of Agriculture and Water in Saudi Arabia, 1984.
27. United Nations, 1982.
28. Jawad, 2011.
29. Ministry of Agriculture and Water in Saudi Arabia, 1984.
30. United Nations, 1982; Krasny et al., 2006.
31. Jawad, 2011.
32. Krasny et al., 2006.
33. Ibid.
34. BGR and ACSAD, 1984.
35. Ministry of Water Resources in Iraq, 2012.
36. Ministry of Agriculture and Water in Saudi Arabia, 1984.
37. Krasny et al., 2006.
38. Ibid.
39. BAAC, 1980.
40. Krasny et al., 2006.
41. Ministry of Agriculture and Water in Saudi Arabia, 1984.
42. Krasny et al., 2006.
43. Jawad, 2011.
44. Krasny et al., 2006.
45. Ministry of Water Resources in Iraq, 2012.
46. Krasny et al., 2006.
47. Khoury, 1982.
48. ACSAD, 1983.
49. Khoury, 1982.
50. Krasny et al., 2006.
51. Ministry of Agriculture and Water in Saudi Arabia, 1984, Krasny et al., 2006.
52. Ibid.
53. Jawad, 2011.
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Chapter 14

Rub'al Khali

Umm er Radhuma-Dammam Aquifer System (South)

Umm er Radhuma-Dammam Aquifer System (South)

Rub' al Khali

EXECUTIVE SUMMARY

The southern section of the Umm er Radhuma-Dammam Aquifer System extends from the Gulf coast in the north and the Oman Mountains in the south-east over about 800 km. It covers a total area of about 680,000 km^2, stretching across the vast Rub' al Khali Desert, the Dhofar-Najd Plain in Oman, and the north-eastern Hadhramaut-Al Mahra Plateau in Yemen. The aquifer system in this section comprises three Paleogene (Paleocene-Eocene) Formations: the Dammam, the Rus and the Umm er Radhuma, of which the Rus is the least important.

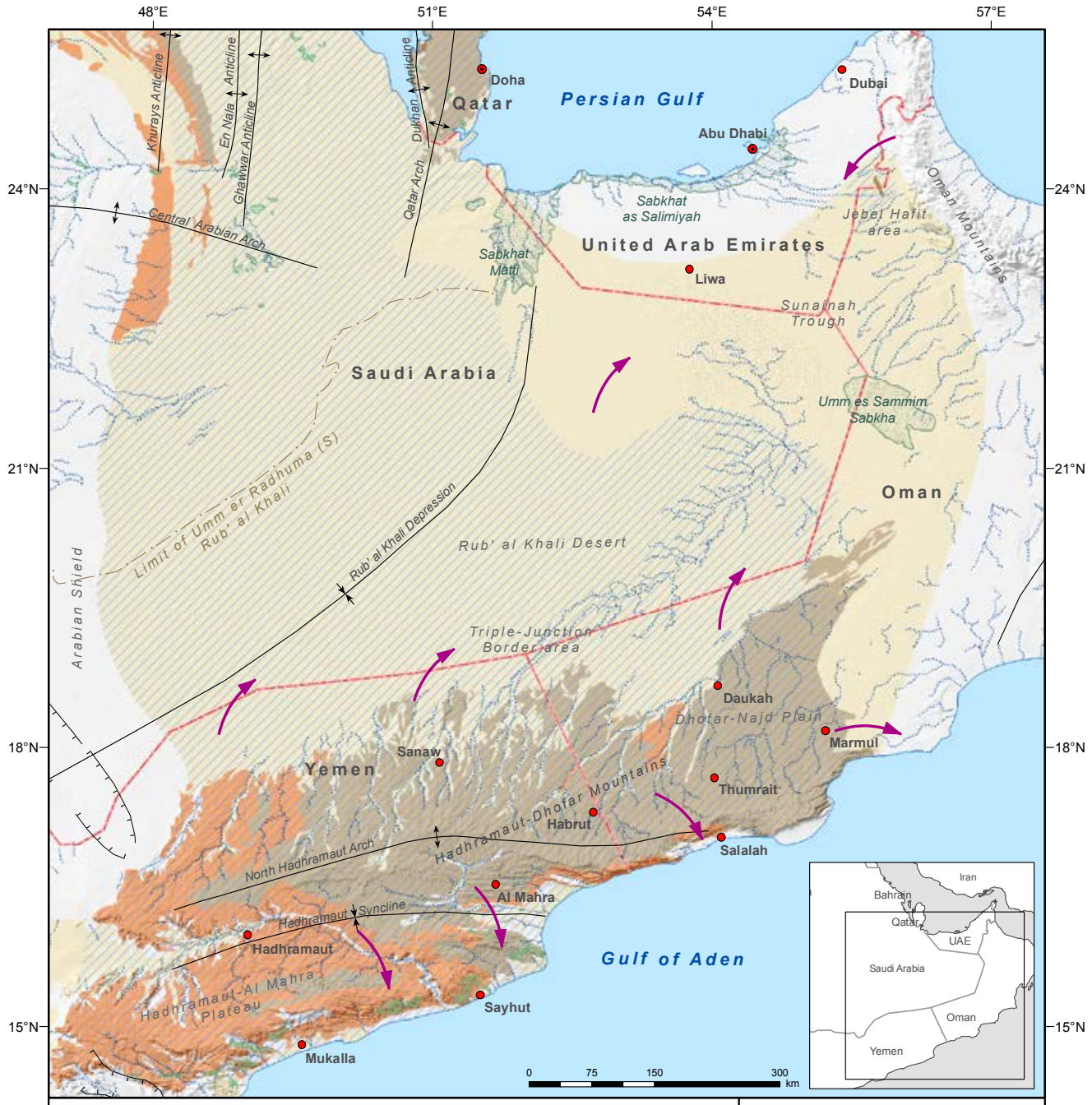
Groundwater flow is generally from the central Arabian Peninsula in the west towards the Gulf coast in the east. Further south and east, flow is mainly north and north-eastward from the Hadhramaut-Dhofar Mountains, and west- and south-west from the Oman Mountains. Most of the groundwater entered the system during the pluvial periods between 20,000 and 10,000 years ago, although there are indications of limited present-day recharge through the Oman Mountains and the Hadhramaut-Dhofar Mountains. Natural discharge occurs through springs emanating from the Umm er Radhuma Aquifer along the edge of the Hadhramaut-Al Mahra Plateau escarpment, or in the form of saline to hypersaline waters that form sabkhas in the lowlands.

At present, the only use of this aquifer system takes place in the Dhofar-Najd region in Oman and United Arab Emirates (UAE) where the water is used for agricultural and domestic purposes, and, to a lesser extent, for recreational or industrial purposes such as water injection for the oil industry.

BASIN FACTS

RIPARIAN COUNTRIES	Oman, Saudi Arabia, UAE, Yemen
ALTERNATIVE NAMES	Umm er Radhuma/Dammam, Hadhramaut Group
RENEWABILITY	Very low to low (0-20 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Weak
ROCK TYPE	Fissured/karstic
AQUIFER TYPE	Unconfined to confined
EXTENT	~680,000 km^2
AGE	Cenozoic (Paleogene)
LITHOLOGY	Mainly limestone and dolomite, with some evaporites
THICKNESS	Dammam: 60-490 m Umm er Radhuma: 50-550 m
AVERAGE ANNUAL ABSTRACTION	Oman: 45 MCM UAE: 7.7 MCM
STORAGE	Najd area: 180-1,100 MCM
WATER QUALITY	Fresh to hypersaline
WATER USE	Agricultural, domestic and oil injection in Oman
AGREEMENTS	-
SUSTAINABILITY	-

OVERVIEW MAP



Umm er Radhuma-Dammam Aquifer System (South): Rub' al Khali

- Capital
- Selected city, town
- International boundary
- Intermittent river, wadi
- Anticline
- Syncline
- Graben
- Umm er Radhuma and Jeza Formations outcrop
- Dammam and Rus Formations outcrop
- Approximate subsurface extent of the aquifer formations
- Approximate extent of exploitable area
- Direction of groundwater flow
- Zone of agricultural development (selection)
- Sabkha

ESCWA الاسكوا

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

Disclaimer
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

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The Umm er Radhuma-Dammam Aquifer System in this Inventory

The Umm er Radhuma-Dammam Aquifer System extends from northern Iraq to the southern coast of the Arabian Peninsula over a distance of 2,200 km. Overall, it covers an area of more than 1,220,000 km^2, of which 363,000 km^2 is covered by outcrops. The total area of this aquifer system in Saudi Arabia, which shares the northern, central and southern sections with neighbouring countries, is 662,000 km^2 (see 'Overview and Methodology: Groundwater' chapter, Map 2).

This system generally comprises three Paleogene (Paleocene-Eocene) Formations: the Dammam, the Rus and the Umm er Radhuma. These formations stretch across Iraq, Yemen and the six Gulf Cooperation Council countries.[1] However, the water contained within these formations cannot be considered shared between all countries. For example, a well pumping from the Dammam Formation in Iraq cannot affect the productivity of this formation in Yemen and vice versa. Furthermore, there is significant variation in the lithostratigraphy of these three formations, particularly the Rus, which is water-bearing in some areas, while acting as an aquitard in others.

Because of the large geographical extent and the lithostratigraphic variations within the formations, the aquifer system has for the purpose of this Inventory been divided into three sections: a northern section (see Chap. 16), a central section (see Chap. 15) and a southern section (see current chapter).[2] This division, which is primarily based on the geographical extent of the formations, also takes relevant geological information into consideration to define the section boundaries.

Liwa Oasis, Abu Dhabi, UAE, 2010. Source: Tom Olliver.

Introduction

LOCATION

The Umm er Radhuma-Dammam Aquifer System (South) extends over a distance of about 800 km from the Gulf coast in the north and the Oman Mountains in south-westerly direction towards the Dhofar-Najd Plateau, where the formations of this aquifer system are not present. It extends across the political borders of Oman, Saudi Arabia, the United Arab Emirates (UAE) and Yemen. Suggested boundaries for this section are the northern limit of the Rub' al Khali Desert and the North Hadhramaut Arch (see Overview Map).

AREA

The southern section of the Umm er Radhuma-Dammam Aquifer System that is covered in this chapter represents around 53% of the aquifer system's total area. Within the boundary of the suggested delineation, the aquifer system covers a total area of 678,000 km^2, of which around 249,000 km^2 lies in Oman, 296,000 km^2 in Saudi Arabia, 61,000 km^2 in the UAE and 72,000 km^2 in Yemen. About 13% of the delineated area (90,000 km^2) is covered by outcrops (Dammam-Rus Formations: 77,000 km^2; Umm er Radhuma-Jeza Formations: 13,000 km^2).

Three major physiographic regions can be identified within this section:

- Rub' al Khali Desert: the world's largest continuous sand desert[3] covering an area of 522,340 km^2.
- Hadhramaut-Al Mahra Plateau: elevated blocks of Paleogene strata dipping very gently in north and north-easterly directions.
- Dhofar-Najd Plain: eastward extension of the Hadhramaut-Al Mahra Plateau consisting of an uplifted monoclinal area and a huge plateau of Tertiary rocks sloping gently in north and north-westerly directions.

CLIMATE

The aquifer system falls almost entirely within the Rub' al Khali agro-climatic zone,[4] which has a tropical arid climate.[5] Rainfall lies below 10 mm/month for most of the year, except during autumn when it can rise to 50 mm over three months, resulting in a total of about 140 mm/yr. Average temperatures range from 14°C-16°C in January to 34°C-36°C in June.[6]

POPULATION

This section of the Umm er Radhuma-Dammam Aquifer System lies in one of the least populated areas in Western Asia. Population density is 0.1-1 inhab./km^2 in the southern areas of Oman and Yemen, and 2-5 inhab./km^2 in Saudi Arabia.[7]

OTHER AQUIFERS IN THE AREA

The Wasia-Biyadh (Middle Cretaceous) Aquifer System (see 'Overview and Methodology: Groundwater' chapter) underlies most of this region. The Wajid Aquifer System (Cambro-Permian) may also be present at great depths in the western area of this section (see Chap. 11). In the mountainous regions at the border between Oman and UAE, the Quaternary gravel plain aquifers are locally important (Box 1).

INFORMATION SOURCES

Limited information was available for the Umm er Radhuma-Dammam Aquifer System (South) in Saudi Arabia, where no development has taken place. Most of the information on the aquifer system was obtained from the central section of Umm er Radhuma-Dammam Aquifer System, which is being developed intensively (see Chap. 15). Data from the central Umm er Radhuma-Dammam was also used to assess groundwater resources in the Northern Hadhramaut Basin in Yemen.[8] The Overview Map was delineated based on various local and regional references.[9]

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

As a sedimentary basin, the Rub' al Khali is bounded by a number of regional structural features:

- The Qatar Arch to the north
- The Central Arabian Arch to the north-west
- The arched-up Arabian Shield to the west (East Interior Homocline and Najd Graben)
- The North Hadhramaut Arch to the south and south-east
- The Oman Mountains to the north-east[10]

The largest outcrops are found in the Hadhramaut-Al Mahra Plateau in Yemen and the Dhofar-Najd Plain in Oman, while smaller outcrops can also be found at the rim of the basin, e.g. at the foot of the Oman Mountains (Jebel Hafit). In accordance with the terrain, the regional aquifer system dips gently from the eastern parts of Yemen (about 800 m asl) to the north-east to the interior plains in the Gulf (approx. 100 m asl). The centre of the basin is overlain by Quaternary sediments and underlain by the Cretaceous Wasia-Biyadh Formations (see Chap. 10, Figure 3). In the north-east of the Arabian Peninsula, the aquifer system is highly fractured and might not be hydraulically connected in all places.

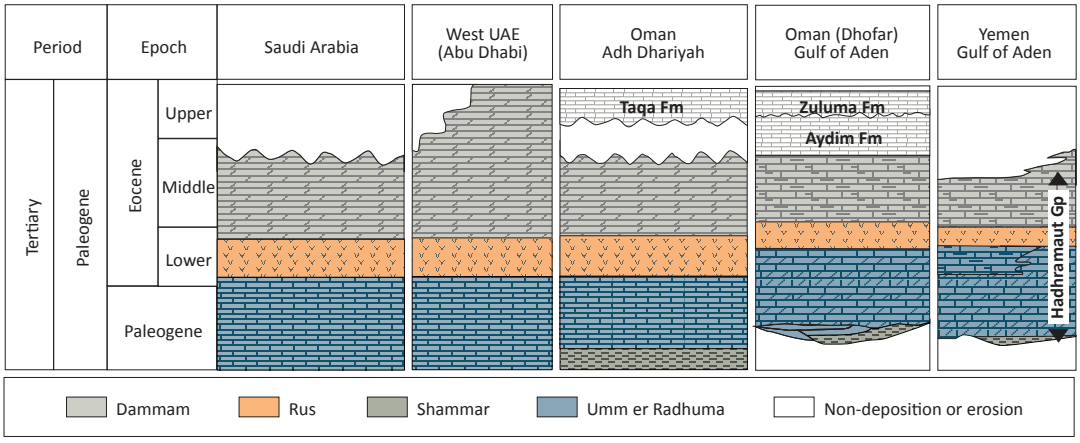
STRATIGRAPHY

The aquifer system within this section comprises three Paleogene (Paleocene-Eocene) Formations: the Umm er Radhuma, the Rus and the Dammam. Hydrogeologically, the Rus is the least important and is mostly considered an aquitard except where it is characterized by dolomitizations or has intercalations of carbonates. The Umm er Radhuma is the principal and most extensive aquifer, especially in the southern areas where it constitutes a continuous aquifer cropping out at the surface or covered by younger aquifer units. Figure 1 indicates that the lithology and stratigraphy of all three aquifer units across the section are similar, except for the fact that the Shammar shale at the base of the Umm er Radhuma is well developed in Oman and Yemen but not in Saudi Arabia and UAE. A more detailed description of the aquifer system in each country is given below.

Oman

Known as the Hadhramaut Group in Oman, the aquifer system extends over a large area from the coastal Dhofar Mountains in the south to the edge of the Oman Mountains in the north.[11]

Figure 1. Lithostratigraphy of the Umm er Radhuma-Dammam Aquifer System (South)



Source: Modified by ESCWA-BGR based on Alsharhan et al., 2001; Beydoun et al., 1998.

The main aquifer within the group is the Umm er Radhuma, which constitutes a regional aquifer in southern and central Oman (Najd and Dhofar areas) and consists of fissured, partly karstic and partly dolomitized limestone.[12] This aquifer is normally divided into Upper Umm er Radhuma (referred to as Aquifers B and C) and Lower Umm er Radhuma (referred to as Aquifer D). It is overlain by the Rus, which consists of bedded gypsum, chalky limestone and dolomitic limestone, and the Dammam, which is composed of crystalline, chalky limestone and dolomitic limestone.[13] Together, the Rus and the Dammam Formations are referred to as Aquifer A. The Hadhramaut Group also occurs in north-western Oman (Sunainah Trough) where the Umm er Radhuma and Rus Formations are absent. Here, the Dammam Formation constitutes an aquifer in the Jebel Hafit area and extends across the Oman-UAE border.[14]

Saudi Arabia

In Saudi Arabia, the extensive Umm er Radhuma Formation forms the main aquifer throughout the Rub' al Khali Desert.[15] The Umm er Radhuma consists mainly of interbedded limestone and dolomite with intercalations of marl and chert, and is overlain by the Rus, which comprises bedded anhydrite, shale, limestone and dolomitic limestone. The Dammam Limestone also constitutes a useful aquifer towards north-western Oman in the Rub' al Khali Desert and adjacent areas in UAE, and probably extends under the northern Rub' al Khali.[16] The upper part of the Dammam (Alat) is only present in the northern and central areas of the Rub' al Khali, but is eroded in the west and south. The lower part of the Dammam (Khobar) has better water-bearing properties than the upper Dammam, which is a relatively poor, generally fine-grained aquifer with low porosity and low permeability.

UAE

In UAE, the aquifer system is located mainly in the emirate of Abu Dhabi. Here, the Umm er Radhuma is composed of four lithological units: a basal unit of shales and marls overlain by three units consisting of different proportions of limestones, dolomite, mudstones and wacke-stones. The Dammam is composed of dolomite with anhydrite in the upper part, packstone and grainstone in the middle part and shales and argillaceous limestone in the lower part.[17] The Rus carbonates constitute an aquifer in the Al Ain region in the emirate of Abu Dhabi and are characterized by extensive dolomitization.[18]

Yemen

The basal Umm er Radhuma Formation of the Hadhramaut Group is prominent and consists predominantly of massive limestones[19] with some marly and dolomitic beds.[20] The Rus is widely developed as an aquifer and is composed predominantly of gypsum with intercalations of limestone and marl.[21] In Yemen, the Jeza Formation, which consists of shales and fine-grained limestone, separates the Rus and the Umm er Radhuma and is considered part of the latter.[22] The top unit of the group, the Habshiyah (the local name for the Dammam), consists of a lower part of shales and marl and an upper part of alternating beds of limestone and chalky limestone.[23] The Habshiyah Formation is either not overlain by any younger deposits or only by superficial deposits.[24] As a rule, it does not constitute an aquifer since it has been 'dewatered', except in some localities where thin perched water is found.[25]

AQUIFER THICKNESS

The total thickness of the aquifer system is only known in some areas:

- In Oman, the Hadhramaut Group was penetrated over a thickness of up to 1,000 m in the Dhofar Mountains area, with a saturated thickness in the order of 400-500 m.[26] Further east in the Najd area, the range of thicknesses obtained for aquifers A, B and C are 1-112 m, 1-43 m, and 31 m, respectively.
- In Saudi Arabia, the Umm er Radhuma is about 150-400 m thick. The thickness of the Khobar is 30-67 m in the north, increasing in the eastern part to 76-90 m.[27]
- In UAE, the Umm er Radhuma has a thickness of 300-550 m in the eastern Jebel Hafit area, while the Dammam ranges from 60-490 m in thickness, with a gradual thickening from west to east in the emirate of Abu Dhabi.[28] The Dammam is 280 m thick in the south-western Liwa area.[29]
- In Yemen, the Rus is about 100 m thick in the north-eastern part of the country,[30] while the Umm er Radhuma is between 150 and 230 m thick in these areas.[31]

AQUIFER TYPE

In Oman, water-bearing horizons within the Hadhramaut Group have especially developed in the confined Umm er Radhuma.[32] Aquifers B, C and D are all confined in the Najd area. In the vicinity of the Dhofar Mountains, all aquifer units

within the group are essentially unconfined with locally "perched" water table conditions in the Dammam Formation where the Rus Formation acts as an aquitard.

In Saudi Arabia, the Umm er Radhuma-Dammam system is generally under artesian and sub-artesian conditions.[33]

In UAE, the aquifer system in the Jebel Hafit area belongs to the confined-flow carbonate aquifer.[34]

In Yemen, the limestones of the Rus are unconfined, while those of the Umm er Radhuma vary from unconfined in the western part to confined, artesian conditions with local pressure heads of 173-269 m in the eastern areas.[35]

AQUIFER PARAMETERS

Data on the hydraulic characteristics of the Umm er Radhuma-Dammam (South) Aquifer System come from Oman and UAE (Table 1 and 2). According to Omani sources,[36] the yields of bore-holes completed in Aquifer C were consistently higher and much more reliable than those from Aquifers A and B.[37]

No aquifer parameter data was available for the southern section in Saudi Arabia, where there is no development. The information presented here comes from the Gulf Basin, where the aquifer system is intensively developed (see Chap. 15). Data from the Umm er Radhuma-Dammam Aquifer System (Centre) was also used to assess groundwater resources in the Northern Hadhramaut Basin in Yemen, where no data was available.[38]

Table 1. Hydraulic parameters of the Dammam in Oman

AQUIFER	TRANSMISSIVITY (m^2/s)	STORATIVITY
A	$5.6x10^{-3}$	$3.2x10^{-6}$
B	$5.4x10^{-4}$	$1.0x10^{-6}$
C	$5.2x10^{-3}$	$2.0x10^{-4}$

Source: Compiled by ESCWA-BGR based on Ministry of Regional Municipalities and Water Resources in Oman, 2009; Alsharhan et al., 2001.

Table 2. Hydraulic parameters of the Umm er Radhuma-Dammam Aquifer System (South) in UAE

AQUIFER	TRANSMISSIVITY (m^2/s)	STORATIVITY
Dammam	$3.6x10^{-5}$-$6.5x10^{-5}$	..
Umm er Radhuma	$4.3x10^{-5}$-$1.6x10^{-4}$	$9.0x10^{-4}$

Source: Compiled by ESCWA-BGR based on Alsharhan et al., 2001.

Lake Hatta in the Oman Mountains, UAE, 2010. Source: Maarten Schäfer.

Hydrogeology - Groundwater

RECHARGE

The aquifer system is mainly replenished by freshwater descending from the Oman and Hadhramaut-Dhofar Mountains. Despite the extreme aridity, studies using remote sensing techniques have demonstrated that recharge does currently occur across the entire Rub' al Khali Basin (650,000 km^2).[39] Recharge rates are estimated at 10%-25% of total precipitation with an average annual rate of 4-10 BCM/yr, which is equivalent to 6-16 mm/yr for the whole Rub' al Khali Basin. While it is not clear how much of this recharge goes to the replenishment of the Paleogene Aquifer System in the section, isotope studies indicated the presence of a local recharge component from present-day rainfall in the Dammam Aquifer in Jebel Hafit in UAE, and the Dammam-Rus system (Aquifer A) in the Najd area in Oman.[40] Estimates show an effective recharge in the order of 11.4 MCM over 300 km^2 in the Najd region of Oman.[41] This would be equivalent to 38 mm/yr and would be almost identical to the highest value (33 mm/yr) estimated for the recharge to the Umm er Radhuma-Dammam Aquifer System (Centre) section (see Chap. 15). This modern recharge is attributed to infrequent storm events that generate sufficient wadi flow to reach the Dammam outcrops and has been estimated to vary between 9.46 and 15.78 MCM/yr, or an average of 12 MCM/yr in the Najd area of Oman.[42] If the recharge component from artesian flow is added (see below), total recharge could even be in the order of 40 mm/yr.

The bulk of the groundwater in the system is, however, believed to have been recharged during the pluvial periods between 20,000 and 10,000 years ago.[43] Carbon-14 dating of Aquifer B in Oman suggests that the age of the groundwater varies from 9,000 to 11,000 years in the east to about 20,000 years in north-western Dhofar.[44] Groundwater ages in Aquifer C were estimated at 4,000-16,000 years in the south (close to the Dhofar Mountains) to 30,000 years in the north-west towards the centre of the Arabian Peninsula. Similarly, ages for Aquifer D were in the order of 9,000 to 26,000 years. An apparent age-distance trend in the Paleogene aquifers from the outer eastern and southern parts toward the inner Rub' al Khali Basin implies that recharge originates in the Umm er Radhuma outcrops of the Dhofar Mountains.[45]

FLOW REGIME

General flow directions

In the northern areas of the Rub' al Khali, groundwater flow generally follows the main flow direction of the Umm er Radhuma-Damman Aquifer System (South), from the central Arabian Peninsula in the west towards the Persian Gulf in the east. This implies that groundwater in the Umm er Radhuma-Dammam Aquifer System may flow across the Saudi-UAE border. From the Hadhramaut-Dhofar Mountains, groundwater flow is mainly north and north-eastward. South of the North Hadhramaut Arch, it flows towards the Gulf of Aden. In the north-eastern part of the region, flow is west and south-westward from the Oman Mountains.[46]

Inter-aquifer flow

While upward groundwater flow has been observed from Aquifers B and C into the overlying aquifers via "leaking", open bore-hole/wells or artesian surface flow, it has not been quantified.[47] A comparison of three leakage scenarios (Table 3) indicates that about 10 MCM/yr of water may be flowing from the upper and middle confined areas of the Umm er Radhuma Aquifers (Aquifers B and C) into Aquifer A (Dammam and Rus) or infiltrate back into Aquifer A via the surface.

Table 3. Inter-aquifer flow in the Paleogene Aquifer System in the Najd region in Oman

LEAKAGE (%)	VOLUME OF UPWARD LEAKAGE (MCM/yr)	RETURN FLOW FROM ARTESIAN SURFACE FLOW (MCM/yr)
5	0.79	1.26
15	2.40	3.70
25	4.10	6.39

Source: Modified by ESCWA-BGR based on Carlson, 1994.

STORAGE

Retrievable groundwater for the three Paleogene aquifers was assessed for the Najd area, which covers an approximate area of 60,000 km^2 (Table 4).

The discrepancy in Table 4 may be ascribed to the fact that these studies applied different values of specific storativity/storage coefficient and defined different aquifer units. No further information was available on groundwater reserves in the Paleogene Aquifer System in this section.

Groundwater reserves in eastern Saudi Arabia were estimated at 190 BCM and 45 BCM for the Umm er Radhuma and the Dammam respectively.[48]

DISCHARGE

Natural discharge of the aquifer system occurs from springs in elevated areas or in saline to hypersaline waters, which form sabkhas in the lowlands. Springs from the Umm er Radhuma Aquifer emanate along the edge of the Hadhramaut Plateau.[49] Numerous springs also emerge at the interface between the Dammam and the Rus, where the latter may act as a locally impervious layer.[50] Further north to north-east, the Umm es Sammim Sabkha acts as a major discharge zone of saline groundwater from the Paleogene Aquifers in the eastern part of the section.[51] The final discharge areas for the aquifer system are mainly the coastal sabkha (Sabkhat Matti) and the inland sabkha (Umm es Sammim Sabkha) and, to a lesser extent, the interior plains along the border of Oman, Saudi Arabia and UAE.

WATER QUALITY

The general distribution of groundwater salinity in this section of the aquifer system (Figure 2) indicates that the aquifer is a potential source of relatively freshwater for Oman, Saudi Arabia and Yemen. Salinity varies locally and freshwater with <2,000 mg/L TDS can be found in the central areas of the aquifer system[52] and further east in the Najd[53] areas. These variations can be attributed to the relative amount of present-day monsoon recharge versus the cyclonic components of paleo-recharge.[54]

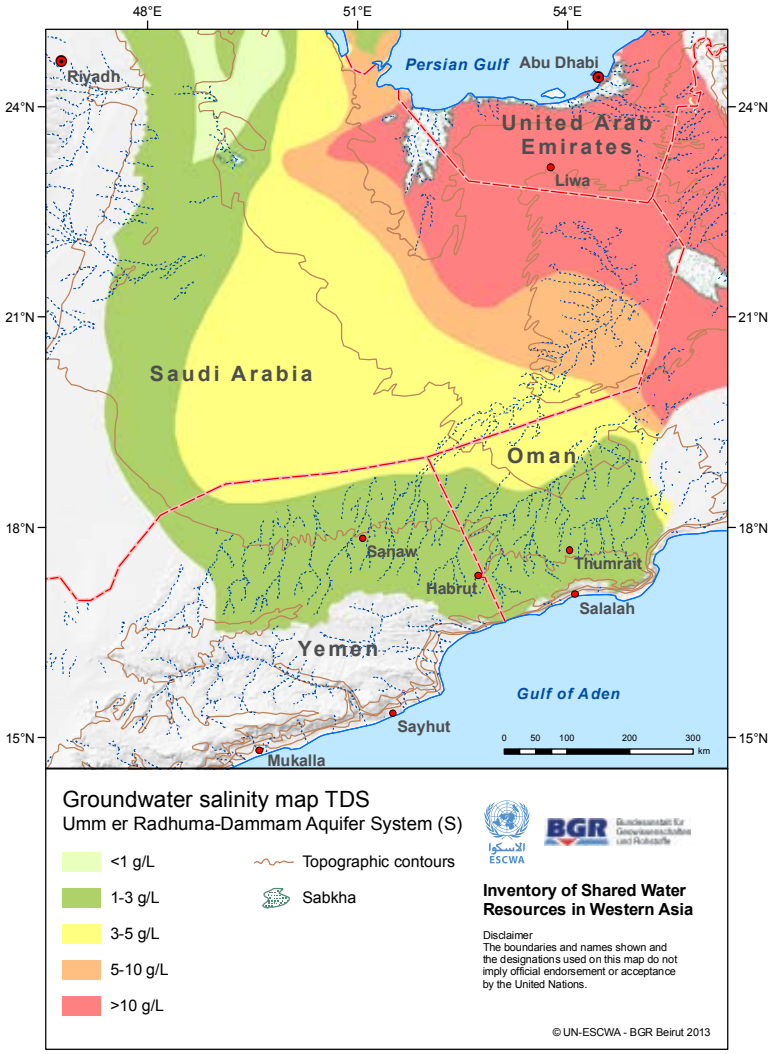
Groundwater with up to 200,000 mg/L TDS has been found in bore-holes where old water ascending through structural discontinuities dissolves evaporites in the subsurface and undergoes substantial near-surface evaporation in groundwater discharge (sabkha) areas.[55] In addition, high radon (Rn) and radium (Ra) contents detected in the groundwater in Jebel Hafit could also be a limiting factor to the use of this aquifer system in some areas.[56] Also, the high fluoride concentrations found in many wells make the water unfit for human consumption unless specific fluoride (F^-) removal processes are applied.[57]

Table 4. Groundwater reserves in the Umm er Radhuma-Dammam Aquifer System in the Najd area in Oman

SOURCE	ESTIMATED RESERVE (MCM)	SPECIFICATIONS
Carlson, 1994.	1,100	Aquifer A: 333 MCM Aquifer B: 277 MCM Aquifer C: 490 MCM Aquifer D: —
Quinn, 1986.	315	200 MCM with EC <2,500 µS/cm excluding Aquifer A
Halcrow, 1975 in Quinn, 1986.	180-600	..

Source: Compiled by ESCWA-BGR.

Figure 2. Groundwater salinity map - Umm er Radhuma-Dammam Aquifer System (South)



Source: Compiled by ESCWA-BGR based on UN-ESCWA and BGR, 1999a; UN-ESCWA and BGR, 1999b.

EXPLOITABILITY

The following criteria were used to delineate the exploitable areas of this aquifer system:

- **Depth to top of aquifer:** The top of the Cretaceous, which underlies the Paleogene Aquifer System, is generally between 200 and 1,200 m bgl,[58] and bore-holes in the Najd area of Oman reach the Cretaceous at 400 m bgl.[59] The most common depth to the Umm er Radhuma-Dammam Aquifer System in this section is 300-500 m bgl.[60]
- **Depth to water level:** In the mid-1980s and early 1990s many wells surveyed in the vicinity of Thumrait and parts of the Najd area flowed at the surface or had a maximum depth of around 100 m bgl.[61]
- **Water quality:** The TDS of the groundwater is generally below 10,000 mg/L except in the north-eastern areas where hypersaline conditions prevail in the vicinity of sabkhas.

Based on the above, it would appear that most of the aquifer system is exploitable except for the north-eastern part. The total exploitable area within the delineated basin (including the Jebel Hafit area) is around 392,000 km^2: 82,000 km^2 in Oman, 232,000 km^2 in Saudi Arabia, 1,000 km^2 in UAE and 77,000 km^2 in Yemen.

An aerial view of Jebel Hafit, with the city of Al Ain to the north, Abu Dhabi, UAE, 2010. Source: Tom Olliver.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

Abstraction from the Paleogene Aquifer System in the Rub' al Khali Desert area that extends across the borders of all four countries is negligible, and essentially limited to the use of hand-dug wells for domestic purposes by nomadic populations. The only significant use of this aquifer system occurs in the Dhofar-Najd areas in Oman and the Jebel Hafit area in UAE, where it is being developed for agricultural and domestic use after treatment and, to a lesser extent, for industrial (water injection for the oil industry) and recreational purposes. The total amount of groundwater currently abstracted from the aquifer system in this section (45 MCM) is much lower than the amount abstracted from the central (Gulf: 720 MCM) and northern (Widyan-Salman: 350 MCM) sections of the Umm er Radhuma-Dammam Aquifer System.

Oman

The town of Thumrait in Najd (Oman) reportedly withdraws about 1.3 MCM/yr from the aquifer system for domestic purposes.[62] The Petroleum Development of Oman (PDO) also produces more than 6 MCM/yr of groundwater in the Marmul area, 130 km north-east of Thumrait, of which about 1 MCM/yr is injected into the oil-producing horizon. In 1985, PDO established the first 40 ha pilot farm at Marmul, which was expanded by a further 60 ha in 1987.[63]

A number of feasibility studies[64] were also prepared for agricultural development in the general area of Thumrait and northward to Daukah. The Omani Government is currently establishing three pilot agricultural projects at Hanfeet, Daukah and Bin Khawta, requiring an expected total abstraction of 75 MCM/yr in addition to the estimated 38 MCM/yr that is already being abstracted at present.[65]

UAE

Fifteen bore-holes in the Jebel Hafit area abstract about 7.7 MCM of groundwater from the Dammam Formation.[66] This water is not suitable for drinking and other domestic purposes because it has high radium (Ra) and radon (Rn) content, high temperature (36.5°C-51.4°C), and high salinity (3,900-6,900 mg/L TDS). While the water is currently only used for recreational purposes, there are plans to use it for health and therapeutic purposes as well as for the production of salt-tolerant crops.[67]

GROUNDWATER QUALITY ISSUES

A number of issues related to the natural composition of the aquifer formations and/or progressive exploitation may be of concern in this area (Figure 2):

- In areas where the groundwater is relatively fresh, inter-aquifer flow and upconing of thermal saline water is likely to impact the quality of the shallow groundwater system (e.g. Jebel Hafit).[68]
- The injection of about 1 MCM of groundwater into the oil-bearing formation in the Marmul area represents a potential source of pollution for the overlying aquifer system.[69]

SUSTAINABILITY ISSUES

The aquifer system already shows signs of over-abstraction locally, especially in the major Aquifer C in the Najd area of Oman, where the water level is dropping at a rate of 2.05 m/yr.[70] Hence sustainability of the use of the aquifer system will become an issue.

Lake Hatta in the Oman Mountains, UAE, 2010. Source: Maarten Schäfer.

BOX 1

The Western Gravel Aquifer

The Western Gravel Aquifer (WGA) is located along the border of Oman and UAE (Figure 3). It extends from the western side of the Oman Mountains (Al Hajar al Gharbi) where wadis descending from the mountains form several alluvial fans that coalesce to constitute a stony, westward-sloping plain.

INFORMATION SOURCES

Most of the information featured in this box is drawn from scientific studies published about UAE.[71] Limited information was also found in official sources from Oman.[72]

SEDIMENTOLOGICAL PROPERTIES

The aquifer consists of conglomerates, gravel and sand with intercalations of clay and silt. These sediments, which generally show decreasing particle size away from the mountains, were mainly deposited by wadis cutting through the Ophiolite rocks in the Oman Mountains.

HYDROLOGICAL FEATURES

Table 5 indicates that there is a significant seasonal and geographic variation in rainfall within the area of WGA. Most of the rain falls between November and March. Some of the rain infiltrates through a large number of buried alluvial channels to recharge the aquifer system. Evaporation rates are usually between 2,400 and 2,600 mm/yr.

HYDROGEOLOGICAL CHARACTERISTICS

The base of WGA sediments forms a wedge that increases in thickness towards the west. Average thickness is around 60 m but a thickness of about 400 m has been reported west of Jebel Hafit.[73] Recharge of these sediments along the gravel plain has been estimated at about 30 MCM/yr,[74] of which about 50% takes place south of the town of Al Ain in an area that constitutes a shared aquifer. This shared part of the aquifer has a storage of 2.6 BCM of freshwater and 18 BCM of brackish water.[75]

GROUNDWATER USE

As the most important aquifer in UAE,[76] WGA is heavily exploited in the Al Ain area, where most of the abstracted water is used for irrigation purposes (Table 6). In 1985, about 95% of total water use in this area relied on WGA.[77] In Oman, WGA is exploited in the Al Dhahirah region, mainly through the aflaj system. The groundwater in the alluvial aquifers in this region has traditionally been used for agriculture, and to meet the domestic water demand of the rural population. Rising groundwater salinity limits the usability of WGA.

The development of the oil industry in recent years has led to increased water demand from the industrial sector for the purpose of reservoir flooding and enhanced oil recovery.[78]

SUSTAINABILITY AND MANAGEMENT ASPECTS

The water table in WGA has declined significantly since the 1970s, especially in the Al Ain area where a number of water well-fields have been established, some of them with more than 100 wells.[79] A reported decline of up to 50 m west of the city of Al Ain[80] indicates that the aquifer is being substantially overdrafted. Landsat satellite images taken in 1995 as part of a German Technical Cooperation project[81] were used to assess the impact of over-abstraction from the aquifer in UAE, including a decline in water table and an increase in salinity. Efforts to launch a joint management strategy for the aquifer have failed to bear any concrete results.[82]

Figure 3. The Western Gravel Aquifer

Source: Compiled by ESCWA-BGR based on Rizk and Alsharhan, 2008; Ministry of Regional Municipalities and Water Resources in Oman, 2005.

Table 5. Mean annual precipitation in the Western Gravel Aquifer in UAE (1976-2004)

PRECIPITATION (mm/yr)	AL DHAID	AL AIN	AL WAGAN
Maximum	414.8	291.1	161.2
Mean	127.4	95.1	66.1
Minimum	—	0.6	1

Source: Compiled by ESCWA-BGR based on Rizk and Alsharhan, 2008.

Table 6. Average annual groundwater use from the Western Gravel Aquifer in the Al Ain area (1985)

USE	FRESHWATER (MCM)	BRACKISH WATER (MCM)	TOTAL	
			MCM	%
Domestic	22.3	—	22.3	5
Recreational	24.1	—	24.1	5.5
Irrigation	70	327	397	89.5
Total	116.4	327	443.4	100

Source: Compiled by ESCWA-BGR based on Hyde, 1992 cited in Rizk and Alsharhan, 2008.

Table 7. Hydrogeological characteristics of the Western Gravel Aquifer in the Al Ain area

DEPTH OF WELLS (m)	DEPTH TO WATER (m bgl)	TRANSMISSIVITY (m^2/s)	STORATIVITY	SALINITY (mg/L TDS)
30-90	15-30	$2.9x10^{-4}$-$4.6x10^{-3}$	$9.2x10^{-4}$	500-6,000

Source: Compiled by ESCWA-BGR based on Rizk and Alsharhan, 2008.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place for the southern part of the Umm er Radhuma-Dammam Aquifer System which is shared between Oman, Saudi Arabia, UAE and Yemen.

COOPERATION

No information was available regarding cooperation between the riparian countries on the aquifer system.

OUTLOOK

This aquifer system is in an early stage of development and would therefore constitute a good opportunity to initiate a comprehensive joint management strategy in order to avoid sustainability issues in the long term. From the point of view of shared water resources, the following two areas could be of interest:

- The Jebel Hafit area where the Dammam and Rus Formations constitute a highly fractured aquifer along the UAE-Oman border. The aquifer here presents high transmissivity and relatively low salinity levels in the upper layers, which appear to receive freshwater recharge directly from local rainfall.[83]
- The Triple-Junction Border area (see Overview Map) where the Umm er Radhuma-Dammam-Rus constitute the main water supply source for nomads and small settlements in the vast desert area between Oman, Saudi Arabia and Yemen.

Rub' al Khali Desert, Oman, 2011. Source: Philipp Weigell.

Notes

1. Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates.
2. This division was based on UN-ESCWA and BGR, 1999b.
3. Edgell, 2006. According to Encyclopædia Britannica, 2013 "Rub' al Khali is a vast desert in the southern Arabian Peninsula [...] in a structural basin lying mainly in southeastern Saudi Arabia, with lesser portions in Yemen, Oman and UAE".
4. As defined by the Ministry of Agriculture and Water in Saudi Arabia, 1995 as cited in Vincent, 2008.
5. PSRCE, 2007.
6. Vincent, 2008.
7. CIESIN, 2010.
8. Rybakov et al., 1995, p. V-44.
9. ESCWA-BGR based on UN-ESCWA and BGR, 1999b; UN-ESCWA and BGR, 1999a; Edgell, 2006; Christian, 2000; Van der Gun and Ahmed, 1995.
10. Edgell, 2006.
11. Ministry of Regional Municipalities and Water Resources in Oman, 2009.
12. Ibid.
13. Alsharhan et al., 2001; Alsharhan and Naim, 1997, p. 426.
14. Ministry of Regional Municipalities and Water Resources in Oman, 2009.
15. Edgell, 1997.
16. Ibid.
17. Alsharhan et al., 2001, p. 94.
18. Alsharhan et al., 2001.
19. Van der Gun and Ahmed, 1995.
20. Beydoun et al., 1998, p. 212.
21. Rybakov et al., 1995, p. V-43.
22. Van der Gun and Ahmed, 1995.
23. Beydoun et al., 1998, p. 80-81.
24. Ibid., p. 83.
25. Rybakov et al., 1995.
26. Ministry of Regional Municipalities and Water Resources in Oman, 2009.
27. UN-ESCWA and BGR, 2001.
28. Alsharhan et al., 2001.
29. Al-Mutawa, 1993 cited in UN-ESCWA and BGR, 1999b.
30. Rybakov et al., 1995.
31. Beydoun et al., 1998, p. 215.
32. Ministry of Regional Municipalities and Water Resources in Oman, 2009.
33. UN-ESCWA and BGR, 2001.
34. Alsharhan et al., 2001, p. 95.
35. Pichugin et al, 1984 cited in Rybakov et al., 1995, p. V-44.
36. Ministry of Regional Municipalities and Water Resources in Oman, 2011.
37. Ibid., 2009.
38. Rybakov et al., 1995, p. V-44.
39. Sultan et al., 2008.
40. Rizk and Alsharhan, 1999, Quinn, 1986.
41. Quinn, 1986.
42. Ibid.
43. Al Lamki and Terken, 1996.
44. Clark et al., 1987 cited in UN-ESCWA and BGR, 2001.
45. UN-ESCWA and BGR, 2001.
46. Al Lamki and Terken, 1996.
47. Carlson, 1994.
48. Dabbagh and Abderrahman, 1997 as cited in UN-ESCWA and BGR, 1999b. A pumping depth of 300 m bgl is taken into account as a limiting factor.
49. Beydoun et al., 1998, p. 216.
50. Ministry of Regional Municipalities and Water Resources in Oman, 2009, p. 61.
51. Edgell, 2006; UN-ESCWA and BGR, 2001.
52. Sultan et al., 2008.
53. Quinn, 1986.
54. Ibid.
55. Sultan et al., 2008.
56. Alsharhan et al., 2001.
57. Binnie and Partners, 1992.
58. Christian, 2000.
59. Rippon and Public Authority for Water Resources in Oman, 1985.
60. Ministry of Defense in Oman and Sir M. Macdonald Partners, 1990; Ministry of Water Resources in Oman, 1994a; Ministry of Water Resources in Oman, 1994b.
61. Ibid.
62. Binnie and Partners, 1992.
63. Mott MacDonald International Ltd., 1991.
64. Ibid.
65. Ministry of Regional Municipalities and Water Resources in Oman, 2011.
66. Alsharhan et al., 2001, p. 95.
67. Ibid.
68. Rizk and Alsharhan, 2008.
69. Ministry of Regional Municipalities and Water Resources in Oman, 2005, p. 72; Ministry of Water Resources in Oman, 1993.
70. Ministry of Regional Municipalities and Water Resources in Oman, 2011.
71. Rizk and Alsharhan, 2008; Alsharhan et al., 2001.
72. Ministry of Regional Municipalities and Water Resources in Oman, 2005.
73. Rizk and Alsharhan, 2008.
74. Hyde, 1992 cited in Rizk and Alsharhan, 2008.
75. Ibid.
76. Rizk and Alsharhan, 2008.
77. Ibid.
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79. Rizk and Alsharhan, 2008.
80. Khalifa 2004, cited in Rizk and Alsharhan, 2008.
81. UN-ESCWA and BGR, 2001.
82. Ibid.
83. Rizk and Alsharhan, 2008.

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Chapter 15

Gulf

Umm er Radhuma-Dammam Aquifer System (Centre)

Umm er Radhuma-Dammam Aquifer System (Centre)

Gulf

EXECUTIVE SUMMARY

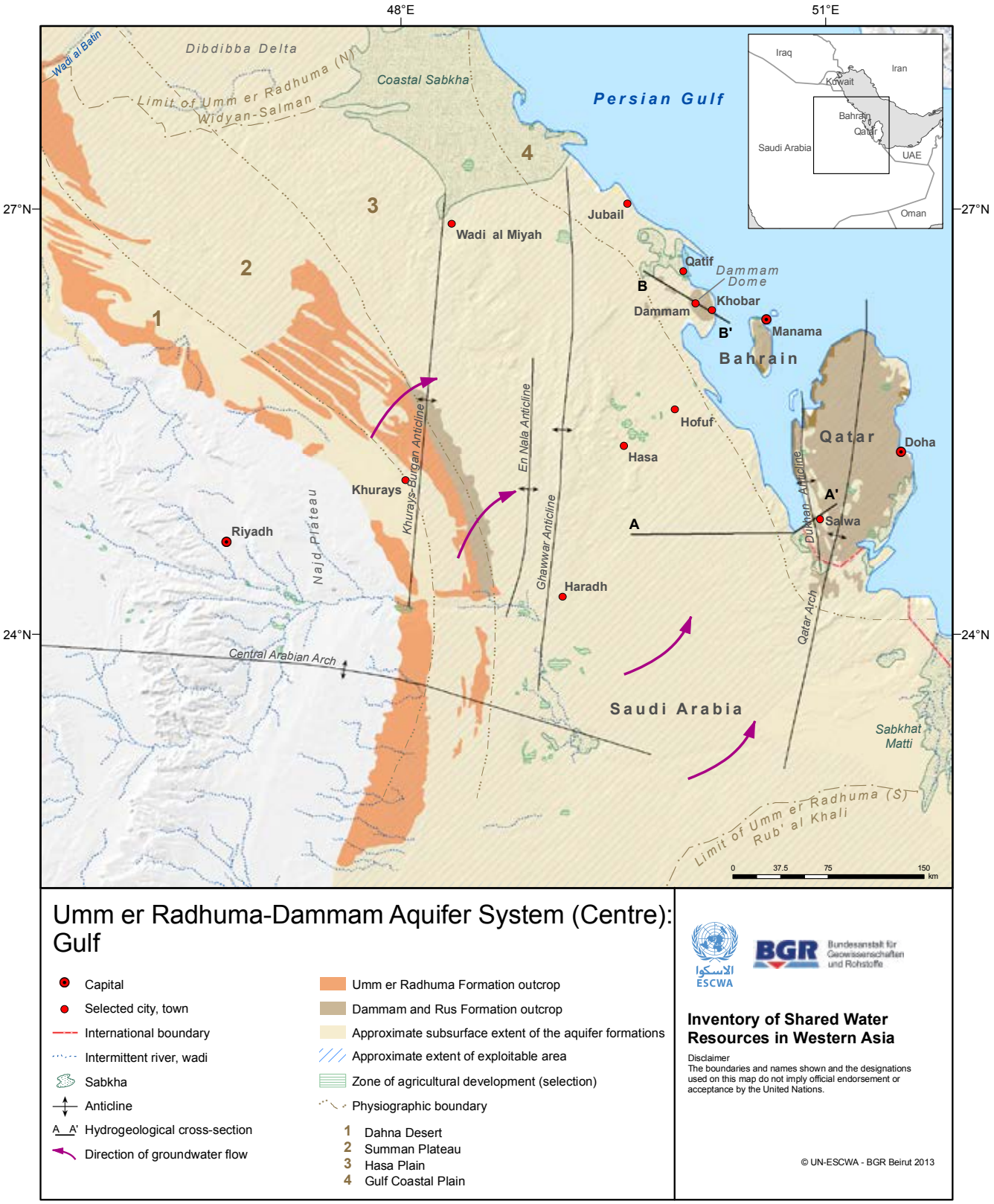
The central section of the Umm er Radhuma-Dammam Aquifer System extends over a 400 km-wide structural platform that stretches across three Gulf States: Bahrain, Qatar and Saudi Arabia. In the western low-plateau areas, the aquifer system is dominated by the Umm er Radhuma, while in the eastern plains it becomes more complex as the Umm er Radhuma and the Dammam are separated by the Rus Formation and overlain by Neogene-Quaternary units. Limited recharge occurs mainly through the Umm er Radhuma outcrops. The general direction of groundwater flow in the aquifer system is from west to east in Saudi Arabia.

The aquifer system is heavily exploited for agricultural development projects in Saudi Arabia, with most water abstracted from the Dammam. The Dammam is also the main source of irrigation water in Bahrain, while the Umm er Radhuma supplies most of the water for domestic and industrial purposes. In Qatar, water is drawn from the Umm er Radhuma and Rus in the north. The Umm er Radhuma-Dammam Aquifer System in the Gulf region is increasingly threatened by salinization as a result of seawater intrusion and over-pumping.

BASIN FACTS

RIPARIAN COUNTRIES	Bahrain, Qatar, Saudi Arabia
ALTERNATIVE NAMES	Alat, Khobar, Dammam, Rus, Umm er Radhuma
RENEWABILITY	Very low to low (0-20 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Weak
ROCK TYPE	Fissured/karstic
AQUIFER TYPE	Unconfined to confined
EXTENT	~281,000 km^2
AGE	Cenozoic (Paleogene)
LITHOLOGY	Mainly limestone and dolomite, with some evaporites
THICKNESS	Dammam: 35-180 m Umm er Radhuma: 240-500 m
AVERAGE ANNUAL ABSTRACTION	Bahrain: Dammam: 97 MCM (2010) Umm er Radhuma: 54.3 MCM (2006) Qatar: 91 MCM (1983) Saudi Arabia: ~608 MCM (2006)
STORAGE	Bahrain: 90 MCM (safe yield) Qatar: 2.5 BCM Saudi Arabia: 235 BCM
WATER QUALITY	Fresh (mostly <1 g/L TDS) to hypersaline in some coastal areas
WATER USE	Mainly agricultural, also domestic, industrial and urban irrigational use
AGREEMENTS	-
SUSTAINABILITY	Over-exploitation and salinization

OVERVIEW MAP



Umm er Radhuma-Dammam Aquifer System (Centre): Gulf

- Capital
- Selected city, town
- International boundary
- Intermittent river, wadi
- Sabkha
- Anticline
- A A' Hydrogeological cross-section
- Direction of groundwater flow
- Umm er Radhuma Formation outcrop
- Dammam and Rus Formation outcrop
- Approximate subsurface extent of the aquifer formations
- Approximate extent of exploitable area
- Zone of agricultural development (selection)
- Physiographic boundary
- 1 Dahna Desert
- 2 Summan Plateau
- 3 Hasa Plain
- 4 Gulf Coastal Plain

ESCWA

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

Disclaimer
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

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The Umm er Radhuma-Dammam Aquifer System in this Inventory

The Umm er Radhuma-Dammam Aquifer System extends from northern Iraq to the southern coast of the Arabian Peninsula over a distance of 2,200 km. Overall, it covers an area of more than 1,220,000 km^2, of which 363,000 km^2 is covered by outcrops. The total area of this aquifer system in Saudi Arabia, which shares the northern, central and southern sections with neighbouring countries, is 662,000 km^2 (see 'Overview and Methodology: Groundwater' chapter, Map 2).

This system generally comprises three Paleogene (Paleocene-Eocene) Formations: the Dammam, the Rus and the Umm er Radhuma. These formations stretch across Iraq, Yemen and the six Gulf Cooperation Council countries.[1] However, the water contained within these formations cannot be considered shared between all countries. For example, a well pumping from the Dammam Formation in Iraq cannot affect the productivity of this formation in Yemen and vice versa. Furthermore, there is significant variation in the lithostratigraphy of these three formations, particularly the Rus, which is water-bearing in some areas, while acting as an aquitard in others.

Because of the large geographical extent and the lithostratigraphic variations within the formations, the aquifer system has for the purpose of this Inventory been divided into three sections: a northern section (see Chap. 16), a central section (see current chapter) and a southern section (see Chap. 14).[2] This division, which is primarily based on the geographical extent of the formations, also takes relevant geological information into consideration to define the section boundaries.

Hofuf Oasis, Saudi Arabia, 2011. Source: Chris Helmkamp.

Introduction

LOCATION

The central section of the Umm er Radhuma–Dammam Aquifer System lies in a nearly flat 400 km-wide structural platform (Interior Platform) stretching from the eastern edge of the Najd Plateau to the Qatar Peninsula. It is bound to the north by Wadi al Batin, the Dibdibba Delta and coastal sabkha. In the south, it borders on the northern limit of the Rub' al Khali Desert and the Sabkhat Matti. This section extends across three Gulf states: Bahrain, Qatar and Saudi Arabia (see Overview Map).

AREA

The central section of the aquifer covered in this chapter represents around 23% of the aquifer system's total area. Within the boundary of the suggested delineation, the aquifer covers a total area of 281,000 km^2, of which about 560 km^2 are located in Bahrain, 11,300 km^2 in Qatar and 269,000 km^2 in Saudi Arabia.

The largest outcrop of the Dammam Aquifer covers almost all of Qatar, with smaller outcrops across Bahrain and around the city of Dammam in Saudi Arabia. The Umm er Radhuma only crops out in Saudi Arabia. The Rus is found in the subsurface across the whole region, separating the two main aquifer units. Outcrops of this formation occur in structurally elevated areas such as the Dammam and Bahrain Domes.

CLIMATE

The eastern part of this section falls within the Southern Gulf Coast agro-climatic zone,[3] while the western part extends to the Summan Plateau and south-eastern Najd agro-climatic zones. Temperatures range from a low of around 14°C in winter to a high of about 36°C in summer, though higher temperatures are not uncommon during this season.[4] Mean annual rainfall lies at 90-95 mm,[5] and is concentrated in winter and spring.

POPULATION

Around 4 million people live in the east of Saudi Arabia, a region which has flourished since the discovery of large quantities of oil in the 1930s. Key cities include Dammam, Dhahran, Khobar and Qatif.[6] Around 3 million people live in Bahrain (1.2 million)[7] and Qatar (1.7 million).[8]

OTHER AQUIFERS IN THE AREA

Large parts of the aquifer system are overlain by Neogene-Quaternary sediments, which constitute a relatively shallow aquifer in this area. This aquifer system is also to varying degrees connected with the Umm er Radhuma-Dammam system. The Wasia-Biyadh Formations underlie the whole area but constitute a source of freshwater only in Saudi Arabia, mainly in the Summan Plateau where it acts as an unconfined aquifer.

INFORMATION SOURCES

The Umm er Radhuma-Dammam Aquifer System constitutes a major aquifer system in Bahrain, Qatar and eastern Saudi Arabia and has been the subject of extensive studies in the three riparian countries. It is the only source of groundwater for Bahrain and Qatar. Most of the information in this chapter is drawn from government documents, United Nations reports and scientific studies. The Overview Map was delineated based on various local and regional references.[9]

Hydrogeology - Aquifer Characteristics

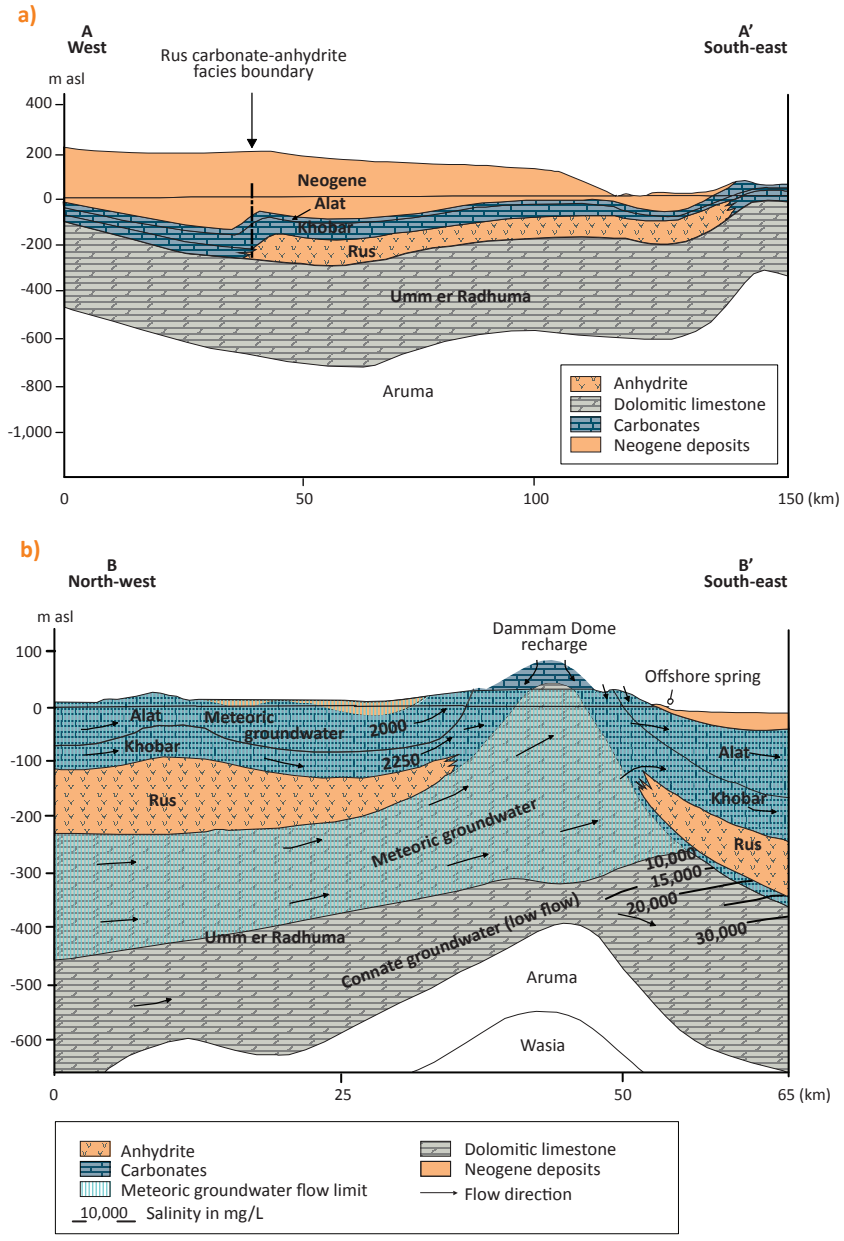
AQUIFER CONFIGURATION

Four main physiographic regions can be identified in this section of the aquifer system:

- **Dahna Desert:** A narrow belt of complex linear dunes with topography that comprises a cuesta landscape of cover rocks that dips gently eastwards towards the Gulf.[10]
- **Summan Plateau:** A relatively low (200-400 m) karstified limestone plateau, barren and extensively eroded, containing hundreds of sinkholes, many of which extend into structurally controlled cave systems of up to 1.1 km in length.[11]
- **Hasa Plain:** A wide plain characterized by locally abundant supplies of freshwater from wells and artesian springs and fertile oases such as Hasa and Hofuf. In the west, the plain is bounded by a prominent east-facing escarpment that cuts into the eastern margin of the Summan Plateau.[12]
- **Gulf Coastal Plain:** An extensive sabkha area constituting the southern part of the Hasa-Kuwait Plain, which extends from the western edge of the Shatt al Arab Delta to the Gulf of Salwa south-west of Qatar.[13]

In the western low-plateau areas, most of the aquifer system is made up of the Umm er Radhuma Formation. The system becomes more complex in the plains where it consists of the Umm er Radhuma and the Dammam, intercalated with the Rus Formation and overlain by the Neogene (Figure 1). Outcrops of the Umm er Radhuma exist only in the Dahna Desert and Summan Plateau in Saudi Arabia. The Dammam outcrops are more common in Qatar and Bahrain, and around the Dammam Dome, from which the formation takes its name. The Dammam Formation is largely eroded in these dome areas which are aligned along a Fault Line. In this area the Rus changes to carbonate facies and acts as an aquifer (Figure 2). The lateral extent of the two main aquifer units (Umm er Radhuma and Dammam) is defined by the saturation limit in the west and by a saline water front to the east.[14]

Figure 1. Hydrogeological section across the Gulf-Coastal Plain (a) near the Saudi-Qatari border, and (b) near the Dammam Dome in Saudi Arabia



Source: Compiled by ESCWA-BGR based on Harhash and Yousif, 1985.

STRATIGRAPHY

In general, the aquifer system consists mainly of alternating layers of limestone and dolomitic limestone with intercalations of anhydrite and argillaceous shales that increase in clay content in the lower layers. The main lithological and stratigraphic features of the aquifer system can be summarized as follows (Table 2, Figure 1):

- The Umm er Radhuma consists predominantly of dolomitic limestone, limestone and calcarenite.
- The Rus Formation ranges in composition between anhydrite facies and carbonate facies so that it can act as an aquifer (mainly in the Dammam and Bahrain Dome areas) or as an aquiclude/aquitard, depending on its composition and thickness in different places.[15]
- The Dammam Formation consists of five units: the lower three units are non-aquiferous shales and the upper two units (Khobar and Alat) are aquiferous carbonates.[16] Although the latter two units are sometimes referred to as one aquifer (Dammam Aquifer), they are in some areas separated by a marl bed (Orange Marl) which plays an important hydraulic role and acts as a leaky confining layer between the Khobar (Lower Aquifer) and the Alat (Upper Aquifer).[17]

Because of their wide extent and thickness, the Umm er Radhuma and Rus Formations make up the main aquifer in this part of the system, particularly in structurally high areas (e.g. Dammam Dome) where the Rus is composed of carbonate facies and is hydraulically connected with the Umm er Radhuma (Figure 1b).

Throughout most areas in this region, the aquifer units of the Paleogene carbonates are overlain and hydraulically connected with Neogene detrital rocks so that they form one aquifer system.[18] By contrast, the vertical connection to the underlying Wasia-Biyadh Formation is so insignificant that the two aquifer systems behave essentially independently, although the intercalated Aruma Formation acts as an aquitard allowing limited upward leakage.[19]

AQUIFER THICKNESS

In Saudi Arabia, the thickness of the Umm er Radhuma decreases from 500 m in the area north of Hofuf to about 300 m over the Ghawwar Anticline,[20] while the Dammam is about 70 m thick around Wadi al Miyah and 35-65 m in the area of Hasa.[21] In Bahrain, the Rus Formation has an average thickness of 105 m, while the Umm er Radhuma is 350 m thick. Both aquifer units of the Dammam (Khobar and Alat) disappear over the crest of the Bahrain Dome, but their thickness increases to the east and west, averaging 15-25 m for the Alat and 20-45 m for the Khobar.[22] In Qatar, the Rus is 28-44 m thick in the northern and central areas, and reaches 110 m in the south-western zone.[23]

AQUIFER TYPE

The presence of intercalated marls, shales and argillaceous limestones means that the Umm er Radhuma Formation does not constitute a complete interconnected aquifer.[24] In areas where it crops out or is covered only by dunes, it acts as an unconfined aquifer. This occurs mainly along the Summan Plateau. It is also unconfined in structurally high areas such as the Dammam and Bahrain Domes, where the overlying Rus Formation is of carbonate facies and in hydraulic connection with the Umm er Radhuma. In these uplifted areas, upward vertical leakage occurs where the Rus Formation is thin. More commonly though, the Umm er Radhuma is confined by the evaporitic unit of the Rus and the shales of the Dammam.

In most of the Gulf region, the Dammam Aquifer is confined from below by the lower shales of the Dammam and from above by the siliceous layers of the Neogene deposits. The latter displays wide vertical and lateral variations and consists of three main formations: the Hadrukh, Dam and Hofuf. Within the aquifer unit itself, the Orange Marl separates the lower Khobar member from the upper Alat. However, the aquifer is unconfined in a number of places due to erosion of one or more of the confining layers and/or the development of karst structures. In south-western Qatar (Abu Samra area), for example, the upper Abarug member of the Dammam exists under both confined and unconfined conditions.[25] Similarly, in Bahrain, the Dammam Aquifer is mostly confined, but its lower Khobar member is unconfined in the northern and south-western parts of the country due to erosion.[26]

AQUIFER PARAMETERS

The Umm er Radhuma-Dammam Aquifer System (Centre) is characterized by several major north-south anticlinal axes that rise above the general level of the platform.[27] Argillaceous fine carbonates of the aquifer units were deposited in the structurally low areas, while deposition of coarser carbonate sediments occurred in high areas.[28] Two other key features affect the water-bearing characteristics of the rock formation in this area:

- Karstification and the development of secondary permeabilities, due to the high intensity of intersecting fissures and other lineaments of different trends.
- Dolomitization, a process that increases porosity and improves the aquiferous nature of the formations.

These lithological and structural features have caused large variations in the hydraulic properties (transmissivity and storativity). In general, elevated areas display higher values than structurally low areas. Available data for the aquifer units in this system has been collected from various sources.[29] Table 1 compiles available data for the aquifer units in this system and summarizes the main findings and observations. Based on the data presented in the table, it can be concluded that:

- Hydraulic parameters of the two main aquifer units (Umm er Radhuma and Dammam) vary by several orders of magnitude, with values in the range of $6.4x10^{-1}$ to $3.0x10^{-6}$ m^2/s for transmissivity and $2.0x10^{-1}$ to $2.0x10^{-9}$ for storativity.
- The higher values are generally from areas where confinement of the aquifer units is removed by uplifting (the crest of the Dammam and Bahrain Domes) or solution collapse (mainly the north-eastern areas). These structures trap local surface runoff[30] and provide "windows" in the virtually impermeable evaporite confining beds through which flow from one aquifer to another may occur.[31]
- In Qatar, the Rus has a lower transmissivity and higher storativity than the Umm er Radhuma.
- In eastern Saudi Arabia, the Alat member, a granular aquifer, has a lower permeability than the Khobar member, which is highly karstified and fissured, particularly in structural highs.[32] In places where the Rus Formation is thin and considerable upward leakage from the Umm er Radhuma occurs (Wadi al Miyah), the Khobar exhibits higher transmissivity values.

Table 1. Hydraulic parameters of the Umm er Radhuma-Dammam Aquifer System (Centre)

COUNTRY		DAMMAM				UMM ER RADHUMA	
		ALAT MEMBER[a]		KHOBAR MEMBER[b]			
		TRANSMISSIVITY (m^2/s)	STORATIVITY	TRANSMISSIVITY (m^2/s)	STORATIVITY	TRANSMISSIVITY (m^2/s)	STORATIVITY
Bahrain		AVG:[c] $4.0x10^{-3}$	$5.3x10^{-4}$-$1.3x10^{-1}$ AVG: $6.5x10^{-2}$	$5.4x10^{-4}$-$4.8x10^{-1}$ AVG: $2.4x10^{-1}$	$5.0x10^{-5}$	$1.3x10^{-3}$-$4.6x10^{-1}$ (Umm er Radhuma-Rus)	$2.0x10^{-1}$ (unconfined), $2.0x10^{-4}$ (confined)
Qatar		$1.1x10^{-4}$-$1.1x10^{-2}$ AVG: $4.1x10^{-3}$	$1.0x10^{-3}$ (south-western)	..	..	Umm er Radhuma: $2.7x10^{-3}$-$9.8x10^{-2}$ Rus: $2.3x10^{-5}$-$5.2x10^{-2}$	Umm er Radhuma: $2.0x10^{-9}$-$2.2x10^{-8}$ (confined, southern) Rus: $6.0x10^{-5}$-$8.6x10^{-1}$ (unconfined to semi-confined)
Saudi Arabia	Coastal region	$2.9x10^{-1}$-$3.1x10^{-4}$	$1.3x10^{-4}$	$9.0x10^{-2}$	$5.3x10^{-4}$	$7.0x10^{-2}$-$6.4x10^{-1}$	$3.5x10^{-5}$-$1.4x10^{-2}$
	Wadi al Miyah region	$2.7x10^{-5}$-$9.0x10^{-4}$	..	$1.4x10^{-4}$-$8.9x10^{-3}$	..	$1.4x10^{-2}$-$4.2x10^{-1}$	..
	Dammam Dome region	$3.1x10^{-4}$-$2.3x10^{-3}$	$1.5x10^{-4}$-$2.6x10^{-4}$	$2.9x10^{-5}$	AVG: $2.1x10^{-5}$	..	..
	Hasa region	$2.6x10^{-5}$-$5.1x10^{-3}$	$2.6x10^{-5}$-$1.3x10^{-4}$	$3.0x10^{-6}$-$1.0x10^{-2}$	$1.0x10^{-4}$-$1.0x10^{-3}$ (confined)	$2.4x10^{-3}$-$6.6x10^{-2}$	..
	Hofuf-Salwa region	..	..	..	..	$5.0x10^{-5}$	..

Source: Compiled by ESCWA-BGR based on UN-ESCWA and BGR, 1999b; Alsharhan et al., 2001; Al-Nouaimy, 1999.
(a) The equivalent of the Alat in Qatar is the Abarug.
(b) The equivalent of the Khobar in Qatar is the Umm Bab (formerly the Simsima Member. See Harhash and Yousif, 1985).
(c) AVG refers to average values.

Table 2. Lithostratigraphy and water-bearing characteristics of the Umm er Radhuma-Dammam Aquifer System (Centre)

COUNTRY	DAMMAM				RUS		UMM ER RADHUMA	
	ALAT MEMBER[a]		KHOBAR MEMBER[b]					
	LITHOLOGY	WATER-BEARING CHARACTERISTICS	LITHOLOGY	WATER-BEARING CHARACTERISTICS	LITHOLOGY	WATER-BEARING CHARACTERISTICS	LITHOLOGY	WATER-BEARING CHARACTERISTICS
Bahrain	Dolomitic limestone.	A secondary aquifer of low productivity.	Dolomitic limestone and dolarenite (dolomitic sandstone).	Major aquifer of high permeability within the upper 5-10 m.	Chalky dolomitic limestone, shale, anhydrite and gypsum.	Forms a continuous hydraulic head with Umm er Radhuma in central Bahrain; otherwise an aquitard.	Dolomitic limestone, calcarenite, partly argillaceous and bituminous.	Upper part: aquifer connected to Rus. Lower part: low permeability and saline.
Qatar	Dolomitic limestone.	A secondary aquifer of low productivity.	Chalky limestone, partly dolomitized.	Forms a continuous aquifer with the Rus Formation in northern Qatar, which contains freshwater lenses above saline water (except for the areas where it is dry or dewatered).	Dolomitic limestone, anhydrite and gypsum.	Aquiferous, but also thinner in the north-central part of the peninsula where hydraulic continuity exists between calcareous deposits within this formation and the Umm er Radhuma.	Dolomite with chert, marl/shale intercalations and anhydrite beds.	Aquifer in the south and in the north where it is hydraulically connected with the Rus.
Saudi Arabia	Limestone, fissured with cavities filled with Neogene.	Moderate aquifer.	Calcarenite and dolomitic limestone, locally fissured.	Aquifer	Anhydritic facies: massive anhydrite, gypsum, marl and limestone layers. Carbonate facies: limestone in places, dolomitic and marly, locally fissured.	Aquiclude Aquifer in hydraulic connection with the Umm er Radhuma.	Limestone and dolomite; calcarenitic in the south, argillaceous and evaporitic in the north.	Calcarenites: good aquifer. Dolomitic zones: moderate aquifer. Anhydritic facies: poor aquifer. Basal shales: aquitard.

Source: Compiled by ESCWA-BGR based on UN-ESCWA and BGR, 1999b; Al-Nouaimy, 1999; Harhash and Yousif, 1985.
(a) The equivalent of the Alat in Qatar is the Abarug.
(b) The equivalent of the Khobar in Qatar is the Umm Bab (formerly the Simsima Member. See Harhash and Yousif, 1985).

Hydrogeology - Groundwater

RECHARGE

Recharge to any aquifer within the system can occur from rainfall (directly or via runoff) or transfer of water by vertical flow from shallower or deeper aquifers. Estimated rainfall-related recharge in eastern Saudi Arabia varies significantly from year to year as a result of erratic rainfall patterns. Between 1952 and 1977, 82% of freshwater replenishment occurred via the Umm er Radhuma, compared to only about 16% via the Neogene and less than 2% via the Dammam. The estimated mean annual recharge from rainfall for the three aquifers (Umm er Radhuma, Dammam, Neogene) was 1,272 MCM[33] (approx. 5.9 mm/yr)[34] for this period, with a minimum of 8 MCM in 1970 and a maximum of 5,423 MCM in 1955. [35]

For the Umm er Radhuma alone, an estimated mean annual recharge between 547.1 MCM (6.7 mm/yr) and 287.6 MCM (9.4 mm/yr) has been estimated for the northern (82,100 km^2) and southern (30,600 km^2) areas of the Gulf section respectively (Figure 2). The highest recharge occurred in 1955 (3,348 MCM), with 2,705.7 MCM (33 mm/yr) in the northern areas and 642.7 MCM (21 mm/yr) in southern areas. In 1970 and 1978 there was no recharge at all.[36]

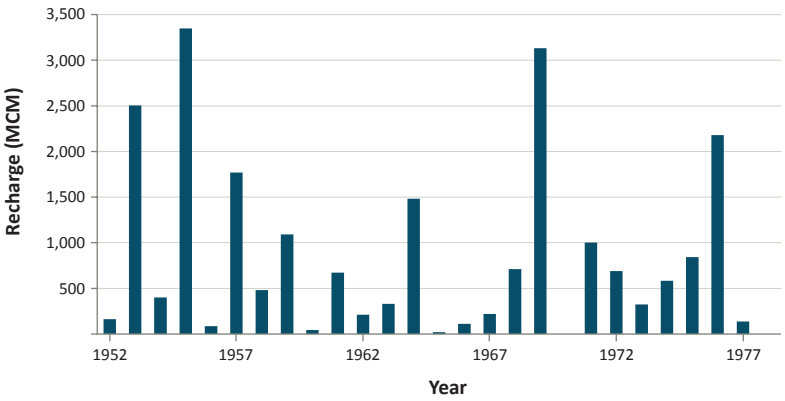
In Bahrain, recharge was estimated at a mean annual rate of 0.5 MCM (approx. 0.7 mm/yr). [37] Direct recharge here is not only insignificant, but also varies considerably from year to year. The lateral inflow from eastern Saudi Arabia into the Dammam Aquifer is more significant here and is estimated at 83-90 MCM/yr.[38]

Recharge data from Qatar indicates an average of 27 MCM/yr (approx. 2.4 mm/yr) for the period 1962/1963-1979/1980, with a minimum of 0.5 MCM and a maximum of 85.75 MCM. Recharge is about 2% from direct rainwater infiltration and 10% by indirect infiltration through wadis.[39]

FLOW REGIME

The flow regime of the Umm er Radhuma and Dammam Aquifer Systems points to the east, generally following the dip of the aquifer system from the outcrop areas in western Saudi Arabia to the Gulf coastline.[40] Potentiometric contour lines for the two aquifer units show that the water level generally lies at about 200-300 m asl in wells tapping the aquifer system in western areas, whereas it may be only tens of metres above sea level in the coastal areas. Within this general trend, there are large variations in the magnitude of the gradient, which can largely be explained in terms of recharge/discharge zones and transmissivity changes. For example, the hydraulic gradient in the Umm er Radhuma Formation is steep in the outcrop areas and becomes quite flat in the central areas before it steepens again suddenly in the coastal area. Other anomalies in the gradient can be explained by the complexity of vertical conditions, which are affected by hydraulic properties of the aquitards, but also by the horizontal flow conditions, which are affected by the presence of stagnant saline water bodies at the lower limit of the Umm er Radhuma.

Figure 2. Recharge estimates from rainfall for the Umm er Radhuma Aquifer in eastern Saudi Arabia (1952-1977)



Source: Compiled by ESCWA-BGR based on Faulkner, 1994.

In Bahrain, groundwater flow in the Dammam follows the regional flow direction from north-west (in the recharge area in Saudi Arabia) to south-east. However, in central and southern Bahrain, the hydraulic gradient of the Umm er Radhuma-Rus does not reflect this general trend, mainly due to the upward circulation of groundwater.[41]

In Qatar, groundwater flows radially outwards from recharge areas, centred over higher land surfaces in the northern and southern zones, and discharges into the adjacent low-lying sabkhas and the Gulf. The main anomalies occur in the north, where the general groundwater direction is interrupted by pumping, and in the

south-western zone, where the Dukhan Anticline creates a physical barrier to groundwater movement.

STORAGE

Assuming a pumping depth of 300 m bgl as a limiting factor, groundwater reserves in eastern Saudi Arabia were estimated at 190 BCM for the Umm er Radhuma and 45 BCM for the Dammam.[42] Other sources estimated the proven reserves of slightly brackish water in the aquifer system to be lower (Table 3).[43] Freshwater reserves (<2,000 mg/L TDS) in the Umm er Radhuma-Rus system in Qatar were reported to be about 2.5 BCM.[44] In Bahrain, storage is estimated on the basis of safe yield, which is 90 MCM.[45]

DISCHARGE

Most of the natural discharge takes place in eastern Saudi Arabia (Hofuf-Hasa-Qatif-Dammam area) where a large number of karst springs discharge about 285 MCM/yr.[46] In low-lying areas, sabkha lakes occur as a result of upward groundwater leakage (mainly through fissures in the confining layers) to the surface due to artesian pressure.

Onshore and offshore springs in the north of Bahrain also discharge groundwater. Sabkha evaporation is about 22% of the potential evaporation rate and occurs on about 80% of the sabkha surface area. [47]

Discharge also takes place via direct transpiration of groundwater from date palm trees in the coastal strip of Saudi Arabia and northern Bahrain (about 158 MCM/yr).[48] The total annual discharge from the system was estimated at 1,311 MCM, of which 65% (855 MCM/yr) occurs via sabkhas.[49] A comparison of this value with the total recharge suggests that the central part of the Umm er Radhuma-Dammam Aquifer System was roughly in balance – at least before abstraction from wells started 40 to 50 years ago.

WATER QUALITY

In general, changes to groundwater quality in the Gulf Coastal Plain reflect the regional groundwater flow from the outcrop (recharge) areas in the west to the coastal (discharge) areas in the east, with increasing salinity as the groundwater evolves from bicarbonate (HCO_3^-)-sulphate (SO_4^{2-}) to chloride (Cl^-) type. Three main factors contribute to significant anomalies within the system:

Table 3. Groundwater reserves in the eastern Umm er Radhuma-Dammam Aquifer System in Saudi Arabia

AQUIFER	SALINITY (mg/L TDS)	GROUNDWATER RESERVES (BCM)		
		PROVEN	PROBABLE	POSSIBLE
Dammam	2,600-6,000	5	25	..
Umm er Radhuma	2,500-5,000	16	40	75

Source: Compiled by ESCWA-BGR based on Sadiq and Hussain, 1997.

Agriculture in Bahrain, 2011. Source: Michele Solmi.

- The occurrence of evaporites and their exposure in several locations (Figure 1a) has resulted in the prevalence of significant amounts of wind-blown and aeolian gypsum particles on the land surface that are dissolved and carried along wadi courses. This often results in elevated sulphate concentrations in the recharge waters.

- Upward leakage of saline water (very slow process) and recharge from the surface along preferential paths (fast process) as inferred from the anomalously young and anomalously old waters in different places.

- The existence of a remarkable inland sabkha line (Figure 3) marks the shore of an ancient seawater body,[50] the imprint of which has not yet been flushed out completely due to the occurrence of low-permeability aquitards and aquicludes between the aquifer units.

The major ion composition of the Umm er Radhuma and Dammam Aquifer units is characterized by comparable concentration levels (Figure 4). Sodium (Na^+) and chloride (Cl^-) are the most common cation and anion respectively, followed by calcium (Ca^{2+}) and sulphate (SO_4^{2-}). Sodium chloride/sulphate water is dominant in most areas, while calcium-bicarbonate water is commonly found in the western area, where the Umm er Radhuma Formation is at the surface or near surface environments.

Also, although most of the groundwater abstracted across the region has a salinity level below 5 g/L, much higher salinities (80-100 g/L) were found in wells in certain coastal areas where there is present-day seawater intrusion or ancient sabkhas exist.

EXPLOITABILITY

The following criteria were used to assess the exploitability of this aquifer system:

- **Depth to top of aquifer:** The depth of wells abstracting water from the Dammam-Khobar area in eastern Saudi Arabia ranges between 300 and 400 m bgl.[51] In structurally elevated areas such as the Dammam Dome and the northern/central parts of Bahrain and Qatar, groundwater can be extracted from much shallower depths. For example, the depth of all wells used for estimating the hydraulic parameters of the aquifer system in Qatar in 1982 ranged between 6 and 69 m bgl.[52] Hence, drilling depth is not a limiting factor.

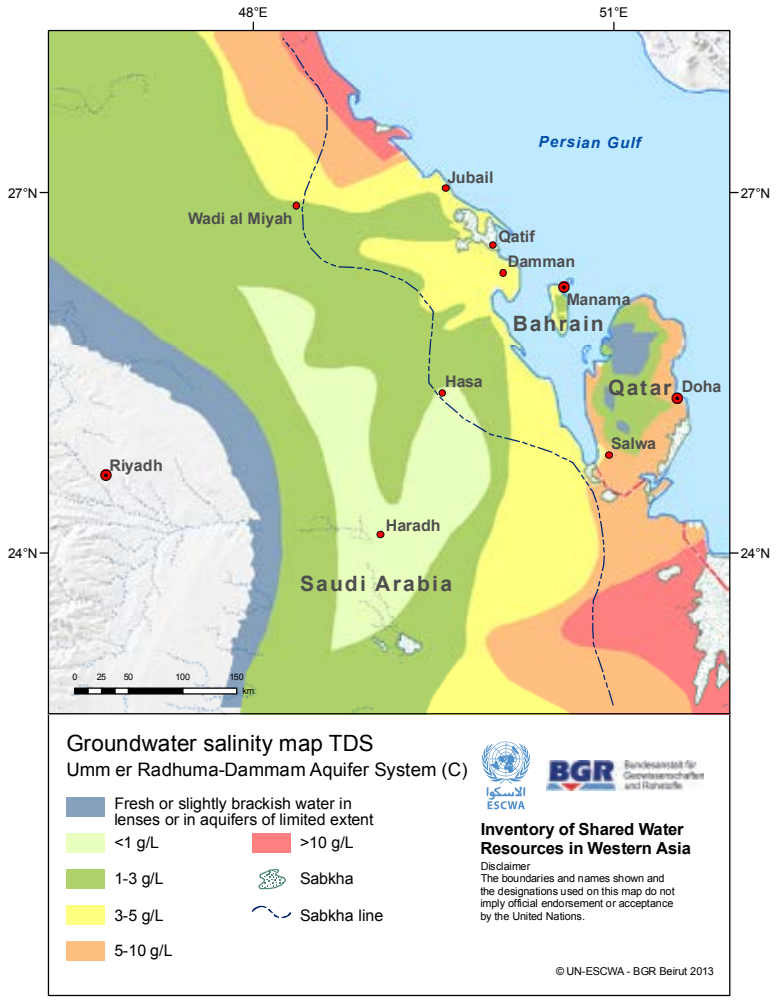
- **Depth to water level:** Depth to water, which was generally less than 25 m bgl in the early 1980s, has probably dropped over the years. However, as the Dammam Formation has limited thickness it is unlikely that the water level would drop below 200 m bgl. Water levels of the Umm er Radhuma Formation may drop much further, particularly where the aquifer is characterized by solution collapse features. For example, by the early 1980s the water level was already at 160 m bgl in wells located in the north-eastern Hofuf area.[53] This would mean that exploitation of the Umm er Radhuma may locally be limited by depth to water.

- **Water quality:** Exploitation of the aquifer system in the eastern areas of this region is limited by the presence of saline and hypersaline waters and the facial change of the Rus Formation to anhydrites (see Overview Map; Figure 1).

- **Transmissivity:** The aquifer system is practically not exploitable in the Dahna Desert since the Dammam Formation is not present and the Umm er Radhuma is discontinuous and does not have enough thickness and storage properties to yield substantial amounts of groundwater.

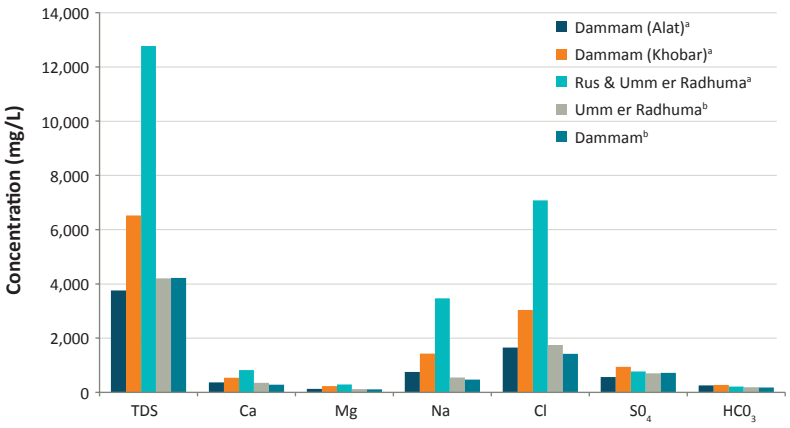
Based on the above, it seems that the aquifer system is exploitable in most parts, except in the coastal areas and other localized zones which are not specified on the map due to their small scale and the lack of specific data.

Figure 3. Groundwater salinity map - Umm er Radhuma-Dammam Aquifer System (Centre)



Source: Compiled by ESCWA-BGR based on UN-ESCWA and BGR, 1999a; UN-ESCWA and BGR, 1999b.

Figure 4. Major element concentrations in the Dammam and Umm er Radhuma Aquifers



Source: Compiled by ESCWA-BGR based on (a) Ministry of Municipalities Affairs and Urban Planning in Bahrain, 2011; (b) Ministry of Agriculture and Water in Saudi Arabia, 1984.

The total exploitable area in the suggested delineated basin is 243,360 km^2, of which 360 km^2 is in Bahrain, 11,000 km^2 in Qatar and 232,000 km^2 in Saudi Arabia.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

The use of wells to abstract water from the aquifer system began in the 1920s in Bahrain, the 1930s in Saudi Arabia,[54] and in the 1950s in Qatar.[55] Since then, groundwater levels are constantly declining, which has resulted in alarming drawdown in both the Dammam and the Umm er Radhuma Aquifers. In the area of Hasa, for example, a decline of 30 to 77 m was reported over a six-year period between1978 and 1984.[56] Water levels in the Dammam Aquifer have dropped at a rate of 4 m/yr and this aquifer is now mostly dewatered in Bahrain and Qatar.[57]

Saudi Arabia

The Umm er Radhuma Aquifer is exploited intensively for agricultural development projects around Haradh, Hofuf and Wadi al Miyah. The King Faisal Bedouin Settlement project, 10 km south-east of Haradh relies heavily on the aquifer, with an annual withdrawal of about 90 MCM. The water is pumped from 51 bore-holes that were drilled by the Ministry of Agriculture and Water in the 1980s.[58] In the northern parts of the aquifer around Wadi al Miyah, the Al Sharqiyah Agricultural Development Company (SHADCO) extracts 38 MCM/yr of groundwater.[59] The aquifer is also used to supply water to industrial and domestic users in the Greater Dhahran urban area (the cities of Dhahran and Khobar), including for landscape irrigation purposes. Over 70 bore-holes were drilled in this area in the vicinity of the Dammam Dome.

The Dammam Aquifer is mainly used in the coastal cities of Dammam, Qatif and surrounding smaller towns such as Sayhat, Anik, Safwa, Umm al Sahik and Ras Tanurah.[60] More than 80% of the extracted water is used for irrigation purposes; the remainder is used for domestic and industrial purposes and to water livestock.

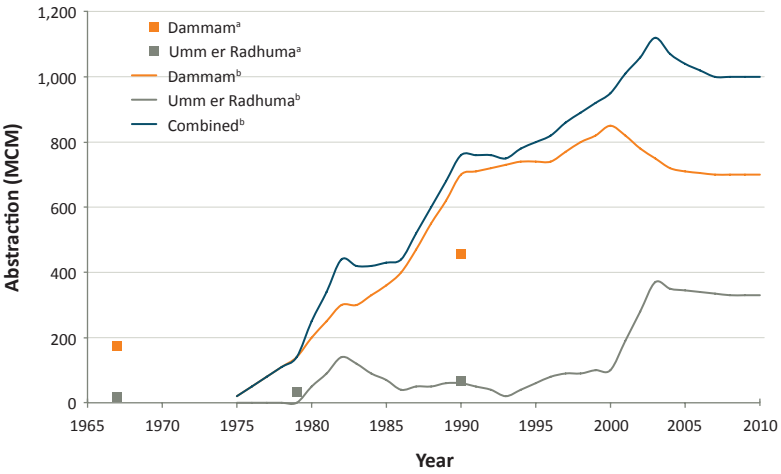
The limited thickness of the Dammam (25-65 m) makes it highly vulnerable to dewatering, which is a real risk in the area of Hasa[61] where there is a long history of groundwater exploitation, particularly from the Dammam Aquifer. Hence, the Umm er Radhuma and Dammam Aquifers are currently only used to a limited extent for irrigation and domestic purposes in the area of Hasa, and springs emanating from the Neogene provide the main supply of groundwater here.

As the Dammam Aquifer has a relatively shallow water level and reasonably good permeabilities, it has been exploited more intensively than the Umm er Radhuma (Figure 5).[62] Pumping records indicate a continuous increase in abstraction rates from the Dammam since 1940 and a marked upward trend after 1965. By 1966, most withdrawals from the Dammam along the coast were from artesian wells that tapped both the Khobar and Alat members. Abstraction from the Alat was reduced in the early 1980s due to decreasing yields in most areas. Instead the Khobar was developed along the coast and in the area of Hasa.[63] In 1990, abstraction from this unit had increased to more than three times the abstraction from the Alat.[64]

Abstraction from the Umm er Radhuma lagged behind, mainly because the average depth to the top of the aquifer was around 220 m in the late 1960s.[65] Total abstraction from this aquifer has increased gradually, particularly since 1979, to reach 66 MCM/yr in 1990 compared to 427 MCM/yr from the Dammam (see Dammam[a], Figure 5). After 2000, when the abstraction from the Dammam reached its highest level (850 MCM/yr), abstraction decreased by about 100 MCM until 2004. This was however compensated by increased abstraction from the Umm er Radhuma, from 100 MCM/yr in 2000 to 370 MCM/yr in 2002 (see Umm er Radhuma[b], Figure 5).

Cumulative total abstraction from the Umm er Radhuma-Dammam Aquifer System in eastern Saudi Arabia was roughly 24.3 BCM between 1967 and 2010.[66]

Figure 5. Historical abstraction from the Dammam and Umm er Radhuma Aquifers in eastern Saudi Arabia (1967-2010)



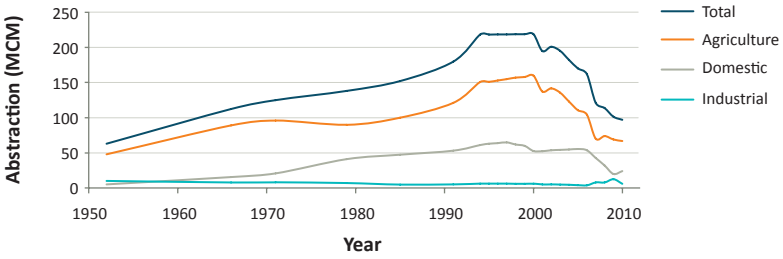
Source: Compiled by ESCWA-BGR based on (a) Abderrahman et al., 1995; (b) Water Watch, 2006.

Bahrain

Bahrain withdraws groundwater from the highly productive Khobar unit in the Dammam Formation, and, to a lesser extent, from the Umm er Radhuma Formation. Development activities in the 1960s significantly increased abstraction, and total withdrawal from the Dammam almost doubled between 1952 and 1966 and continued to rise from then on to reach 218 MCM in 1994. Figure 6 suggests that abstraction may have stayed at this level until 2000 before it started dropping as withdrawal for the agricultural sector was reduced. By 2010, abstraction levels had declined to 97 MCM/yr and 54.3 MCM/yr for the Dammam and the Umm er Radhuma respectively.[67] In general, abstraction points for domestic and irrigation purposes are concentrated in the western and northern areas, where the best-quality groundwater is found, while industrial wells are mostly limited to the eastern coast and south-central areas.

The cumulative total abstraction from the Dammam Aquifer in Bahrain was roughly 3.8 BCM between 1952 and 2010.[68]

Figure 6. Historical abstraction from the Dammam Aquifer in Bahrain (1952-2010)



Source: Compiled by ESCWA-BGR based on Zubari et al., in UN-ESCWA and BGR, 1999b; Ministry of Municipalities Affairs and Urban Planning in Bahrain, 2011.

Qatar

Groundwater abstraction has steadily increased in Qatar since 1971. This is mainly due to the expansion of agricultural activities, which consumed 98% of the groundwater in 1993.[69] The remaining 2% was used for domestic purposes. Abstraction more than doubled between 1971 and 1983, from about 43 to 91 MCM/yr.[70] More than 70 MCM/yr (77%) of this abstraction is from the Umm er Radhuma and Rus Aquifers and takes place in the north of the peninsula where many farms are located and water quality is better.[71] The remaining 23% is withdrawn from the Rus Formation in the south of the peninsula.

GROUNDWATER QUALITY ISSUES

Continuous over-exploitation of the Umm er Radhuma-Dammam Aquifer System has rendered the groundwater prone to salinization. This may make the aquifer unsuitable for use in the future. Several factors contribute to groundwater salinization in this area:

- Formation (connate) water at depth is rising to shallow environments in the eastern part of the Arabian Peninsula (Dammam and Bahrain Domes and central Qatar) and mixing with the groundwater in the aquifer system.
- The progressively declining water table heightens the risk of saline connate water upconing along major fault systems such as the En Nala and Khurays-Burgan Anticlines in Saudi Arabia and the Qatar Arch in Qatar.
- Water-level decline would also enhance the formation of more solution collapse features and hence provide new "windows" through which saline water could rise and mix with the relatively freshwater along the coast of Saudi Arabia.
- Changes in hydraulic gradients of the aquifer system due to over-pumping in inland areas could further enhance the advance of the seawater wedge along the coast of eastern Saudi Arabia, eastern Bahrain and around Qatar.
- Over-abstraction enhances the migration of saline sabkha water into unconfined areas of the coastal parts of the aquifer system, for example in the southern parts of Bahrain.

Overall, salinization of the aquifer system in the near future is a threat.

SUSTAINABILITY ISSUES

The unsustainable use of the aquifer system over the past 30 to 40 years, and the resulting salinization and drop in water table have already restricted the use of this aquifer system in Bahrain and possibly in some parts of Qatar and Saudi Arabia. The Dammam and Rus Formations, which used to be the only source of freshwater in Bahrain and Qatar respectively, are particularly at risk of salinization and/or total depletion.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place for Umm er Radhuma-Dammam Aquifer System (Centre) which is shared between Bahrain, Qatar and Saudi Arabia.

COOPERATION

No information was available regarding cooperation between the riparian countries on the aquifer system. However, there are cooperation activities under the umbrella of the Gulf Cooperation Council which include investments in water infrastructure projects. Bahrain has also underlined its need and interest to cooperate over the management of shared groundwater resources.[72]

OUTLOOK

Joint management of the aquifer system would help ensure its long-term sustainability, as this section of the aquifer system is threatened by complete salinization in the near future.

Jebel al Qarah, Saudi Arabia, 2011. Source: Chris Helmkamp.

Notes

1. Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates.
2. This division was based on UN-ESCWA and BGR, 1999b.
3. As delineated by the Ministry of Agriculture and Water in Saudi Arabia (Ministry of Agriculture and Water,1995 as cited in Vincent, 2008).
4. PSRCE, 2007.
5. Al-Jerash, 1985 as cited in Vincent, 2008.
6. Central Department of Statistics and Information in Saudi Arabia, 2011.
7. Central Informatics Organisation in Bahrain, 2010.
8. Statistics Authority in Qatar, 2012.
9. UN-ESCWA and BGR, 1999b; UN-ESCWA and BGR, 1999a; Alsharhan et al., 2001; and Alsharhan and Nairn, 1997.
10. Vincent, 2008.
11. Edgell, 2006, p. 18-19.
12. Chapman, 1978.
13. Edgell, 2006, p. 12.
14. UN-ESCWA and BGR, 1999b.
15. Alsharhan et al., 2001; UN-ESCWA and BGR, 1999b.
16. Ministry of Agriculture and Water in Saudi Arabia, 1984.
17. Alsharhan et al., 2001.
18. Ibid.
19. BRGM, 1977 cited in Alsharhan et al., 2001.
20. Ministry of Agriculture and Water in Saudi Arabia, 1984.
21. Alsharhan et al., 2001.
22. Al-Nouaimy, 1999.
23. Harhash and Yousif, 1985.
24. Alsharhan et al., 2001.
25. UN-ESCWA and BGR, 1999b.
26. Al-Nouaimy, 1999.
27. Powers et al., 1966.
28. Alsharhan et al., 2001.
29. Ibid; UN-ESCWA and BGR, 1999b.
30. Alsharhan et al., 2001.
31. Bakiewicz et al., 1982.
32. UN-ESCWA and BGR, 1999b.
33. Bakiewicz et al., 1982.
34. The recharge calculation was done for an area of 215,800 km^2 in eastern Saudi Arabia. This includes most of the northern and central part of the study area, but not all areas stated in Faulkner, 1994.
35. Bakiewicz et al., 1982.
36. Faulkner, 1994.
37. UN-ESCWA and BGR, 1999b.
38. Al-Nouaimy, 1999.
39. Harhash and Yousif, 1985.
40. UN-ESCWA and BGR, 1999b.
41. Al-Nouaimy, 1999.
42. Dabbagh and Abderrahman, 1997 as cited in UN-ESCWA and BGR, 1999b.
43. Sadiq and Hussein, 1997 as cited in UN-ESCWA and BGR, 1999b.
44. Parker and Pike, 1976 as cited in UN-ESCWA and BGR, 1999b.
45. Ministry of Municipalities Affairs and Urban Planning in Bahrain, 2011.
46. Bakiewicz et al., 1982.
47. GDC, 1980 as cited in UN-ESCWA and BGR, 1999b.
48. Bakiewicz et al., 1982.
49. Ibid.
50. FAO Near East Cooperative Program, 1979.
51. Ministry of Agriculture and Water in Saudi Arabia, 1984.
52. Harhash and Yousif, 1985.
53. Ministry of Agriculture and Water in Saudi Arabia, 1984.
54. Ibid.
55. Zubari et al. 1993 cited in UN-ESCWA and BGR, 1999b; UN-ESCWA, 1981.
56. UN-ESCWA and BGR, 1999b.
57. Zubari et al. 1993 cited in UN-ESCWA and BGR, 1999b.
58. Dabbagh et al., 1988 cited in UN-ESCWA and BGR, 1999b.
59. Abderrahman et al., 1995.
60. Not shown on the Overview Map due to scale.
61. Ministry of Agriculture and Water in Saudi Arabia, 1984.
62. Ibid.
63. Ibid.
64. Abderrahman et al.,1995.
65. Italconsult, 1969 cited in Abderrahman et al., 1995.
66. Based on estimated groundwater abstraction for the period 1967-2004, according to Water Watch, 2006; a constant abstraction of 1,000 MCM/yr was assumed for the period 2005-2010.
67. Ministry of Municipalities Affairs and Urban Planning in Bahrain, 2011.
68. A constant abstraction of 218.6 MCM/yr was assumed for the period 1995-1999 in Bahrain based on Zubari et al 1993, cited in UN-ESCWA and BGR, 1999b; Ministry of Municipalities Affairs and Urban Planning in Bahrain, 2011.
69. Joudeh, 1994.
70. Harhash and Yousif,1985.
71. Ibid.
72. Ministry of Municipalities Affairs and Urban Planning in Bahrain, 2011.

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Chapter 16

Widyan-Salman

Umm er Radhuma-Dammam Aquifer System (North)

Umm er Radhuma-Dammam Aquifer System (North)

Widyan-Salman

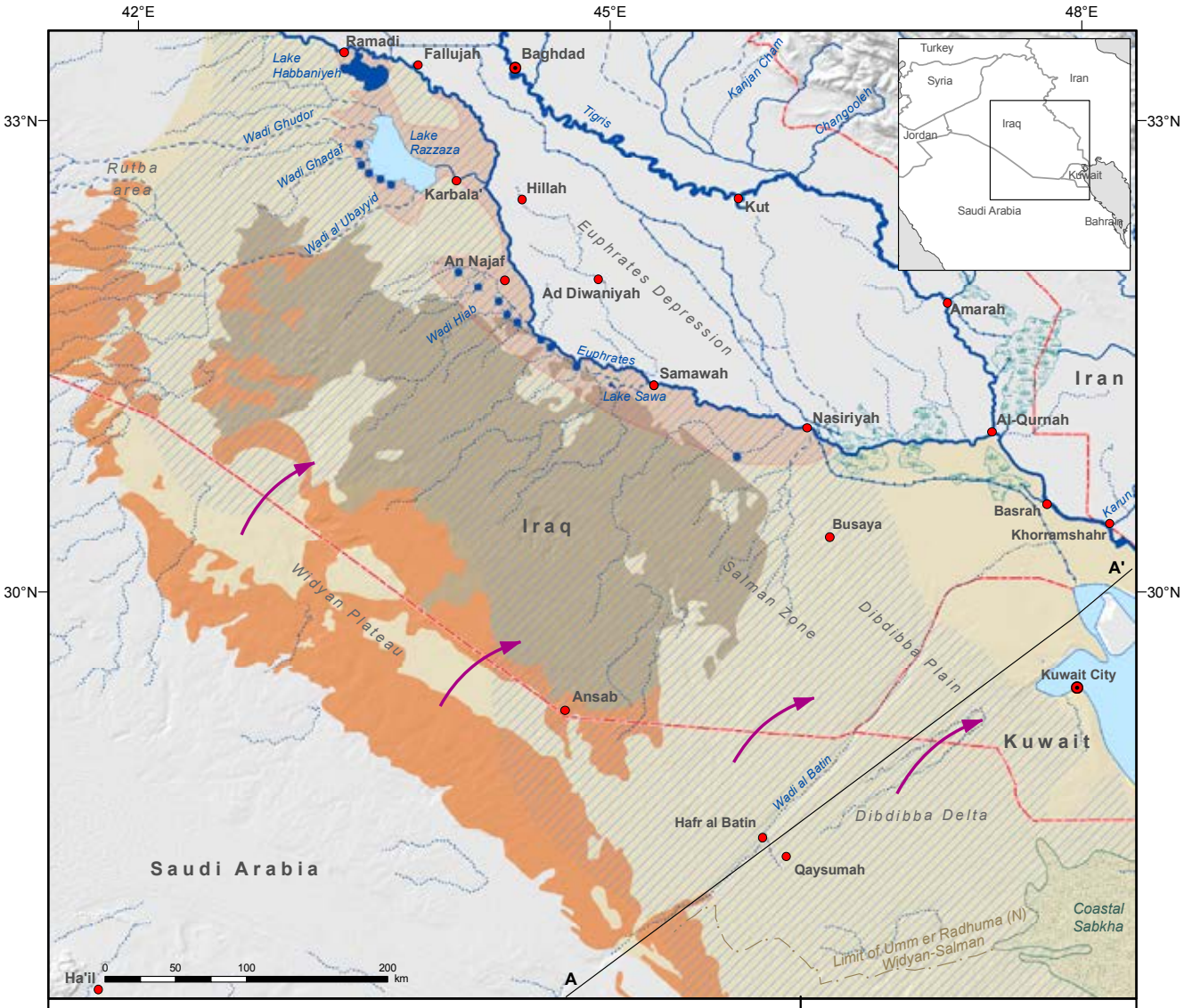
EXECUTIVE SUMMARY

The Umm er Radhuma and Dammam Formations constitute the main aquifers in this system, which stretches from the Rutba-Widyan area eastward through the Salman Zone to the Dibdibba Delta, forming a shared aquifer system between Iraq, Kuwait and Saudi Arabia. The two main aquifer formations are composed mainly of limestone and exhibit a shallow water table (0 - <250 m bgl). Limited recharge occurs mainly through the Umm er Radhuma outcrops. The general groundwater flow direction is from the outcrops in the south-west towards the Euphrates Depression and the Gulf coast in the north-east. Good quality water is found around the Salman Zone in Iraq, while springs along the Euphrates River naturally discharge slightly more saline groundwater. Available information indicates that the three riparian countries currently exploit the aquifer system, primarily in the Dammam and the upper part of the Umm er Radhuma Formations, resulting in a water-level decline of up to 60 m in both formations. Nevertheless, the aquifer system remains exploitable in most of this section, except in the Widyan Plateau that straddles the Saudi-Iraqi border and coastal areas where it is either dry or contains saline water.

BASIN FACTS

RIPARIAN COUNTRIES	Iraq, Kuwait, Saudi Arabia
ALTERNATIVE NAMES	Euphrates-Northern Gulf Basin, Euphrates-Dibdibba
RENEWABILITY	Very low to low (0-20 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Weak
ROCK TYPE	Fissured/karstic
AQUIFER TYPE	Unconfined to semi-confined or confined
EXTENT	~246,000 km^2
AGE	Cenozoic (Paleogene)
LITHOLOGY	Mainly limestone and dolomite, with some evaporates
THICKNESS	Dammam: 30-80 m Umm er Radhuma: 240-600 m
AVERAGE ANNUAL ABSTRACTION	Iraq: ~45 MCM (early 1990s) Kuwait: ~90 MCM (1993) Saudi Arabia: ..
STORAGE	..
WATER QUALITY	Fresh to hypersaline
WATER USE	Agricultural, industrial and domestic use except for drinking
AGREEMENTS	-
SUSTAINABILITY	Over-abstraction resulting in lowering of the water table and salinity increase due to upconing of saline water and seawater intrusions

OVERVIEW MAP



Umm er Radhuma-Dammam Aquifer System (North): Widyan-Salman

- Capital
- Selected city, town
- International boundary
- River
- Intermittent river, wadi
- Freshwater lake
- Saltwater lake
- Spring
- Canal, irrigation tunnel
- Umm er Radhuma Formation outcrop
- Dammam and Rus Formations outcrop
- Approximate subsurface extent of the aquifer formations
- Approximate extent of exploitable area
- A__A' Hydrogeological cross-section
- Direction of groundwater flow
- Sabkha
- Artesian zone
- Wetland

ESCWA

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

Disclaimer
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

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Introduction

The Umm er Radhuma-Dammam Aquifer System in this Inventory

The Umm er Radhuma-Dammam Aquifer System extends from northern Iraq to the southern coast of the Arabian Peninsula over a distance of 2,200 km. Overall, it covers an area of more than 1,220,000 km^2, of which 363,000 km^2 is covered by outcrops. The total area of this aquifer system in Saudi Arabia, which shares the northern, central and southern sections with neighbouring countries, is 662,000 km^2 (see 'Overview and Methodology: Groundwater' chapter, Map 2).

This system generally comprises three Paleogene (Paleocene-Eocene) Formations: the Dammam, the Rus and the Umm er Radhuma. These formations stretch across Iraq, Yemen and the six Gulf Cooperation Council countries.[1] However, the water contained within these formations cannot be considered shared between all countries. For example, a well pumping from the Dammam Formation in Iraq cannot affect the productivity of this formation in Yemen and vice versa. Furthermore, there is significant variation in the lithostratigraphy of these three formations, particularly the Rus, which is water-bearing in some areas, while acting as an aquitard in others.

Because of the large geographical extent and the lithostratigraphic variations within the formations, the aquifer system has for the purpose of this Inventory been divided into three sections: a northern section (see current chapter), a central section (see Chap. 15) and a southern section (see Chap. 14).[2] This division, which is primarily based on the geographical extent of the formations, also takes relevant geological information into consideration to define the section boundaries.

LOCATION

The northern section of the Umm er Radhuma-Dammam Aquifer System extends south-eastwards from the Rutba area in Iraq to the Dibdibba Delta in Saudi Arabia, covering two wide plateaus – the Widyan Plateau and the Salman Zone (see Overview Map) – from which it derives its name. This section is delimited by the Euphrates River in the north and constitutes a shared aquifer system between Iraq, Kuwait and Saudi Arabia.

AREA

The northern section of the aquifer as covered in this chapter only represents about 20% of the aquifer system's total area. Within the boundary of the suggested delineation, the northern section of the aquifer system covers a total area of 246,000 km^2, of which around 150,000 km^2 is located in Iraq, 16,000 km^2 in Kuwait and 80,000 km^2 in Saudi Arabia.

CLIMATE

Most of this section of the aquifer system falls within the Summan Plateau agro-climatic zone, except for the coastal areas, which constitute the Southern Gulf Coast agro-climatic zone.[3] Average temperatures range from lows of 14°C in winter to highs of 34°C in summer, except in the coastal areas where temperatures can reach up to 60°C in July. Mean annual precipitation is around 90 mm,[4] with rainfall concentrated in winter and spring.

POPULATION

The entire state of Kuwait, which has an estimated population of 3.3 million,[5] falls within the Umm er Radhuma-Dammam Aquifer System (North) section. This population partly relies on the aquifer system for irrigation, industrial and domestic uses other than drinking. In Iraq, the governorates of Basrah, Muthanna and An Najaf[6] fall within this region, with a total population of approximately 4.5 million inhabitants. In Saudi Arabia, the area is sparsely populated with a total of 240,000 inhabitants, or 2-5 inhab./km^2,[7] in the Ar'ar and Rafha Governorates.[8]

OTHER AQUIFERS IN THE AREA

The overlying (Neogene) Kuwait Group Aquifer is heavily used in Kuwait and to a lesser extent in Iraq, where it is known as the Dibdibba Aquifer (see Chap. 26). The northern section of the Umm er Radhuma Aquifer System is underlain by the Cretaceous Aquifers of the Aruma in Saudi Arabia and Hartha-Tayarat-Digma in Iraq (see Chap. 13).

INFORMATION SOURCES

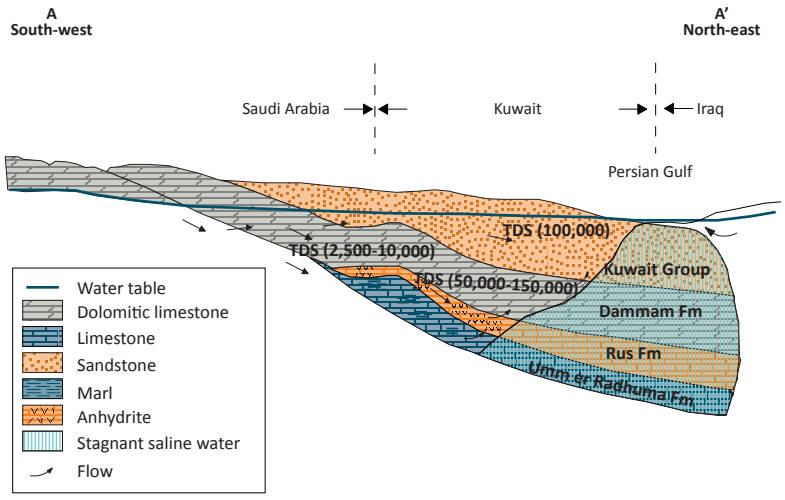
While hydrogeological data on the Umm er Radhuma-Dammam Aquifer System (North) is available, data on abstraction is limited and mostly outdated. Data included in this chapter was mainly collected from Iraq and Kuwait. Delineation of the Overview Map was based on various local and regional references.[9]

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

The Umm er Radhuma and the Dammam Formations constitute the main aquifers in the system, while the Rus (or Jil)[10] Formation separating them acts mainly as an aquitard and may retain poor-quality water in specific locations.[11] The top of the Umm er Radhuma is generally situated 100-400 m asl, but drops rapidly in the centre of the Wadi al Batin area and its eastern extension to the Dibdibba Plain, where it can reach 800 m bsl. The top of the Dammam lies about 200 m higher than the Umm er Radhuma and crops out over larger areas north-west of the Salman Zone in Iraq. In the late 1990s, the water table in the Umm er Radhuma was 100-200 m asl in the central part of this section of the aquifer system.[12] Further east, where the Dammam and younger sediments cover the Umm er Radhuma, the water table was 50-200 m asl.

Figure 1. Hydrogeological cross-section of the Umm er Radhuma-Dammam Aquifer System (North) across the Kuwait-Saudi border



Source: Modified by ESCWA-BGR based on UN-ESCWA and BGR, 1999.

STRATIGRAPHY

The lithology of the two major units that form the aquifer system displays some variation both vertically (within a country) and laterally (across countries), as indicated in Figure 1 and Table 1.

The lower aquifer, the Umm er Radhuma, crops out extensively along the Widyan Plateau and intensive karstification of these outcrops has been reported, particularly in the border

Table 1. Lithostratigraphy and water-bearing characteristics of the Umm er Radhuma-Dammam Aquifer System (North) Paleogene Formations

COUNTRY	UMM ER RADHUMA		DAMMAM	
	LITHOLOGY	WATER-BEARING CHARACTERISTICS	LITHOLOGY	WATER-BEARING CHARACTERISTICS
Iraq (Salman Zone)	Upper: limestone, dolomite. Lower: marly limestone, dolomite, marl, evaporites.	Upper: aquifer with moderate productivity; generally confined. Lower: aquitard; locally poor aquifer.	Limestone, dolomite.	Major, extensive and productive aquifer; confined or semi-confined.
Kuwait	Marly limestone, dolomite, some anhydrite.	Brackish to saline water.	Upper and middle: chalky and karstified limestone. Lower: dolomitic limestone, anhydrite, shale.	Upper and middle: major aquifer. Lower: aquitard; locally poor aquifer.
Saudi Arabia	Chalky and dolomitic limestone, dolomite, with significant layers of anhydrite and chert in the upper part.[13]	Brackish to saline water.	Limestone and marl.	Moderate aquifer.

Source: Compiled by ESCWA-BGR based on United Nations, 1999; Jassim and Buday, 2006b; Ministry of Agriculture and Water in Saudi Arabia, 1984.

area of Ansab between Iraq and Saudi Arabia. Accordingly, yield and water quality vary laterally and vertically. The Damman Aquifer is generally more extensive and productive in the Salman Zone and often has better water-bearing characteristics than the Umm er Radhuma Aquifer. The Rus (Jil) crops out mainly in the central to north-eastern areas and consists predominantly of anhydrite with some limestone, shale and marl.

AQUIFER THICKNESS

The Umm er Radhuma has a thickness of 240 m at the type section in the Wadi al Batin area in Saudi Arabia[14] and in the Nukhaib area in Iraq.[15] Thickness generally increases towards the east where it can reach 600 m.[16] The Dammam is generally thinner, with a saturated thickness decreasing towards the northern parts of the Salman Zone (30-80 m). In some areas of the Umm er Radhuma-Dammam Aquifer System (North), perched groundwater occurs above low permeability layers at shallow depths within the Dammam.

AQUIFER TYPE

In most of the western areas of this section where the Umm er Radhuma crops out, the formation is either unsaturated, contains discontinuous groundwater occurrences, or comprises discontinuous perched or shallow aquifers.[17] In the central part, where the Umm er Radhuma is confined by the Rus at shallow depths, it constitutes an aquifer with moderate productivity. The Dammam is of unconfined or semi-confined nature in the Salman Zone in Iraq and neighbouring areas of south-western Kuwait. By contrast, it is confined in the Wadi al Batin area in Saudi Arabia. In the lowland areas to the east and south of the outcrops (i.e. the Euphrates Valley, Wadi al Batin area and Dibdibba-Kuwait Plain), the Dammam is also confined below an aquitard layer composed of Neogene marls.

AQUIFER PARAMETERS

Groundwater in this aquifer system is produced mainly from the Dammam Formation and the upper part of the Umm er Radhuma Formation, which are usually hydraulically connected through the Rus Formation. The transmissivity of this aquifer system is largely controlled by karstification, lineaments and facies changes within the carbonate rocks. In general, transmissivity is high in karstified areas and low where marl occurs more frequently. Therefore, the aquifer system has a wide range of transmissivity values (Table 2).[18] Strong karstification occurs where the upper part of the Umm er Radhuma and Rus (Jil) Formations crop out, causing dissolution of the underlying gypsum and producing sinkholes and depressions in the overlying carbonates.[19]

Table 2. Hydraulic parameters of the Umm er Radhuma-Dammam Aquifer System (North)

COUNTRY	UMM ER RADHUMA		DAMMAM	
	TRANSMISSIVITY (m^2/s)	STORATIVITY	TRANSMISSIVITY (m^2/s)	STORATIVITY
Iraq (Salman Zone)	$1.2x10^{-4}$-$2.0x10^{-2}$	..	$3.5x10^{-5}$-$1.7x10^{-2}$	$1.0x10^{-2}$-$2.8x10^{-1}$
Kuwait	..	..	$1.5x10^{-4}$-$5.4x10^{-2}$ AVG:[a] $5.6x10^{-3}$	$6.0x10^{-7}$-$3.9x10^{-1}$
Saudi Arabia	$4.0x10^{-5}$-$1.1x10^{-2}$	..	$2.7x10^{-3}$ (Wadi al Batin)	..

Source: Compiled by ESCWA-BGR based on Ministry of Agriculture and Water in Saudi Arabia, 1984; UN-ESCWA and BGR, 1999.
(a) AVG refers to average values.

Hydrogeology - Groundwater

RECHARGE

Only 4-8 mm/yr (7-13%) of the estimated 60 mm/yr of rain that falls on the Umm er Radhuma outcrop infiltrates into the aquifer.[20] This area lies mainly within Saudi Arabia and probably has the highest rate of replenishment to the aquifer system, since the upper part of this formation is the most karstified. In the Salman Zone, where outcrops of the Dammam Formation are most common, the average recharge rate is estimated at 6-7.5 mm/yr.[21]

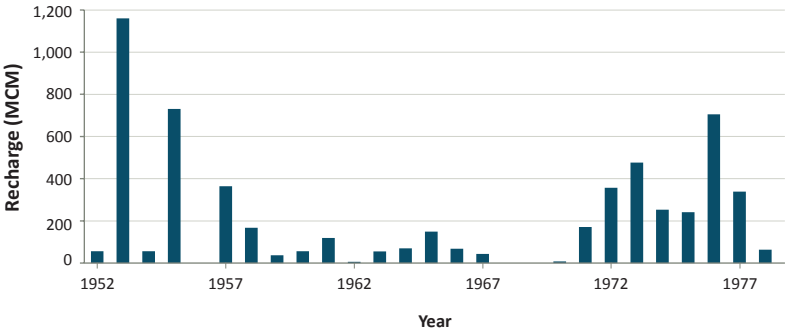
North-west of Wadi al Batin, total annual recharge to the Umm er Radhuma outcrops over an area of 82,400 km^2 ranged between nil and 1,160 MCM (0-14.1 mm/yr) for the period 1952-1978 (Figure 2) with an average annual recharge of 213 MCM (2.6 mm/yr).[22] The relatively significant but highly variable observed recharge can be attributed to three characteristic factors in this zone:

- The prevalence of high-intensity rainfall in desert-type storms which creates overland flow.
- The widespread occurrence of elevated gravel ridges, which are a remnant of old paleo-river drainage systems that still act as drainage paths in times of heavy rainfall, resulting in the formation of ponds.
- The exposed karst features in Paleogene and younger sediment outcrops, particularly in solution collapse areas allowing for fast infiltration.[23]

FLOW REGIME

The general groundwater flow direction is from the recharge areas in the south-west to the discharge areas in the north-east. In northern areas, the flow is towards the Euphrates Depression that was created by a major regional fault. In the Wadi al Batin area and Dibdibba Delta areas further south, groundwater flows towards the Gulf coast and Shatt al Arab with the formation of a large sabkha at the surface.

Figure 2. Recharge estimates for the Umm er Radhuma-Dammam Aquifer System (North) north-west of Wadi al Batin



Source: Compiled by ESCWA-BGR based on Faulkner, 1994.

STORAGE

The Umm er Radhuma probably has significantly higher storage than the Dammam for the following reasons:

- The Dammam is thinner and has over the years been tapped by thousands of wells due to the shallow depth to water.
- Most of the aquifer system replenishment area is covered by Umm er Radhuma outcrops.[24]

However, no data was available on the volume of storage in both formations.

DISCHARGE

In places where the Paleogene outcrops are covered by Neogene-Quaternary sediments in Iraq, natural discharge occurs from springs along the western bank of the Euphrates River and Lake Razzaza,[25] as well as in the small natural, groundwater-fed Lake Sawa. Total annual discharge in this area has been estimated at 50 MCM, with a discharge of 33 MCM from large springs in the artesian zone around the Euphrates Depression, 3 MCM from small springs on the plateau area west of the valley, and 14 MCM through evaporation from Lake Sawa.[26]

From the early 1950s to late 1970s, annual discharge from the Umm er Radhuma in Saudi Arabia was virtually identical to recharge, indicating that abstraction was within the sustainable yield[27] before development started and water levels began to drop.

WATER QUALITY

While groundwater is relatively fresh in the western (Widyan-Nukhaib) area (<1,000 mg/L TDS), it becomes brackish (TDS up to 5,000 mg/L) in the central (Salman-Hafr al Batin) area and changes drastically to hypersaline brines (TDS 50-150 g/L) over a short distance along the coastal Dibdibba Plain (Figure 3; see also Figure 1). Hence, the groundwater salinity generally increases along the flow path from the recharge areas (Umm er Radhuma outcrop) to the discharge areas along the Euphrates Depression and Gulf coast. This is also reflected in the major ion composition of groundwater, which changes from HCO_3-type in the Widyan-Nukhaib area to SO_4-Cl-type in the Salman-Hafr al Batin area to Cl-type in the Dibdibba Plain.

EXPLOITABILITY

The following criteria were used to delineate the exploitable areas of this aquifer system:

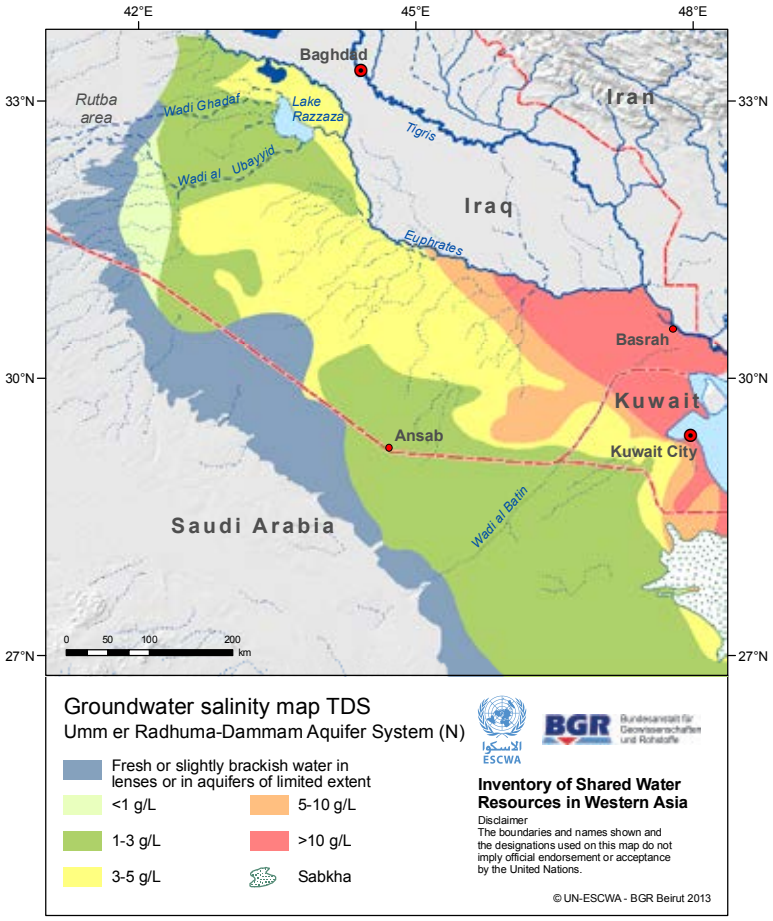
- **Depth to top of aquifer:** the average depth to the top of the Dammam in Saudi Arabia was reported at 80-120 m bgl.[28] In the Salman Zone and the western part of Wadi al Batin, the top of the Umm er Radhuma is at 50-100 m bgl[29] and the depth of exploitation bore-holes is 50-150 m bgl.[30] Hence drilling depth is not a limiting factor to exploitability in this section of the Aquifer System.

- **Depth to water level:** depth to groundwater in the Salman Zone was found to be around 50 m bgl rising to 5-20 m bgl[31] along the Euphrates River where groundwater is also discharged on the surface. This indicates that groundwater is shallow enough for exploitation.

- **Water quality:** salinity is a limiting factor in the coastal areas in the Dibdibba Plain (Figure 3).

Based on the above, most of the Umm er Radhuma-Dammam Aquifer System (North) appears to be exploitable (see Overview Map), with the exception of the Widyan Plateau and the coastal areas where the aquifer is either of limited extent or contains saline water as shown in Figure 3. The total exploitable area within the delineated basin is 179,000 km^2 of which around 123,000 km^2 lies in Iraq, 9,000 km^2 in Kuwait and 47,000 km^2 in Saudi Arabia.

Figure 3. Groundwater salinity map - Umm er Radhuma-Dammam Aquifer System (North)



Source: Modified by ESCWA-BGR based on UN-ESCWA and BGR, 1999.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

Available data indicates that the three riparian countries currently exploit the aquifer system.

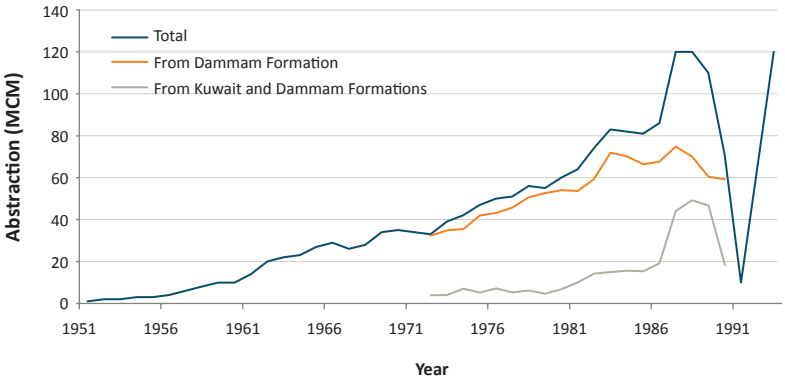
In Kuwait, pumping of about 1 MCM/yr, mainly from the Dammam, started in 1951, slowly increasing to 10 MCM/yr by 1960. Over the next three decades abstraction rates rose significantly to reach 120 MCM/yr in 1988 (Figure 4). The sharp drop in production during the period 1990-92 can be ascribed to the reduction in operations and destruction of well fields during the Second Gulf War. However, even during the war, the growing demand could not be satisfied from the Dammam Aquifer alone and exploitation of the overlying Kuwait Group Aquifer supplemented supply through the expansion of the Umm Gudair well fields.[32] By 1993, groundwater abstraction had returned to pre-war levels (120 MCM/yr) through the use of dual wells in the Dammam and overlying Kuwait Aquifers (Figure 4). About 75% of the abstracted water (excluding private wells) came from the Dammam.[33] More dual completion well fields with an operation capacity of 66 MCM/yr were planned in the late 1990s.[34] Data about their implementation was not available.

In Saudi Arabia, abstraction from the Umm er Radhuma-Dammam Aquifer System takes place mainly in the central section of the aquifer system in the Gulf area. By 2004, around 720 MCM had been extracted from the Umm er Radhuma, and 350 MCM from the Dammam Formation (see Chap. 15). Abstraction from the much less heavily populated Umm er Radhuma-Dammam Aquifer System (North) is thought to be significantly less, though no data is available.

In Iraq, abstraction through pumping in the early 1990s was concentrated in the Salman Zone where 50 bore-holes withdrew around 3.5 MCM/yr.[35] Most of the abstraction in Iraq (approx. 40 MCM/yr) takes place from springs in the Euphrates Depression.

Declining water levels indicate that stored groundwater is being depleted in the Umm er Radhuma and Dammam Aquifers. In Kuwait, a comparison of the potentiometric surface for the Dammam Aquifer in 1960 (pre-development phase) and 1990 registered a drop of 40-60 m.[36] The drop in water level was accompanied by a salinity increase from 5,000 to 10,000 mg/L TDS.[37] Official data indicates that the water level is still declining at a rate of $3.2x10^{-1}$-$9.1x10^{-1}$ m/yr.[38]

Figure 4. Annual groundwater abstraction from well fields in Kuwait



Source: Compiled by ESCWA-BGR based on UN-ESCWA and BGR, 1999.

In Kuwait, groundwater is abstracted mostly for agricultural, industrial and domestic purposes other than drinking water. Groundwater is also occasionally blended with desalinated water for drinking purposes.[39] In Iraq, groundwater in the Salman Zone is mainly suitable for irrigation and watering livestock, except in wells near recharge karst depressions where the groundwater is suitable for domestic purposes.[40] While the saline to hypersaline groundwater is not suitable for human use, its discharge at the surface and the formation of natural reservoirs such as Lake Sawa contributes significantly to local ecosystems.

GROUNDWATER QUALITY ISSUES

In the areas of highest abstraction (i.e. Kuwait), groundwater levels are close to sea level and hence the aquifer system has been subject to and is at great risk from further seawater intrusion. Furthermore, a significant increase in groundwater salinity between 1980 and 1990 was attributed to upward leakage from the deeper zones through a deep fault system that hydraulically connects the Dammam with the underlying saline Umm er Radhuma.[41]

SUSTAINABILITY ISSUES

As indicated above, the aquifer system is at risk from salinization, and deteriorating groundwater quality may become an increasingly limiting factor to groundwater use.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place for the Umm er Radhuma-Dammam Aquifer System (North) which is shared between Iraq, Kuwait and Saudi Arabia.

COOPERATION

Kuwait and Saudi Arabia are reportedly preparing a joint study of the shared aquifer.[42]

OUTLOOK

Monitoring of groundwater quality in general and the groundwater-seawater interface in particular would allow for the detection of increasing salt concentrations. Effective joint management decisions could decrease the risk of salinization and make the aquifer system more sustainable.

Desert near Basrah, Iraq, 2012. Source: Earth & Marine Environmental Consultants (EAME).

Notes

1. Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates.
2. This division was based on UN-ESCWA and BGR, 1999.
3. Ministry of Agriculture and Water in Saudi Arabia, 1995 as cited in Vincent, 2008.
4. Al-Jerash, 1985 as cited in Vincent, 2008.
5. Kuwait Government Online, 2012.
6. Central Organization for Statistics in Iraq, 2010.
7. CIESIN, 2010.
8. Central Department of Statistics and Information in Saudi Arabia, 2004.
9. UN-ESCWA and BGR, 1999; Jassim and Buday, 2006b.
10. The Rus Formation contains some evaporates like anhydrite, which dissolves completely in some localities. Jassim et al., 1984 (cited in Jassim and Goff, 2006) introduced the name Jil in Iraq for the Rus equivalent at outcrop areas where the anhydrite has been dissolved.
11. UN-ESCWA and BGR, 1999; Jassim and Buday, 2006b.
12. UN-ESCWA and BGR, 1999.
13. Ministry of Agriculture and Water in Saudi Arabia, 1984.
14. Ibid.
15. Jassim and Buday, 2006a.
16. Ministry of Agriculture and Water in Saudi Arabia, 1984.
17. UN-ESCWA and BGR, 1999.
18. Ministry of Agriculture and Water in Saudi Arabia, 1984.
19. Jassim and Buday, 2006a.
20. Ministry of Agriculture and Water in Saudi Arabia, 1984.
21. Al Mashadani, 1995, cited in UN-ESCWA and BGR, 1999.
22. Faulkner, 1994.
23. Ibid.
24. Ministry of Agriculture and Water in Saudi Arabia, 1984.
25. A manmade lake created by surface water diversion from the Euphrates River in Iraq.
26. Al Mashadani, 1995, cited in UN-ESCWA and BGR, 1999.
27. Faulkner, 1994.
28. Ministry of Agriculture and Water in Saudi Arabia, 1984.
29. UN-ESCWA and BGR, 1999.
30. Krasny et al., 2006.
31. Ibid.
32. UN-ESCWA and BGR, 1999.
33. Ibid.
34. Ibid.
35. Al Mashadani, 1995 cited in UN-ESCWA and BGR, 1999.
36. UN-ESCWA and BGR, 1999.
37. Ibid.
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39. UN-ESCWA and BGR, 1999.
40. Krasny et al., 2006.
41. UN-ESCWA and BGR, 1999 (see also Figures 18 and 19 in this reference).
42. Ministry of Electricity and Water in Kuwait, 2011.

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Chapter 17

Wadi Sirhan Basin

Tawil-Quaternary Aquifer System

Tawil-Quaternary Aquifer System

Wadi Sirhan Basin

EXECUTIVE SUMMARY

The Wadi Sirhan Basin is situated in Jordan and Saudi Arabia and forms a central depression surrounded by basalt and sedimentary plateau areas in the north and south. The basin surface is covered by Paleogene and Quaternary deposits, which make up the upper part of the exploited aquifer system. In the subsurface, thick deposits of Cretaceous and Tawil-Sharawra Formations occur in the depression and along the boundaries of the aquifer system. They constitute the lower part of an aquifer system that is denoted as the Tawil-Quaternary Aquifer System in this Inventory.

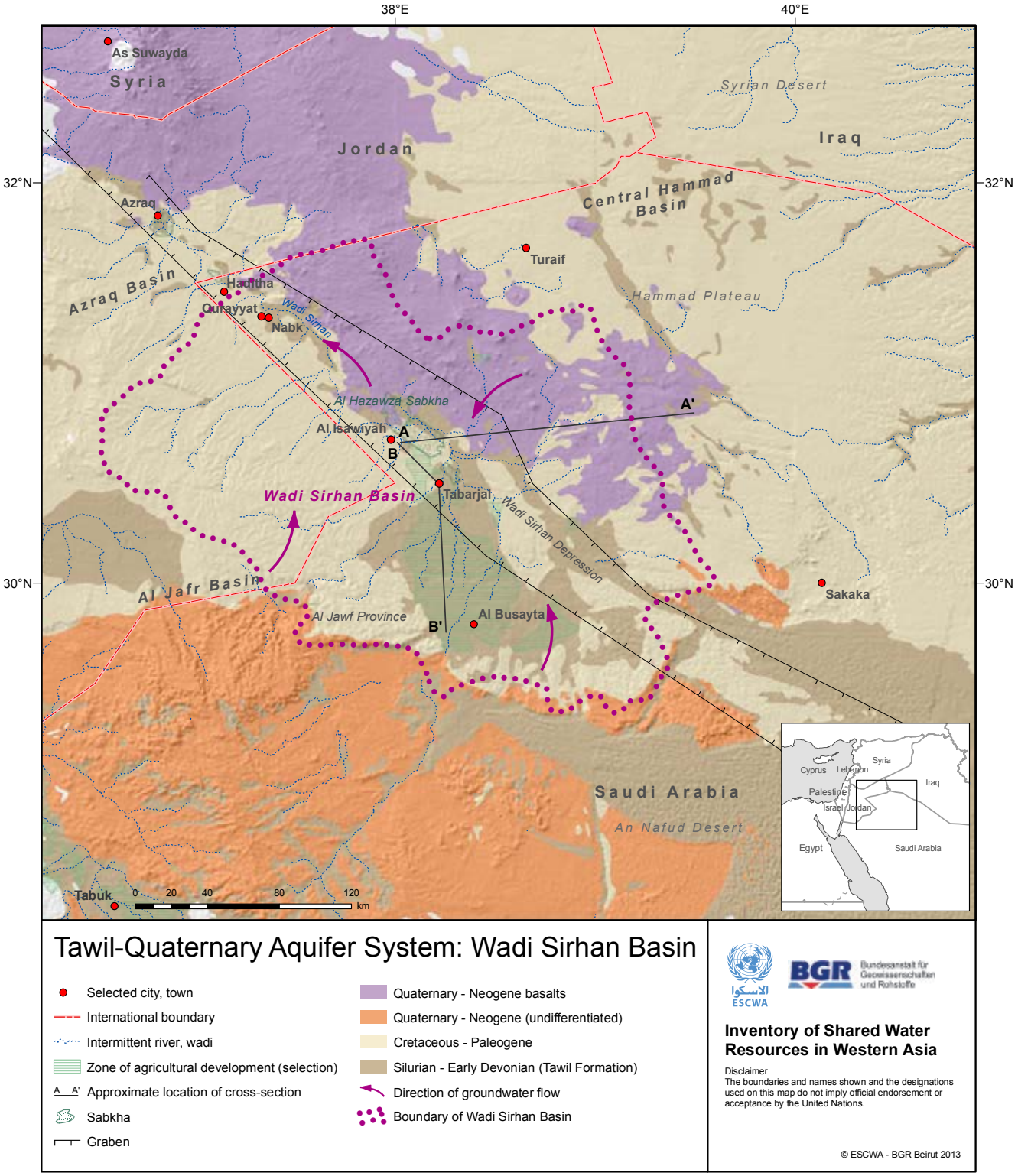
This aquifer appears to have evolved as part of the groundwater system in the Sakaka-Azraq areas, with limited recharge entering the system in the form of Mediterranean-type rainwater. Groundwater flows from the basalt and limestone plateau areas towards the central depression where it follows the hydraulic gradient in a south-east/north-west direction.

Since exploitation of the aquifer system started in 1986, annual abstraction for irrigation purposes has risen from about 100 MCM in 1984 to almost 3,500 MCM in 2004. However, the lower part of the aquifer system appears to have potential for further exploitation as only a few of the approximately 100 wells tapping this part of the aquifer system show signs of significant drawdown.

BASIN FACTS

RIPARIAN COUNTRIES	Jordan, Saudi Arabia
ALTERNATIVE NAMES	Azraq Graben, Secondary-Tertiary-Quaternary Aquifer Complex (STQ), Sharawra, Sirhan Basin, Sirhan-Hamza Graben
RENEWABILITY	Very low (0-2 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Weak
ROCK TYPE	Porous to fractured
AQUIFER TYPE	Mainly unconfined
EXTENT	~44,000 km^2
AGE	Upper part: Upper Cretaceous to Quaternary Lower part: Early Devonian-Silurian
LITHOLOGY	Basalt, alluvium, limestone and sandstones with some marl
THICKNESS	Upper part: <1,300 m Lower part: 200-300 m
AVERAGE ANNUAL ABSTRACTION	1984: 100 MCM 2004: 3,500 MCM
STORAGE	22 BCM
WATER QUALITY	Fresh to saline
WATER USE	Irrigation
AGREEMENTS	-
SUSTAINABILITY	Over-exploitation of the upper part of the aquifer system, especially in the south for irrigation

OVERVIEW MAP



Tawil-Quaternary Aquifer System: Wadi Sirhan Basin

- Selected city, town
- International boundary
- Intermittent river, wadi
- Zone of agricultural development (selection)
- A A' Approximate location of cross-section
- Sabkha
- Graben
- Quaternary - Neogene basalts
- Quaternary - Neogene (undifferentiated)
- Cretaceous - Paleogene
- Silurian - Early Devonian (Tawil Formation)
- Direction of groundwater flow
- Boundary of Wadi Sirhan Basin

ESCWA

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

Disclaimer
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

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Introduction

LOCATION

The An Nafud Desert in northern Saudi Arabia is separated from the Syrian Desert (Badiyet esh Sham) by the Hammad Plateau, which extends across the borders of Iraq, Jordan, Saudi Arabia and Syria. On the basis of surface water drainage and the directions of groundwater flow, six hydrogeological basins have been defined in the Hammad Plateau.[1] The Tawil-Quaternary Aquifer System (Wadi Sirhan Basin), which extends from the eastern boundaries of the Basalt Aquifer (South-East) (see Chap. 22) towards the Sakaka-Al Jawf area, constitutes the south-western region of the Hammad Plateau.[2] This chapter covers the aquifers within the Wadi Sirhan Basin. In order to place the aquifer system in a regional context, however, the geographical extent of its formations beyond the boundaries of the Tawil-Quaternary Aquifer System is shown on the Overview Map. A brief description of these aquifers is also provided.

AREA

The Tawil-Quaternary Aquifer System constitutes the southern part of a large depression along the eastern edge of the Jordan Uplift (Wadi Sirhan Depression), in which thick Paleogene and Neogene-Quaternary sediments have accumulated.[3] The basin is largely shaped by its geomorphologic landscape,[4] which can be divided into three main regions:[5]

- The central topographic depression, which runs in a north-west/south-east direction at an altitude of 500-600 m asl.
- The western Widyan area (900-1,100 m asl), from where the main tributaries of the Wadi Sirhan drain.
- The basalt plateau (800-900 m asl), which extends over about 220 km from the Jebel al Arab region into Saudi Arabia.

The boundaries of the basin are defined by:

- Surface water divides that separate the Wadi Sirhan Basin from the Al Jafr and Azraq Basins in the west and the Central Hammad Basin in the east (see Overview Map).
- The Wadi Sirhan Graben structure, which largely controls groundwater flow.

Based on the boundaries described above, the basin covers an area of about 44,000 km^2, of which about 80% (35,000 km^2) lies in Saudi Arabia, and the remaining 9,000 km^2 (20%) in Jordan. A range of outcrops occur in the basin, including Quaternary-Neogene undifferentiated outcrops (10,000 km^2), volcanic outcrops (12,000 km^2), Cretaceous- and Paleogene-age outcrops (20,000 km^2), and Silurian- and Early Devonian-age outcrops.

CLIMATE

The Tawil-Quaternary Aquifer System lies in an arid region with an average annual precipitation of 35-120 mm and average temperatures between 16°C and 21°C. Annual evapotranspiration is estimated at 1,460-1,680 mm. Aridity generally increases from north to south. The area along the southern Jordanian border commonly receives less than 50 mm/yr of rainfall, which occurs in the form of infrequent, short rain storms of varying intensity.[6] Potential evaporation is more than 3,500 mm/yr,[7] while actual evaporation is greater than 90% of total rainfall.[8]

POPULATION

In 1980, one third of the total population of the Hammad Plateau (33,000 people) lived in the Wadi Sirhan Basin.[9] Since then, the population has increased significantly due to rapid agricultural development, mainly in Saudi Arabia.

Most of the population presently abstracting water from the aquifer system lives in the lower depression areas in Al Jawf Province in Saudi Arabia. The total population in this province has been estimated at about 440,000 inhabitants,[10] who mainly live between the towns of Al Jawf in the south and Al Haditha in the north.

OTHER AQUIFERS IN THE AREA

Other aquifer systems in the area include the underlying Saq-Ram and Jubah-Jawf Aquifers (Paleozoic).[11] The Jubah-Jawf is exploited in the Sakaka area along the eastern end of the Tawil-Quaternary Aquifer System, while the Saq-Ram Aquifer System (West) (see Chap. 10) is exploitable in the north-eastern part of the Wadi Sirhan Basin towards the Azraq Basin (see Chap. 22).[12]

INFORMATION SOURCES

Key information on the aquifer system and the delineation of the basin are based on reports from 1983 and 1990,[13] which are complemented by data from more recent publications.[14] The Overview Map was delineated based on various local and regional references.[15]

Area north and north-west of Al-Jafr, Jordan, 2008. Source: Robert Bewley, Aerial Photographic Archive for Archaeology in the Middle East.

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

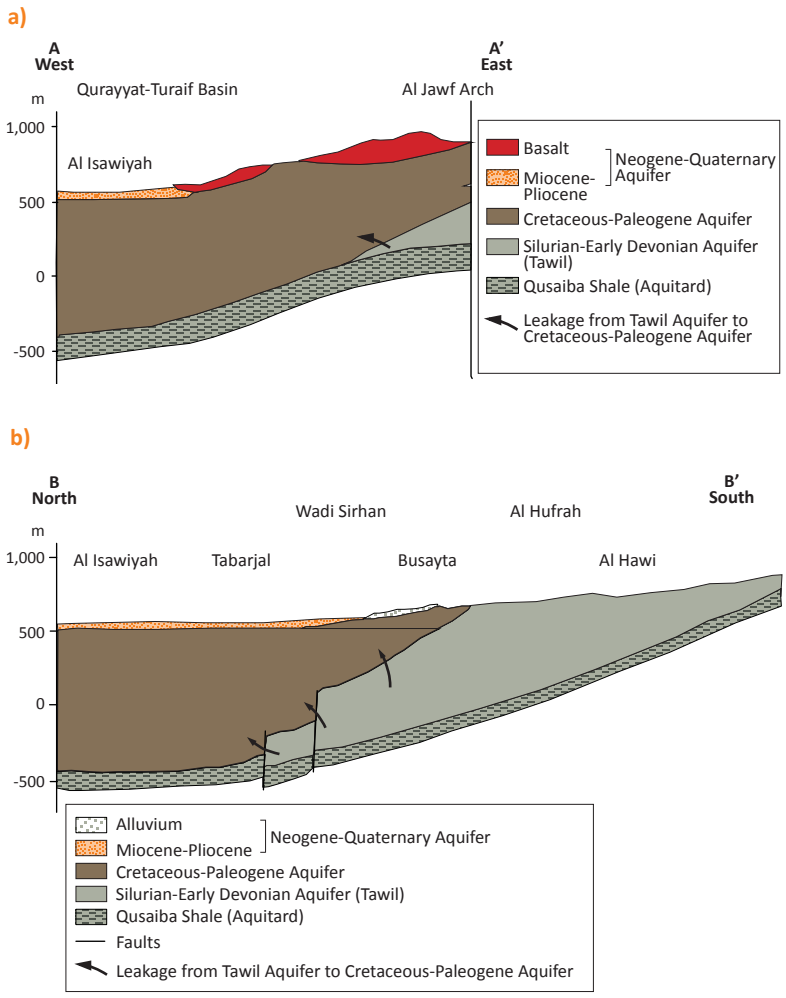
The Wadi Sirhan Basin presents water-bearing sediments/formations in a zone of subsidence shaped by subsurface faults associated with major crustal movements. These water-bearing formations were subjected to deep and significant fracturing with large vertical displacement (50-1,500 m), which affected the deposition of the Upper Cretaceous layer. Subsequent faults created smaller displacements during the Paleogene-Neogene.[16] This tectonic setting resulted in the deposition of thick sediments since the late Cretaceous time, which dip towards the centre of the depression.

In the subsurface, the Tawil-Quaternary Aquifer System is a narrow and very deep asymmetrical trough, with a steep slope on the northern flank and a gentler slope on the southern flank.[17] The graben is filled with geological units that have different aquifer properties and range in age from the Cambro-Ordovician to the Quaternary. Thick deposits of these geological units are found inside the graben and along its western boundary. Outcrops of the younger formations (Paleogene to Quaternary) cover the surface of the basin, while the Cretaceous and older formations are found only in the subsurface (Figure 1).

STRATIGRAPHY

The Tawil-Quaternary Aquifer System is made up of an upper part (Upper Cretaceous to Quaternary) and a lower part (mainly Silurian-Early Devonian) as shown in Table 1. Within the lowlands of the Wadi Sirhan Graben, the Early Devonian Tawil Formation disappears and the water from this formation flows through the Upper Cretaceous to the Quaternary Formations. As a result, this water-bearing formation becomes vertically connected with overlying layers (Figure 1). This is confirmed by the chemical composition of the groundwater, which suggests that it is a result of mixing of fresh Tawil water with brackish Wadi Sirhan water.[18] These two aspects (i.e. upward flow and northern joining) create a strong direct linkage which allows for the Neogene-Quaternary Aquifer, the Cretaceous-Paleogene Aquifer[19] and the Tawil Aquifer to be treated as one aquifer system within the basin's geographical area.

Figure 1. (a) East-west and (b) north-south cross-section of the Tawil-Quaternary Aquifer System



Source: Redrawn by ESCWA-BGR based on BRGM and CNABRL, 1985.

AQUIFER THICKNESS

The following range of thicknesses has been reported:[20]

- Neogene to Quaternary sediments: <200 m
- Basalt: <560 m
- Paleogene: <560 m
- Upper Cretaceous: ~300 m
- Early Devonian: ~200-300 m

However, values obtained from well data may be significantly different from these modelling results. For example, the thickness obtained

Table 1. Lithostratigraphy of the Tawil-Quaternary Aquifer System in the Wadi Sirhan Basin

NAME	AGE	HYDROGEOLOGICAL UNIT		LITHOLOGY	COMMENTS
		JORDAN	SAUDI ARABIA		
Upper part	Neogene (N) to Quaternary (Q)	Alluvium	Alluvium	Gravel, sand, silt, clay and different basalt flows and volcanic tuffs (Q); sand, marl and limestone (N).	Mostly in low areas.
		Basalt	Basalt		
	Paleogene (Eocene-Paleocene)	Shallala (B5)	Mira-Umm Wu'al	Sequence of marl, limestone (marly or silicified) and chert.	-
		Rijam (B4)			
		Muwaqqar (B3)	-		
	Upper Cretaceous	Amman-Wadi as Sir (A7/B2)	Wasia-Aruma	Limestone, dolomites and marl with some chert and sand intercalations.	Considered in Jordan as Middle Aquifer System; exploitation in the eastern part of the country limited due to high salinity.
Lower part	Upper Cretaceous	Ajlun (A1/A6)	Wasia-Aruma	Limestone, dolomites and marl with some chert and sand intercalations.	Known as the Lower Ajlun Aquitard, but changes into sandy facies in eastern Jordan to form an aquifer.
	Lower Cretaceous	Kurnub (K1-2)	Biyadh-Wasia (probably Buwaib)	Sandstones and sandy limestones with some shale and clays.	Exploitation proved unsuccessful due to high salinity and low productivity.
	Silurian-Early Devonian	Worm Burrows-Alna[a]	Tawil-Sharawra	Sandstone with some gypsum near the top.	A good to moderate aquifer which feeds the STQ[b] in Saudi Arabia and extends into Jordan.

Source: Compiled by ESCWA-BGR based on UN-ESCWA, 1990; Margane et al., 2002; Abunayyan Trading Corporation and BRGM, 2008; Barthelemy et al., 2010.
(a) Abunayyan Trading Corporation and BRGM, 2008 reported that the Tawil, which crops out in the Saudi Arabian part of the Tawil-Quaternary Aquifer System, disappears towards the north. However, more recent regional investigation has confirmed its extension into Jordan within the Tawil-Quaternary Aquifer System and further north-east to the Iraqi border. It is apparently equivalent to unnamed formations described on the 1:250,000-scale geological map of Jordan as 'Worm Burrows' and 'Red Brown Argillaceous Sandstones' (Barthelemy et al., 2010).
(b) Secondary-Tertiary-Quaternary Aquifer Complex.

for the Basalt (300 m and 480 m)[21] and the Paleogene (>550 m) formations in the Wadi Sirhan Depression do not differ significantly from the modelling results.[22] However, the value obtained for the Tawil Formation (550 m) from well data is significantly different.[23]

AQUIFER TYPE

The Quaternary-Neogene sediments are usually unconfined, but confined conditions occur in areas where the wadi deposits comprise both Quaternary sands and calcareous Neogene deposits. In general, confined conditions could be more dominant towards the central parts of the basin.[24] The Eocene-Paleocene formations are usually confined, except in some outcrop areas along the plateau. The Cretaceous and the Devonian-Silurian formations are also mostly confined,[25] except in outcrop areas in the southern part of the basin.

AQUIFER PARAMETERS

Table 2 shows the range of transmissivity and storativity values obtained for aquifers in the Tawil-Quaternary Aquifer System. The highest transmissivity ($3.5x10^{-2}$ m^2/s) and the lowest storativity ($1.0x10^{-5}$) values for the Tertiary formations were found in the Al Isawiyah area.[26] The highest transmissivity for the Neogene formations ($1.8x10^{-1}$ m^2/s) was obtained from a 150 m deep bore-hole.[27]

Table 2. Hydraulic parameters of the Tawil-Quaternary Aquifer System

AQUIFER	TRANSMISSIVITY (m^2/s)		STORATIVITY	
Quaternary-Neogene	$1.1x10^{-4}$-$3.4x10^{-3}$	$2.8x10^{-3}$-$1.8x10^{-1}$	$1.0x10^{-2}$	$1.0x10^{-5}$-$3.7x10^{-2}$
Eocene-Paleocene	$5.8x10^{-4}$-$2.9x10^{-4}$	$2.8x10^{-3}$-$1.8x10^{-1}$	..	$1.0x10^{-5}$-$3.7x10^{-2}$
Cretaceous	$1.1x10^{-3}$-$4.0x10^{-3}$	$5.0x10^{-3}$-$1.0x10^{-2}$	$1.0x10^{-2}$	$1.0x10^{-2}$
Early Devonian	$1.1x10^{-3}$-$4.0x10^{-3}$	$1.0x10^{-4}$-$2.3x10^{-2}$	$1.0x10^{-2}$	$3.0x10^{-2}$
Source	ACSAD, 1983a.	BRGM and CNABRL, 1985.	ACSAD, 1983a.	BRGM and CNABRL, 1985.

Source: Compiled by ESCWA-BGR.

Hydrogeology - Groundwater

RECHARGE

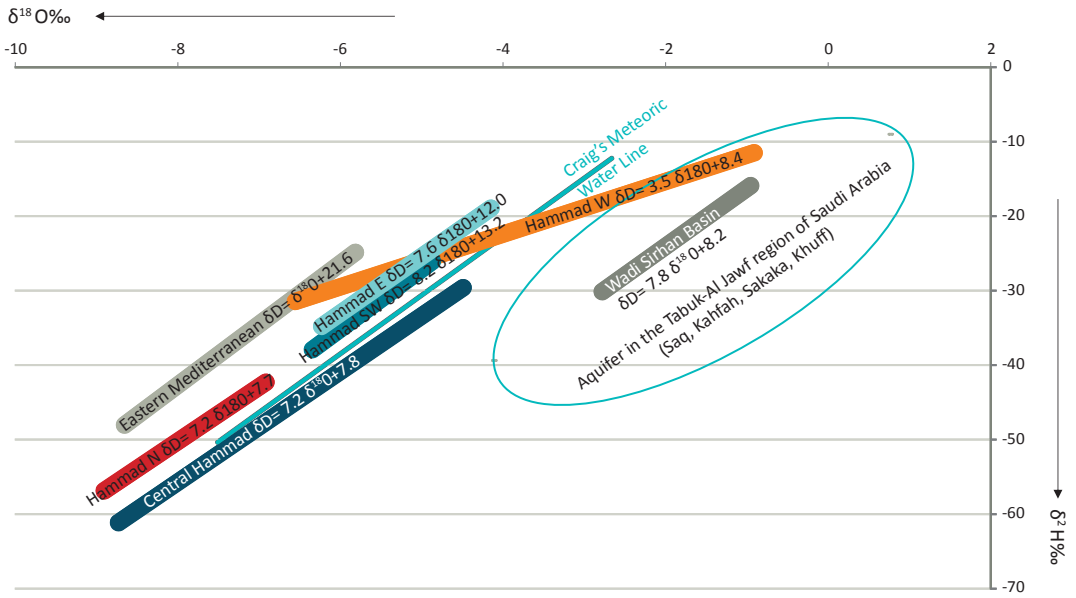
The Wadi Sirhan Basin receives an estimated total annual precipitation of 600 MCM[28] of which 5% or 30 MCM/yr is expected to infiltrate the shallow aquifer systems as natural recharge.[29] This corresponds to an annual recharge of less than 2 mm, which means the aquifer system can be considered to have limited renewability. Carbon-14 and tritium data have revealed recent recharge in shallow deposits in Wadi Sirhan.[30] This recharge water comes from the Mediterranean and displays isotopic similarities with the Basalt Aquifer System[31] (see Chap. 22) and the Paleozoic-Mesozoic Aquifers in the Al Jawf-Sakaka area.[32] The groundwater in the Wadi Sirhan Basin of the Hammad Plateau has been shown to be unique (Figure 2) in that the aquifers were recharged by rain of continental rather than Mediterranean origin in previous pluvial periods.[33] This major Southern Pluvial period ended 26,000 years ago and was followed by two younger pluvial periods 20,000-16,000 years ago (Northern Pluvial) and 8,500-3,900 years ago (Neolithic Pluvial).[34]

These findings suggest that, unlike the rest of the groundwater systems in the Hammad Plateau, the groundwater in the Wadi Sirhan Basin evolved as part of the groundwater system in the Sakaka-Azraq areas. The close similarity of the isotope composition of groundwater in this area and in the Tabuk area to the south-west confirms the southern continental origin of the groundwater in the Wadi Sirhan Basin.

FLOW REGIME

In general, groundwater follows the direction of surface water flow, which is south-west from the basalt plateau area and north-east from limestone plateau area. Groundwater flow is then directed towards the main wadi channel, which runs in a north-east/south-west direction across the Jordanian-Saudi border. The hydraulic gradient in the central depressions is about 0.002.[35] The flow direction of groundwater beneath the wadi bed has been depicted in the carbon-14 age of groundwater, which increases from 5,300 years in the north-west to

Figure 2. Meteoric Water Lines ($\delta^2H/\delta^{18}O$ graph) of the various hydrogeological regions in the Hammad Plateau



Source: Redrawn by ESCWA-BGR based on Geyh et al., 1985.
Note: The Global Meteoric Water Line (GMWL) is an equation developed by Craig, 1961 and states the average relation between hydrogen (δ^2H) and oxygen ($\delta^{18}O$) isotope ratios in natural terrestrial waters, expressed as a worldwide average. Craig's line is specifically global in application, and is an average of many local or regional meteoric water lines which differ from the global line due to varying climatic and geographic parameters (USGS, 2004).

30,000 years in the south-east.[36] Before heavy abstraction from the aquifer system started in the 1990s, depth to water was reported at less than 10 m bgl.[37]

STORAGE

Before heavy abstraction from the Tawil-Quaternary Aquifer System started in the 1990s, groundwater reserves at 300 m depth were estimated at 58 BCM or more, of which about 17 BCM were located in the until-then untouched Tawil Formation.[38] In 2005, a total of 876 MCM was abstracted from the Tawil. This was reported to be equivalent to 4% of exploitable reserves in this formation, which would mean that these reserves were reassessed at about 22 BCM.[39]

DISCHARGE

The Wadi Sirhan Basin is considered a closed basin, in which groundwater discharges upward (Figure 1). Discharge at the surface is evidenced by a large number of mud flats and salt lakes in the central part of the basin[40] including the approximately 400 km^2 Al Hazawza Sabkha.[41] The presence of a number of saline springs and a clear increase in soil salinity in wide zones along the main wadi bed provide further evidence of internal groundwater discharge.[42]

WATER QUALITY

Analysis of groundwater samples collected in 1980 from the Neogene Aquifer in the central depression zone indicated natural salinity levels that were generally below 3,000 mg/L, though higher salinities up to 4,000 mg/L were observed in some wells.[43] The salinity level of the Paleogene formations beneath the Quaternary-Neogene Aquifer was reported to be in the range of 1,000-1,500 mg/L.[44] Salinity increased to 800-2,000 mg/L in the south-eastern part of the basin and 2,000-3,000 mg/L in the north-western part, reflecting the longer residence time of the groundwater as indicated by isotopic signature. This trend was observed across all formations.

Available data indicates that water in the Tawil Formation is fresh (less than 500 mg/L TDS) in the heavily exploited Al Busayta area south-west of the Wadi Sirhan Depression.[45] Inside the graben, salinity generally increases with depth and TDS values of 7,280-9,200 mg/L have been measured in deep wells in the group overlying the Disi Formation.[46] Moreover, Electrical Conductivity (EC) values of up to 10,000 µS/cm (about 7,000 mg/L TDS) were measured in some localities along the central depression zone.[47]

Table 3. Groundwater reserve estimates in the Tawil-Quaternary Aquifer System

DEPTH (m bgl)	STORAGE (BCM)		
	TAWIL FORMATION	CRETACEOUS-TERTIARY FORMATIONS[a]	TOTAL
100	0.70	8.50	9.2
200	6.84	22.66	29.5
250	11.39	30.71	42.1
300	16.88	40.93	57.81
Top of aquifer is less than 1,500 m bgl.			

Source: Compiled by ESCWA-BGR based on BRGM and CNABRL, 1985.
(a) BRGM and CNABRL, 1985 does not explicitly mention why the Quaternary deposits were not included in the assessment. However, as the only abstraction from the Wadi Sirhan Basin in Saudi Arabia during 1983-1984 was from the Paleogene-Neogene formations, it is possible that groundwater reserve in the Quaternary was negligible.

Table 4. Water levels in different bore-holes in the Wadi Sirhan Basin (1978-1980)

NAME	AQUIFER UNIT	TOTAL DEPTH (m)	DEPTH TO WATER (m bgl)
Nabk abu Kasr	Wadi deposits (Quaternary Alluvium)	50	7.7
Al Qurayyat	Wadi deposits (Miocene-Eocene)	223	Flowing
Al Isawiyah	Wadi deposits (Miocene-Pliocene)	180	8.8
Al Haditha	Eocene deposits	200	17.7

Source: Compiled by ESCWA-BGR based on ACSAD, 1983b.

This substantial increase in salinity can be attributed to the effect of evaporation from sabkhas and shallow water levels, rather than upconing of saline water from depth.

EXPLOITABILITY

Until the mid-1980s, the shallow aquifer units (Quaternary-Tertiary) were the main target of water resource development. Table 4 shows that water level and drilling depth did not limit exploitation. Groundwater salinity in the main zone of abstraction (Al Isawiyah-Qurayyat) was 1,000-3,000 mg/L TDS,[48] indicating that the quality of water was not a limiting factor.

The deepest formation in the aquifer system, the Tawil, has the following characteristics:[49]

- **Depth to top of aquifer:** ≤1,000 m bgl.
- **Depth to water level:** 250 m bgl maximum.
- **Water quality:** <10,000 mg/L TDS.

Hence it can be concluded that the aquifer system is exploitable throughout the basin.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

Currently, only Saudi Arabia exploits the aquifer system in the Wadi Sirhan Basin. The Jordanian part of the basin has not yet been developed.[50] In 1979, there were only 80 wells in the Wadi Sirhan Basin with an estimated abstraction of 2.5 MCM/yr. Most of these dug wells were located in the central depression where agricultural activities were being developed.[51]

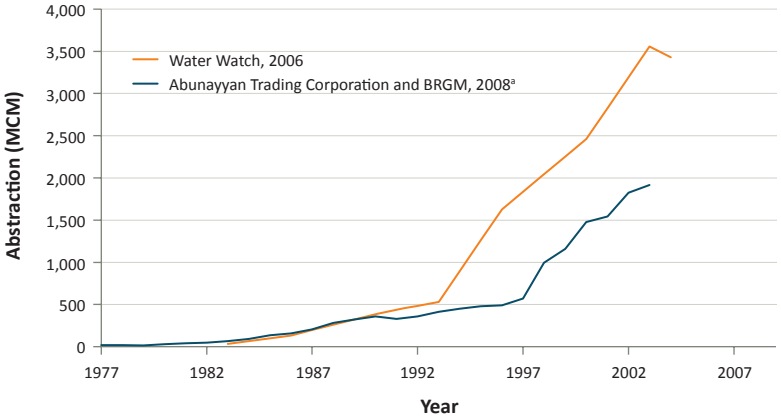
In the following years the number of wells in the basin increased rapidly to reach nearly 1,000 in 1982 and over 1,500[52] in 1986, mainly in the Tubarjal-Al Isawiyah area in Saudi Arabia. As a result, abstraction increased from around 100 MCM/yr in 1984 to at least 500 MCM/yr and maybe as much as 1,000 MCM/yr in the mid-1990s (Figure 3). Agricultural activities were further expanded after 1996, increasing abstractions in Al Jawf Province to between 1,900 MCM (2003) and 3,500 MCM (2004).

In the early years, groundwater production focused on shallow wells in the Wadi Sirhan Depression that tapped the Quaternary-Neogene Aquifer System, but after 1996 deeper aquifer layers were also exploited. The most relevant aquifers in the Tawil-Quaternary Aquifer System are the Tawil-Sharawra Formations and the Secondary-Tertiary-Quaternary (STQ) Aquifer Complex.[53] In the period from 1984 to 2005, abstractions rose from 39 to 876 MCM/yr in the Tawil Aquifer and from 141 to 1,388 MCM/yr in the STQ Aquifer Complex, resulting in a total abstraction of 2,264 MCM in 2005[54] (including abstractions from areas outside the Tawil-Quaternary Aquifer System as defined in this Inventory). Domestic and industrial water consumption in Al Jawf Province is estimated at 27.9 MCM/yr, or 1.4% of total abstractions.[55]

Agricultural census data from Al Jawf Province is available from 1989 onwards, but other studies have estimated groundwater-irrigated area at just 7 ha in 1979,[56] mainly in the central part of the depression. At the time, agricultural production only took place in small farms which cultivated dates, wheat and vegetables for personal and local consumption. From the mid-1980s onwards, the area became the focus of large-scale agricultural development projects and the irrigated area expanded to 30,000-40,000 ha in 1996 (Figure 4 and 5). [57]

The real boom in agricultural development took place after 1996 with ambitious land reclamation projects irrigating 160,000 ha[58] in the Al Jawf area between 2004 and 2007. A remote-sensing assessment suggested that by 2004, 24 BCM were abstracted from the Tawil.[59]

Figure 3. Historical abstraction in Al Jawf Province in Saudi Arabia (1977-2004)

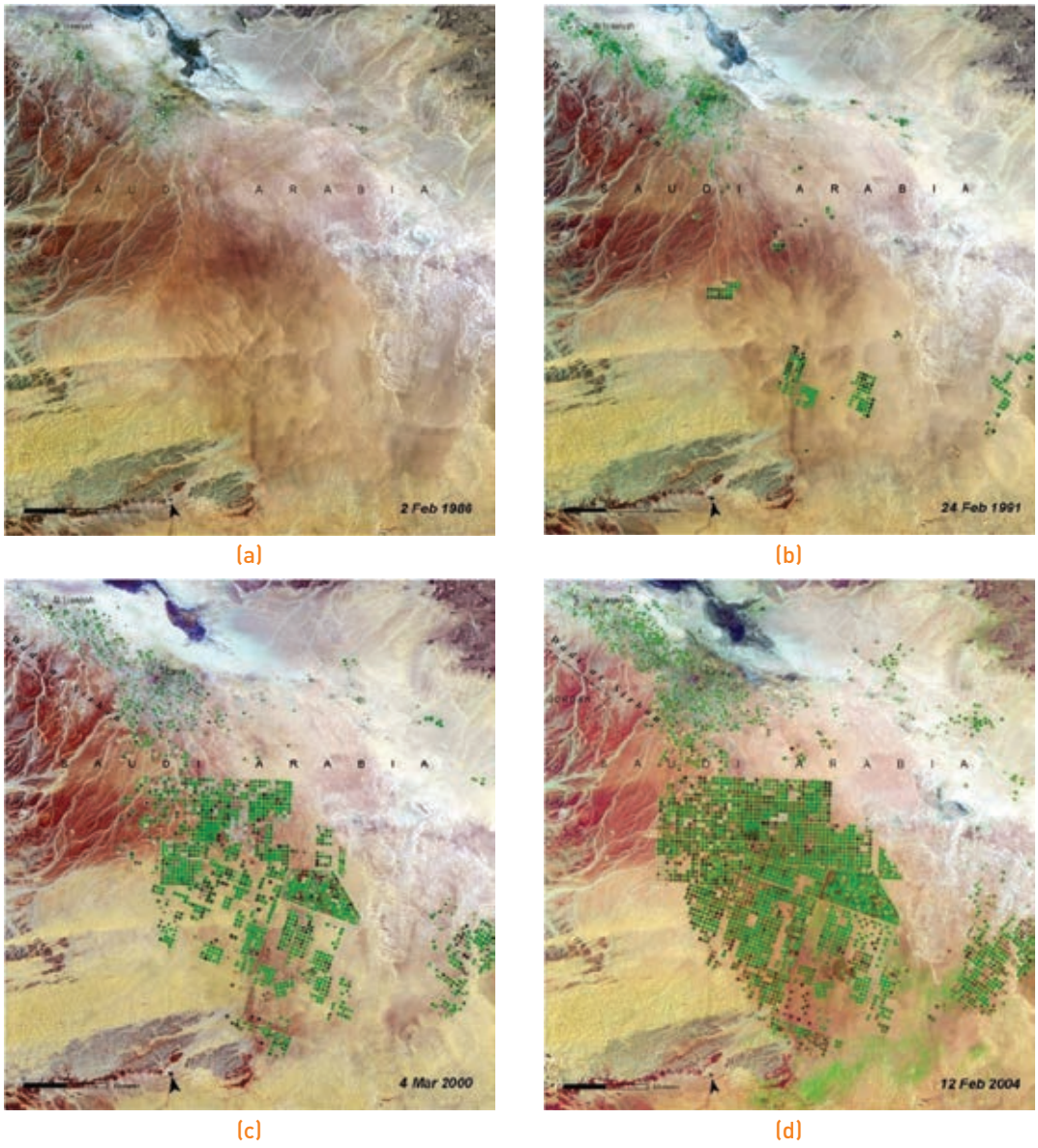


Source: Compiled by ESCWA-BGR.
Note: Census data as well as study estimates are usually available for the Al Jawf Province, which encompasses all development in the Wadi Sirhan basin, including the Tubarjal-Al Isawiyah areas. Smaller developments in the Sakaka area, outside the Wadi Sirhan basin, are also part of Al Jawf Province and hence included in this data.
(a) Data on abstraction in Al Jawf Province was digitized from the electronic version of the report (Figure 24, p.42), with resulting inaccuracies.

Large commercial farms were established, mainly in the Al Busayta area south and south-west of Tabarjal, where most of the wells tap the Tawil and Sharawra Formations. The largest farming corporations include the NADEC Al Jawf (7,200 ha),[60] Watania (30,000 ha),[61] JADCO (60,000 ha)[62] and Domat Al-Jandal (60,000 ha)[63] Farms.

Cropping patterns in Al Jawf Province also changed over the years. In 1990, around 30% of the agricultural area was dedicated to wheat cultivation (8,871 ha). Permanent cultures accounted for 40% of production yield and fodder production was marginal (Figure 6). Wheat production rapidly decreased after 1990 (possibly in response to a reduction in agricultural subsidies), reaching a low in 1996 when it covered only 16% of the area. While other cereals (26% of area) and fodder crops (25% of area) had gained dominance at the start of the second agricultural boom in 1996, wheat quickly recovered in the late 1990s. Wheat production peaked between 2004 and 2007, covering up to 76% (124,000 ha) of all irrigated areas in Al Jawf province with a production of around 800,000 ton/yr. Fodder production was also significant in these years, at around 200,000 ton/yr, even though it covered less than 8% of all irrigated areas in Al Jawf Province.

Figure 4. Centre-pivot irrigation systems in the Al Isawiya-Tabarjal-Al Busayta area (Saudi Arabia) in (a) 1986; (b) 1991; (c) 2000; and (d) 2004



Source: Compiled by ESCWA-BGR based on UNEP, 2008-2009.

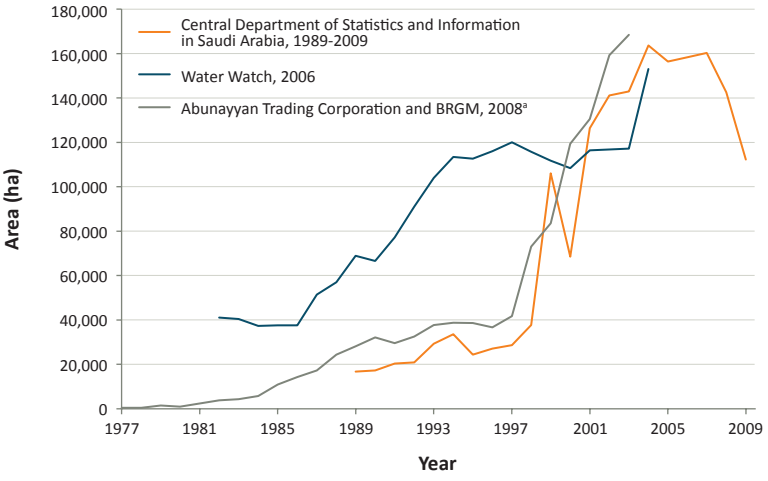
Overall, agricultural development in Al Jawf Province took place later than in other parts of Saudi Arabia.

Using the abstraction estimates above, cumulative total abstraction from the different aquifers in Al Jawf Province in Saudi Arabia between 1977 and 2011 ranges between 25.8[64] and 49.3 BCM.[65] These values include abstractions from areas outside the Wadi Sirhan Basin as defined in this Inventory.

Effect of abstraction on water tables

Calculations based on transmissivity values and gradient for an estimated inflow zone of about 400 km^2 revealed that the abstractions in 1982 were already far above the safe yield of 17.5 MCM/yr of the aquifer system and twice the

Figure 5. Irrigated area in Al Jawf Province in Saudi Arabia



Source: Compiled by ESCWA-BGR.
Note: See note in Figure 3.
(a) Data on abstraction in Al Jawf Province was digitized from the electronic version of the report (Figure 22, p.42), with resulting inaccuracies.

total volume of freshwater inflow (50 MCM/yr). Yet a drawdown of only one metre was observed in heavy abstraction areas. This slow rate of groundwater depletion was attributed to the fact that abstraction is taking place in the discharge area and groundwater is being refilled from recharge areas of the Neogene deposits in the plateau areas. This is confirmed by the pressure head, and it is therefore likely that the rate of depletion will accelerate significantly as the overdraft progresses and extends to the Paleogene Formations below.[66] Available data shows that this is not yet the case.

GROUNDWATER QUALITY ISSUES

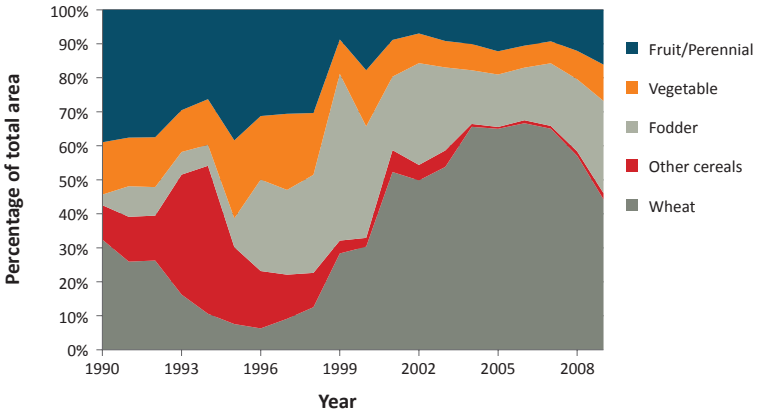
The Quaternary and Neogene deposits are rich in gypsum and gypsiferous soils are common in the southern and south-western parts of the basin.[67] Saline deposits rich in sodium (Na) also accumulate in sabkha areas along the central depression where the water table can be quite shallow. This has led to an increase in groundwater salinity and poses a risk of further groundwater quality deterioration. The rapid expansion of large-scale agriculture in the area endangers human health through the use of pesticides and the potential rise in nitrates in the groundwater from leaching of fertilizers. Also, the continuous reduction in upward flow of freshwater from the Tawil Formation, which normally dilutes the brackish water in the overlying aquifers, is expected to lead to a rise in groundwater salinity in the Tawil-Quaternary Aquifer System.

SUSTAINABILITY ISSUES

There are two important factors that make groundwater development in this basin critical: (1) the present-day recharge to the aquifer system is limited, and (2) the closed nature of the basin. This means that the ongoing heavy abstraction of water for agricultural production is depleting the aquifer system (quantity issues) and increasing the deposition of salts and other irrigation-related chemicals and toxic elements on the surface (quality issues). The rapid growth in well numbers between 1980 and 1982 led scientists to recommend a complete stop in well drilling. Such measures were, however, never implemented and no plan for the development of the aquifer systems within the above-mentioned limitations appears to exist.

The fact that only a few of the wells tapping the Tawil Aquifer show significant drawdown (≥40 m) and that remote areas south of Al Busayta are not yet affected by abstraction suggest that the volume of groundwater removed from storage is still small. Model calculations indicate that at the present extraction rate, about 20% of the reserves will have been abstracted by 2055.[68] These contradictory conclusions need to be resolved in order to understand the status of the aquifer system with respect to sustainability.

Figure 6. Main crops in Al Jawf Province in Saudi Arabia as a percentage of production yield



Source: Compiled by ESCWA-BGR based on Central Department of Statistics and Information in Saudi Arabia, 2011.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place for the Tawil Quaternary Aquifer System, which is shared between Jordan and Saudi Arabia.

COOPERATION

No information was available regarding cooperation between the riparian countries on the aquifer system.

OUTLOOK

The effect of heavy abstraction on the shallow aquifer over the past years should be assessed. There may be opportunities for more abstraction from the deeper aquifer in a sustainable and cooperative manner.

Agricultural fields in the Wadi Sirhan Basin, Saudi Arabia, 2012. Source: Expedition 30 Crew.

Notes

1. The six hydrogeological basins are (1) Wadi al Miyah; (2) Eastern Hammad; (3) Central Hammad; (4) Wadi Sirhan; (5a) Azraq; (5b) Sabkhat Munq'a or Rutba; and (6) Sabkhat al Moh (ACSAD, 1983a).
2. Ibid.; UN-ESCWA, 1990.
3. Khoury, 1982.
4. ACSAD, 1983a.
5. UN-ESCWA, 1990.
6. ACSAD, 1983a.
7. Ibid.
8. Ministry of Interior in Saudi Arabia, 2010.
9. Ibid.
10. Central Department of Statistics and Information in Saudi Arabia, 2011. Note that the terms "province", "region" or "emirat" are used interchangeably in official sources but all three refer to the same area geographically.
11. Abunayyan Trading Corporation and BRGM, 2008.
12. Ibid.
13. ACSAD, 1983a; UN-ESCWA, 1990; ACSAD, 1983b.
14. Abunayyan Trading Corporation and BRGM, 2008; Barthelemy et al., 2010.
15. ACSAD, 1983a; USGS and Central Energy Resources Team, 2004; BRGM and CNABRL, 1985.
16. UN-ESCWA, 1990.
17. Abunayyan Trading Corporation and BRGM, 2008.
18. Ibid.
19. BRGM and CNABRL,1985 and Abunayyan and BRGM, 2008 treat these two aquifers as one and refer to it as the Secondary-Tertiary-Quaternary Aquifer Complex (STQ).
20. Abunayyan Trading Corporation and BRGM, 2008. The thickness range corresponds to the maximum thickness encountered within the areas derived from the geological model. The formation thickness encountered at the outcrop is in most cases largely inferior to the maximum thickness found towards the centre of the sedimentary basin.
21. ACSAD, 1983a; Margane et al., 2002.
22. Margane et al., 2002.
23. BRGM and CNABRL, 1985.
24. BGR et al., 1999.
25. Abunayyan Trading Corporation and BRGM, 2008.
26. Ibid.
27. Ibid.
28. This is total precipitation in the central part of the basin, which covers about 9,500 km^2. This brings the total annual precipitation to 63 mm.
29. ACSAD, 1983a.
30. BGR et al., 1999.
31. UN-ESCWA et al., 1996.
32. BGR et al., 1999.
33. ACSAD, 1983a.
34. BGR et al., 1999.
35. ACSAD, 1983b.
36. Geyh et al., 1985.
37. ACSAD, 1983b.
38. BRGM and CNABRL, 1985.
39. Abunayyan Trading Corporation and BRGM, 2008.
40. ACSAD, 1983a.
41. UN-ESCWA, 1990.
42. ACSAD, 1983b.
43. Ibid.
44. UN-ESCWA and BGR, 1999.
45. Abunayyan Trading Corporation and BRGM, 2008.
46. Barthelemy et al., 2010.
47. Geyh et al., 1985.
48. BRGM and CNABRL, 1985.
49. Abunayyan Trading Corporation and BRGM, 2008; Barthelemy et al., 2010.
50. BRGM and Ministry of Water and Irrigation in Jordan, 2010.
51. ACSAD, 1983a; BRGM and Ministry of Water and Irrigation in Jordan, 2010.
52. Abderrahman, 2006.
53. The Saq Aquifer, although present, is too deep for economic production in the Wadi Sirhan-Al Jawf area.
54. Abunayyan Trading Corporation and BRGM, 2008.
55. Abunayyan Trading Corporation and BRGM, 2008, p. 46: public groundwater abstractions out of a total abstraction of 1,934 MCM for an unspecified year.
56. ACSAD, 1983b.
57. Approximate value in the census data around 30,000 ha; similar results of around 40,000 ha obtained in remote sensing study by Abunayyan Trading Corporation and BRGM, 2008.
58. Census and remote sensing data by Abunayyan Trading Corporation and BRGM, 2008 on total crop area or irrigated area respectively, generally correspond for the Al Jawf region, in contrast to values obtained by Water Watch, 2006 for the period before the late 1990s.
59. Water Watch, 2006 estimated that up to 28 BCM of groundwater was abstracted from the Tawil-Jawf Aquifers between 1983 and 2004. As 86%, or 937 wells out of a total of 1,086 abstracting wells in Al Jawf Province were tapping the Tawil Aquifer (Abunayyan Trading Corporation and BRGM, 2008), this ratio is used to adjust the Water Watch data.
60. Nadec, 2010.
61. Al Watania Agri, 2010.
62. JADCO, 2008.
63. Talib, 2010.
64. Based on annual abstraction data digitized from Abunayyan Trading Corporation and BRGM, 2008, p. 42, figure 24, resulting in a considerable degree of uncertainty for calculated cumulative abstraction; for the missing years 2004-2011 an abstraction of 1,500 MCM/yr was assumed.
65. Based on results by Water Watch, 2006; for the missing years 2005-2011 an abstraction of 2,500 MCM/yr was assumed.
66. ACSAD, 1983b.
67. Ibid.
68. Abunayyan Trading Corporation and BRGM, 2008.

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Chapter 18

Anti-Lebanon

Anti-Lebanon

EXECUTIVE SUMMARY

The Anti-Lebanon Mountain range is located at the Lebanese-Syrian border between the Bekaa Plain in the west and the Damascus Plain in the east. The mountain range stretches from the Homs Plain in the north to beyond its highest peak, Mount Hermon, in the south. The Anti-Lebanon receives significant precipitation, especially along its western flank, and is an important source of water, both locally and in the wider regional context, as it forms the source of a number of rivers in the Mashrek.

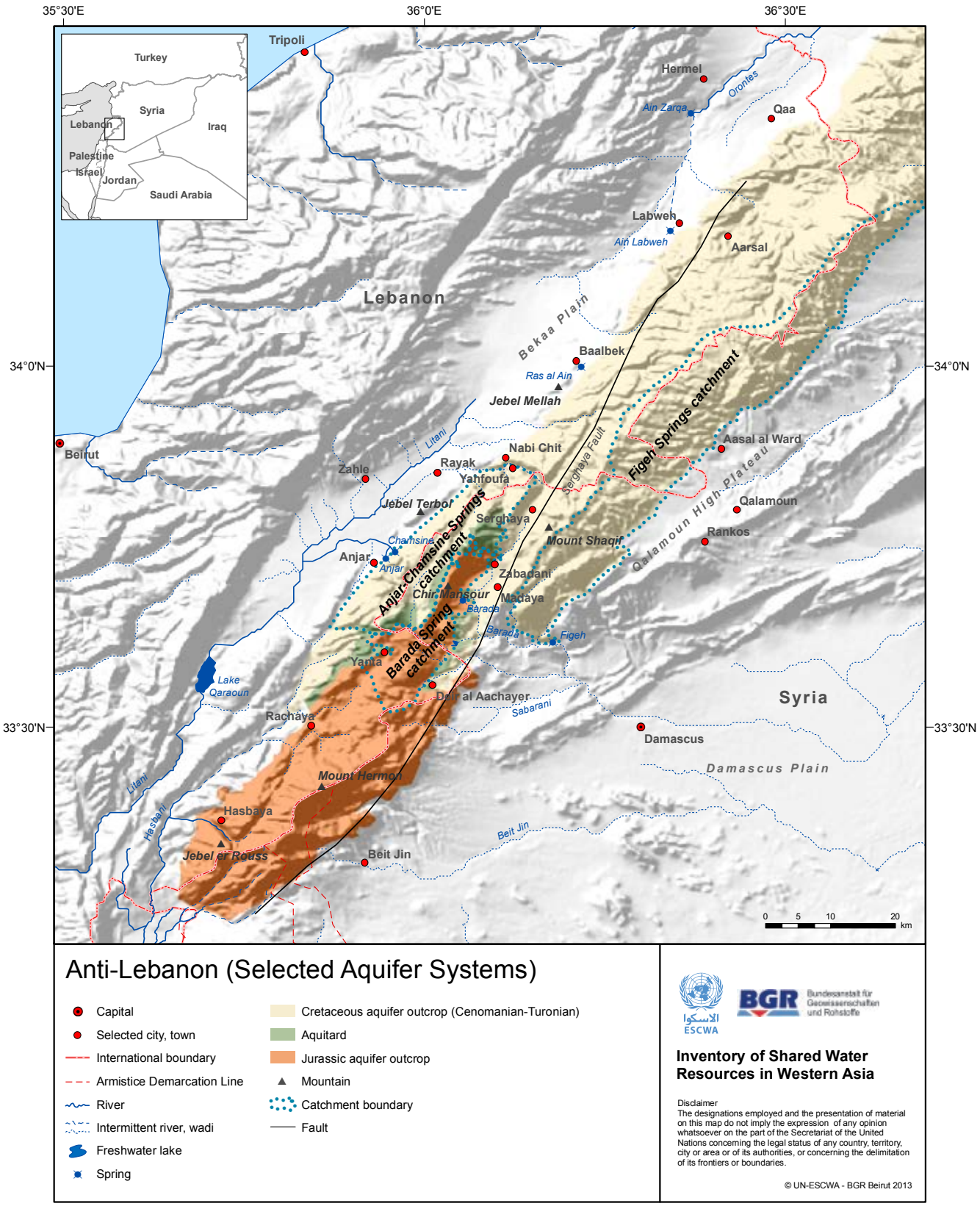
The hydrology and hydrogeology of this deeply faulted mountain range is highly complex and poorly understood to date, also in terms of the transboundary nature of surface and groundwater basins. Groundwater in the Anti-Lebanon is mainly stored in highly fractured and karstified Jurassic and Cretaceous (Cenomanian-Turonian) carbonate rocks, which often extend across political borders. Several large springs emanate from these aquifers and contribute to the Awaj, Barada, Litani, Orontes and (Upper) Jordan Rivers.

This chapter describes the Anti-Lebanon Mountain range in general terms, introduces the main aquifer systems and provides more detailed information on the catchments of the Anjar-Chamsine, Barada and Figeh Springs as examples of shared groundwater resources in the mountain range (see table opposite). Despite the potential benefits of joint investigations, management and protection schemes, there is limited cooperation between Lebanon and Syria on shared water resources in the Anti-Lebanon. The springs and catchments that originate in the southern part of the Anti-Lebanon and contribute to the headwaters of the Jordan River are covered in more detail in Chapter 6.

BASIN FACTS

RIPARIAN COUNTRIES	Lebanon, Syria
MAIN AQUIFERS	Cretaceous (Cenomanian-Turonian), Jurassic
ALTERNATIVE NAMES	-
SHARED BASINS	Anjar-Chamsine, Barada, Figeh
RENEWABILITY	Medium to high (20 - >100 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Strong
ROCK TYPE	Carbonate, karstic
AQUIFER TYPE	Anjar-Chamsine: unconfined-confined Barada: .. Figeh: unconfined, semi-confined, confined
EXTENT OF CATCHMENT	Anjar-Chamsine: 248 km^2 Barada: 149 km^2 Figeh: 658 km^2
AGE	Mesozoic (Upper Cretaceous, Jurassic)
LITHOLOGY	Limestone, dolomites, marls
THICKNESS	Anjar-Chamsine: 900 m (AVG) Barada: 2,000-2,200 m Figeh: 480-680 m
AVERAGE ANNUAL ABSTRACTION	-
STORAGE	-
WATER QUALITY	Anjar-Chamsine: .. Barada: <500 mg/L TDS Figeh: 200-600 mg/L TDS
WATER USE	Agricultural, domestic and industrial
AGREEMENTS	-
SUSTAINABILITY	Local abstractions and contamination in catchments may impact quantity and quality of discharge from springs

OVERVIEW MAP



Anti-Lebanon (Selected Aquifer Systems)

- Capital
- Selected city, town
- International boundary
- Armistice Demarcation Line
- River
- Intermittent river, wadi
- Freshwater lake
- Spring
- Cretaceous aquifer outcrop (Cenomanian-Turonian)
- Aquitard
- Jurassic aquifer outcrop
- Mountain
- Catchment boundary
- Fault

ESCWA

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

Disclaimer
The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

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Introduction

LOCATION

The Anti-Lebanon Mountain range is oriented in a north/north-east to south/south-west direction, parallel to the Lebanon Mountain range in the west. It stretches into the Israeli-occupied Syrian Golan Heights in the south (see Overview Map), with Mount Hermon (2,814 m asl) forming the highest peak in the Anti-Lebanon Mountain range.

The political border between Lebanon and Syria runs through the Anti-Lebanon Mountain range, but has never been clearly defined. This Inventory uses the border delineations applied by the United Nations Cartographic Section.[1] However, future revisions to the Lebanese-Syrian border may impact the identification and description of shared aquifer systems as presented in this Inventory.

AREA

The Anti-Lebanon Mountain range extends from the area south of Mount Hermon to the Homs Plain in the north over a length of 120 km. With a width of about 20 km, it is laterally bounded by the Bekaa Plain in the west and the Damascus Plain (680 m asl) and the Qalamoun High Plateau in the east. The central part of the mountain range comprises a western and an eastern section, which are separated by the Madaya-Serghaya Corridor.

The western section extends from the Mount Hermon foothills at Yanta to Baalbek, with a width of 10 km in the south and 3 km in the north. It is composed of three parallel orographical units:

- A line of hills reaching 1,300 m asl and lining the Bekaa Plain, including Jebel Fawar Terbol and Jebel Mellah.
- A mountain range with peaks at 1,400-1,700 m asl, including Jebel ash Sharqi east of Anjar and Jebel er Rouss.
- The main range, with Jebel Chir Mansour (1,885 m asl) and Dahr el Ghorbane (1,750 m asl), which slopes down towards Baalbek.

The units are separated by narrow corridors with the same orientation through which seasonal wadis flow. They slope westward, and are steep toward the Madaya-Zabadani Plain (1,100 m asl, 4 km wide) and the Sahl er Ramli-Serghaya Plain (1,400 m asl, 1 km wide).

The eastern section begins to the north of Jebel Mazar (1,634 m asl). A crest line extends from Jebel Habil (1,320 m asl), south of the Barada River to Jebel Khorm (1,700 m asl), Jebel Shaqif (2,420 m asl) and Jebel Ayoun al Berdi (2,462 m asl). The elevation remains around 2,200 m asl and drops to 1,150 m asl at Jebel Hessia. In the north, the Anti-Lebanon Mountain range progressively sinks underneath the Neogene age formations and Quaternary alluvium of the Homs Plain (600 m asl on average). The high mountain domain is a rough and bare limestone massif, gently sloping towards the northern Bekaa and the Hessia Plain with a 9%-10% slope.

The Anti-Lebanon Mountain range is regularly intersected by dry valleys, which are transformed into detrital fans encroaching on alluvial plain sediments. Wadi Yahfoufa near Nabi Chit is the only deeply entrenched valley on the western Anti-Lebanon flank. On the eastern side, the relief is more rugged, featuring the large intra-mountainous Zabadani and Serghaya Basins.

The Anti-Lebanon Mountain range is the primary source of water for several of the region's rivers. In the north/north-western part of the Anti-Lebanon, groundwater contributes to the Orontes River (see Chap. 7), which flows north from Lebanon through Syria and Turkey, and discharges into the Mediterranean Sea at Antakya. Groundwater in the western and south-western parts of the Anti-Lebanon Mountain range flows to the Litani River in Lebanon, which flows south through the Bekaa Valley and then veers west to discharge into the Mediterranean Sea. In the eastern and central part of the Anti-Lebanon Mountain range groundwater feeds the Barada River, which flows eastward into the endorheic Damascus Basin. Groundwater in the southern part of the Anti-Lebanon Mountain range discharges on the western slopes of Mount Hermon and contributes to springs that feed the Jordan River in Israel, Lebanon and Syria (see Chap. 6). The eastern slope of Mount Hermon feeds the springs of the Awaj River, which flows eastward into the Damascus Basin.

CLIMATE

The climate in the Anti-Lebanon Mountain range is continental and semi-arid, with cold, humid

winters and hot, dry summers. The mean annual air temperature west of the Anti-Lebanon Mountains at Rayak (930 m asl) in the central Bekaa Plain was 14°C for the period 1965-1972, while average precipitation for the period 1931-1960 was 600 mm in Rayak and 510 mm at Anjar.[2] Average annual precipitation on the ridge reaches 1,200 mm, in winter mainly in the form of snow, while the eastern flank is drier, with an average annual precipitation of 450 mm in Madaya and 200 mm in the Damascus Basin.

POPULATION

Exact population figures are not available for the Anti-Lebanon Mountain range. The main towns along the western flank of the mountain range in Lebanon are Aarsal and Baalbek in the north; Anjar, Chamsine, Majdal Anjar and Rayak in the central part; and Deir al Aachayer in the south. Most towns are small, with 5,000-10,000 inhabitants.[3]

The main towns in the Syrian part of the Anti-Lebanon Mountain range are Bloudan, Madaya, Serghaya and Zabadani and smaller villages in the Zabadani Plain, which has an estimated total population of 105,340 inhabitants.[4] Towards the east, the area in the immediate vicinity of the Figeh Spring is sparsely populated. Towns such as Rankos and Aasal al Ward have between 8,000 and 12,000 inhabitants.[5]

The ruins of Anjar, Lebanon, 2011. Source: Khalid Albaih.

Overview of Aquifer Systems

MAIN SPRINGS AND AQUIFER SYSTEMS

Four main aquifers provide groundwater in the Anti-Lebanon Mountain range:

- Jurassic limestone and dolomite formation
  The formation constitutes the core of the Anti-Lebanon Anticline with large outcrops, especially in the southern and central parts. Groundwater discharges to the east in Syria at Beit Jin into the Sabarani and Genani Rivers and the Barada Spring. The catchments of these springs and the aquifers are shared between Lebanon and Syria.

- Upper Cretaceous (Cenomanian-Turonian) limestone formations
  Groundwater from these formations discharges mainly at the Ain Zarqa, Anjar and Chamsine, Labweh and Ras al Ain Springs in Lebanon, and at the Bisan, Boukein and Figeh Springs in Syria. Since it is the largest outcropping aquifer formation, it is certainly the main aquifer in the Anti-Lebanon Mountain range, with the largest resources and storage capacity. The outcrops cover more than 3,000 km^2.[6] The aquifer is shared between Lebanon and Syria.

- Eocene limestone
  The formation forms a discontinuous line of hills on both flanks of the Anti-Lebanon Mountain range. Groundwater discharges from a number of local springs, such as the springs at Mount Terbol in Lebanon (Ain al Bayda, Ain al Khadra and Ain al Saheb) and the Mneen Springs in Syria. The respective aquifers are mostly of local nature and not necessarily connected to each other. There is also no evidence that these aquifers extend across the Lebanese-Syrian border. As such, the Eocene limestone is not considered a shared aquifer.

- Quaternary alluvial aquifers
  The alluvial aquifer in the Bekaa Plain in Lebanon is multilayered and – in its shallow part – connected to the Orontes River in the north and to the Litani River and its tributaries in the south. The Bekaa Valley sediments are not considered part of the formation in the Anti-Lebanon Mountain range. Local alluvial aquifers are also present in some valley fills. As these alluvial fills are of a local nature and do not reach substantially across the Lebanese-Syrian border, they are not considered in this Inventory.

The main Jurassic and Upper Cretaceous aquifers are generally separated by thick aquiclude formations. However, the faulting and erosion that have occurred since the formation of the Bekaa Plain and the uplift of the ridges may have created some interconnection between the aquifers at depth.

Geographically, the importance of the respective transboundary aquifers varies.

In the northern part of the Anti-Lebanon, the main springs are Ain Zarqa and Ain Labweh located in Lebanon which feed the Orontes River (see Chap. 7). In the central part of the Anti-Lebanon, the main spring in Lebanon is Ain Anjar, while in Syria the Barada and Figeh Springs contribute to the Barada River.

Further south, in the area of Mount Hermon the aquifer is mainly of Jurassic age and feeds springs on both flanks of the Anti-Lebanon Mountain range. This includes the Barada Spring, the springs issuing from the slopes of Mount Hermon in Syria, the Hasbani and Wazzani Springs in Lebanon, the Banias Spring in the Israeli-occupied Syrian Golan Heights and the Dan Spring[7] in Israel. The springs in the south-western part of the Anti-Lebanon Mountain range contribute to the Upper Jordan River (see Chap. 6).

This chapter focuses on the catchments of the three main springs in the central part of the Anti-Lebanon Mountain range: the Anjar-Chamsine, Barada and Figeh Springs. They discharge into the Barada and Litani Rivers.

STRATIGRAPHY

Table 1 shows the general hydrostratigraphy of the Anti-Lebanon Mountain range in Lebanon and Syria.

The regional basement is formed by Jurassic age formations. These crop out on the flanks of Mount Hermon in Lebanon and Syria and on the western and southern hills in the Zabadani Plain. The formations are made up of a 1,500 m thick series of limestones and dolomites,

overlain by 200 m thick interbedded marls and limestones.

The Lower Cretaceous is characterized primarily by terrigenous, silty sediments, including a thin limestone layer. At the lower end it starts with a 50-250 m thick formation (C1) made of coastal sandstone. Many small springs discharge from this aquifer at an average rate of $3.2x10^{-2}$-$4.7x10^{-2}$ MCM/yr, with a nearly constant year-round flow. They form an important local source of irrigation water. This pre-upper Aptian Formation is followed by 150-250 m thick Aptian ferruginous sandstone and pelitomorphic limestone (C2). The following Albian 150 m thick yellow limestone (C3) is difficult to separate from the Cenomanian-Turonian age formations (C4-C5).

The Cenomanian-Turonian age formations comprise the main aquifers of the Anti-Lebanon Mountain range. The 900 m-thick limestone covers about 2,200 km^2 in Lebanon and 2,500 km^2 in Syria. It is made of metric beds that include thin interbedded marl with ammonites at the C4-C5 transition. The top of Cenomanian and Turonian-age formations are frequently dolomitized.[8]

It follows the Upper Cretaceous with a 500 m thick series of Senonian white marls (C6), characterizing the series of depressions between the Anti-Lebanon flank and the foothills lining the Bekaa Plain.

The Middle and Upper Eocene is made of 200 m thick reefal limestone, which ends with the general uplift and emersion.

The source of the Barada Spring in the Anti-Lebanon Mountains in Syria, 2009. Source: Adel Samara.

Table 1. Lithostratigraphy of Lebanon and Syria

ERA	PERIOD		EPOCH	STAGE	INDEX	HYDROGEOLOGICAL UNIT	LITHOLOGY
Cenozoic	Quaternary		Holocene	-	Q	Aquiclude to aquitard.	Volcanic, alluvial, lacustrine and proluvial deposits.
			Pleistocene	Upper		Semi-aquifer, local water-bearing formations can be found in the alluvial and proluvial deposits.	Unconsolidated lacustrine, alluvial, volcanogenic, proluvial and effusive deposits.
				Middle			
				Lower			
	Tertiary	Neogene	Pliocene	Upper	P	Aquitard/aquifer Neogene System.	Limestone, reefal limestone, lacustrine and alluvial deposits.
				Lower			
			Miocene	Middle	M		
				Lower			
		Paleogene	Oligocene	-	Missing	-	-
			Eocene	Upper	E	Aquitard of Eocene series, locally water bearing.	White and cream marbly limestone. At the bottom, limestones with intercalations of marl and clay.
				Middle			White and light grey chalk-like limestone.
				Lower			-
			Paleocene	-	Missing	-	-
Mesozoic	Cretaceous		Upper	Senonian/ Conacian/ Santonian/ Campanian/ Maastrichtian/ Danian	C6	Aquiclude	Marls
							Chalky, argillaceous limestone.
							Chalky limestone.
				Turonian	C5	Cenomanian-Turonian aquifer.	Massive karstified limestone with occasional intercalation of dolomitic limestones.
				Upper Cenomanian	C4b		Alternation of organogenous, pelitomorphic, argillaceous and dolomitic limestone and compact marls.
				Lower Cenomanian	C4a		Alternation of organogenous, pelitomorphic, argillaceous and dolomitic limestone and compact marls.
			Lower	Albian	C3	Aquitard/aquifer of the Albian series.	Massive pelitomorphic limestone alternating with argillaceous limestones.
				Upper Aptian	C2	Aquitard/aquifer of the Aptian series.	Ferruginous quartz sandstones.
							Pelitomorphic limestone (Muraille Blanche).
				Pre-Upper Aptian	C1		Brown hematite, clayey, and clay-sandy with limonite and marcasite concretion.
							Ferruginous clays with intercalations of argillaceous sandstone.
				Aptian basalt	Bc	Aquiclude	Basalt
	Jurassic		Upper	Titonian	J	Jurassic Aquifer.	Karstified limestone, dolomite.
				Kimmeridgian			..
				Oxfordian			
			Middle	Callovian			
				Bathonian			

Source: Compiled by ESCWA-BGR based on Khawlie and Shaban, 2003; Selkhozpromexport, 1986.

The Anjar-Chamsine Springs

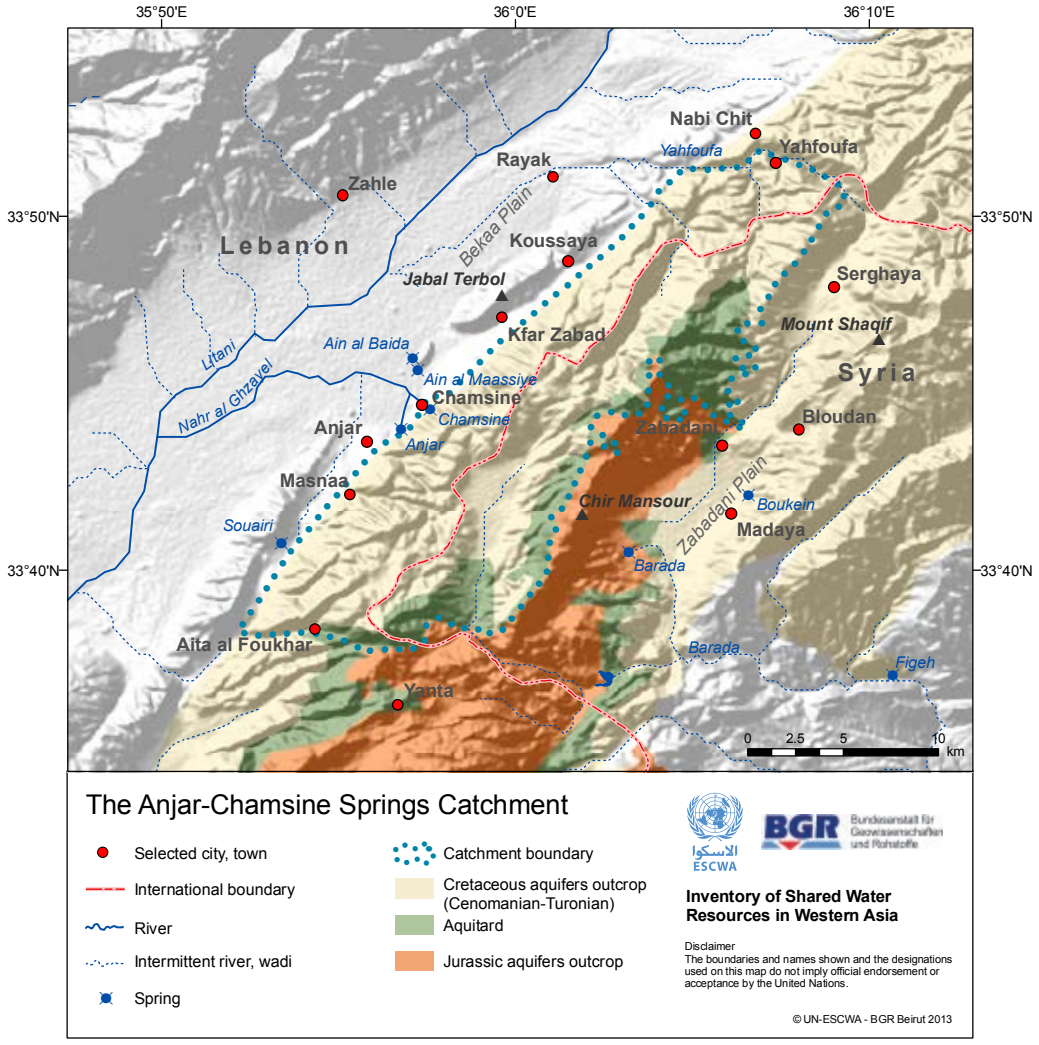
INTRODUCTION

The Anjar-Chamsine Springs[9] are located at the foot of the Anti-Lebanon Mountains in the east of the Bekaa Plain in Lebanon, north of the village of Anjar. The spring outlets are located at an altitude of 870 m asl, discharging from the Cretaceous (Cenomanian-Turonian) Aquifer in the Anti-Lebanon Mountain range. The springs at Anjar-Chamsine include the Anjar Spring, the Chamsine Spring and the smaller Souairi Spring to the south (Figure 1). The Anjar-Chamsine Springs contribute to the Litani River, which flows south through the Bekaa Valley and then veers west to discharge into the Mediterranean Sea. Water from the Anjar-Chamsine Springs is used locally for irrigation and in fish farms, while water from the Litani River is used for irrigation purposes and hydropower at Lake Qaraoun.[10]

Area

The lateral boundaries of the overall catchment area of the Anjar-Chamsine Springs are assumed to be mainly the outcrop area of the Cenomanian-Turonian age formations (C4-C5), and possibly some of the aquitard/aquiclude outcrop areas in the east.[11]

Figure 1. Overview Map of the Anjar-Chamsine Springs catchment area



Source: Compiled by ESCWA-BGR based on Dubertret et al., 1955; Khawlie and Shaban, 2003.

The catchment is further limited by the Yahfoufa River valley in the north and Aita al Foukhar Valley at Masnaa in the south (Figure 1). Within the boundaries, the extent of the Anjar-Chamsine Springs catchment is approximately 248 km^2, of which 49% is located in Lebanon and 51% in Syria.[12]

HYDROGEOLOGY

Aquifer configuration

The northern and eastern limits of the Anjar-Chamsine Springs catchment area include impermeable layers. The layers allow for concentrated recharge, which is likely to be at the origin of conduit development, particularly in the Yahfoufa River valley along the northern limit of the catchment. The western limit is only related to recharge and point discharge locally at the Anjar and Chamsine Springs. However, the aquifer develops at depth below the Upper Cretaceous, Tertiary and Quaternary sediments where it may discharge towards or be recharged from other systems.

The lateral boundaries of the catchment can be described as follows:

- The western limit is formed by the contact between the Cenomanian-Turonian (C4-C5) limestone and the impermeable Senonian (C6) marls. The aquifer develops at depth in the west below a confining sediment cover from Senonian marls to Miocene and Quaternary continental sediments.
- In the north, the water of the Yahfoufa River is partly swallowed, recharging the aquifer when crossing the karstified C4-C5 limestone.
- In the north-east, the limit is imposed by the anticline axis, which is close to the surface watershed.
- The eastern limit of the spring catchment reaches at least to the eastern extent of the C4-C5 outcrop. The surface runoff on the underlying aquitard to the east frequently flows westwards, towards the C4-C5 outcrop. The eastern limit of the catchment thus extends beyond the eastern limit of the C4-C5 outcrop to include the westward draining surface catchment of the underlying impermeable Lower Cretaceous formations. Surface runoff infiltrates, recharging the C4-C5 aquifers in concentrated or diffuse form over their outcrop area.
- The south-eastern limit is formed by what is probably an impermeable fault between the C4-C5 limestone and the Jurassic formations.
- In the south, the limit follows the Aita al Foukhar Valley.

Aquifer thickness

The Cenomanian-Turonian limestone (C4-C5) has an average thickness of 900 m. The upper section (Turonian, C5) is made up of up to 200 m of white stylolithic reef limestone with typical reef fossils.

Aquifer type

The aquifer is unconfined in the eastern part and confined in the west where it slopes at depth below a sediment cover, from Senonian marls (C6) to Miocene and Quaternary continental sediment. As a strongly karstified aquifer system, it comprises two different flow components: a conduit-controlled and a matrix-controlled flow system.

Aquifer parameters

Little is known about the hydraulic characteristics of the aquifer around the Anjar-Chamsine Springs. Two sets of pumping tests resulted in different transmissivity values and storage coefficients.[13] Pumping tests conducted in the 1970s at the Anjar Spring found a transmissivity value of 1.1×10^{-2} m^2/s at the source and 1.5×10^{-2} m^2/s at a test well. The storage coefficient was estimated at 0.032. A more recent study from 2005 included the results of pumping tests in bore-hole adjacent to the spring and demonstrated that there is no correlation between transmissivity and distance to the spring. The aquifer transmissivities in six bore-holes were estimated between 1.5×10^{-2} and 6.9×10^{-1} m^2/s with an average transmissivity of 3.3×10^{-1} m^2/s and an average storage coefficient of 0.032.[14]

Recharge

The mean annual precipitation in the catchment area of the Anjar-Chamsine Springs was estimated at 750 mm, which is equivalent to 165 MCM over an assumed catchment area of 220 km^2.[15] The actual evapotranspiration rate was estimated at 518 mm, which is equivalent to a total annual evapotranspiration of 114 MCM.[16] Thus the annual recharge was estimated at 232 mm or 51 MCM for the whole catchment area. It is also assumed that point recharge takes place from swallow holes along the Yahfoufa River, at a rate of up to 150 L/s or 4.75 MCM/yr. Water budget calculations indicated that further recharge may take place from the Jurassic age aquifers or from the C4-C5 aquifers at the bottom of the Bekaa Plain.

Flow regime

The principal flow direction in the Anjar-Chamsine Springs catchment is from east to west. As recharge occurs over the whole outcrop area and point recharge occurs in the Yahfoufa River valley, flow is also directed from the northern and southern boundaries towards the spring outlets. Little is known about water levels, heads and gradients.

Storage

The system has considerable storage: dynamic storage is estimated at around 100 MCM, varying from one year to another between 70 and 165 MCM, depending on the annual precipitation, making total storage even higher.[17] The residence time in the phreatic zone is estimated at around two years, which is relatively long for a karstic aquifer.[18]

Discharge

The total annual discharge of the Anjar-Chamsine Springs is estimated at 89.42 MCM, which is calculated as the sum of the total mean annual discharge of the Anjar Spring (74.16 MCM), the Chamsine Spring (13.68 MCM) and the Souairi Spring (1.58 MCM).

GROUNDWATER USE AND SUSTAINABILITY ISSUES

The Anjar-Chamsine Springs have been in use for centuries and were probably already developed in the 8th century CE, with large stone blocks raising the spring outlet and distributing water throughout the valley via channels.

Until the late 1990s, the C4-C5 aquifers were mainly exploited by pumping water from the springs. Around 2.52 MCM/yr is abstracted from the Chamsine Spring, while seasonal withdrawal for irrigation purposes from the Anjar Spring may be up to 18.9 MCM/yr. Additional water is used locally in a fish farm, which discharges its water back to the river.

More recently, several wells with depths up to 200 m were drilled in the plain near the limestone outcrops. Abstraction has been estimated at a few tens of litres per second, with seasonal withdrawal from the most productive wells. The situation is likely to impact spring discharge during the low-flow period and threatens the public water supply.[19]

Groundwater quality issues

There is limited information on water quality. However, the Bekaa Water Establishment regularly monitors bacteria levels and major dissolved solids at the Chamsine Spring, which is used for domestic purposes. Unconfirmed reports suggest that the spring water is polluted with faecal bacteria, which would explain why it is chlorinated before use.

All springs display seasonal variations in their chemical content, which is typical of karstic springs. However, the range of variation is low. Chloride (Cl^-) (approx. 9 mg/L) and nitrate (NO_3^-) (approx. 12 mg/L) content is low compared to potable water standards, but significantly higher than in non-contaminated groundwater in the same region (Cl^-: 2 mg/L; NO_3^-: about 3 mg/L).

Contamination probably originates from the villages located on the Cenomanian (C4) limestone and Senonian (C6) marls (Chamsine, Deir al Ghazal, Kfar Zabad, Koussaya and Yahfoufa), none of which are equipped with individual septic tanks or wastewater treatment plants. All the villages are located in the area where the main karst conduit develops from the Yahfoufa River swallow holes to the Anjar Spring, where the aquifer is particularly vulnerable to pollution.

Sustainability issues

The water level in wells used for domestic purposes and irrigation water supply has reportedly decreased over the past decade, forcing farmers in the area to abandon or deepen their wells. That suggests over-exploitation of the aquifer system. As spring discharge is not accurately measured, it is not clear whether pumping from private irrigation wells already affects flow. Moreover, actual spring discharge cannot be measured as several users withdraw water directly from the spring pool or from wells around the spring pool during low-flow periods. The absence of initiatives to improve environmental management – specifically groundwater protection – means that groundwater in the catchment remains at risk from domestic and agricultural pollution.

The Barada Spring

INTRODUCTION

The Barada Spring[20] is located around 30 km north-west of the Syrian capital Damascus. The spring outlet is located in the Zabadani Basin at an altitude of 1,095 m asl. The Barada Spring is the largest spring discharging from the Jurassic Aquifer in the Anti-Lebanon Mountain range. In spring time, the Barada Spring outlets fill Lake Barada and form the source of the Barada River, which flows through Damascus. Barada spring water is used for domestic water supply in Damascus and for irrigation purposes.

Area

Figure 2 shows the estimated boundaries of the Barada Spring catchment area. Further studies are required to delineate the boundaries more precisely, especially in the area of the Lebanese-Syrian border and towards Mount Hermon. The preliminary delineation covers an area of approximately 149 km^2 of which 54% is located in Lebanon and 46% in Syria.

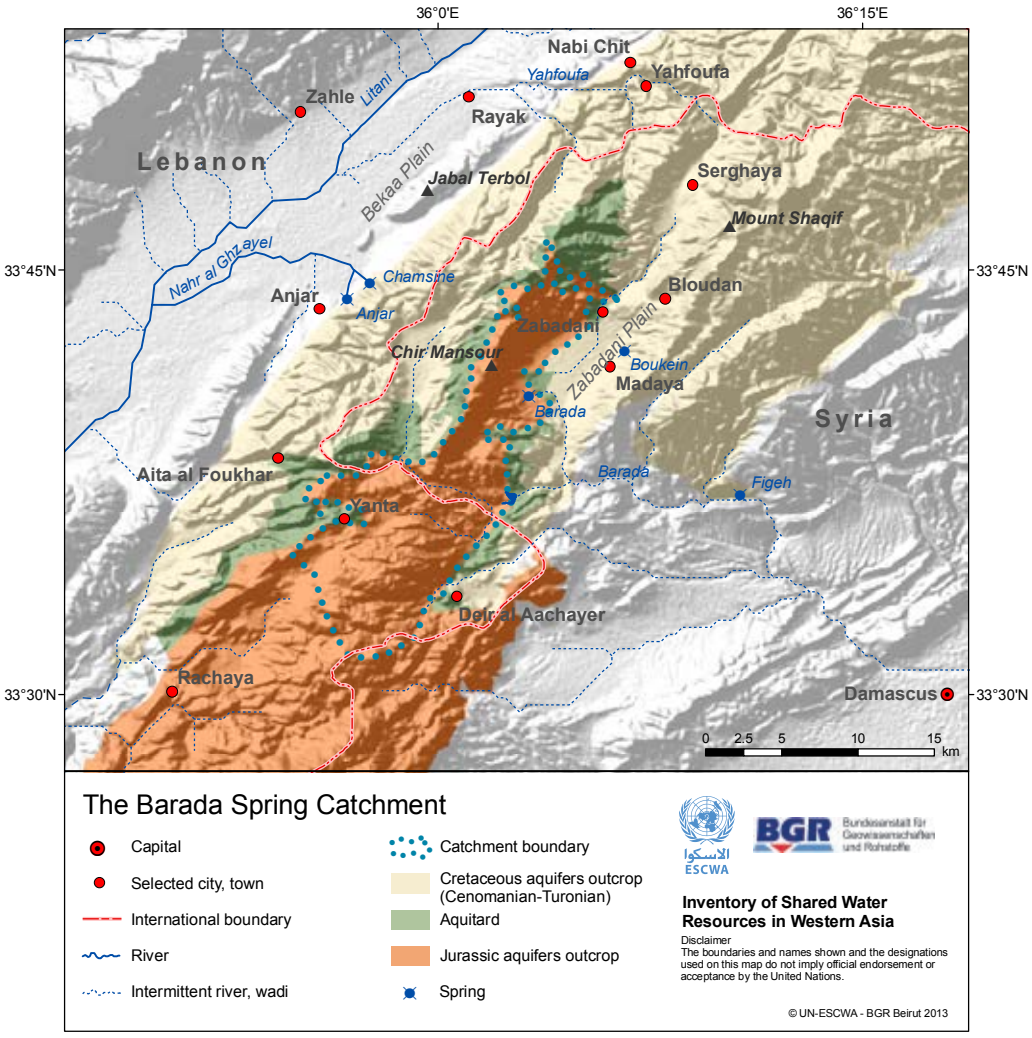
HYDROGEOLOGY

Aquifer configuration

Three major aquifers exist in the catchment area of the Barada Spring:

- The karstified limestones of the Jurassic Aquifer.
- The Lower Cretaceous ferruginous sandstone and the Upper Cretaceous karstified limestone and dolomite.

Figure 2. Overview Map of the Barada Spring catchment area



Source: Compiled by ESCWA-BGR based on Dubertret et al., 1955; Khawlie and Shaban, 2003.

- The unconsolidated Neogene and Quaternary aquifer in the Zabadani Plain.

Besides those major aquifers, local perched aquifers contribute to various spring outlets. The perched aquifers consist of clay-rich sediments, large alluvial fan deposits found perpendicular to the steep hills around the Zabadani Plain, and local basalts deposited along the western slope of Jebel Shaqif.[21]

The Barada Spring discharges mainly from the Jurassic aquifer, the most productive aquifer in the area. The permeability of the Jurassic aquifer is higher than the Cretaceous and two orders of magnitude higher than the Neogene and Quaternary aquifers. However, all aquifer units in the catchment of the Barada Spring are hydraulically interconnected and contribute to spring discharge.

Aquifer thickness

The units of this aquifer system crop out only in the western and southern areas of the catchment, within the limits of the Chir Mansour Mountains, Mount Hermon and Jebel Shaqif. The aquifer system dips under the Aptian strata on the flanks of the mountains. Total thickness reaches 2,000-2,200 m.

Aquifer type

The aquifer system is made up of intensively karstified limestone interbedded with dolomite, dolomitized limestone, marls and spilite.[22] In the outcrops, the carbonate rocks are intensively karstified and all varieties of karstic land forms can be encountered in the field. The zone of karstification can be several hundred metres thick. Karstic features were recorded at a depth of 270 m, while at greater depth (966 m) leakages were recorded, indicating the presence of other karstic caverns.[23] The existence of deep karstification suggests the presence of a thick zone of free water exchange in the Lower and Upper Jurassic formations. No information was available regarding confinement conditions in the aquifer system.

Aquifer parameters

Pumping test data in the Barada Spring catchment does not provide sufficient spatial coverage. Depending on the degree of fracturing, the pumping test data shows high variability.[24] Table 2 shows different transmissivity classes for the Barada Spring catchment.

Table 2. Transmissivity classes in the Barada catchment area

SOURCE	TRANSMISSIVITY (m^2/d)		GEOLOGY
	RANGE	AVERAGE	
GCBAB[a] and private drilling data.	<50	10	Neogene Conglomerates (south-eastern margin)
Selkhozpromexport, 1986.	2-150	40	Neogene and Quaternary Graben fill
Selkhozpromexport, 1986.	70-340	150	Aptian Sandstones (western block)
GCBAB estimation.	25-300	275	Cretaceous, eastern block Zabadani Basin
Selkhozpromexport, 1986.	250-300	275	Cretaceous, western block Zabadani Basin
Selkhozpromexport, 1986.	>1,000	1,500	Jurassic limestone

Source: Compiled by ESCWA-BGR based on Droubi et al., 2008a.
(a) General Commission for Barada and Awaj Basin in Syria.

Recharge

The recharge area of the Barada Spring can be subdivided into three different tectonic blocks: the Chir Mansour Mountain range (Chir Mansour Horst-Anticline), the Zabadani Plain (Zabadani Graben), and Jebel Shaqif (Shaqif Monocline).[25] The catchment area of the Barada Spring was determined on the basis of a regional hydraulic model. Recharge originates mostly from direct infiltration of meteoric water. The mean recharge altitude of the Barada Spring is 1,250 m asl[26] and recharge rates may be as high as 56%-70% from precipitation.[27]

Flow regime

The following flow boundaries are assumed:[28]

- The Chir Mansour Mountain range forms the western border of the aquifer system. The intensive fracturing and jointing of the Jurassic limestone indicate that there is no dip-dominant flow direction.
- The Shaqif Mountain range marks the eastern border of the aquifer system. Both borders can be assumed to be no-flow boundaries for the Barada Spring catchment area.
- The south-eastern border is a no-flow boundary.
- Mount Hermon marks the south-western boundary of the aquifer, which extends southward across the border into Lebanon.

Storage

Total and dynamic storage are unknown, but the relatively high tritium values in the Barada Spring indicate newer groundwater and most probably a smaller reservoir size than in the nearby Figeh Spring (see below).[29]

Discharge

The Barada Spring has an average yield of 3.12 m^3/s (98 MCM/yr). Minimum annual average discharge was $3.2x10^{-1}$ m^3/s (10 MCM/yr) in 2000/2001 and maximum annual average discharge was 4.12 m^3/s (130 MCM/yr) in 1991/1992.[30] Since 2000, the spring falls dry in spring and summer due to intensive pumping in the catchment and in the immediate vicinity of the spring. Due to the lower average recharge height – especially compared to the Figeh Spring – there is no snow-water buffer retention. Two major flow systems prevail in the system: a fast-conduit and slow-matrix flow system. Discharge peaks can be observed shortly after major rainfall events, but the discharge signal of the spring is more damped than the Figeh discharge signal, which may be attributed to a higher degree of karstification (Figure 4).

Water quality

Most of the groundwater in the Zabadani Valley is characterized by a Ca-Mg-HCO_3 water type; the anion sequence is as follows: $HCO_3 \rightarrow Cl \rightarrow SO_4$, while Ca+Mg concentration exceeds Na+K concentration.[31] This water type reflects the predominance of calcareous and dolomitic aquifers in the Zabadani Valley.

The three springs in the Zabadani Valley (Barada, Boukein and Nabaa Arak) discharge low mineralized groundwater of Ca-Mg-HCO_3 type. In September 2008, the mineral content was measured as 240 mg/L for calcium (Ca^{2+}), 270 mg/L for magnesium (Mg^{2+}) and 320 mg/L for bicarbonate (HCO_3^-). Similar values were recorded in 1989/1990.

The saturation indices for calcite and dolomite indicate that most of the groundwater samples taken in the Zabadani Valley are slightly over-saturated (SI>0) with respect to calcite and slightly under-saturated (SI<0) with respect to dolomite. The predominance of calcium over magnesium is also reflected by low Mg/Ca ratios (0.08 to 0.47). It might also be an indication of rapid groundwater recharge and short groundwater residence time. Groundwater in equilibrium with a limestone aquifer would have Mg/Ca ratios in the range 0.5 to 0.7.

GROUNDWATER USE AND SUSTAINABILITY ISSUES

Groundwater use

No precise data regarding abstraction and use was available for the Barada Spring. However, population growth in the Damascus Plain has led to a sharp rise in demand from the agricultural and domestic sector over the last 60 years.

Historically, the Barada River formed the main source of water for Damascus, with water from the Barada and Figeh Springs (see below) supplying farmers and domestic users in the Barada Valley and the Damascus Plain (Damascus City and surrounding villages). The main agricultural area is the Damascus Ghuta, a 25,000 ha agricultural plain that once fully surrounded the Syrian capital.[32]

However, rapid population growth over the last 60 years has led to a sharp rise in demand, resulting in intersectoral competition over the limited resources, particularly during the irrigation season from late spring to autumn. Local farmers have dug dozens of licensed and unlicensed wells in the Barada Spring catchment area in recent years. The wells are used for irrigation and domestic purposes in the Zabadani Valley.[33] In addition, a well field made up of 22 wells in the Barada Spring catchment area pumps water to the Figeh Spring and on to Damascus. The well field was commissioned in 1995 and became fully operational a year later with a pumping rate of 1 m^3/s (15.76 MCM/yr).[34] An additional well field at Jabous in a different area of the Barada catchment supplements drinking water supply.[35]

Sustainability issues

Over-abstraction from the Barada Spring catchment area and the Barada River has led to a gradual decrease in spring discharge, with the Barada Spring today only flowing for a period of seven to eight weeks a year. Climate change and the predicted decrease in rain- and snowfall is likely to further impact spring flow and pose a growing threat to the sustainability of the Barada Spring.

The Figeh Springs

INTRODUCTION

The Figeh Springs[36] are located around 15 km north-west of the Syrian capital Damascus. The springs have four main outlets: Figeh Main, New Figeh Side, Old Figeh Side and Haroush Springs. The springs have been utilized since Roman times or before, with canals from the spring supplying several towns and villages in the area. Figeh spring water provides up to two thirds of the water supply for the Damascus.

Area

No detailed information was available on the limits of the hydrogeological catchment. The boundaries of the Figeh Springs as shown in Figure 3 represent the boundaries of the protection zone. The protected area covers approximately 658 km^2, of which 16% is located in Lebanon and 84% in Syria. The actual hydrogeological catchment is probably smaller.

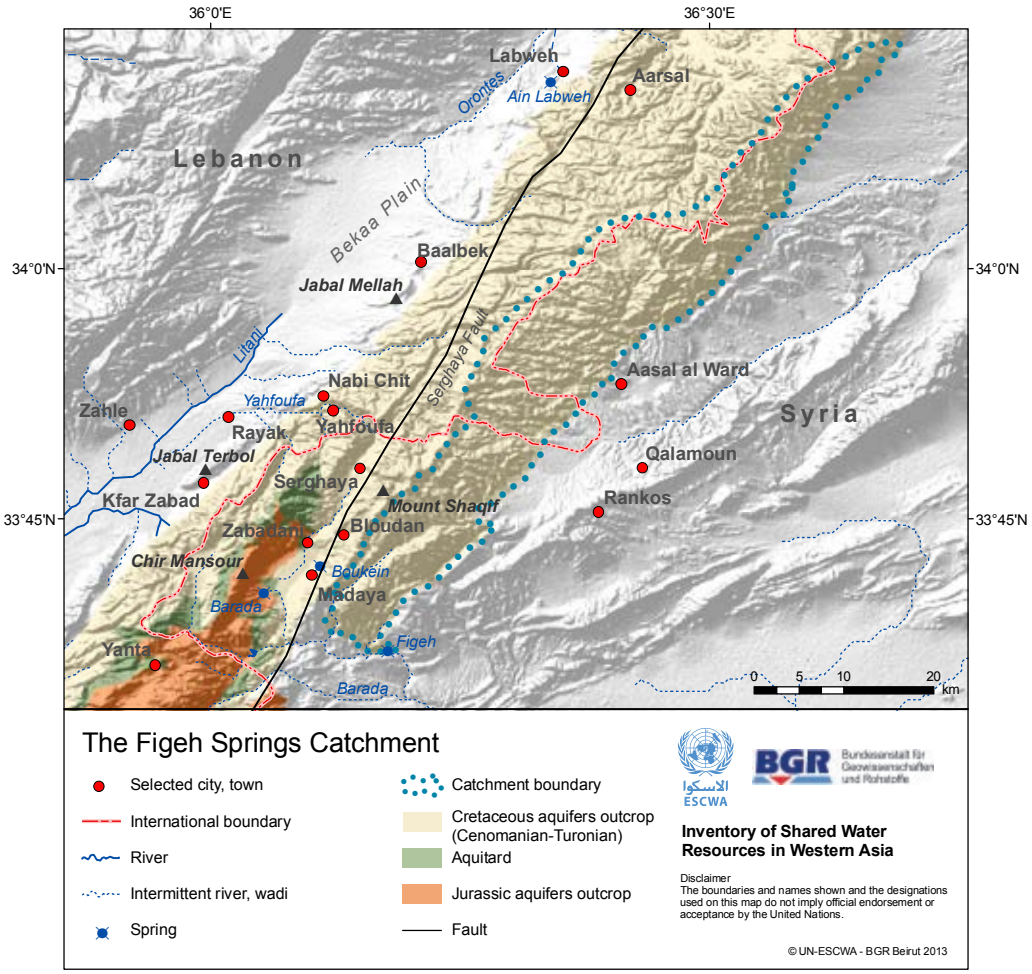
HYDROGEOLOGY

Aquifer configuration

The exposed rocks in the Figeh Springs catchment area belong to the Cretaceous Period. The aquifer system of the Figeh Springs comprises limestones and dolomites of the Upper Cretaceous, from the Cenomanian and Turonian stages.[37]

The recharge area of the Figeh Springs includes a north-east-trending part of the Anti-Lebanon

Figure 3. Overview Map of the Figeh Springs protection zone



Source: Compiled by ESCWA-BGR based on Dubertret et al., 1955; Khawlie and Shaban, 2003.

Mountain range. The eastern and south-eastern boundaries are marked by a Tertiary Basin.[38] The dominant structure of the Figeh Springs catchment area is a south-east dipping monocline, which originates near the Serghaya Fault in the west. The eastern boundary of the Figeh catchment is marked by the Jarajeer lineament, which separates the Cretaceous-age rocks from the Tertiary.[39]

Aquifer thickness

The most complete section of the Cretaceous sequence is exposed near Bloudan and has a thickness of around 1,800 m.[40] The thickness of the Cenomanian and Turonian aquifers varies from around 680 m in the south[41] to 480 m in the north.[42]

Aquifer type

For most of the catchment, the aquifer is assumed to be unconfined, becoming confined or semi-confined towards the outlet of the different springs. The confining beds consist of the uppermost Cretaceous to Eocene chalks and chalky limestones. Several small local perched aquifers exist within the catchment area of the Figeh Springs, none of which discharges significant amounts of spring water.

Aquifer parameters

Due to its karstic nature, two flow components prevail within the aquifer: a fast-conduit-controlled and a slow-matrix-controlled flow component. This discharge behaviour is reflected in the discharge curves of the spring (Figure 4).

Recharge

The recharge area lies in the north-east-trending part of the Anti-Lebanon Mountain range. Stable isotope analyses estimated a mean recharge altitude of around 2,100 m asl.[43] The total extent of the catchment was previously estimated to cover a limestone outcrop area of 665 km^2.[44]

Present-day recharge consists solely of infiltration from precipitation. More than 70% of the precipitation falls as snow, thus forming an important intermediate storage buffer of water in the mountains. Climate change may considerably affect the high snow quota and result in the loss or severe reduction of the temporary snow-water buffer.[45]

The mostly drought-resistant vegetation with very sparse ground cover results in low soil moisture retention capacity in the recharge area. An infiltration rate of around 60% of the annual precipitation volume was recorded at two low-altitude locations (1,500 m asl) in and near the Figeh catchment.[46] Since more than 90% of the Figeh catchment is located at more than 1,500 m asl, the infiltration rate is probably higher.[47]

Flow regime

Limited information is available on water levels and flow directions in the Figeh catchment. During a study undertaken in the 1970s, several deep observation wells were drilled within a radius of a few hundred metres around the Figeh Main Spring.[48] Today the wells are blocked or refilled. As there are no other observation wells in the catchment area, groundwater levels, divides and flow patterns can only be estimated.

Hydraulic (flow/no-flow) boundaries can be outlined as follows:

- To the north-west and west, the Serghaya Fault acts as a no-flow boundary. In the area between Madaya and Serghaya, the fault has a vertical displacement of more than 1,000 m.
- The Barada River marks the southern boundary of the spring catchment. In the south-western part of the boundary, stable isotope investigation showed that no or very limited groundwater arrives from the high-altitude Figeh catchment area. It remains unclear whether groundwater in the catchment area flows beyond the surroundings of the spring outlet in the south-east.

The Anti-Lebanon Mountain range near Bloudan, Syria, 2009. Source: Cristen Rene.

- Towards the east and south-east, the Jarajeer lineament forms the eastern boundary between the Cretaceous Anti-Lebanon Mountain range and the Tertiary-Quaternary Qalamoun Basin. The boundary is not a no-flow boundary, since stable isotope samples from wells drilled to the east of it indicate high-altitude recharge. Therefore the groundwater recharge area is related to the high mountains in the Figeh catchment area and indicates a certain leakage through the boundary.

The Cenomanian-Turonian strata are intensively fractured. Groundwater infiltration and flow in the central part of the recharge area are controlled by the south/south-eastern stratigraphic dip. The flow path is also controlled by the south/south-east-trending normal faults and the north-south-trending fault system, which carry water towards the Figeh Spring outlets.

Storage

The maximum storage capacity of the Figeh Springs reservoir is 3.9 BCM, while the residence time of groundwater is 50 to 60 years.[49]

Discharge

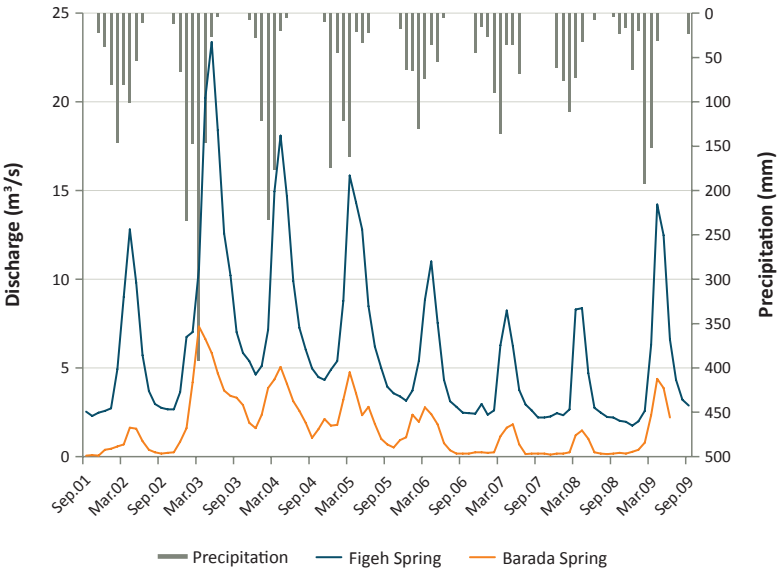
The grey massive-bedded dolomites and dolomitic limestones of the Turonian stage host the Figeh Spring outlets.[50] The long-term average discharge of the Figeh Springs is 243 MCM/yr or 7.7 m^3/s.[51] The discharge of the Figeh Spring is, however, highly variable with fluctuations of between 1.4 and 28.3 m^3/s at the Figeh Main Spring outlet.[52] The highest discharge at the Figeh Main Spring is usually observed during and after the rainy season. Lowest discharge occurs before the beginning of the rainy season (Figure 4).

Water quality

The water of the Figeh Springs is only slightly mineralized and salinity ranges from 200 to 600 mg/L in the Cenomanian-Turonian age formations.[53] The predominant water type is Ca-Mg-HCO_3 and the Mg/Ca ratios above 0.7 indicate that most of the groundwater samples that have been analysed correspond to a dolomitic aquifer environment. The salinity of groundwater abstracted from the Upper Cretaceous ranges from 360 to 430 mg/L TDS.[54]

Variations in ion concentrations and specific electrical conductivity are relatively small during the dry season. However, their values decrease during peak-flow season. The Old

Figure 4. **Hydrographs of Figeh and Barada Springs and monthly precipitation at Bloudan**



Source: Redrawn by ESCWA-BGR based on Al-Charideh, 2012.

Haroush Spring and Old Side Spring as well as the Barada River show a sharp decrease in calcium (Ca^{2+}) concentration and a less pronounced in magnesium (Mg^{2+}) concentration during the high-flow season (flood period). This may suggest rapid recharge from precipitation or even a hydraulic contact between the river and surrounding springs. On the other hand, Figeh Main Spring exhibits a sharp decrease in magnesium concentration and a slight increase in calcium concentration, suggesting rapid recharge and a stronger influence of dolomitic layers during the dry season.[55]

GROUNDWATER USE AND SUSTAINABILITY ISSUES

The Figeh Springs provide around two thirds of the water supply for Damascus. Supply and distribution is managed by the Damascus Water Supply and Sewerage Authority (DAWSSA), which operated under the umbrella of the Syrian Ministry of Housing and Construction until June 2012. Besides a small share used by local farmers in the village of Ain al Figeh, water from the Figeh Spring is used for domestic purposes. Law No. 10 of 1989 established a protection zone in the catchment area (Figure 3). The law banned well drilling, construction and any commercial, industrial and agricultural activities in the area and outlined how landowners affected by the implementation of the law are to be compensated, as well as the punishments that follow violations of the restrictions.

During the high-flow period, the natural outflow of Figeh Main Spring is sufficient to cover demand from Damascus. When spring discharge exceeds demand from Damascus, excess water is discharged into the Barada River. During the

medium- to low-flow period, additional wells and caissons near the springs pump water from the aquifer to increase water production. Over-exploitation has affected groundwater flow patterns and water quality. Changes in hydraulic flow conditions suggest that the delineation and definition of the protection zone need to be reassessed.

Groundwater quality issues

The protection area delineated in Law No. 10 of 1989 extends beyond the Figeh Springs catchment.[56] Prior to the issuing of the law, increased abstraction and over-exploitation affected groundwater flow patterns in the vicinity of the spring outlets, resulting in infiltration of contaminated water from untreated domestic wastewater in the Barada River. Water quality increased significantly when DAWSSA took measures to protect the groundwater.

Sustainability issues

In the past, Figeh Spring discharge met Damascus water demand, but today additional resources are needed to overcome reduced discharge and growing demand, especially in the summer months. Additional well development and groundwater abstractions from the aquifer feeding the Figeh Springs has already affected water quality as discussed above. DAWSSA is implementing measures to safeguard the quality of the Damascus water supply. However, in the longer term additional water resources will be needed to meet the growing needs of the capital and investigations in other parts of the Anti-Lebanon Mountain range are ongoing.

The Anti-Lebanon Mountain range near Bloudan, Syria, 2009. Source: Cristen Rene.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place for any part of the Anti-Lebanon Mountain range, nor for the three shared spring catchments described in this chapter.

COOPERATION

The two riparians coordinate shared water resources management issues through the Syrian-Lebanese Joint Committee for Shared Water, which also implements the agreements in place over the Nahr el Kabir and the Orontes River (see Chap. 7 and 8). However, it is not clear whether the shared aquifer systems in the Anti-Lebanon Mountain range have been addressed under this umbrella for cooperation.

OUTLOOK

There is limited understanding of the shared aquifer systems presented in this chapter as well as other surface and groundwater basins in the Anti-Lebanon Mountain range. The riparian countries could benefit from closer cooperation in the domain of joint research into shared catchments, including the detailed delineation of catchment areas and protection zones, the determination of water balances and the potential impact of climate change.

Bekaa Valley, Lebanon, 2011. Source: Karan Jain.

Notes

1. The border delineation applied by the United Nations is based on the 1920 French Mandate border, which was never formally changed.
2. Service Météorologique du Liban, 1977.
3. Verdeil et al., 2007, p. 72, 78.
4. Central Bureau of Statistics in the Syrian Arab Republic, 2005. According to a 2004 population census.
5. Ibid. According to a 2004 population census.
6. El-Hakim, 2005. However, according to GIS calculations the value is 2,200 km^2, from the map, Dubertret and Vautrin, 1950.
7. The spring is also known as Liddan in Arabic.
8. Sabbagh, 1961.
9. Information on the Anjar-Chamsine Springs is mainly drawn from El-Hakim, 2005, who undertook the most detailed study of the springs to date.
10. Plans to transfer water from the Lake Qaraoun out of the Litani Basin are currently being implemented. The water is intended for irrigation development in southern Lebanon and domestic use in Beirut.
11. Surface runoff feeds additional water for recharge at the eastern margins of the Cenomanian-Turonian outcrop.
12. Water budget calculations by El-Hakim, 2005 indicate that the catchment area may be up to 265 km^2, which probably includes the aquiclude area.
13. UNDP, 1970; Din, 1971; El-Hakim, 2005.
14. Transmissivities and other aquifer parameters in such a karstified aquifer are highly variable.
15. According to the GIS calculations, the catchment area is 248 km^2, as mentioned above. However, in El-Hakim, 2005, the recharge is calculated on an area of 220 km^2.
16. Based on an average annual rainfall of 750 mm, mean annual air temperature of 10.9°C, a mean elevation of 1,370 m asl and with area calculations based on El-Hakim, 2005.
17. The estimate is calculated from the recession curve. The dynamic storage corresponds to the volume of groundwater flowing at the beginning of the recession stage, which is lower than the total stored volume.
18. Residence time in karst aquifers is usually shorter than six months.
19. El-Hakim, 2005.
20. Information on the Barada Spring is mainly based on Droubi et al., 2008a and Droubi et al., 2008b.
21. Droubi et al., 2008a.
22. Selkhozpromexport, 1986.
23. Ibid.
24. According to pumping tests undertaken by Selkhozpromexport, 1986.
25. The structure of the units is described in detail in Droubi et al., 2008a and Dubertret and Vautrin, 1950.
26. Kattan, 1997.
27. Selkhozpromexport, 1986.
28. The description of boundaries is based on Droubi et al., 2008b.
29. Kattan, 1997.
30. Alammareen, 2010.
31. Selkhozpromexport, 1986.
32. de Chatel, 2013.
33. JICA, 1996.
34. Ibid.
35. The creation of the well field had a severe impact on river flow and after the wells started pumping water out of the catchment in 1996, the level of the Barada River dropped dramatically (de Chatel, 2013.)
36. Information on the Figeh Springs is largely drawn from Lamoreaux et al., 1989, who produced the most detailed published study of the springs to date.
37. Dubertret and Vautrin, 1950.
38. Lamoreaux et al., 1989.
39. Ibid.
40. Ibid.
41. Dubertret and Vautrin, 1950.
42. Al Hafez et al., 1999.
43. Al-Charideh, 2011.
44. SOGREAH, 1973.
45. Ulbrich et al., 2006.
46. Lamoreaux et al., 1989.
47. That is based on the assumption that precipitation is higher and evaporation rates are lower at higher elevations. Lamoreaux et al., 1989.
48. SOGREAH, 1973.
49. Al-Charideh, 2011.
50. Over time, an extensive cave system developed. According to Lamoreaux et al., 1989 the continuous cave evolution has and will lead to cave collapse and might change the Figeh outlet points with time, as indicated by 70 m of breccias which deposited on a cave floor.
51. Al-Charideh, 2011.
52. Kattan, 1997.
53. Selkhozpromexport, 1986.
54. Burdon and Safadi, 1964.
55. All information in this paragraph based on Kattan, 1997.
56. In particular, the middle and northern part of the protection zone may also contribute to recharge in the Qalamoun Basin, a high plateau located to the east of the Anti-Lebanon Mountains.

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Chapter 19

Western Aquifer Basin

Western Aquifer Basin

EXECUTIVE SUMMARY

The Western Aquifer Basin is the most productive water basin in Israel and Palestine, yielding the highest-quality water in the area. The aquifer formation extends from the western slopes of the West Bank, through large parts of Israel to the north of the Sinai Peninsula. The aquifer's water resources and groundwater flow are concentrated to the north of the mostly impermeable Afiq Channel and its extention running along a line from the city of Gaza via Be'er Sheva in Israel to the southern limits of the West Bank.

Average annual abstraction over recent decades exceeds the estimated long-term average annual recharge, which means the aquifer is gradually being depleted. Israel currently controls 100% of the aquifer and abstracts 94% of its water, while Palestinians abstract only 6%. Egyptian use of the aquifer is negligible.

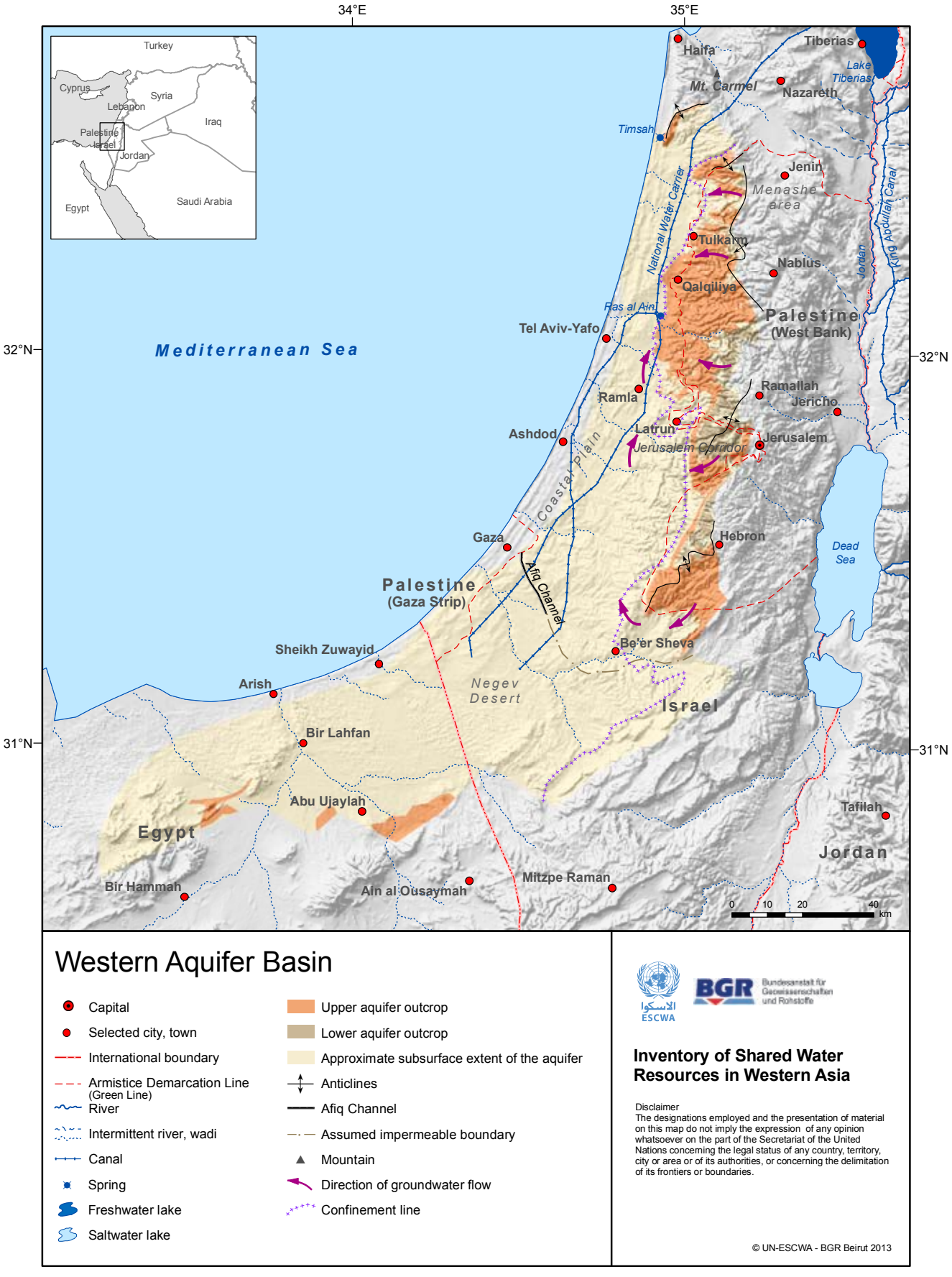
Riparian cooperation on water resources management in the Western Aquifer Basin is largely related to the Israeli-Palestinian conflict. While there is no basin-wide agreement between the three riparians, Israel and PLO have signed two temporary bilateral agreements (Oslo I and II) that both include articles on water resources in the aquifer basin. In particular, the 1995 Oslo II agreement established a Joint Water Committee (JWC), which is responsible for regulating water resources use in the West Bank, including licensing of wells and changes in water allocations. However, in practice the committee has had limited impact and the complicated licensing procedures form a major obstacle to the development of Palestinian infrastructure in the basin. Since the Oslo II agreement, no high-level technical or political negotiations on water-related issues have taken place.

As a productive aquifer with high-quality water, the Western Aquifer Basin is considered a key resource by Israelis and Palestinians. It will therefore form an important point of discussion during final peace negotiations between the two parties.

BASIN FACTS

RIPARIAN COUNTRIES	Egypt, Israel, Palestine
ALTERNATIVE NAMES	Palestine: Western Mountain Aquifer, Ras al Ain-Timsah Aquifer Israel: Yarkon-Taninim Aquifer
RENEWABILITY	Low to medium (2-100 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Groundwater from the basin used to discharge through two major springs in Israel and Palestine
ROCK TYPE	Fractured, karstic carbonates
AQUIFER TYPE	East (recharge area): unconfined Centre and west: confined
EXTENT	Total: 9,000-14,167 km^2 Hydrologically most active: 6,035-6,250 km^2
AGE	Middle to Late Cretaceous (Albian to Turonian)
LITHOLOGY	Limestone and dolomite, some marl and chalk
THICKNESS	600-1,000 m
AVERAGE ANNUAL ABSTRACTION	Total: ~390 MCM Israel: 368.7 MCM (1970-2008) Palestine: 23.7 MCM (1995-2011)
STORAGE	..
WATER QUALITY	Very good
WATER USE	Agricultural, domestic and industrial
AGREEMENTS	Israel-Palestine (PLO) 1993 - Oslo I 1995 - Oslo II
SUSTAINABILITY	Over-abstraction; infiltration of untreated sewage

OVERVIEW MAP



Western Aquifer Basin

- Capital
- Selected city, town
- International boundary
- Armistice Demarcation Line (Green Line)
- River
- Intermittent river, wadi
- Canal
- Spring
- Freshwater lake
- Saltwater lake
- Upper aquifer outcrop
- Lower aquifer outcrop
- Approximate subsurface extent of the aquifer
- Anticlines
- Afiq Channel
- Assumed impermeable boundary
- Mountain
- Direction of groundwater flow
- Confinement line

ESCWA

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

Disclaimer
The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

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Introduction

LOCATION

The Western Aquifer Basin is the most productive aquifer basin in Israel and Palestine, yielding the highest-quality water in the area. The aquifer basin stretches from the West Bank mountain tops in the east, down the western slopes to the Coastal Plain and the Mediterranean Sea in the west. From north to south it extends from the Mount Carmel foothills to the northern Sinai Peninsula. The Western Aquifer Basin is also referred to as the Western Mountain Aquifer or named after its principal historic outlets, the Ras al Ain Spring[1] north-east of Tel Aviv-Yafo and the Timsah Spring[2] south of Mount Carmel.

AREA

The Western Aquifer Basin covers a total area of 9,000 to 14,167 km^2, depending on the definition of the aquifer's southern boundary in the Sinai Peninsula.[3] This chapter focuses on the area north of the Afiq Channel (see section on Hydrogeology below), which is the more productive part of the aquifer. Different studies estimate the surface area of this part of the basin between 6,035 and 6,250 km^2,[4] of which approximately 70% lies in Israel and 30% in the West Bank.

CLIMATE

The Western Aquifer Basin is characterized by a semi-arid climate. The West Bank mountains cause orographic lifting, which results in precipitation from moisture-laden clouds drifting in from the Mediterranean Sea. Average annual precipitation lies between 550 and 700 mm, with rain- and snowfall occurring mainly between October and March. On the Coastal Plain, average annual precipitation ranges from around 600 mm in the north to 250 mm in the south, while the arid Sinai Peninsula receives no more than 50 mm.

POPULATION

The total population within the most hydrologically active part of the basin north of the Afiq Channel is estimated at around 4.6 million. Around 1 million people live in the Palestinian part of the basin, including populations in the governorates of Bethlehem, Qalqiliya, Salfit and Tulkarm, and part of the governorates of Hebron and Ramallah/Al Bireh.[5] The number of Israeli settlers in the Western Hills was estimated at 148,000.[6] Around 3.4 million people live in the Israeli part of the basin, including populations in the Central District, and parts of the districts of Tel Aviv, Haifa (Hadera Sub-district), Jerusalem (Bet Shemesh), as well as the Southern District (Ashkelon and Be'er Sheva Sub-districts).[7]

OTHER AQUIFERS IN THE AREA

The Western Aquifer Basin is surrounded by seven aquifers, with which it stands in partial flow contact.[8] In the north, it is bounded by the Carmel Coastal, the Western Galilee and the North-Eastern Aquifer Basins. To the west, it is overlain by the Coastal Aquifer Basin (see Chap. 20), while to the east it is bounded by the Eastern Aquifer Basin. To the south, the Western Aquifer Basin is in contact with the Negev Aquifers, the shallow Coastal Aquifer and the deep Kurnub Aquifers in the Sinai Peninsula.

INFORMATION SOURCES

This chapter focuses on the parts of the Western Aquifer Basin that are located in Israel and the West Bank and draws on data published in scientific studies, official government documents and organization reports as listed in the bibliography. Certain data (e.g. spring discharge, well abstractions) was obtained directly through the Inventory's Country Consultation process. Very little information was available for the part of the aquifer located in the Sinai Peninsula. The Overview Map was delineated based on local and regional references.[9]

Al Khadr, South Hebron Hills, West Bank, 2010. Source: EWASH.

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

On a local and sub-regional scale, the Western Aquifer Basin contains two aquifer horizons (a lower and an upper), which act as a single combined aquifer unit on a regional and basin-wide scale.[10]

The lower aquifer crops out along the crest of the West Bank Anticlinorium,[11] predominantly within the West Bank, but occasionally also in Israel (e.g. the Jerusalem Corridor) and dips with increasing steepness towards the coast in the west. Similarly, the upper aquifer crops out in the middle and lower slopes of the West Bank, with small outcrop areas to the west of the Green Line.[12] Both series plunge deep beneath thick impermeable Neogene series in the Coastal Plain and in most of the Sinai Peninsula.[13]

The aquifer outcrops, which cover a total area of about 1,976 km^2, mainly occur in the mountains and foothills of the West Bank. Based on the total aquifer extent, the West Bank contains 65% of the total combined outcrop area (1,276 km^2), while 25% of the outcrops occur in Israel and 10% in the Sinai Peninsula.[14]

In the mountainous regions, the aquifer strata dip more steeply than the slopes and expose the deepest formations – the core of the anticline – at the mountain tops. That means that the aquifer is receptive to direct rainfall recharge in the mountains and foothills, especially in the eastern part of the aquifer basin. Here, active epikarst systems develop with wide fractures, cracks, channels and even caves that allow for rapid, deep infiltration of the percolating waters and remarkably high recharge rates (up to 57% of rainfall).[15]

The lateral boundaries of the aquifer (see Overview Map) have been discussed at length in the literature.[16] Of particular importance for the aquifer configuration is the Afiq Channel, which stretches from Be'er Sheva in the east to northern Gaza in the west.[17] This buried erosion channel is filled with impermeable series (evaporites, fine clastics etc.) that deeply bisect the aquifer basin into a northern, hydrologically active aquifer and a southern part, which barely contributes to the active flow system. The section to the east of the Afiq Channel (east and south-east of Be'er Sheva) does not contribute significantly to the hydraulic system of the Western Aquifer Basin, due to lower flow, saturated thickness, recharge and conductivities.[18]

STRATIGRAPHY

The Western Aquifer Basin is composed of Upper Cretaceous (Upper Albian, Cenomanian and Turonian) carbonatic sediments, layers of limestone and dolomite,[19] alternating with confining layers of marl and some chalk. On a local and supra-local scale two aquifer horizons (lower and upper) can be identified, which act as one combined aquifer system on a regional and basin-wide level.[20] Parts of the aquifer are strongly karstified, which explains high local productivity rates.

Table 1. Lithostratigraphy of the Western Aquifer Basin

AGE	FORMATION		LITHOLOGY		HYDROSTRATIGRAPHY	
Senonian	Abu Dees		Chalk, chert, marl		Aquitard	
Turonian	Daliya	Jerusalem	Chalky marl	Limestone	Aquitard	Upper aquifer
Cenomanian	Undifferentiated Talme Yafe	Bethlehem		Dolomite, limestone, marl, chalk.		
		Hebron				
		Yatta		Chalk, marl, limestone.		Aquitard
Albian		Beit Kahel		Dolomite, limestone, marl.		Lower aquifer
		Qattana		Marl, clay.		Aquitard

Source: Compiled by ESCWA-BGR based on Abusaada, 2011, p. 46, fig 2.3 (modified after PWA and UNuT, 2004 and Weinberger and Rosenthal, 1994).

The aquifer basin is underlain by the Qattana Formation,[21] an aquitard of the Aptian and Lower Albian Kobar Group sediments, which consists of a 300-500 m-thick succession of mostly impermeable marl, clay and shale with thinner intercalations of carbonates.[22]

In the Coastal Plain in Israel and most of the Sinai Peninsula, the aquifer basin is overlain by thick sequences of impervious younger sediments, such as the Senonian Mount Scopus and Neogene Saqiye Groups.[23]

AQUIFER THICKNESS

The upper and lower aquifers have a combined thickness of 600-900 m.[24] On average, the upper and lower aquifers each have a thickness of around 350 m. The layers are incompletely separated by less permeable and impermeable marly and chalky series with a thickness of 100-150 m. This results in an overall thickness of 700-1,000 m for the entire aquifer system.[25]

AQUIFER TYPE

The aquifer system is generally unconfined in the mountain and slope areas in the eastern part of the basin.[26] Saturation increases gradually towards the west, first in the lower and then the upper aquifer. West of the confinement line – which runs roughly along the Green Line – the aquifer system experiences strongly confined hydraulic (in the past even artesian) pressure, which brings water levels in bore-holes in the Coastal Plain up to a few dozen metres below ground level and feeds the (now partially dried up) Ras al Ain and Timsah Springs.

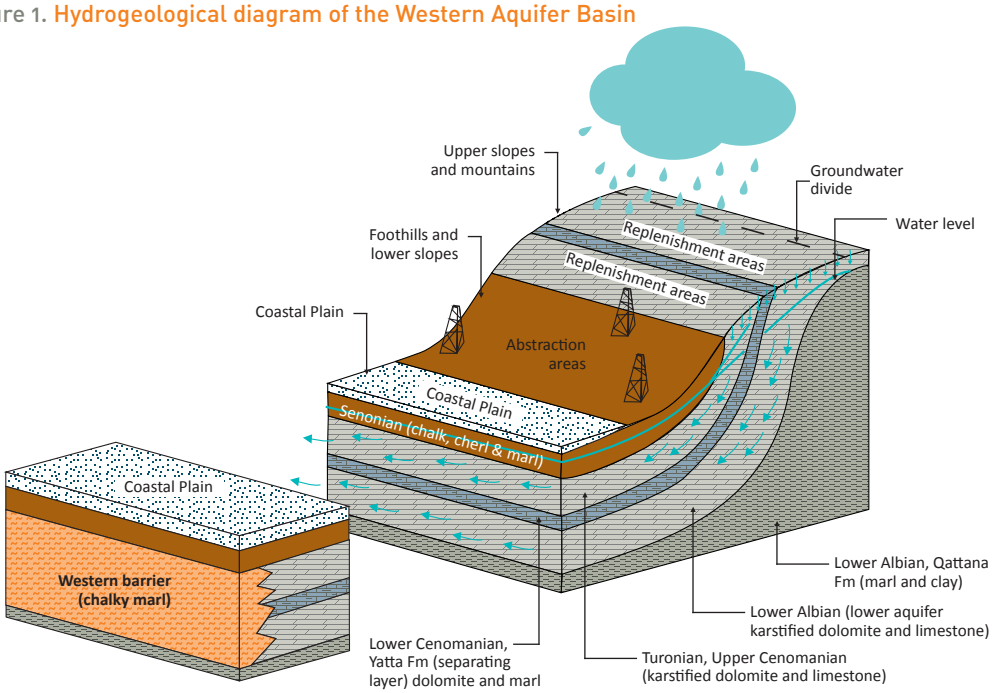
AQUIFER PARAMETERS

Aquifer parameters in karst aquifers are generally highly variable. Annual well discharges range from less than $1x10^{-1}$ MCM to more than 7.5 MCM. Specific yield was found to vary between 1% and 8%,[27] while storativity in the confined areas ranges between 10^{-6} and 10^{-4}.[28]

In the confined areas in the Coastal Plain, transmissivities of between $1.7x10^{-1}$ and $4.63x10^{-1}$ m^2/s have been reported, while they only reach several hundred square metres per day in the unconfined area near the margins of the aquifer basin.[29] In the most productive wells transmissivity can reach up to 1.16 m^2/s. Transmissivity values derived from groundwater model calibrations were sometimes double or triple the values measured in specific wells,[30] which may confirm the double continuum system in the aquifer basin, with diffuse and conduit flow systems.

Horizontal conductivities for the upper and lower aquifer are considered mostly similar, except in the mountain areas where the values increase along the flow path from less than 1-10 m/d (Hebron, Jerusalem, Ramallah) to 5-15 m/d (Tulkarm), 85-160 m/d (Timsah) and 85-600 m/d in the most productive, central parts of the Coastal Plain.[31] The vertical conductivities in the aquifer are estimated to be much lower,[32] ranging between $1.3x10^{-6}$ and $2.2x10^{-4}$ m/d.[33] Conductivities in the aquitard between the upper and lower aquifers can be as low as $7.9x10^{-3}$ m/d.[34]

Figure 1. Hydrogeological diagram of the Western Aquifer Basin



Source: Redrawn by ESCWA-BGR based on Abusaada, 2011, p. 44, fig 2.1.

Hydrogeology - Groundwater

RECHARGE

Recharge in the Western Aquifer Basin is mainly natural from direct infiltration along the karstified outcrops in the mountainous and sloped areas in the eastern part of the aquifer system. Around 73% of recharge to the aquifer takes place in the West Bank.[35] In Israel, recharge mainly takes place in the northern part of the basin (Menashe area) and in the Jerusalem Corridor. Sparse aquifer outcrops and low average annual rainfall in the Negev (Al Naqab) Desert in Israel and the Sinai Peninsula allow for only negligible recharge amounting to less than 1 MCM/yr.

A wide range of values for annual recharge is reported in the literature, from 318 to 430 MCM (Table 2). This Inventory uses the results of a recent study, which estimated a long-term average annual recharge value of 385 MCM for the period 1970-2006.[36] However, pronounced inter-annual variations in recharge are the norm and annual recharge values can range from 212 to 864 MCM, depending on precipitation and other meteorological factors.[37]

Other, smaller sources of recharge to the aquifer system include network losses, agricultural and wastewater return flows, infiltration from wadis, seawater intrusion[38] and artificial recharge through deep-injection wells. Limited agricultural development and water use in the West Bank means that the sources of recharge are less important than direct infiltration from precipitation. In Israel, where the Western Aquifer Basin is mainly confined hundreds of metres below ground, both precipitation and return flows infiltrate the overlying Coastal Aquifer.

Table 2. Recharge estimates for the Western Aquifer Basin

SOURCE	RECHARGE (MCM/yr)	COMMENT
Goldschmidt and Jacobs, 1955, p. 8.	318	Mass balance, based on low outflows from the main springs: Ras al Ain and Timsah.
Bachmat, 1995.	330, 332	Coastal Plain flow model (Goldschmidt/ Jacobs).
Assaf et al., 1993, in Hughes et al., 2008, p. 848.	350	-
Sabbah and Miller, 2012.	350	Based on the 10-year (2001-2010) average.
HSI, 2008, p. 221.	358	Estimate for the period 1970-2007.
Israel and the PLO, 1995.	362	So-called "aquifer potential"; method not specified.
HSI, 1999, in Hughes et al., 2008, p. 4.	366	Rainfall recharge over outcrops.
EXACT, 1998, p. 22.	366	Sum of outflows.
Abusaada, 2011.	385	Estimate for the period 1970-2006 based on water-level fluctuation/storage change.
Messerschmid, 2008, p. 20.	389	Water-level fluctuation, mass balance calculation.
PWA and UNuT, 2004, p. 16.	408	Maximum perennial yield (calibrated steady state and transient models).
PWA and UNuT, 2003b, p. 86.	410	Water budget calculation for Steady State Model.
Hughes et al., 2008, p. 853.	430	Modelled with wetting threshold and soil moisture deficit.

Source: Compiled by ESCWA-BGR.

FLOW REGIME

The flow in the Western Aquifer Basin is generally from east to west in the mountains and turns gradually from south to north in the Coastal Plain. South of the Afiq Channel, the flow is very limited under natural flow conditions.[39] Steep gradients in the elevated recharge and accumulation zone are followed by gentle gradients in the foothills and the lower-lying productive zone. In the recharge zone, water levels generally lie at 300-600 m asl. A gradual increase in saturation occurs in the accumulation zone, and water levels in the lower aquifer drop from 300 to 60 m asl in an east-west direction. In the foothills, water levels lie below 50 m asl, while in the Coastal Plain, a very gentle gradient slopes from more than 30 m asl in the south (Be'er Sheva), to less than 20 m asl in the centre (Ras al Ain Spring) and 5 m asl in the north (Timsah Spring).

Most of the flow is transboundary from the West Bank into Israel. Average annual inflow from the West Bank to Israel amounts to 212 MCM, of which 87% comes from the northern West Bank.[40] Locally, large-scale abstraction from Israeli wells has altered flow lines considerably, for example near Latrun. Flow from and to Egypt is negligible. The aquifer's most productive and exploitable zone lies in the Coastal Plain along the border with the West Bank (Figure 2).

The shallow Carmel Coastal Aquifer and the Coastal Aquifer Basin receive inflow from the Timsah Springs in the northern part of the Western Aquifer Basin. The Coastal Aquifer directly overlies the Western Aquifer near Qalqiliya, with modest recharge.[41]

The North-Eastern Aquifer Basin and the Western Aquifer Basin share a flow boundary in the northern sections of the West Bank mountains. The Eastern Aquifer Basin only has minor flow boundaries with the Western Aquifer Basin; most of the boundary is no-flow or even a structurally divided erosion zone between the basins along the axis of the West Bank Anticlinorium. The Negev Aquifers in the south receive some groundwater from both the Eastern and the Western Aquifer Basins.[42] Occasionally, deep-seated upward leakage along faults occurs from the Jurassic Aquifers below.[43]

STORAGE

Information on groundwater storage was not available.

DISCHARGE

Before the large-scale development of the aquifer in the 1950s, natural discharge occurred almost exclusively from the two principal spring groups, the Ras al Ain and Timsah Springs, which had an average historic discharge of 220 MCM/yr and 100 MCM/yr respectively.[44]

Since the 1950s, spring discharge has decreased sharply due to groundwater abstractions from Israeli and Palestinian wells, resulting in the drying up of the Ras al Ain Spring in the 1960s. The average discharge of the Timsah Spring also dropped to 40 MCM/yr after 1970 (Figure 3).[45] The time series shows that the springs respond quickly to wet years, underlining the highly karstic nature and interconnectivity of the aquifer.[46] After the very wet year in 1991/92, the Ras al Ain Spring started flowing again and discharge from the Timsah Spring increased significantly. However, the increase only lasted a few years and the overall discharge trend continues to be negative, due to sustained over-abstraction from the aquifer.

Figure 2. Aquifer productivity in the Lower and Upper Western Aquifer

Source: Compiled by ESCWA-BGR based on Messerschmid and Abu-Sadah, 2009.

Groundwater levels exhibit similar behaviour (Figure 3) for selected groundwater cells located in the lower, coastal part of the basin.

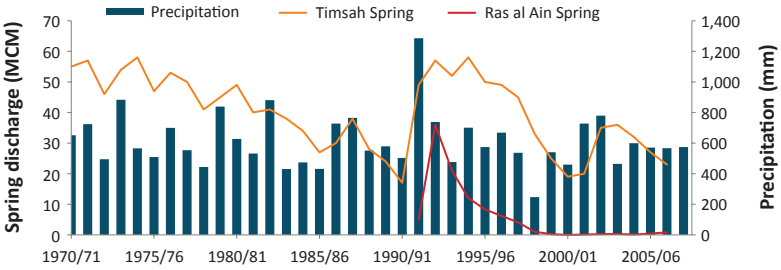
WATER QUALITY

Groundwater in the West Bank is generally fresh with chloride (Cl^-) levels mostly below 100 mg/L.[47] In Israel water is fresh in the vicinity of the Green Line, but becomes slightly brackish (250-600 mg/L) to the west (Figure 4). In the western part of the central Coastal Plain, salty and sulphate-rich leakage from overlying aquifers (e.g. the Eocene Avedat Group) is a local source of additional salt. Farther to the west, groundwater is brackish to highly brackish (600-1,000 mg/L).

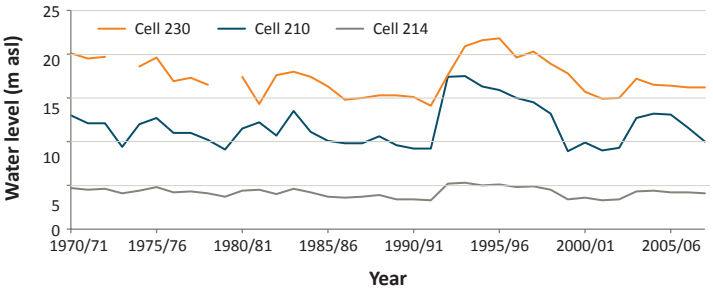
In the north-western part of the basin near the Timsah Springs, seawater intrusions of 3.5-3.9 MCM/yr[48] occur alongside deep saline water bodies at the bottom of the aquifer (>1,000 mg/L). In the area south of the Afiq Channel, most groundwater can be assumed to be strongly brackish to saline (up to approx. 2,000 mg/L), making it unfit for human consumption.

Figure 3. (a) Annual discharge of the Timsah and Ras al Ain Springs and average annual precipitation in the Western Aquifer Basin area (1970-2007); (b) annual water level fluctuations of different groundwater cells in the Israeli part of the basin (1970-2007)

a)



b)



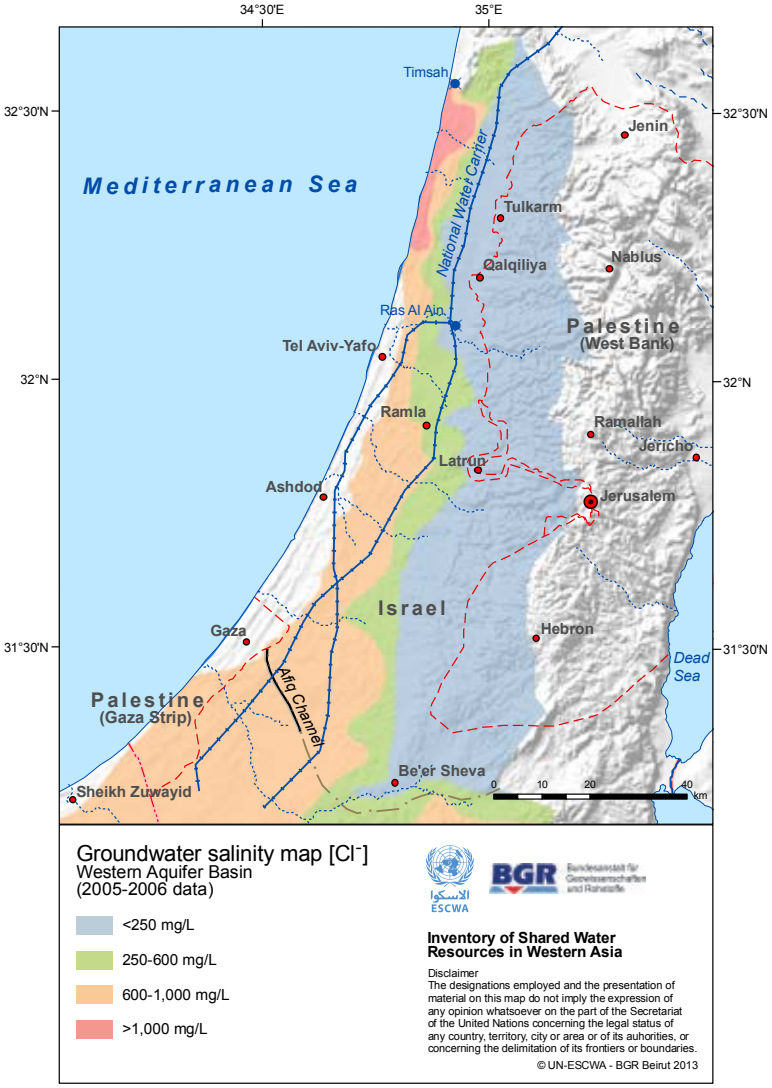
Source: Compiled by ESCWA-BGR based on PWA, 2012a.

South Hebron Hills, West Bank, 2010. Source: Adam Groffman.

EXPLOITABILITY

According to the standardized exclusion criteria used to assess exploitability in this Inventory,[49] the aquifer basin can be classified as theoretically exploitable across most of its extent, with the possible exception of the recharge zone near the eastern margin due to limited saturation and the depth of the groundwater table. More detailed studies of the renewable and intensively developed aquifer basin were found in the literature. Figure 2 shows the productivity for the upper and lower aquifer in the basin. The main productive zone of the aquifer lies near the Green Line and in the Coastal Plain in Israel, and hence constitutes only a relatively small part of the overall basin.

Figure 4. Groundwater salinity map - Western Aquifer Basin



Source: Compiled by ESCWA-BGR based on Messerschmid, 2011 with data from HSI 2008, p. 211, 231.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

Palestine (West Bank)

Local farmers, villagers and city dwellers used the Ras al Ain and Timsah Springs together with the water of small local springs. Abstractions from the Western Aquifer through bore-holes started only during the British Mandate period.[50] During the period from the early 1960s to 1967 when Jordan controlled the West Bank, abstraction from private wells with depths up to 150 m amounted to around 20 MCM/yr.[51] The water was mainly used for agricultural purposes.

Since the Israeli occupation of the West Bank in 1967, Palestinian water use in the Western Aquifer Basin has not substantially increased due to Israeli restrictions (Box 1). There are around 140 operational Palestinian wells[52] in the Western Aquifer Basin. Average annual abstraction for the period 1980-1999 was around 21.3 MCM, of which 15.5 MCM was for agricultural use and 4.7 MCM for municipal use.[53]

The Israeli-Palestinian Interim Agreement on the West Bank and the Gaza Strip (also known as the Oslo II Accords), which was signed in 1995 to cover a five-year period until 1999, allocated Palestinians in the Western Aquifer Basin an annual 22 MCM.[54]

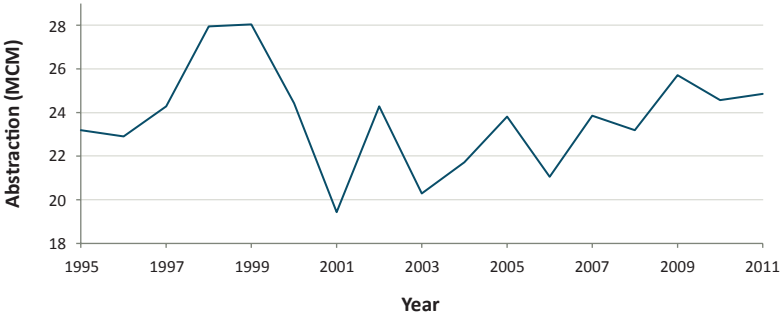
During the period between 1995 and 2011, the annual average Palestinian abstraction from wells was 23.7 MCM, exceeding the value outlined in the Oslo II agreement by 1.7 MCM/yr, or 8% (Figure 5).[55] On average, Palestinian abstractions account for approximately 6% of total abstractions from the Western Aquifer Basin.

Additional abstractions from the Western Aquifer Basin in the West Bank include around 2 MCM/yr from five Israeli operated wells.[56]

Most of the shallow private wells and the few small springs (from intermediate perched aquifer horizons) with discharges of less than $1x10^{-1}$ MCM/yr (1 L/s) are used for small-scale irrigation or to provide supplementary domestic supply during the dry summer months. In 2009, the combined discharge from those small springs was about 2.4 MCM.[57]

In the entire West Bank, local water production in 2010 amounted to 98.3 MCM, of which 71.5 MCM were pumped from around 250 wells and 26.8 MCM were produced in springs.[58] Agriculture accounted for approximately 70% of local water use in the West Bank. An additional 55.5 MCM were purchased from Israel's national water company Mekorot in 2010, mostly for domestic use.[59]

Figure 5. Palestinian abstractions from wells from the Western Aquifer Basin (1995-2011)



Source: Compiled by ESCWA-BGR based on PWA, 2012a.

South Hebron Hills, West Bank, 2010. Source: Adam Groffman.

Israel

Groundwater development in Israel experienced rapid and sustained growth in the early 1950s.[60] Exploitation of the Western Aquifer Basin in the Coastal Plain accelerated after 1958, mainly from Mekorot wells. Today around 500 wells abstract water from the Israeli part of the Western Aquifer Basin.[61] Most Israeli wells are situated in the productive zone of the aquifer and individual well yields are far higher than Palestinian well yields in the West Bank, which are generally older and shallower.

From 1970 to 2008, average annual pumping from the Western Aquifer Basin in Israel was 368.7 MCM (Figure 6)[62] or 94% of total abstractions from the aquifer basin.[63] Israel also has exclusive access to a number of large springs which discharge an annual average of 43.9 MCM, bringing the total average yield from the aquifer basin in Israel to 412.6 MCM.[64]

Israeli abstractions have remained high since 1970, without a clear trend. Annual abstractions vary with rainfall, and the maximum and minimum annual abstractions of 245 MCM (1991/92) and 576 MCM (1998/99) are inversely correlated to the years of highest (1991/92) and lowest (1998/99) rainfall (Figures 3 and 6).

The Oslo II Accords allocated Israel a temporary share of 340 MCM from the Western Aquifer Basin.[65] Figure 6 shows that Israel's average annual abstraction from wells in the basin reached 393.3 MCM for the period 1995-2008, 53.3 MCM or around 15% more than the volume outlined in the agreement. In addition, if full use of spring discharge is taken into account, Israel's total annual average use after 1995 amounts to 429.3 MCM, which represents 89.3 MCM or 26% more than the amount stipulated in the Oslo II agreement.[66]

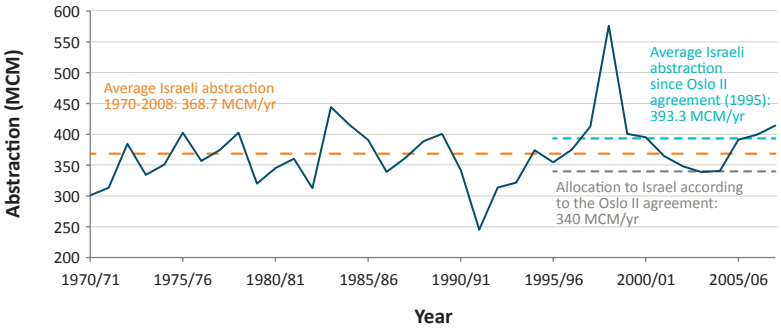
Israeli over-abstraction has led to continuously dropping water levels, which in turn increases salinity problems, particularly in the north of the aquifer basin.[67] Spring flow has also sharply diminished (see section on Discharge above). Israel has used the deep aquifer to compensate for reduced surface water availability from the Jordan River and Lake Tiberias, especially after successive dry winters.[68] Artificial recharge of the Western Aquifer in Israel was introduced early on, reaching 55 MCM/yr in the mid-1970s. After 1995, this figure dropped to 3 MCM/yr.[69]

No information is available on the sectoral allocation of Israeli abstractions in the basin. Most Israeli wells in the Western Aquifer Basin are connected to and feed centrally into Israel's National Water Carrier system,[70] which distributes water from different sources across the country for municipal and agricultural use. It is therefore difficult to trace where the water that is abstracted from the Western Aquifer Basin in Israel is used and for which purposes. Figures from 2010 show the following sectoral allocation of total available water sources in Israel: 57% was used in agriculture, 36% for domestic purposes and 7% in the industrial sector.[71]

Egypt

A few bore-holes have been drilled into the Cenomanian series of the Western Aquifer Basin in the Sinai Peninsula. However, no data is available on abstractions and use in Egypt.

Figure 6. Israeli abstractions from wells in the Western Aquifer Basin (1970-2008)



Source: Compiled by ESCWA-BGR based on PWA, 2012a, similar to Zeitoun et al., 2009.

Table 3. Groundwater use from wells and springs with differing salinity values in the Western Aquifer Basin (1994-2007)

SOURCE	SALINITY		GROUNDWATER USE (MCM)		
	Type	Cl (mg/L)	Israel	Palestine	Total
Well abstraction	Very fresh	0-99	132	19	151
	Fresh-brackish	100-399	225	7	232
	Brackish-saline	>400	7	—	7
	TOTAL		364	26	390
Spring flow	Very fresh	<50	0.07	1.95	2.02
	Fresh-brackish	50-399	1.42	..	1.42
	Brackish-saline	>400	37.16	..	37.16
	TOTAL		38.6	2	40.6

Source: Compiled by ESCWA-BGR based on HSI, 2008; PWA, 2010.

GROUNDWATER QUALITY ISSUES

As shown above, only 7 MCM/yr (<2%) of all abstractions from the Western Aquifer Basin are brackish-saline (Table 3). The sustained over-abstraction of the aquifer has increased the risk of salinization in the aquifer.[72] Spring outflow has declined drastically and groundwater levels have dropped substantially, which increases the risk of saline water being drawn into the northern and western part of the aquifer.

Pollution by untreated sewage is another threat in the outcrop and recharge areas, both in Israel[73] and the West Bank, where domestic wastewater from Palestinian towns and villages and Israeli settlements is released into the environment without treatment.[74] This raw sewage flows through wadi beds and seeps into the aquifer below. Over 2 million people live in outcrop and recharge areas in the eastern part of the aquifer basin in Israel and the West Bank. The lack of adequate wastewater treatment facilities and the absence of sound agricultural

practices mean that nitrate levels locally exceed the World Health Organization guidelines. While few wells have been affected to date, nitrate levels reach 100-145 mg/L in the area of Tulkarm and Qalqiliya and 60-80 mg/L in the Hebron area.[75]

SUSTAINABILITY ISSUES

The water resources in the Western Aquifer Basin have come under increasing pressure since the 1950s, with abstraction rates rising close to and beyond sustainable levels. It is beyond the scope of this Inventory to provide a reliable and detailed water balance estimate, but a simple comparison of long-term annual averages may be indicative of the over-abstraction of groundwater that has taken place in the Western Aquifer Basin.[76]

In the period 1970-2006, average annual outflows reached 434 MCM, while average annual recharge from rain amounted to 385 MCM. The injection of 15 MCM/yr of water into the aquifer has made up for part of the overdraft, but leaves a 34 MCM deficit, which is equal to nearly 9% of natural recharge.[77]

There are pronounced variations in annual recharge and abstractions however, and while available data points to over-abstraction, the aquifer partially and/or locally recovers in particularly wet years, as reflected in spring and groundwater levels (Figure 3).[78] It is important to note that the data series mostly refer to locations in the western part of the basin, which is the confined and productive zone. The effects of over-abstraction may be felt quite differently in the eastern part of the West Bank, where groundwater is located at greater depth, is partly unconfined and undergoes more pronounced fluctuations. A more detailed study on sustainability in the Western Aquifer Basin, covering a longer time period and taking into account spatial and temporal variations as well as cyclical climate patterns, was not available during the preparation of this Inventory.

Finally, it is important to point out that the current use pattern in the aquifer basin and the respective abstractions by the two main riparians take place within the context of the ongoing Israeli-Palestinian conflict. Since the Israeli occupation of the West Bank in 1967, Palestinians have been unable to freely access, use or develop water resources in the West Bank, including the Western Aquifer Basin (Box 1). Thus in addition to unsustainable use of the aquifer, the issue of inequitable use of the Western Aquifer Basin also needs to be addressed.

BOX 1 Palestinian Access to Water in the West Bank

Since the start of the Israeli occupation of the West Bank in 1967, the Palestinian population living in the Western Aquifer Basin area has been unable to further develop or at times maintain its water infrastructure. A series of military orders issued by the Israeli authorities in the late 1960s requires Palestinians to obtain different permits and authorizations for all water-related projects including the drilling of new wells, increasing abstraction from existing wells or carrying out maintenance work on supply and distribution networks. The military orders remain in force today.[a]

As a result, Palestinians have not been authorized to drill a single well in the Western Aquifer since 1967.[b] Networks, reservoirs and pumping stations no longer meet current needs and are often severely run down, while the Israeli army regularly destroys private household rainwater harvesting cisterns if they lack proper permits.[c]

The multiple restrictions mean that Palestinians in the West Bank suffer from chronic water scarcity. Overall, average actual domestic availability and consumption for Palestinians in the West Bank is estimated at about 50 L/cap./d, with many households consuming as little as 20 L/cap./d.[d] The extremely low levels of consumption place most West Bank communities well below accepted international standards.[e]

In addition, many areas in the relatively water-rich West Bank experience annual supply shortages and interruptions during the dry summer months, with inhabitants in parts of Hebron Governorate consuming 10-15 L/cap./d, and receiving water only every 40 days.[f] Many communities have to transport water by tanker from filling points to their village. However, the supply is unreliable, partly because of checkpoints and the Israeli regulation of the operation of filling points. It is also much more expensive than water from the municipal network. Water availability is further restricted by the fact that permit applications for well repair are regularly rejected (Figure 7).

Overall, Israeli restrictions on Palestinian water development projects mean that water supply from Palestinian-controlled wells and springs in the West Bank no longer meets the demands of the growing population. While average abstraction from wells has remained nearly constant at around 61-62 MCM/yr over the past 30 years, average discharge of Palestinian-controlled springs has dropped from an average of 64 MCM/yr in the period 1980-1999 to 40 MCM/yr in the period 1999-2010, a 40% decrease.[g] Overall, average groundwater availability for Palestinians in the West Bank dropped from 126 MCM/yr in 1980-1999 to 101 MCM/yr in 1999-2010, a 20% decrease. In combination with high population growth rates, the gradual reduction in access to water sources strains per capita water availability.[h] As a result, Palestinians in the West Bank are increasingly dependent on water from the Israeli water company Mekorot and purchased an estimated 55.5 MCM for domestic use in 2010.[i]

(a) Officially only in Area C, de facto in Areas A and B.
(b) ECHO, 2009.
(c) Amnesty International, 2009, p. 12.
(d) World Bank, 2009, p. 107.
(e) The World Health Organization (WHO) recommends a standard of 100 L/cap./d for optimal water supply.
(f) World Bank, 2009, p. 16.
(g) For the period 1980-1999, average annual values are available in PWA and UNuT, 2001b: abstraction from Palestinian wells in the West Bank was 62 MCM and discharge of Palestinian springs amounted to 64 MCM, giving a total annual water yield of 126 MCM. For the years 1999-2010, annual averages were calculated based on water statistics in the Palestinian Territory Annual Reports 2000-2012: abstraction from wells was 60.9 MCM and spring discharge amounted to 39.6 MCM, giving a total water yield of 100.5 MCM.
(h) According to official censuses, the Palestinian population in the West Bank grew from 1.87 million in 1997 to 2.35 million in 2007, a 26% increase.
(i) PWA, 2012b, p. 17.

Agreements, Cooperation & Outlook

AGREEMENTS

Riparian cooperation on water resources management in the Western Aquifer Basin is inextricably linked to the Israeli-Palestinian conflict. There is no agreement in place for the aquifer basin as a whole, which is shared between Egypt, Israel and Palestine.

However, Israel and the Palestine Liberation Organization (PLO) have signed two bilateral agreements regarding the use, protection and allocation of water resources in the Western Aquifer Basin. Officially referred to as the Declaration of Principles on Interim Self-Government Arrangements (DOP), the 1993 Oslo Accords between Israel and PLO were the result of extensive negotiations in the aftermath of the Madrid Conference.[79] The agreement dedicates a short paragraph to water, outlining principles of cooperation, joint management, water rights and equitable use.[80]

The Oslo Accords were followed in 1995 by the Israeli-Palestinian Interim Agreement on the West Bank and the Gaza Strip or Oslo II, which addressed the topic of water and sewage in Article 40 of the Protocol on Civil Affairs

BOX 2 The Western Aquifer Basin in the Oslo II Agreement

A section of the Oslo II agreement emphasized the importance of safeguarding the existing use of the Western Aquifer Basin in Israel and the West Bank. Schedule 10, entitled "Data Concerning Aquifers", stipulated "existing extraction, utilization and estimated potential" and, where applicable, the "remaining quantities" for each of the Eastern, North-Eastern and Western Aquifers. The exact nature, origin and relationship of the numbers provided were not specified. Schedule 8 of the agreement stated that the
"...average annual quantities (...) shall constitute the basis and guidelines for the operations and decisions of the JWC".[a] The decisions included the licensing and drilling of wells, increases in extraction, etc.

For the Western Aquifer Basin, an annual average of 362 MCM/yr was given, based on estimates of Israeli and Palestinian "existing utilization" (or shares) of 340 MCM/yr and 22 MCM/yr, respectively, and there were no remaining quantities. The Joint Water Committee (see section on Cooperation) has not approved further development of the Western Aquifer Basin in the West Bank.

Using the data from this Inventory, existing use in the Western Aquifer Basin prior to 1995 was 426 MCM, 64.5 MCM or nearly 18% more than the figure stated in the Oslo II agreement.[b] Other sources published similar findings[c] and recent average annual recharge estimates for the basin are also higher (Table 2).

(a) Joint Water Committee.
(b) For the period from 1970-1995, Israeli average annual abstractions were 355.8 MCM and spring discharge amounted to 47.7 MCM (PWA, 2012a). Assuming a Palestinian abstraction of 23 MCM, the total pre-Oslo yield was 426.5 MCM.
(c) HSI, 2008, p. 221 calculated total outflows from the Western Aquifer Basin before 1995 at 404 MCM/yr, representing 42 MCM/yr or 12% more than the existing use according to Oslo II.

Timsah Spring, Israel, 2012. Source: Adi Faran.

(Annex III) and which was intended to cover the five-year period 1995-1999. The agreement recognized Palestinian water rights in the West Bank, which are to be negotiated in permanent status negotiations.[81] It also acknowledged the need to develop additional water resources[82] for various uses and the importance of safeguarding existing use (Box 2).

Other topics covered in Oslo II include the mutual avoidance of harm and protection of the aquifer from over-abstraction and pollution. Water purchases at full cost and mutual cooperation in studies and future projects, training, research and knowledge transfer, emergency situations and data exchange were also addressed in the agreement.[83] Furthermore, the Interim Agreement made provisions for the parties to establish a permanent Joint Water Committee (JWC) for the interim period. The body was charged with regulating water resources use in the West Bank.[84]

In Israel, the Oslo II agreement is widely seen as a turning point that shifted responsibility for the Palestinian water sector to the Palestinian Authority. Yet in practice it did not change the scope of Israeli control,[85] and all Palestinian abstractions and water resources development projects in the Western Aquifer Basin remain subject to Israeli approval.

COOPERATION

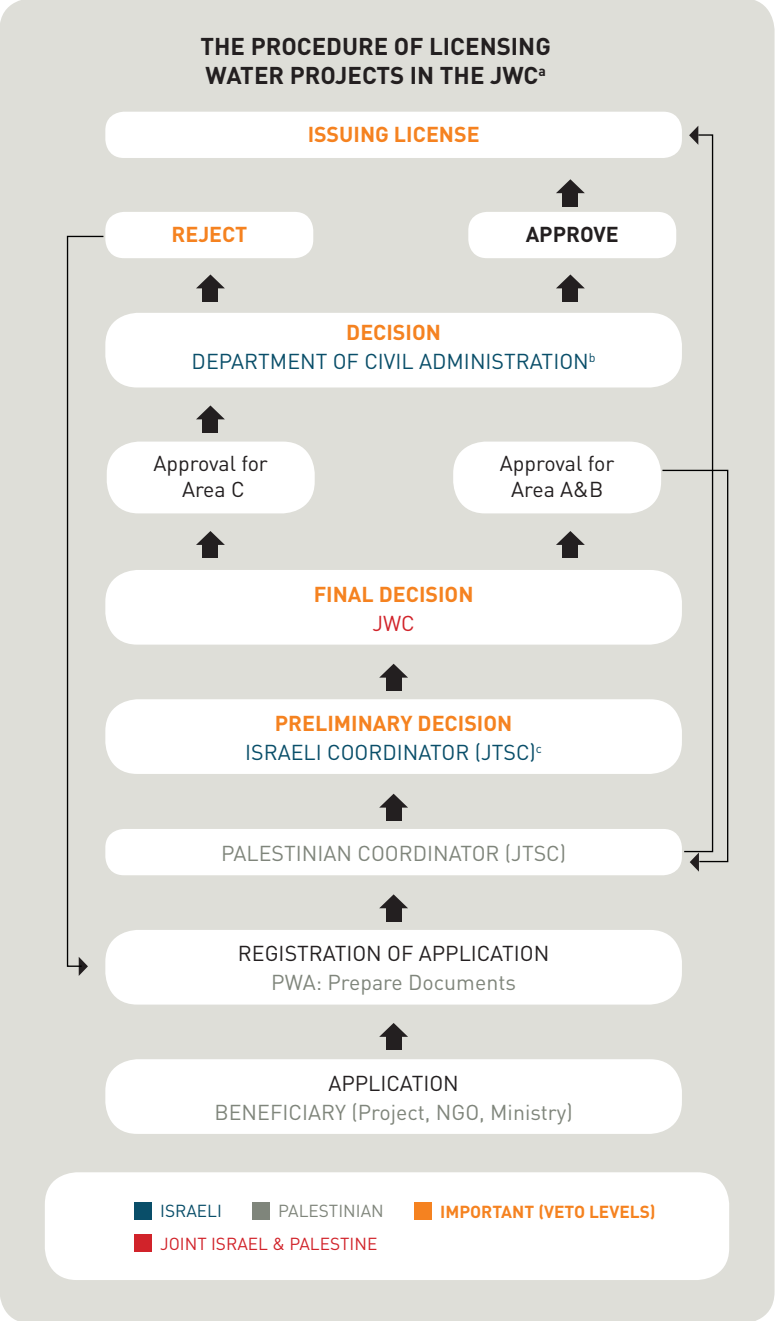
In 1994, in accordance with the Interim Agreement, the parties established the Joint Water Committee (JWC), which comprises an equal number of Israeli and Palestinian representatives.[86] According to the agreement, JWC was established to discuss and decide upon the licensing and drilling of new wells, increasing extractions, development of water resources and systems, allocation of additional water, and changes in allocations. In addition, JWC was given the responsibility to establish and annually update a schedule of extraction quotas based on existing licences and permits.[87]

Although it was hailed as success story for Israeli-Palestinian cooperation, the committee's work has had limited impact.[88] Critics have described JWC as ineffective and as a means of "dressing up domination as cooperation".[89]

While both parties have full veto power over development activities in the section of the Western Aquifer Basin that is located in the West Bank, Israel's water resources development projects are concentrated in the aquifer's main production zone in the Coastal Plain in Israel, over which JWC has no mandate. As a result, Palestinians have no say over Israeli water development projects in the Western Aquifer Basin, while Israel regularly exercises its veto right to obstruct Palestinian plans to build new water infrastructure or carry out maintenance work on existing structures.[90]

The Israeli minister of the environment and the Palestinian minister of water conceded in December 2011[91] that JWC was ineffective. While they disagreed on how it could be remedied, they both called for the re-examination of the committee's structure and operational mechanism.[92]

Figure 7. Licensing water projects through the Joint Water Committee



Source: Redrawn by ESCWA-BGR based on Attili, 2007.
(a) JWC: Joint Water Committee.
(b) The Department of Civil Administration (DCA) is part of the Israeli Army, established to manage local governance issues and security operations in the West Bank and Gaza. Following the Oslo process, the DCA retains this role in Area C (World Bank, 2009).
(c) JTSC: Joint Technical Sub-Committee.

The licensing of Palestinian water projects, including gaining approval for the drilling of a well, remains a long process that is often obstructed by complicated procedures as shown in Figure 7. After registration of the application needed for the licence, it is submitted to the Palestinian coordinator of the Joint Technical Sub-Committee (JTSC), and then to the Israeli coordinator who takes a preliminary decision before submitting it to JWC. The final decision is taken by JWC and at this stage both the Palestinian and Israeli side have a veto right. For projects approved in Area A and B[93], the project approval is re-submitted the Palestinian coordinator of JTSC, which is responsible for issuing the licence. Projects approved in Area C require a second approval by the civil administration which has the right to reject the application. More than half of the West Bank remains under the control of the Israeli military (Area C), further restricting Palestinian water infrastructure development.

OUTLOOK

Final status negotiations and agreements have stalled since 1996 and the five-year interim period outlined in the Oslo II agreement elapsed more than a decade ago. In addition, no high-level technical negotiations on water-related issues have taken place in the intervening period.[94]

From a Palestinian perspective, the inequitable distribution of water resources from the Western Aquifer Basin and the issue of water rights form the crux of the conflict. In addition, the JWC licensing procedure continues to form a key obstacle to the development of Palestinian infrastructure in the basin. Israel, on the other hand, maintains pressure on Palestinians to improve wastewater treatment in recharge areas in the West Bank, and also claims that in contradiction of the agreement, Palestinians have drilled several hundred unauthorized wells in the West Bank, and are not developing new water sources such as reuse of treated wastewater or desalination.[95]

Palestinian negotiators have developed a position based on the principles of international water law with the aim of ensuring long-term sustainable and equitable use of the basin's water resources.[96] However, given that the wider Israeli-Palestinian conflict remains unresolved, the inequitable distribution of water resources from the Western Aquifer Basin is unlikely to be addressed in the foreseeable future.

Potential future land swaps[97] and their relevance to recharge zones and/or productive abstraction zones in the aquifer basin are also likely to play an important role in future negotiations.[98]

Yarkon Spring (Ras al Ain Spring), Israel, 2009. Source: Ian W. Scott.

Notes

1. Referred to as the Yarkon Spring in Hebrew.
2. Referred to as the Taninim Spring in Hebrew.
3. PWA, 2012a estimates the Western Aquifer Basin area at 11,862 km^2 with Egyptian, Israeli and Palestinian basin shares of 19%, 62% and 19%, respectively. Abusaada, 2011 estimates the total area at 9,000 km^2, while Messerschmid, 2008, p. 25 indicates an area of 14,167 km^2. Generally, the depth of extension of the aquifer basin into the Sinai Peninsula is a matter of contention: Sheffer et al., 2010 quote an area of 13,000 km^2. Dafny et al., 2010, p. 2 just provide a lower limit of >10,500 km^2; Guttman and Zukeman, 1995 discuss different Israeli models such as Shakhnai, 1980 who extends the basin in the Sinai Peninsula "towards Jabal Hilal and further to El-Arish" while Guttman, 1988 is quoted to have "shifted the boundary from the Boqer Anticline to the structure of the Shalid El-Arish fields" (Guttman and Zukerman, 1995, p. 2) and the basin area is quoted as 10,481 km^2 (Guttman and Zukerman, 1995, p. 14). SUSMAQ reports mostly assume the maximum area size quoted here, but also a slightly smaller area of 14,148 km^2 (PWA and UNuT, 2003b, p. 6). Weinberger et al., 1994, p. 233 extend the area into the Sinai Peninsula as well, but without giving a value for area size.
4. Messerschmid, 2008, and Abusaada, 2011 respectively.
5. The population estimate for the area of the basin situated in Palestine is based on a 2007 population census by PCBS, 2009.
6. PCBS, 2011.
7. The population estimate for the area of the basin situated in Israel is based on a 2008 census by Central Bureau of Statistics in Israel, 2009.
8. Messerschmid, 2010, p. 6.
9. Abusaada, 2011; Messerschmid, 2010, PWA and UNuT, 2001a.
10. PWA and UNuT, 2005, p. 37. See also Avisar et al., 1997. On a local scale, however, many more subdivisions are noticeable (Dafny et al., 2010, p. 6; PWA and UNuT, 2003b; PWA and UNuT, 2003a).
11. The West Bank Anticlinorium is composed of the Anabta Anticline (in the north), the Ramallah Anticline (in the centre) and the Hebron Anticline (in the south). See Overview Map.
12. The Green Line was delineated in the 1949 Armistice Agreements after the 1948 Arab-Israeli war and refers to the demarcation line between Israel and neighbouring countries. The line was maintained as a boundary until 1967, when Israel occupied the Jordanian-controlled West Bank and East Jerusalem, as well as the Egyptian-held Gaza Strip and the Syrian Golan Heights. Today, the part of the Green Line that runs between Israel and the West Bank is used to differentiate between areas administered by the Israeli government and those under the authority of the Israeli military or the Palestinian National Authority.
13. PWA and UNuT, 2002, p. 178.
14. Outcrop calculations by Messerschmid, 2011. Other authors reach similar figures (PWA and UNuT, 2003a; Weinberger et al., 1994).
15. Abusaada, 2011, p. 82.
16. Such as Weinberger et al., 1994; PWA and UNuT, 2001a; Messerschmid, 2010; Abusaada, 2011.
17. PWA and UNuT, 2001a, p. 37.
18. PWA and UNuT, 2001a.
19. PWA and UNuT, 2001a, p. 113.
20. PWA and UNuT, 2005, p. 37. Also see Avisar et al., 1997.
21. Abusaada, 2011.
22. Messerschmid, 2003, p. 6. In the Israeli petroleum industry and the domain of geophysical stratigraphy, the aquitard is also referred to as Yakhini.
23. PWA and UNuT, 2002, p. 178.
24. Ibid., p. 166.
25. PWA and UNuT, 2002.
26. Confined conditions may also be observed locally in the eastern part of the basin, according to PWA, 2012a.
27. Zukerman, 1999 estimates a specific yield range of 1.8% to 8%, while recent model calibrations (Abusaada, 2011) suggest a range of 1% to 7.5%.
28. Guttman and Zukerman, 1995 found storativity to be within a range of 10^{-5} to 10^{-4}. Based on model calibrations, Abusaada, 2011 reports a different range of 10^{-6} to 10^{-5}.
29. Guttman and Zukerman, 1995, p. 19.
30. Dafny et al., 2010; Abusaada, 2011.
31. Ibid. The estimates are based on model calibrations and largely confirm earlier assessments. See Guttman and Zukerman, 1995; Zukerman, 1999 and PWA and UNuT, 2002.
32. Abusaada, 2011.
33. Weiss and Gvirtzman, 2007.
34. Dafny et al., 2010, p. 12, fig.10.
35. PWA, 2011.
36. Abusaada, 2011 reviewed a number of recharge methods and concluded that the method using water level, fluctuation and storage change provides the best estimate for yearly groundwater recharge. The method was used to calculate the long-term annual recharge of 385.2 MCM for the period 1970-2006.
37. Guttman and Zukerman, 1995, in PWA and UNuT, 2003a, p. 49.
38. Water discharging from the Timsah Springs is a mixture of freshwater and seawater. More than 3 MCM/yr of seawater is estimated to discharge from the springs (Paster et al., 2006).
39. Near Be'er Sheva intensive abstraction has altered natural flow lines (PWA and UNuT, 2001a, p. 39).
40. Messerschmid and Abu-Sadah, 2009. The areas of Baqa, Qalqiliya, Rantis and Tulkarm.
41. Messerschmid, 2010.
42. Ibid.
43. Weinberger and Rosenthal, 1994.
44. HSI, 2004 in Paster et al., 2006, p. 157. The values refer to pre-1950s spring discharge.
45. HSI, 2008, p. 221.
46. See also Abusaada, 2011, p. 136.
47. HSI, 2008, p. 211.
48. Paster et al., 2006, p. 164,166.
49. The following criteria are used to assess exploitability in this Inventory: drilling depth/depth to top of aquifer; groundwater level; and water quality/salinity. For more information on the approach, see 'Overview & Methodology: Groundwater' chapter. See Figure 4 for information on water quality. Depth to top of aquifer was determined using the Middle East Geological Map (MEG-Maps), sheet "Cretaceous": the deepest part of the basin reaches 800 m, while the area north of the Afiq Channel is less than 600 m deep. Groundwater level data was not available (see section on Flow regime).

50. Harpaz and Schwarz, 1967, p. 83.
51. According to PWA and UNuT, 2001c.
52. Most sources only provide well numbers for the entire West Bank. Many of the shallow, older production wells have low productivities or are no longer operational and due to Israeli restrictions, only a few have been rehabilitated. PWA and UNuT, 2001b states an average of 144 Palestinian production wells in the Western Aquifer Basin for the period 1980-1999. PWA, 2011 states 137 in 2009.
53. All figures from PWA and UNuT, 2001b. The total figure of 21.3 MCM includes an additional abstraction of around 1.1 MCM by the West Bank Water Department. Palestinian Statistics count domestic and industrial use under municipal supply.
54. According to Schedule 10 of the agreement, the Palestinian allocation of 22 MCM/yr in the Western Aquifer Basin includes 20 MCM/yr of unspecified origin and 2 MCM/yr from springs near Nablus.
55. This assumes that the Palestinian abstraction figures presented in Figure 5 include the spring abstractions near Nablus mentioned in the Oslo II agreement. Otherwise average Palestinian abstractions of 23.7 MCM/yr represent an excess of 3.7 MCM/yr or 18% of the Oslo II value of 20 MCM/yr.
56. According to PWA and UNuT, 2001b there were four Israeli wells with an average annual abstraction of 2.1 MCM in the period 1980-1999. PWA, 2011 stated that Israel absracted 2 MCM annually from five wells in the West Bank.
57. PWA, 2011.
58. PWA, 2012b, p. 22, 81.
59. Ibid., p. 17, 23. According to IWA, 2012 a slightly lower quantity of 52.6 MCM was provided to the Palestinian Authority in the West Bank in 2010; Palestinian water purchases from Mekorot have risen steadily from 27.9 MCM in 1995.
60. Zeitoun et al., 2009.
61. PWA, 2011. More than 500 Israeli wells according to PWA and UNuT, 2001c.
62. Data on Israeli abstractions was provided by PWA, 2012a and is based on records of the Hydrological Service of Israel for the various groundwater cells in the Western Aquifer Basin. Some doubt remains as to whether the data sets represent Israeli abstractions only as Palestinian sources affirm. The data sets may also include Palestinian abstractions in the West Bank, though it is not clear which level of abstraction is assumed. In the latter case, all Israeli values in the text need to be corrected (reduced) accordingly.
63. Assuming Palestinian abstractions of 23 MCM/yr; PWA, 2011 states the same percentage.
64. Data on spring discharge in Israel provided by PWA, 2012a.
65. The Israeli allocation of 340 MCM in Schedule 10 of the agreement does not specify the origin of utilized water (i.e. from wells or springs). It is, however, specified for the Eastern and North-Eastern Aquifer Basins which are also covered in Schedule 10.
66. All water use figures in this paragraph are from the data set provided by PWA, 2012a. See note 62 as well. If the data sets include Palestinian abstractions in the West Bank, Israel's average annual abstraction since 1995 would have to be corrected (reduced) accordingly.
67. HSI, 2008.
68. Zeitoun et al., 2009.
69. HSI, 2008, p. 221.
70. Israel's National Water Carrier is a 200 km conduit that conveys water from Lake Tiberias in the Jordan River Basin to urban centres along the Israeli coast and further south to the Negev (Al Naqab). See Chap. 6 for more information.
71. Central Bureau of Statistics in Israel, 2012. See Chap. 6 for more information on sectoral water use in Israel.
72. Zeitoun et al., 2009.
73. Particularly the sewage from Jerusalem. For 40 years, untreated sewage has flowed into the streambed of Nahal Soreq, located west of Jerusalem in the Western Aquifer Basin recharge area (Haaretz, 2008).
74. FoEME, 2004.
75. Ibid.
76. In the following approximation, average annual outflows are composed of Israeli and Palestinian abstractions and discharge of major springs. Israeli abstractions (366.5 MCM) and spring discharge (44.4 MCM) for the period from 1970-2006 were calculated from the data set provided by PWA, 2012a as presented in figures 3a and 6. Due to the lack of data prior to 1995, Palestinian abstractions were assumed to be 23 MCM/yr throughout, giving a total average outflow of 433.9 MCM/yr. Inflows considered in the approximation include recharge from rain, which amounted to 385.2 MCM/yr on average for the period 1970-2006 according to Abusaada, 2011. An additional average inflow of 14.5 MCM/yr for the same period stems from artificial groundwater injection to groundwater cells 210 and 211 as listed in the data set provided by PWA, 2012a. The remaining deficit amounts to 34.2 MCM.
77. The deficit is only a rough approximation and may even represent a serious over-estimation as Israeli abstractions in the PWA, 2012a data set may already include unspecified Palestinian abstractions in the West Bank (see note 62 above), in which case Palestinian abstractions would have been counted twice as outflows. If a correction of 23 MCM is made, the remaining overall deficit amounts to only 11 MCM/yr or 3% of recharge. Given the uncertainties and errors inherent in all of those estimates, a 3% gap may not be sufficient to conclude that there is over-abstraction from the aquifer.
78. PWA, 2012a provided water level data for groundwater cells 210, 211, 212, 214, 220 and 230 for the period 1964-2007. While a falling trend due to over-abstraction can be observed throughout much of the observation period, water levels rose after the wet winters of 1991/92 and 2002/03.
79. The Madrid Conference, which was held in Spain in October 1991, was led by the United States of America and jointly sponsored by the Soviet Union. Its aim was to initiate a negotiated peace process involving Israel and Palestinians, as well as other Arab countries, including Jordan, Lebanon and Syria. The conference comprised negotiations on various issues, including shared water resources and is considered the catalyst for the later Oslo Accords (Hiro, 2003; MERIP, 2012).
80. Israel and the PLO, 1993, Annex III, partly focuses on cooperation in the field of water and mentions the joint establishment of a water development programme as a basis for cooperation on water management, water rights and the equitable use of joint water resources.
81. Israel and the PLO, 1995, Annex III, Article 40.
82. The additional quantities of water described in the agreement are: 28.6 MCM/yr, to be made available immediately and 70-80 MCM/yr to be made available over the interim period until 1999/2000 (Israel and the PLO, 1995, Annex III, Article 40, Paragraph 7).

83. Israel and the PLO, 1995, Annex III, Article 40, Schedule 11.
84. Israel and the PLO, 1995, Annex III, Article 40, Schedule 8.
85. Zeitoun, 2008.
86. Israel and the PLO, 1995, Annex III, Article 40, Schedule 8.
87. Ibid.
88. Rouyer, 2000.
89. Selby, 2003. Similarly, Amnesty International, 2009 refered to JWC as a pretence of cooperation.
90. World Bank, 2009.
91. The discussion took place as part of the panel "Cross-Border Waters and Regional Sustainability" moderated by Gidon Bromberg, Israeli Director of Friends of the Earth Middle East. The Palestinians have suspended their participation in JWC since September 2011, arguing that the committee is unable to effectively address any water-related issue. A number of sub-committees are still active but the main decision- making body is not working.
92. According to Bromberg's conclusion of the meeting. See EMWIS, 2012.
93. Following the Oslo II agreement, the West Bank was split into three Areas A, B, and C, with different security and administrative arrangements and authorities (Israel and the PLO, 1995, Article 11) Area C is under full control of the Israeli military for both security and civilian affairs related to territory, including land administration and planning. See Chap. 6, Box 11 for more information.
94. In Camp David (July 2000), water negotiations did not reach the level of specific technical discussions on allocations. At Annapolis (2008/09), only exploratory negotiations in the domain of water were initiated.
95. IWA, 2012. However, most of the wells are located outside the Western Aquifer Basin.
96. Phillips et al., 2007, p. 250.
97. Rothem, 2008. In the context of future negotiations towards a final status agreement, Israel has proposed land swap deals to compensate Palestinian loss of land in the West Bank as a result of settlement activity.
98. Israel's separation barrier, constructed mainly in the West Bank, east of the 1967 Green Line, further diminishes Palestinian access to the productive zone of the aquifer. See Messerschmid and Abu-Sadah, 2009, p. 16.

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Chapter 20

Coastal Aquifer Basin

Coastal Aquifer Basin

EXECUTIVE SUMMARY

The Coastal Aquifer Basin stretches along the eastern Mediterranean coast from the northern Sinai Peninsula in Egypt, via the Palestinian Gaza Strip into Israel. It consists of mostly consolidated alluvium increasing in thickness towards the sea. Groundwater originates from the recharge areas inland and generally flows towards the sea where it discharges.

Most of the abstraction in the basin originates from Israel (around 66% of total abstraction), while the Gaza Strip is responsible for 23% and Egypt has the lowest abstraction at about 11%. Both Egypt and Israel have invested in alternative water supply options for the coastal areas through inter-basin transfer and the use of non-conventional water resources. The Gaza Strip does not have access to alternative water resources and depends almost entirely on the Coastal Aquifer Basin for its water supply. However, as the aquifer in the Gaza Strip is severely threatened by over-abstraction and pollution, desalination is currently being explored as a major alternative source of water supply.

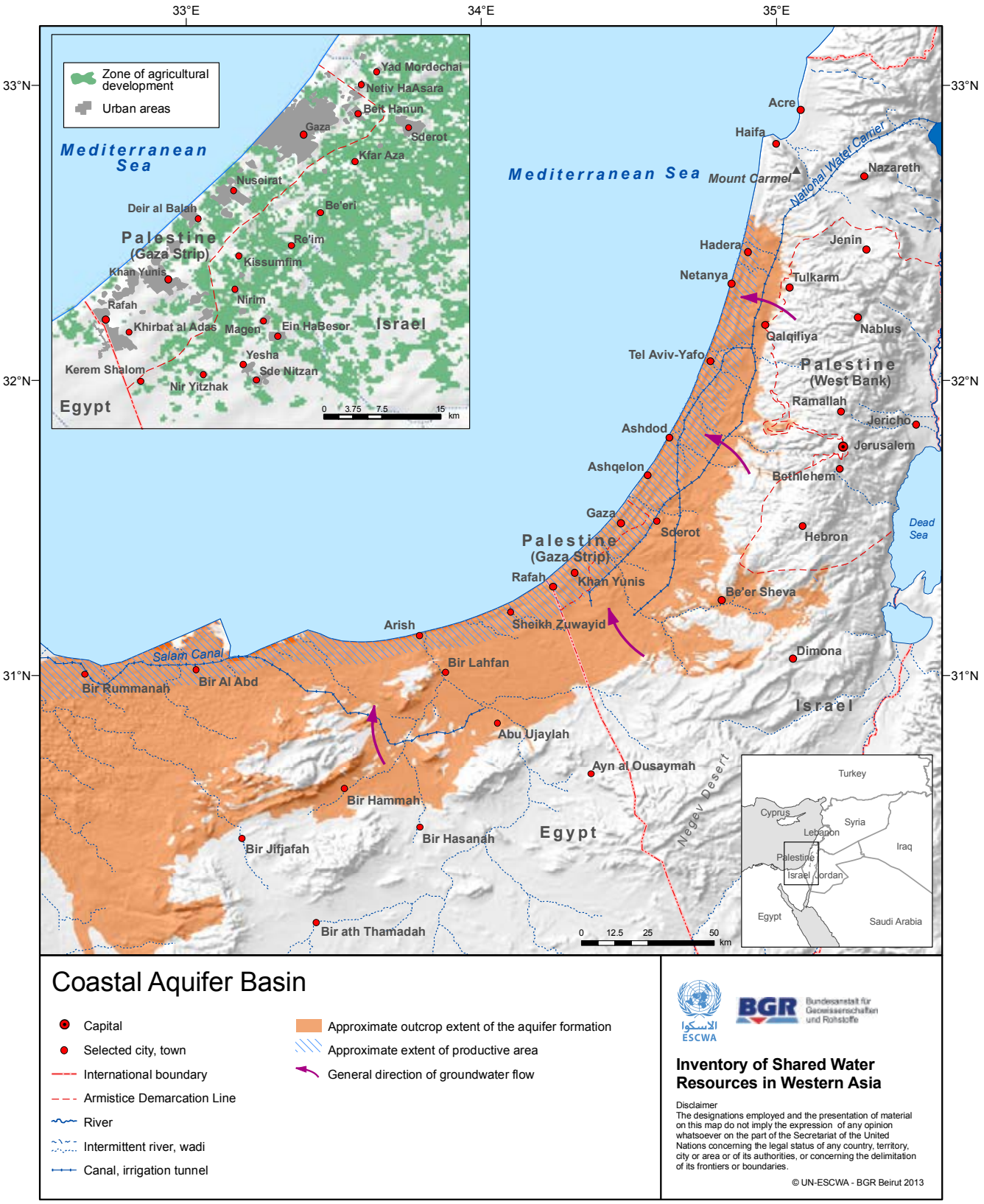
Pollution from untreated sewage, agricultural return flows and seawater intrusions coupled with continued over-abstraction, has led to increased salinization of the aquifer. As a result, water use has been greatly impaired, particularly in the Gaza Strip.

There are no formal or informal agreements for the optimization of use or protection of the aquifer. Political constraints currently make riparian cooperation over water resources in the Coastal Aquifer Basin unlikely, particularly between Israel and Palestine.

BASIN FACTS

RIPARIAN COUNTRIES	Egypt, Israel, Palestine
ALTERNATIVE NAMES	-
RENEWABILITY	Medium to high (20 - >100 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Moderate
ROCK TYPE	Porous
AQUIFER TYPE	Mostly unconfined
EXTENT	18,370 km^2
AGE	Cenozoic (Pleistocene-Holocene)
LITHOLOGY	Clastic series of sandstone, dune sand, gravel and conglomerate
THICKNESS	60-140 m
AVERAGE ANNUAL ABSTRACTION	Egypt: 70-80 MCM Gaza: 150-180 MCM Israel: 400-480 MCM
STORAGE	..
WATER QUALITY	Fresh to brackish
WATER USE	Domestic and agricultural
AGREEMENTS	Israel-Palestine (PLO) 1993 - Oslo I 1995 - Oslo II
SUSTAINABILITY	Over-abstraction resulting in a lowering of the water table and seawater intrusion; pollution from sewage, agricultural runoff

OVERVIEW MAP



Coastal Aquifer Basin

- Capital
- Selected city, town
- International boundary
- Armistice Demarcation Line
- River
- Intermittent river, wadi
- Canal, irrigation tunnel
- Approximate outcrop extent of the aquifer formation
- Approximate extent of productive area
- General direction of groundwater flow

ESCWA

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

Disclaimer
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Introduction

LOCATION

The Coastal Aquifer Basin stretches along the Mediterranean coast from the foot of Mount Carmel in Israel, through the Palestinian Gaza Strip into the Sinai Peninsula in Egypt (see Overview Map). The Mediterranean coastline forms the natural western and northern boundaries of this aquifer. Inland, the aquifer thins out to the east and south.

The Coastal Aquifer is comparatively shallow, renewable and mainly unconfined. The basin's productive zone forms a narrow strip along the coast, with groundwater generally flowing from the hinterland towards the sea. Direct transboundary dynamics and interlinkages exist mainly in the central section of the aquifer, where the Gaza Strip is located in a groundwater flow position downstream of Israel and where lateral effects across the political borders may occur.[1] While providing general information on the Coastal Aquifer Basin as a whole wherever possible, this Inventory focuses on the section that lies in the Gaza Strip and nearby areas in Egypt and Israel.

AREA

In an all-inclusive approach, based on the overall extent of the aquiferous Pleistocene-Holocene deposits, the Coastal Aquifer Basin covers a total area of 18,370 km^2, of which around 71% lies in Egypt, 27% in Israel and 2% in Palestine, mainly in the Gaza Strip (see Overview Map).[2]

The majority of the literature on the Coastal Aquifer Basin focuses on the aquifer in Gaza and Israel, extending only marginally into Egypt. Therefore, estimates from the literature on the basin area are usually lower than in this Inventory.

From a transboundary perspective, a small sub-section is most relevant, comprising the Gaza Strip and adjacent areas in Egypt and Israel, whereby the hinterland is of particular importance. A more refined delineation of the shared aquifer section would require specific groundwater dynamics and flow pattern studies in this area, which were not available for this Inventory. Area estimates for the shared aquifer section are therefore not included.

Table 1. Geographic features of the Coastal Aquifer Basin

	EGYPT	PALESTINE	ISRAEL	TOTAL
Length (km)	200	40	150	390
Width (km)	40-130	7-12	12-45	7-130
Area (km^2)[a]	12,950	365 (Gaza Strip) 49 (West Bank)[c]	5,006	18,365
Population	395,000[b]	1,644,000[d]	3,816,000[e]	5,628,000
Population density (inhab./km^2)	31	4,504[f]	762	307

Source: Compiled by ESCWA-BGR.
(a) The basin outline in Israel and Gaza is based on Bartov, 1994.
(b) The population estimate for the area of the basin situated in Egypt is based on CAPMAS, 2012.
(c) According to the 1948 boundary, the map shows that the outcrop of the aquifer in the West Bank is 49 km^2 (Messerschmid, 2011).
(d) Projection for 2012 by PWA, 2012. The last population census in Gaza was carried out in 2007 and published by PCBS, 2012. It states a population of 1,416,966. The population estimate for the area of the basin situated in Israel is based on Central Bureau of Statistics in Israel, 2006; Central Bureau of Statistics in Israel, 2010.
(e) The population estimate for the area of the basin situated in Israel is based on Central Bureau of Statistics in Israel, 2006; Central Bureau of Statistics in Israel, 2010.
(f) Only the population in the Gaza Strip is included in the count based on data availability.

CLIMATE

Annual precipitation diminishes from north to south, with approximately 600 mm in central Israel and less than 50 mm in Egypt. Precipitation levels also gradually decline away from the coast. The Gaza Strip receives 200-400 mm/yr, with a mean value of 302-345 mm/yr.[3]

POPULATION

The total population in the Coastal Aquifer Basin is estimated at about 5.6 million, with about 3.8 million inhabitants in the Israeli part of the basin and 1.6 million in the Gaza Strip. The Egyptian part of the basin which is mostly made up of desert comprises 395,000 people. Population density in the Coastal Aquifer Basin varies immensely, with density rates in the Gaza Strip 145 times higher than in Egypt and nearly six times higher than in Israel (Table 1).

OTHER AQUIFERS IN THE AREA

The basin is surrounded by and partly in contact with deeper carbonate aquifers, such as the Eocene (Negev and Gaza) and the Cretaceous Mountain Aquifer (Mount Carmel, West Bank, Negev and part of Sinai. See Chap.19, Western Aquifer Basin).

While the hydraulic connections with the aquifers can be locally important, they are assumed to be insignificant at an overall, regional scale, particularly from the perspective of shared water resources. They are therefore not further explored in this Inventory.

An exception is the hydraulic connection with Eocene formations near Palestine (Gaza), which allows for lateral groundwater inflow into the Gaza Strip.

INFORMATION SOURCES

This chapter focuses on the parts of the Coastal Aquifer Basin that are located in Palestine (Gaza) and Israel and draws on data published in scientific studies, official government documents and organization reports as listed in the bibliography. Certain data was obtained directly through this Inventory's Country Consultation process.[4] Very little information was available for the part of the aquifer located in the Sinai Peninsula, and West Bank.

Agricultural fields near Tel Aviv, Israel, 2011. Source: Janie Easterman.

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

The Coastal Aquifer Basin is a shallow, mostly consolidated, alluvial aquifer system with soil, dune, sand or loess alluvial as a cover. It dips and drains towards the sea (Figure 1).[5] The Pleistocene formations of the marine Kurkar A and continental Kurkar B are at an average depth of 50 m and 100 m respectively.

STRATIGRAPHY

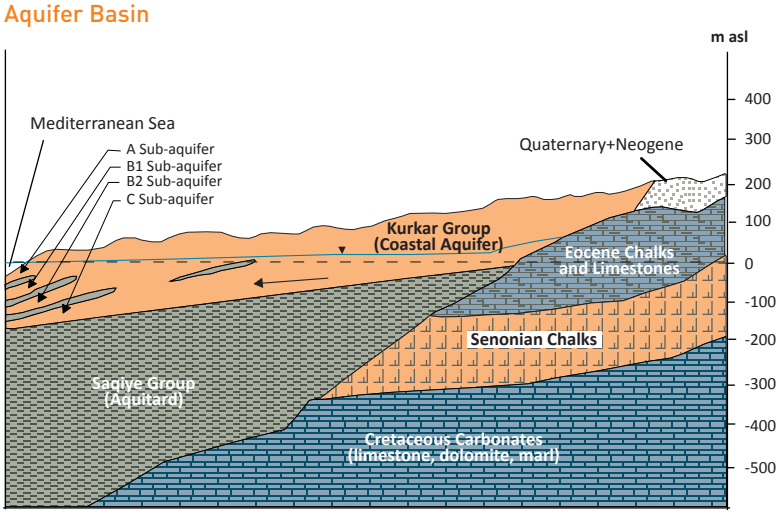
The aquifer formations are of Pleistocene and Holocene age, consisting of clastic series such as sandstone, dune sand, gravel and conglomerate with some top cover of loess and a marly bottom. Intermediate loamy and clayey "red bed" intercalations in the aquifer belong to the marine Kurkar A and continental Kurkar B Group.[6] They extend 2-5 km inland and divide the aquifer into four sub-aquifers, referred to as A, B1, B2 and C (Figure 1). Further inland, the clay layers thin out and the entire aquifer column forms one connected aquifer system.[7] The Pleistocene is mostly underlain by impermeable Neogene strata (Saqiye Group), but locally also by the Eocene, as is the case near the Gaza Strip (Table 2).

The lithology of the part of the aquifer basin situated in the Sinai Peninsula comprises coastal dunes and bars, fluviatile wadi deposits, calcarenites and shallow marine sands. The aquifer is considered to be more productive along the Sinai coast than further inland in Egypt[8] and the Kurkar A is often the most productive formation.[9] Locally, the main aquifer formations of the continental alluvial (gravel, sandstone and clay) Kurkar B and the marine Kurkar A sandstone are overlain by Holocene sand dunes.[10]

AQUIFER THICKNESS

Total aquifer thickness varies between 60 and 140 m. The aquifer thins out as it extends inland from the coast. The mostly unsaturated Holocene cover is typically less than 10 m thick, while the Kurkar B is 30-70 m thick. The Kurkar A is made up of 30-40 m thick sandstones, less than 10 m thick conglomerates and less than 10 m thick marls (Table 2). However, along the coast of the Sinai Peninsula, the aquifer's freshwater zone is limited to a thin layer of 2-5 m of saturated thickness.

Figure 1. Schematic hydrogeological cross-section of the Coastal Aquifer Basin



Source: Modified by ESCWA-BGR based on Greitzer,1967 in UNEP, 2009, p. 55.

Table 2. Lithostratigraphy of the Coastal Aquifer Basin

AGE	NAME	LITHOLOGY, ROCK FACIES	THICKNESS (m)[a]
Holocene	-	Sand and loess (dunes, soil alluvium)	0-10
Pleistocene	Kurkar B (continental)	Calcareous sandstone[b]	30-70
	Kurkar A (marine)	Shelly sandstone, with loamy, clayey "red beds"	30-40
		Conglomerates[c]	<10
		Marl	<10
Neogene	Saqiye	Shale, clay horizons	0-300
Eocene	Avedat	Limestone, evaporites	..

Source: Compiled by ESCWA-BGR based on Salem, 1963, p. 94-97; Gvirtzman, 2002, p. 63; CAMP and USAID, 2000; Vengosh et al., 2005, p. 4; HWE, 2010, p. 13; Mills and Shata, 1989, p. 789.
(a) HWE, 2010, p. 13-15.
(b) "Always cemented, very porous and friable", according to Salem, 1963, p. 94.
(c) Pliocene conglomerates and Mio-Pliocene dark grey marl (or marly shale) are not part of marine Kurkar A, according to Salem, 1963, p. 94.

AQUIFER TYPE

Near the coast, where intercalations with clay lenses occur, the upper sub-aquifer (A) is unconfined, whereas at deeper levels some confined parts (B and C) can be identified (Figure 1). Perched aquifers can also occur in the dune belts, but are only of very local importance.

Further inland, at a distance of 2-5 km from the coast, the clays thin out and the entire aquifer column forms one hydraulically connected, unconfined (phreatic) aquifer.[11]

AQUIFER PARAMETERS

Pump tests in 24 wells[12] in Gaza showed a transmissivity ranging between $2.0x10^{-3}$ and $6.9x10^{-2}$ m^2/s, with averages of $2.0x10^{-2}$-$2.3x10^{-2}$ m^2/s. Hydraulic conductivities range between 15 and 140 m/d, with averages of 50-60 m/d. Specific yields are estimated at 15%-30%.[13]

Sewage outflow on the Gaza coast, 2010. Source: Cara Flowers.

Hydrogeology - Groundwater

RECHARGE

The Coastal Aquifer is a shallow, renewable aquifer and natural groundwater recharge varies annually and seasonally according to distribution of rainfall and other factors. In Israel, the long-term average natural recharge from rainfall was estimated at 247 MCM/yr.[14] In the Gaza Strip, rainfall recharge estimates range from 35 to 48 MCM/yr, depending on the methodology used and the base year or period (Table 3). It is likely that the dense building fabric and spread of impervious surfaces in the highly urbanized Gaza Strip has dramatically reduced

Table 3. Estimates of groundwater recharge and flow components in the Gaza Strip

FLOW TYPE	ESTIMATE (MCM/yr)	SOURCE	COMMENT
Recharge from rain	45	CAMP and USAID, 2000.	From schematic flow chart.
	35	Vengosh et al., 2005.	Base year and method not specified.
	48.2	HWE, 2010, p. 24.	Maximum value.
	41	Aish, 2004.	Groundwater model, estimate for 2000.
	43	Baalousha, 2005.	Cumulative rainfall departure method, long-term average.
	37	CAMP and USAID, 2000 in Baalousha, 2005, p. 890.	Based on land use recharge coefficient.
	40-45		Groundwater model.
	40	Moe et al., 2001.	Groundwater model.
Infiltration from wastewater effluents, network losses, wells, reservoirs, agricultural return flows	54.2	HWE, 2010.	-
	52	Moe et al., 2001.	Estimate for 1998, a drier than average year.
	41.4	Aish, 2004.	-
Lateral inflow from the hinterland	37	Moe et al., 2001.	-
	51.8	Aish, 2004.	Estimate for 2000.
	10-15	Al-Yaqubi, 2006.	-
	20	Al-Yaqubi, 2010.	-
Seawater intrusion	7 (1935) 46 (2003)	Qahman and Larabi, 2006.	Estimates for 1935 and 2003.
Discharge to sea	55 (1935) 10 (2003)	Qahman and Larabi, 2006.	Estimates for 1935 and 2003.
	4.2	Aish, 2004.	Estimates for 2000.
	2	Al-Yaqubi, 2010.	-
Recharge from Wadi Gaza	1.5-2	Al-Yaqubi, 2006.	-
Groundwater deficit	31	Moe et al., 2001.	Estimates for 1998, a drier than average year.
	16	Aish, 2004.	Estimates for 2000.
	42	PWA, 2007 in Hamdan et al., 2011.	Estimates for 2006.

Source: Compiled by ESCWA-BGR.

recharge rates. Historic in-situ rain infiltration may have been 20% higher than today.[15] In the large, arid Sinai Peninsula, erratic rainfall and episodic infiltration from storm runoff results in a natural recharge of less than 100 MCM/yr,[16] with an annual average of 70-85 MCM.[17] Based on the above, total direct recharge to the Coastal Aquifer Basin from rainfall lies in the range of 350-375 MCM/yr.

Other reports that focus on the section of the Coastal Aquifer Basin in Palestine (Gaza) and Israel refer to an estimated total sustainable yield of 360-420 MCM/yr, of which 15% (approx. 55 MCM) are available in the Gaza Strip.[18] The values include lateral subsurface inflow of groundwater from the interior into the Gaza Strip (see section on Flow regime below), and possibly also limited recharge from Wadi Gaza (Box 1).

In addition, artificial recharge occurs from recharge reservoirs, infiltration and injection of wastewater effluents and agricultural return flows. Water inflows can be significant in densely populated areas such as the Gaza Strip and have a negative impact on water quality. Estimated at 40-55 MCM/yr, artificial recharge in the Gaza Strip exceeds freshwater recharge from rain (Table 3). In Israel, artificial recharge was estimated at 177 MCM for the hydrological year 2006/2007.[19] A large part of the water used in coastal areas in Israel was either imported from other basins and aquifer systems, or originated from desalination activities along the coast. Water from different sources also contributes to groundwater recharge.

FLOW REGIME

The Coastal Aquifer Basin is a shallow, renewable aquifer and groundwater flows vary annually and seasonally in quantity depending on distribution of rainfall, abstractions and other factors. The general flow in the Coastal Aquifer Basin follows the dip of the aquifer towards the coast. The western boundary of the aquifer follows the coastline where both outflows of freshwater to the sea and inflows (intrusion) of seawater occur. Heavy abstraction has led to local diversion of groundwater flow and disturbed the flow balance along the coast.

In the Gaza Strip, total annual aquifer outflow to the sea ranges between 2 and 10 MCM, while seawater intrusion has risen to 7-20 MCM/yr (Table 3).

BOX 1

Wadi Gaza Basin

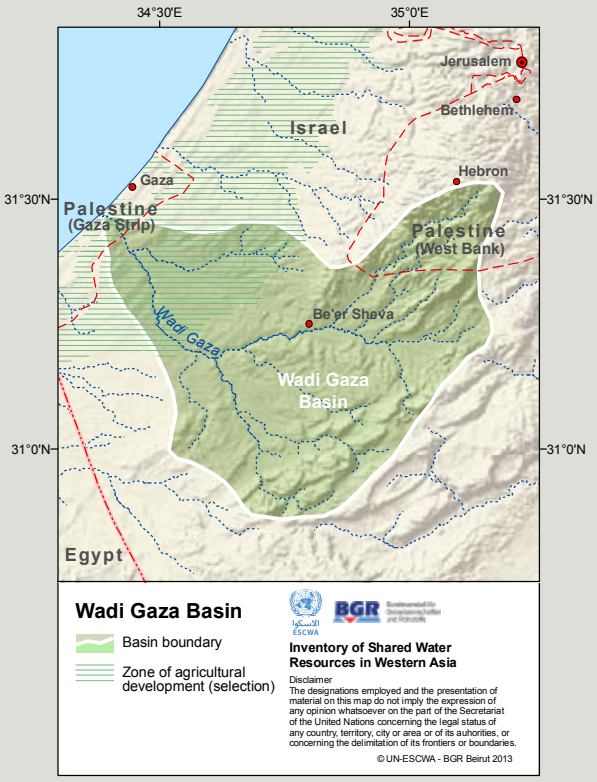
Known in Israel as the Besor River, Wadi Gaza originates from sources in the Hebron Mountains in the West Bank and the northern Negev in Israel, with Wadi Alshari'a and Wadi Shallala forming the main tributaries. The seasonal river flows westward from its source areas through the Negev Desert and into the Gaza Strip, where it feeds a small wetland at the wadi mouth and discharges into the Mediterranean Sea. Wadi Gaza has a total length of around 105 km and a catchment area of around 3,500 km^2.[a]

Wadi Gaza has a highly irregular flow pattern characteristic of seasonal rivers in arid to semi-arid climates with intense, short-lived storm floods. Most recently, torrential rains in January 2010 caused large-scale flooding along Wadi Gaza.[b] Overall discharge volumes may lie in the range of 5-30 MCM/yr,[c] with high inter-annual variability. In the past, Wadi Gaza flowed regularly for at least two months in winter.[d] Runoff in Wadi Gaza has changed over time due to the construction of dams and diversion schemes in Israel, which use almost all the river's water.[e] No data is available on historic recharge to the Coastal Aquifer Basin from Wadi Gaza. However, today it is estimated at less than 1.5-2 MCM/yr.[f]

Today, most of the water in the wadi depression in the Gaza Strip originates from the discharge of raw sewage, causing serious environmental problems and risks to public health.

(a) Laronne et al., 2004.
(b) IFRC-DREF Operation, 2010.
(c) Laronne et al., 2004, p. 9 mentions 5-10 MCM for the Besor Stream, Committee on Sustainable Water Supplies for the Middle East, 1999 mentions 15 MCM, MedWetCoast Project, 2001 quotes 20 MCM for 1994/1995, PWA, 2011b quotes 30 MCM.
(d) MedWetCoast Project, 2001, p. 18.
(e) PWA, 2011b, p. 17.
(f) Al-Yaqubi, 2006.

Figure 2. Wadi Gaza Basin



In Egypt and Israel, seawater intrusions amount to 2 MCM/yr[20] and 3 MCM/yr[21] respectively, but aquifer outflows are probably still greater than intrusions. In Israel, current aquifer outflows to the sea were estimated at 20-23 MCM/yr.[22]

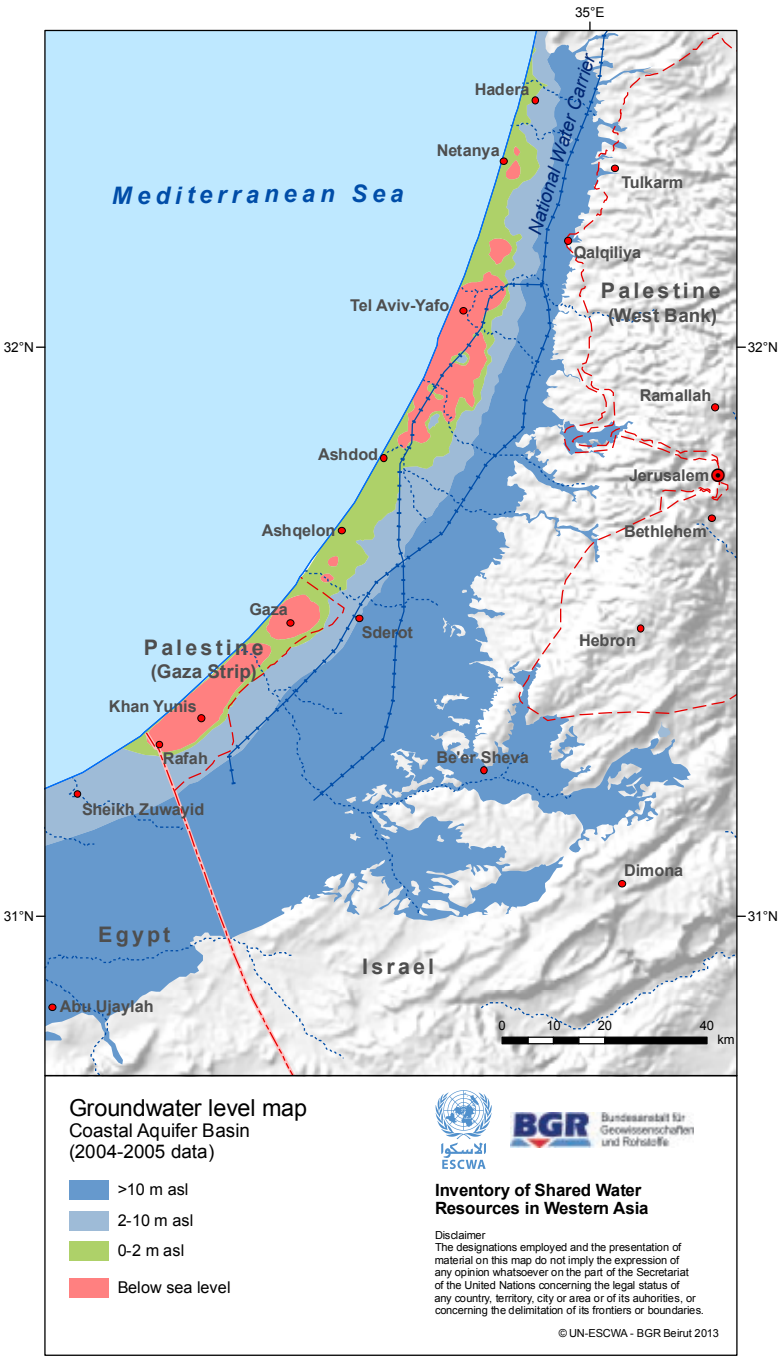
The southern foothills of Mount Carmel form the northern boundary of the Coastal Aquifer Basin, where lateral outflow into/from the shallow Carmel Coastal Aquifer may occur, depending on piezometric regimes of both aquifers. On the south-western edge of the Sinai Peninsula, the aquifer is bound by the highly productive intergranular aquifer that extends from the Nile Delta.[23] Possible flow linkages are mainly of local relevance, and are therefore not further explored in this Inventory.

The Gaza Strip lies downstream of Israel. Subsurface groundwater inflow from the interior in Israel forms an important component of the overall water balance of the Gaza Strip. In the south-eastern Gaza Strip, subsurface inflow from Israel originates from the salty Eocene Avedat Formation, contributing to natural salinization of the Coastal Aquifer.[24] Estimates for overall subsurface lateral inflow range from 10 to 52 MCM/yr (Table 3), presumably with a rising trend as over-abstraction in Gaza steepens the groundwater gradient towards the cones of depression. In recent years, Israel has drilled new wells to the north-east of the Gaza Strip.[25] However, no information could be found as to whether and to what extent pumping from the wells affects the lateral inflow and the water balance in the Gaza Strip.

Groundwater flow between Egypt and Gaza is assumed to be less than 5 MCM/yr.[26] The cones of depression caused by heavy groundwater abstraction in the southern Gaza Strip near Rafah and Khan Yunis extend across the south-western border of the Gaza Strip (Figure 3),[27] thus potentially accelerating groundwater inflow from Egypt. Flow from the Gaza Strip into Israel and from Israel to Egypt has not been reported, but is expected to be very limited.

Prior to the intensive development of the aquifer, groundwater in the Coastal Aquifer Basin was generally shallow and above sea level. Travelling away from the coast, water levels rose to over 20 m asl on the eastern edge of the aquifer and up to 50 m asl in the south-eastern corner of the basin near Be'er Sheva (Figure 3). Along the Sinai coast, water levels are less than 5 m asl,[28] with a depth to water of 15-30 m bgl. There are also some perched aquifers with water levels at 0-5 m bgl,[29] especially in the dune belts. Water levels have dropped considerably, however, as a result of over-abstraction (see section on groundwater use below).

Figure 3. Groundwater level map – Coastal Aquifer Basin



Source: Compiled by ESCWA-BGR based on HSI, 2006, p. 76; HWE, 2010, p. 43.

STORAGE

The Coastal Aquifer Basin is a shallow, renewable aquifer and storage estimates are rarely provided. Given that aquifer depletion from over-abstraction is partially compensated by intruding seawater, freshwater storage estimates depend on water quality and salinity criteria. Based on the World Health Organization drinking water standard for chloride (Cl^-) (<250mg/L), only 10% (450-600 MCM) of the aquifer below Gaza is considered freshwater

storage.[30] The total storage volume of the part of the aquifer situated beneath Gaza would then be 4,500-6,000 MCM.[31] If a chloride concentration threshold of 500 mg/L is applied, freshwater storage increases to 1,400 MCM.[32] Across the Sinai Peninsula, recharge is limited and the total storage of brackish and saline groundwater was estimated at around 2,000 MCM,[33] including aquifers not directly linked to the Coastal Aquifer Basin.

DISCHARGE

No major springs discharge from the Coastal Aquifer Basin. Historically, almost all discharge flowed into the Mediterranean Sea through the subsurface, while water also evaporated from the large swamps in the Coastal Plain. Today, the wetlands have disappeared and sabkha conditions are only found in the northern Sinai Peninsula west of Arish. Discharge to the sea in the Gaza Strip has also been reduced from 55 MCM/yr in 1935[34] to less than 10 MCM/yr in 2003.[35] Today, seawater intrusion occurs in areas of high abstraction.

Small amounts of groundwater leak downward into deeper, underlying aquifers where direct contact exists (near Qalqiliya). Lateral discharge into the adjacent shallow Carmel Coastal Aquifer in the north may occur, but depends on the piezometric regimes of both aquifers.

WATER QUALITY

Rainwater recharge in the Coastal Aquifer Basin provides very freshwater with chloride concentrations below 200 mg/L. In the northern Negev in Israel and Sinai Peninsula, aquifer connections to saline groundwater pockets and deeper or adjacent salty aquifers cause chloride levels to rise above 1,000 mg/L. The south-eastern Gaza Strip also experiences lateral inflow of saline groundwater and upward leakage.[36] In addition, in the southern parts of the Coastal Plain in Israel and the Gaza Strip, salt levels have increased as a result of over-abstraction (Figure 6).

In the Sinai Peninsula, most of the groundwater in the littoral part of the Coastal Aquifer Basin remains brackish and saline with chloride levels at more than 2,000 mg/L. In the interior, in the shallow north and central Sinai aquifer, salinity ranges from 2,000 to 9,000 mg/L. A natural groundwater stratification of shallow, sweet water lenses[37] resting on a more saline groundwater body can be observed in the Sinai.[38]

EXPLOITABILITY

According to the standardized exclusion criteria used to assess exploitability in this Inventory,[39] the aquifer basin can be classified as theoretically exploitable across most of its extent, with the possible exception of the eastern, inland margin due to limited saturation and high salinities. More detailed studies of exploitability and productivity in this renewable and intensively developed aquifer basin are, however, available in the literature. In practice, the main productive zone of the aquifer is located in a small strip along the coast. High salinities, whether natural or as a result of over-abstraction, have hampered development of the aquifer in many parts of the basin.

Raw sewage flowing to the sea at Deir al Belah, 2009. Source: Olly Lambert.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

The shallow alluvial aquifer along the coast of Egypt and historic Palestine was easily accessible and the first wells in the area of the aquifer became operational in the late Ottoman period.

Egypt

There are about 1,800 wells in the Egyptian part of the aquifer basin, mainly situated in and around coastal cities in the Sinai Peninsula.[40] Annual abstraction from the alluvial aquifer in the north and central Sinai was estimated at 82.9 MCM in 2001, of which 72.3 MCM are abstracted in the coastal cities of Arish, Bir al Abd and Rafah.[41] Part of the abstractions are fresh and, for all of Sinai, 27.3 MCM/yr of brackish water (mostly 2,000-5,000 mg/L TDS) is abstracted.[42] An annual 1.2 MCM of brackish groundwater is desalinated in electro-dialysis plants at Arish[43] and in other Sinai cities.[44]

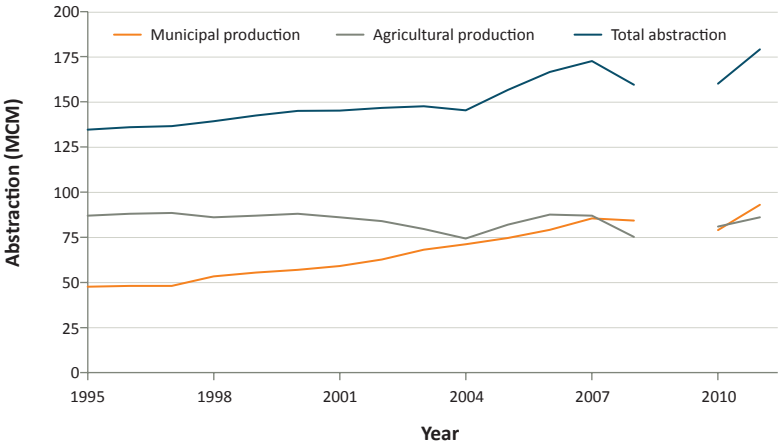
Although available data is incomplete, it appears that most groundwater abstractions in the Sinai Peninsula are used for domestic and industrial purposes (approx. 42 MCM/yr for each sector).[45]

Most of the large irrigation projects that are being developed in the region use water from outside the basin for agricultural development, with a pipeline from Port Said to Rafah providing 16.4 MCM/yr of water.[46] In addition, the partially completed Salam Canal[47] was designed to convey water from the Nile Basin to the Sinai Peninsula, mainly for irrigation purposes. In the long term, the projects aim to expand irrigated area in the Sinai Peninsula from the current 105,500 to 168,100 ha by 2017. However, water imports into the basin could also be used in the domestic sector, which would allow for a reduction in groundwater abstractions.

Israel

Israel has over 1,500 wells in the Coastal Aquifer Basin with a total annual abstraction of 443 MCM in 2006/2007, of which about 45% (200 MCM) was used for agriculture and about 55% (243 MCM) for domestic and industrial purposes.[48] In 2009, Israel expanded its groundwater abstractions by roughly 10% with some 40 MCM/yr drawn from 35 new bore-holes in the area north-east of the Gaza Strip near Ashdod and Sderot.[49]

Figure 4. **Groundwater abstractions from the Coastal Aquifer Basin in the Gaza Strip (1995-2011)**



Source: Compiled by ESCWA-BGR based on PWA, 2012.

Israel imports significant quantities of water to the coastal region from various sources, including the Upper Jordan River (380 MCM/yr),[50] other aquifers such as the Western Aquifer Basin (402 MCM/yr),[51] and desalinated seawater, which is used in all sectors. Desalination projects are expected to provide 650 MCM/yr of Israel's water supply by 2020. Desalinated seawater is also used for irrigation in the Negev Desert.[52]

Palestine (Gaza Strip)

The development of the Coastal Aquifer in Gaza gained momentum in the early 1930s as a result of increased demands from a growing population and the intensification of irrigated agriculture.[53] By 1943, 76 wells had been drilled in the area that today comprises the Gaza Strip.[54] Abstraction rates have increased dramatically over the last 70 years due to high population growth and the drilling of numerous unlicensed agricultural wells.[55] This also includes abstractions by Israel through its settlements, present until 2005 in the Gaza Strip. At present, there are about 1,750 licensed agricultural wells and 217 licensed domestic wells. In addition, there are about 2,700 unlicensed but registered wells and an estimated 2,000 unregistered and unlicensed wells in the Gaza Strip, most of which are used for agricultural purposes. For the period 1995-2011 alone, total annual abstractions increased more than 30%, from around 135 MCM to nearly 180 MCM, mainly due to growing municipal demand (Figure 4).[56]

In 2010, the total agricultural area in the Gaza Strip covered around 10,191 ha, of which 7,524 ha were cultivated and 1,889 ha were under temporary fallow.[57] Fruit trees and vegetables were the dominant crops, covering around 40% and 26% of the agricultural lands respectively.

Unlike the other riparian countries, the Gaza Strip does not have access to water from other sources. Currently the only water transfer into the Gaza Strip is the 4-5 MCM/yr bought from the Israeli water company Mekorot.[58]

Impact on water levels

More than 95% of all wells in the Coastal Aquifer Basin abstract water from the Kurkar A aquifer unit. The water balance in the Coastal Aquifer Basin varies per year and also depends on location, rainfall and abstractions, but a continuous decline in water levels and seawater intrusion along the coast suggest that the three riparians generally abstract water at a rate higher than recharge and that the aquifer is being depleted. In the Gaza Strip, the deficit has been estimated at 16-42 MCM/yr (Table 3).

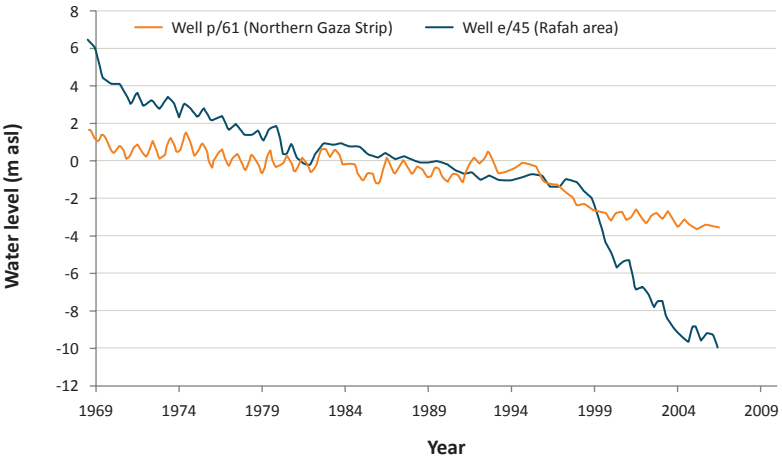
The deepest cones of depression are found near large population centres such as Arish and Rafah in Egypt, Tel Aviv-Yafo in Israel,[59] and most of the Gaza Strip (Figure 3). In the Egyptian town of Rafah, water levels have dropped by up to 5 m since 1984.[60] In Arish, water levels have dropped 2-6 m in the 30 years after 1962.[61] The shallow freshwater lenses are rapidly being depleted. Most dramatically, in the Gaza Strip water levels have been dropping at rates of up to 1 m/yr and water levels in many areas now lie near or below sea level. In the northern Gaza Strip, groundwater levels have dropped by about 5 m in the period 1969-2007, while a drop of over 15 m was observed in the Rafah area in the southern Gaza Strip, with a clear acceleration from 1998 onward (Figure 5). Locally, the decline of groundwater tables may reach more than 15 m bsl, and many shallow wells have dried up, especially in the southern part of the Gaza Strip, while other wells show a decrease in bore-hole yields.[62] This has led to seawater intrusion and an increase in brackish groundwater inflow from the east, south-east and from Sinai.[63]

Current trends include decreases in natural recharge due to urbanization and increases in mostly contaminated return flows from agriculture and sewage. Those conditions increase the long-term sustainability challenges with regard to water quantity and quality.

GROUNDWATER QUALITY ISSUES

Groundwater salinization has long been an issue of concern throughout the Coastal Aquifer Basin. Nowadays, anthropogenic pollution and over-abstraction have worsened salinization and affected groundwater quality in several respects. Four main factors contribute to the deterioration of groundwater in the basin:

Figure 5. Groundwater levels in two wells in the Gaza Strip



Source: Compiled by ESCWA-BGR based on PWA, 2012.

(1) **Seawater intrusion:** Seawater intrusion occurs in the vicinity of large cones of piezometric depression resulting from groundwater abstractions (Figure 3). In Gaza, two major cones/zones of depression exist, which have increased in size, extended towards each other and may soon join, thus providing conditions for seawater intrusion all along the coast. Currently, total seawater intrusion[64] still lies below natural lateral saline groundwater inflows, but already affects the overall quality of many drinking water wells, together with other sources of pollution. Israeli wells further inland are less prone to seawater intrusion, with a net outflow of 20-23 MCM/yr[65] of groundwater from the Coastal Aquifer Basin to the sea occurring in the Israeli part of the basin. In the Sinai Peninsula, groundwater levels have also dropped below sea level in the vicinity of major population centres like Arish and Rafah. Seawater intrusion is, however, partly prevented by the infiltration of wastewater and agricultural return flows, which creates local groundwater highs.[66]

(2) **Lateral Inflow of saline groundwater:** The water in the hinterland of the Coastal Aquifer Basin is generally more saline. In Israel, lateral hydraulic connections to older saline groundwater exist in the hinterland. As the salt front has moved from inland areas towards the coast, salinity has increased considerably over the past 70 years (Figure 6). In the Gaza Strip, inflow of natural brackish groundwater from the east and south-east is significant and affects most areas.[67] Israeli abstractions east of Gaza are likely to intercept part of the lateral groundwater inflow, but it is not clear to what extent it will affect salinity levels inside the Gaza Strip. In the Sinai Peninsula, it can be assumed that there are connections between the Coastal

Aquifer Basin and brackish/salty groundwater in the hinterland. Some upward leakage along fault lines from the more saline Lower Cretaceous Kurnub Sandstone Aquifer has been suggested.[68]

(3) **Upconing of deeper saline water:** This phenomenon, which is closely related to abstraction rates, occurs in the Sinai Peninsula, where thin freshwater lenses occur above saline layers within the same aquifer formation. In 1961, the TDS level in wells in this area was 2,000 mg/L. Over the following 20 years the level doubled and continues to rise. In Gaza, upconing occurs in the deeper wells that tap sub-units B and C as shown in Figure 1.[69]

(4) **Infiltration of sewage effluents and agricultural return flows:** As the unsaturated zone above the water table is permeable and just a few metres thick throughout the Coastal Aquifer Basin, it provides only limited protection from pollution.

In the Egyptian part of the basin, public health has already been affected and diseases such as hepatitis, diarrhoea, dysentery, kidney diseases and blue baby syndrome have been reported in Arish and Rafah.[70] The completion of the Salam Canal and the implementation of related large-scale irrigation schemes are expected to trigger considerable population growth and an increase in economic activity, which may in turn exacerbate the pollution problem. In particular, return flows from large-scale irrigation may harm groundwater quality. Due to the relatively saline mix of Nile water with drainage return flows, leaching requirements will be substantial.[71]

In Israel, leachate from non-point urban pollution or industrial waste and agricultural return flows has infiltrated into the basin for decades, which has seriously affected groundwater quality and led to the relocation or abandoning of many wells. Furthermore, as much of the contamination is located in the unsaturated zone and migrates slowly downwards, current pollution has not yet fully impacted the aquifer.[72] Israel has started to address the contamination through the introduction of wastewater treatment plants and environmental legislation, and by cleaning up rivers and wadis.

The water quality situation is the worst in Gaza. Besides the lateral inflow of saline groundwater and seawater, the principle source of pollution is poorly treated or raw sewage (Table 3). About 78% of Gaza households are connected to a sewage network,[73] but as most treatment plants are currently not or only partly functional, only small amounts of sewage are be treated. As a result, wastewater is discharged into wastewater lagoons, wadis, open cesspits or directly into the Mediterranean Sea.[74] Agricultural fertilizers and leachate from solid waste disposal sites further contribute to the deterioration of groundwater quality.[75]

As a consequence, over 90% of the groundwater in Gaza is unfit for domestic use according to internationally accepted guidelines.[76] Chloride levels are mostly above the World Health Organization permissible maximum of 250 mg/L. In addition, high nitrate (NO_3^-) levels above 50 mg/L are found in many wells throughout the Gaza Strip,[77] while TDS values may reach up to 5,000 mg/L.[78] Given that the Gaza Strip covers a small surface area and has

Figure 6. Groundwater salinity map – Coastal Aquifer Basin

Source: Compiled by ESCWA-BGR based on HSI, 2006 (by-map); assumptions for Sinai based on Vengosh et al., 2005; Allam et al., 2002; Ministry of Water Resources and Irrigation in Egypt, 2005b; Mills and Shata, 1989.

a high population density, it is not an option to close or relocate wells as in Israel.

More than three quarters of the households in the Gaza Strip (83%) buy their water from unregulated private water vendors, who distribute water in tankers or jerry cans.[79] Poverty has forced many more people to drink water from private and agricultural wells that are polluted by agricultural runoff and wastewater seepage.[80] Water-borne diseases caused by the lack of clean drinking water are on the rise, including diarrhoea, hepatitis A, typhoid fever, paratyphoid, and gastro-enteritis. High salinities in drinking water are also a major cause of kidney problems. An estimated 26% of diseases in Gaza are water related, with children being among the most vulnerable.[81]

SUSTAINABILITY ISSUES

Continued over-abstraction forms a threat throughout the Coastal Aquifer Basin, with seawater intrusion and infiltration of agricultural runoff and untreated wastewater posing an ongoing threat to the future of the aquifer basin in Egypt, the Gaza Strip and Israel.

Overall, the sustainability of the Coastal Aquifer Basin is most threatened in the Gaza Strip, where high population growth and density drive sustained over-abstraction from the aquifer. The absence of alternative sources of water supply in the Gaza Strip further complicates the situation. Rainfall and lateral groundwater inflow constitute the main freshwater input to the Gaza water budget. Common estimates of total renewable freshwater resources suggest an annual availability of 50-80 MCM/yr.[82] This corresponds to an annual per capita availability of 31 m^3, which is less than a tenth of the threshold for severe water scarcity (500 m^3/yr).[83] Even under the theoretic assumption that the entire volume of rainfall would be available for human use and that high levels of fresh lateral groundwater inflow occurred, Gaza's renewable total freshwater resources would not exceed 160 MCM/yr.[84] This would correspond to an annual per capita availability of 100 m^3, which is a fifth of the threshold for severe water scarcity.

Projections to 2020 estimate that domestic water use in Gaza will rise to between 110[85] and 170 MCM/yr,[86] while agricultural water use will increase from 73.7 to 88 MCM/yr.[87] In view of the sustained population growth, per capita freshwater availability will further decline and the stress on the aquifer will rise. Already now, total groundwater abstractions are higher than the long-term sustainable yield, leading to accelerated aquifer depletion and salinization. Additionally, since 2009, Israel intercepts groundwater flow before it enters Gaza, which may increase water shortage there. All of the above has sparked growing concerns about the eventual collapse of the aquifer, which would make all of Gaza's groundwater unfit for domestic or agricultural use.

Domestic water use in the Sinai Peninsula and Israel is also projected to increase.[88] Given that the Coastal Aquifer Basin is already over-used, increasing demand can only be met by water imports or the introduction of non-conventional water sources, such as desalination.

Egypt and Israel perform large-scale water transfers into the Coastal Aquifer Basin, with varying impacts on the aquifer basin.

The Egyptian Government plans to convey about 2,800 MCM/yr to the Sinai Peninsula through the Salam Canal, but it is not clear whether this will lead to a reduction in groundwater abstractions from the shallow coastal aquifers. Israel transfers an annual 700-900 MCM of water to the Coastal Plain from the Jordan River Basin and the Western Aquifer Basin.

Palestinians in the Gaza Strip currently cannot rely on such inter-basin transfers. Plans for the construction of a north-south Water Carrier from Israel into Gaza, or from Egypt into Gaza via the Salam Canal have not materialized due to budget constraints, Israeli sanctions and other political issues.[89]

Seawater desalination is considered an option to alleviate water stress and increase water supply in all three riparian areas. Israel plans to desalinate around 650 MCM/yr by 2020,[90] while Egypt plans to desalinate 1.8-3.7 MCM/yr.[91] Desalination in the Gaza Strip is currently still very limited but is expected to increase significantly in the coming years. In 2011, the European Union announced its support for the construction of a short-term low-volume desalination plant to supply 75,000 people in the Khan Yunis and Rafah Governorates.[92] The Union for the Mediterranean has also announced its support for a large desalination plant for Gaza with a capacity of 100 MCM/yr, but funding for this project has not been secured.[93] In the meantime, small-scale desalination, mainly of brackish water by private water vendors (around 40 plants, estimated production of around $7x10^{-1}$ MCM/yr) and at the household level (possibly up to 20,000 home plants) forms a temporary solution,[94] producing a total of around 4-5 MCM/yr.[95]

Agreements, Cooperation & Outlook

AGREEMENTS

Riparian cooperation on water resources management in the Coastal Aquifer Basin is inextricably linked to the Israeli-Palestinian conflict. There is no basin-wide agreement in place for the aquifer basin as a whole, which is shared between Egypt, Israel and Palestine.

However, Israel and the Palestine Liberation Organization (PLO) have signed two bilateral agreements regarding the use, protection and allocation of water resources in the Coastal Aquifer Basin. Officially referred to as the Declaration of Principles on Interim Self-Government Arrangements (DOP), the 1993 Oslo Accords between Israel and PLO were the result of extensive negotiations in the aftermath of the Madrid Conference.[96] The agreement dedicated a short paragraph to water, outlining principles of cooperation, joint management, water rights and equitable use.[97]

The Oslo Accords were followed in 1995 by the Israeli-Palestinian Interim Agreement on the West Bank and the Gaza Strip or Oslo II, which addressed the topic of water and sewage in Article 40 of the Protocol on Civil Affairs (Annex 3). The agreement was intended to cover the five-year period from 1995 to 1999. In addition to detailing other aspects of water resources management in the West Bank and Gaza Strip,[98] Oslo II stipulated a water transfer of 5 MCM/yr from Israel to the Gaza Strip.

Since then, final status negotiations and agreements have stalled and the various high-level multilateral summits and conferences[99] have not addressed joint management of the Coastal Aquifer Basin. Since the Israeli withdrawal from the Gaza Strip in 2005 and in light of ongoing political tension and violent conflict between Israel and Palestine, the Oslo agreement and other provisions regarding water supply, the building of infrastructure and data sharing have been neglected.

Recent official reports from Israel exclude the Gaza Strip from maps of the Coastal Aquifer Basin.[100] This may indicate that Israel no longer considers the aquifer shared, an argument which is also being developed in recent regional research.[101] Such a position would represent a clear shift away from the Oslo Accords,[102] as well as Israel's own long-standing practice[103] and considerable amounts of Israeli and international scientific literature, which consider the basin a shared water resource.[104]

COOPERATION

The three riparian countries do not cooperate over any aspect of water management or use. Israel exercised control over water resources in the Gaza Strip between 1967 and 2005 and applied Israeli water law in the territory. Palestinians in the Gaza Strip had to secure Israel's permission to build wells, networks, pumping stations and treatment plants. Today, major water and sewage projects still require Israeli de facto approval due to the restrictions on the importation of material to the Gaza Strip. Israel did not develop water infrastructure for the Palestinian population in the Gaza Strip and focused its attention on water supply development for Israeli settlements.

After the outbreak of the Second Intifada in September 2000, Israel destroyed thousands of Palestinian wells throughout the Gaza Strip.[105] When Israel withdrew from the Gaza Strip in 2005, it did not sign any cooperation agreements with the Palestinian Authority. Most of the water infrastructure left behind by the departing settlers was damaged before the Palestinian Water Authority (PWA) could establish control.

Since then, PWA has been negotiating an increase in the water transfer from Israel to the Gaza Strip. This would require the construction of a north-south water carrier in the Gaza Strip, which has been hampered by Israel's blockade of Gaza and the heavy restrictions on the import of construction materials. Other details of the water transfer, such as the type to be delivered (desalinated or blue water) and the cost, remain unclear.

There is no information on Egyptian plans to develop a strategy for shared water resources management with Israel or Palestine.

OUTLOOK

Political constraints currently make riparian cooperation over water resources in the Coastal Aquifer Basin unlikely, particularly between Israel and Palestine. Instead, the three

riparians will probably continue implementing unilateral water management strategies for the foreseeable future.

Egypt continues to develop the northern Sinai Peninsula through the implementation of large-scale inter-basin water transfers.

Israel relies on seawater desalination and inter-basin transfer to supply water to the Coastal Plain[106] and has not addressed shared management of the Coastal Aquifer Basin. In the context of future negotiations towards a final status agreement, it has proposed land swap deals to compensate Palestinian loss of land in the West Bank as a result of settlement activity.[107] Under such a deal, Israel would maintain control over annexed land in the West Bank, while Palestine would receive territory along the south-eastern border of the Gaza Strip in exchange. However, groundwater in this region is mainly brackish or saline.

Palestinians in Gaza have little room to implement unilateral development of their water supply in a sustainable manner. In order to avert further degradation of the aquifer, Gaza would have to ban all agricultural groundwater abstractions. That is not a viable option under the current circumstances as Gaza's economy lacks alternatives to agriculture, and industrial production has sharply declined under the Israeli blockade. In addition, a further reduction of domestic supply, which already lies below minimum acceptable levels, is not feasible. Theoretically, there are four options available to Palestinians in the Gaza Strip:

- Water transfer from the West Bank.
- Increased water transfer from Israel.
- Transfer from Egypt through the Salam Canal.
- Seawater desalination.

In practice, PWA continues to seek an increase in water allocations from Israel. It is also working with international organizations, including the European Union and the Union for the Mediterranean, to finance and construct a number of desalination plants.

In conclusion, it is clear that closer riparian cooperation is needed to protect water resources in the Coastal Aquifer Basin from over-abstraction and pollution, particularly in the Gaza Strip. However, in the short term, such cooperation is unlikely to materialize, and the sustainability of the Coastal Aquifer Basin will remain at risk.

The Gaza coast, Palestine, 2009. Source: Stuart Reigeluth.

Notes

1. Groundwater in the shallow, renewable and narrow Coastal Aquifer Basin does not drain to one outlet but generally discharges to the sea along the entire length of the aquifer. Impacts of groundwater abstraction or other management measures are felt predominantly along groundwater flow lines, i.e. from the hinterland towards the coast. Lateral impacts, perpendicular to flow lines and in a south-west/north-east direction along the coast are probably limited in horizontal range.
2. All area figures from GIS calculations are based on the Overview Map. An area of 49 km^2 in the basin lies in the West Bank.
3. Qahman et al., 2011 gives a range of 302-333 mm/yr depending on method; Abu-Maila and Abu-Maila, 1991 estimates 306 mm/yr; Hallaq and Elaish, 2008 gives a range of 335-345 mm/yr.
4. Groundwater level data for selected wells.
5. As Figure 2 shows, the upper sub-aquifer (A) is unconfined, whereas at deeper levels, some confined sub-horizons (B and C) can be identified, especially near the coast. In the hinterland, all aquifer sub-units are connected.
6. The facies name "Kurkar" is used in Israel and Egypt. Israeli authors sometimes also apply it to the Gaza Strip.
7. HWE, 2010, p. 14.
8. Ministry of Water Resources and Irrigation in Egypt, 2001, p. 32.
9. HWE, 2010.
10. Sometimes the Holocene strata bear another shallow perched sub-aquifer unit, such as in Al Mawasi in the southern Gaza Strip.
11. HWE, 2010, p. 14.
12. CAMP and USAID, 2000 in HWE, 2010, p. 15, Table 3.1.
13. HWE, 2010, p. 15, Table 3.2.
14. Average for the period 1971-2007 (HSI, 2008, p. 108), partly accounting for an estimated 70-150 MCM/yr of loss in infiltration due to urbanization (Shamir and Carmon, 1999, p. 409).
15. On the one hand, approximately 20% of Gaza is covered with impervious surfaces or building fabric, which has reduced infiltration. On the other hand, irrigation return flows have increased with the intensification of agriculture in recent decades.
16. Ministry of Water Resources and Irrigation in Egypt, 2001, p. 33.
17. MWRI 2001 states that current annual abstractions of 83 MCM (of which 72 MCM takes place in coastal cities) are near the "limit" of the aquifer. Overall return flows are probably negligible due to the low population density.
18. The values are referred to in World Bank, 2009, p. 27 (total value and 15% share) and PWA, 2011b, p. 3 (55 MCM) but original sources are not given; Al-Yaqubi, 2006 estimates combined freshwater recharge in the Gaza Strip at 57-62 MCM/yr.
19. HSI, 2008. This includes 31 MCM from agricultural return flow.
20. Ministry of Water Resources and Irrigation in Egypt, 2001.
21. HSI, 2008, p. 107-110.
22. HSI, 2008, p. 107-110 calculated 23 MCM; Livshitz and Issar, 2010 state an outflow of 20 MCM.
23. BGS and MacDonald, 2010.
24. Vengosh et al., 2005; Weinthal et al., 2005.
25. In 2009, it was estimated that 40 MCM was abstracted from around 35 additional wells (Haaretz, 2009).
26. This assumption is based on water level maps and declines in water levels on both sides of the Rafah border between Egypt and Gaza (Geriesh et al., 2004, p. 44-45; Al-Yaqubi, 2010).
27. Simulated groundwater level maps for the Gaza Strip in HWE, 2010, p. 43-44 for different years in the period 2000-2008 show the expansion and deepening of the cones of depression in Gaza, especially in the south-western part. The simulated depression clearly extends into Egypt.
28. Allam et al., 2002, p. 21, Table 1.
29. Such as in the dune belt near Al Mawasi in the southern Gaza Strip, see HWE, 2010, p. 106.
30. Moe et al., 2001.
31. Al-Yaqubi, 2006 quotes total storage of 5,000 MCM.
32. Al-Yaqubi, 2006.
33. Allam et al., 2002, p. 22.
34. Qahman and Larabi, 2006. The value is close to later estimates of sustainable yield.
35. Qahman and Larabi, 2006 state 10 MCM for the year 2003. Aish, 2004 estimates 4.2 MCM.
36. The isotopic fingerprint of the brackish water in the south-eastern Gaza Strip is clearly different than that of Mediterranean seawater, including higher boron (B) levels, as shown by Vengosh et al., 2005, p. 18.
37. Pumped at only 2 MCM/yr (Allam et al., 2002, p. 20).
38. Ministry of Water Resources and Irrigation in Egypt, 2005a.
39. The following criteria are used to assess exploitability in this Inventory: drilling depth/depth to top of aquifer; groundwater level; and water quality/salinity. For more information on the approach, see 'Overview & Methodology: Groundwater' chapter. See Figure 3 for information on groundwater levels and Figure 6 for information on water quality. Drilling depth is not a limiting factor in this shallow aquifer.
40. Ministry of Water Resources and Irrigation in Egypt, 2001, p. 31.
41. Ibid.
42. Abou-Rayan et al., 2001, p. 5. This includes all coastal aquifers in Sinai, along the Mediterranean and Red Sea coasts with a total area of 20,000 km^2.
43. Ministry of Water Resources and Irrigation in Egypt, 2001, p. 34, Table 15.
44. Allam et al., 2002, p. 22.
45. Ministry of Water Resources and Irrigation in Egypt, 2005a.
46. The 158 km pipeline (700 mm diameter) was built in 1986 and provides water to Arish, Bir al Abd, Bir er Rumana, Rafah and Sheikh Zuwayid, with a total capacity of 45,000 m^3/d (Abou-Rayan et al., 2001; Ministry of Water Resources and Irrigation in Egypt, 2001).
47. Construction of the canal began in 1997 and brings water from the Damietta Branch of the Nile, under the Suez Canal to the Sinai Peninsula (Egypt Independent, 2012). It was designed to provide 4.45 BCM of Nile water mixed with agricultural drainage water in order to reclaim and cultivate 260,000 ha (Yehia and Sabae, 2011; Abou-Rayan et al., 2001). To date, it has reached a little further than the region of Bir al Abd (based on Google Earth observations) and 76,000 ha have been reclaimed (Ministry of Water Resources and Irrigation in Egypt,

2009). Upon completion, the Salam Canal is expected to stretch to Arish (Ministry of Water Resources and Irrigation in Egypt, 2005a).

48. HSI, 2008, p. 107-110.
49. This groundwater is brackish and needs to be desalinated before it can be used as drinking water, according to Haaretz, 2009, p. 1.
50. Gvirtzman, 2002, p. 35, Fig. 3.3. Israel transfers water out of the Jordan River Basin to the coastal region and the Negev Desert through the National Water Carrier, a 200 km conduit originates from Lake Tiberias (see Overview Map). See Chap. 6 for more information.
51. HSI, 2008, p. 221.
52. Yermiyahu et al., 2007.
53. G.S.I.H.Q. Palestine, 1943, p. 46-93; Messerschmid, 2008, p. 5.
54. G.S.I.H.Q. Palestine, 1943, p. 46-93.
55. PWA, 2011b, p. 3.
56. PWA, 2012. Another estimate from 2010 showed similar results, with about 4,600 wells abstracting around 80 MCM/yr for agricultural use and an additional 197 wells abstracting about 94.2 MCM/yr for domestic and industrial use, according to HWE, 2010, p. 42.
57. All figures in this paragraph from PCBS, 2011; World Bank, 2009, p. 31 estimates total irrigated area at 8,200 ha.
58. PWA, 2010, p. 9.
59. This has been a problem for decades. In 1958, water levels already reached 10 m bsl (Gvirtzman, 2002, p. 69).
60. Geriesh et al., 2004 predicted another two-metre drop.
61. Ghodeif and Geriesh, 2003, p. 192.
62. PWA, 2012.
63. Al-Yaqubi, 2010 estimates brackish groundwater inflow at 1-5 MCM.
64. Al-Yaqubi, 2010 estimated a rate of 20 MCM/yr.
65. HSI, 2008, p. 107-110 calculated 23 MCM; Livshitz and Issar, 2010 state an outflow of 20 MCM.
66. Ghodeif and Geriesh, 2003, p. 198.
67. Vengosh et al., 2005, p. 1-2.; Weinthal et al., 2005.
68. Mills and Shata, 1989, p. 801.
69. HWE, 2010, p. 1-3.
70. Ghodeif and Geriesh, 2003, p. 7; Allam et al., 2002, p. 20.
71. Ministry of Water Resources and Irrigation in Egypt, 2005a, p. 108.
72. HSI, 2008, p. 115.
73. PCBS, 2012.
74. World Bank, 2009, p. 30-31: an estimated 70,000-80,000 m^3 or 50% of total wastewater is discharged to the sea.
75. UNEP, 2009, p. 19, 82.
76. ECHO, 2010; PWA, 2011b.
77. PWA, 2011b, p. 5-7.
78. PWA, 2012; PWA, 2011b.
79. UNICEF and PHG, 2010, p. 15.
80. Ibid., p.26.
81. World Bank, 2009, p. 30; UNICEF, 2011 in PWA, 2011b.
82. Including aquifer recharge from rain and lateral inflow according to Table 3. Green water is not considered in this estimate.
83. According to Falkenmark, 1989.
84. This is based on an estimated total rainfall volume of 120 MCM/yr (around 330 mm) and lateral inflow of 40 MCM/yr.
85. PWA, 2010, p. 16.
86. PWA, 2012.
87. PWA, 2010, p. 17.
88. For Israel compare IWA, 2002; for Egypt/Sinai compare to Ministry of Water Resources and Irrigation in Egypt, 2001; Ministry of Water Resources and Irrigation in Egypt, 2005b.
89. PWA, 2012.
90. Dreizin et al., 2008.
91. Allam et al., 2002, p. 24.
92. EWASH, 2011.
93. UfM, 2011; PWA, 2011a.
94. World Bank, 2009, p. 28.
95. Estimate according to PWA, 2012.
96. The Madrid Conference, which was held in Spain in October 1991, was led by the United States of America and jointly sponsored by the Soviet Union. Its aim was to initiate a negotiated peace process involving Israel and Palestinians, as well as other Arab countries, including Jordan, Lebanon and Syria. The conference comprised negotiations on various issues, including shared water resources and is considered the catalyst for the later Oslo Accords (Hiro, 2003; MERIP, 2012).
97. Israel and the PLO, 1993, Annex III, partly focuses on cooperation in the field of water and mentions the joint establishment of a water development programme as a basis for cooperation on water management, water rights and the equitable use of joint water resources.
98. As outlined in Israel and the PLO, 1995; specific to the Gaza Strip and pursuant to Paragraph 25, Schedule 11 deals with the operation and management of water and wastewater infrastructure, the exchange of data on abstractions and water quality, the provision of additional water from Israel to Gaza, the protection of water systems and the establishment of technical sub-committees.
99. In Camp David (July 2000), water negotiations did not reach the level of specific technical discussions on allocations. At Annapolis (2008/09), only exploratory negotiations in the domain of water were initiated.
100. HSI, 2008 includes a map of the Coastal Aquifer Basin that delineates the aquifer up to the groundwater cell line at Nir 'Am north of the Gaza Strip.
101. FoEME, 2012.
102. JMCC, 1996 p.254, Oslo I.
103. Dating back to 1937, see also Messerschmid, 2008b p.14
104. E.g. in HSI 2005; HSI, 2006; HSI 2007; Gvirtzman, 1969; Gvirtzman, 2002; Vengosh et al., 2005; Vengosh et al., 2007.
105. UNEP, 2009.
106. "To finance these and other steps, the government has allocated NIS 12 billion over a five-year period", from 2009 to 2013 (Haaretz, 2008).
107. Rothem, 2008.

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Chapter 21

Yarmouk Basin

Basalt Aquifer System (West)

Basalt Aquifer System (West)

Yarmouk Basin

EXECUTIVE SUMMARY

The Yarmouk Basin constitutes the western section of the Basalt Aquifer Complex. It extends between the Jebel al Arab Mountain, the Hauran Plateau and the south-eastern foothills of Mount Hermon. In the south-west, the Basalt Aquifer stretches into the Golan Heights to Lake Tiberias.

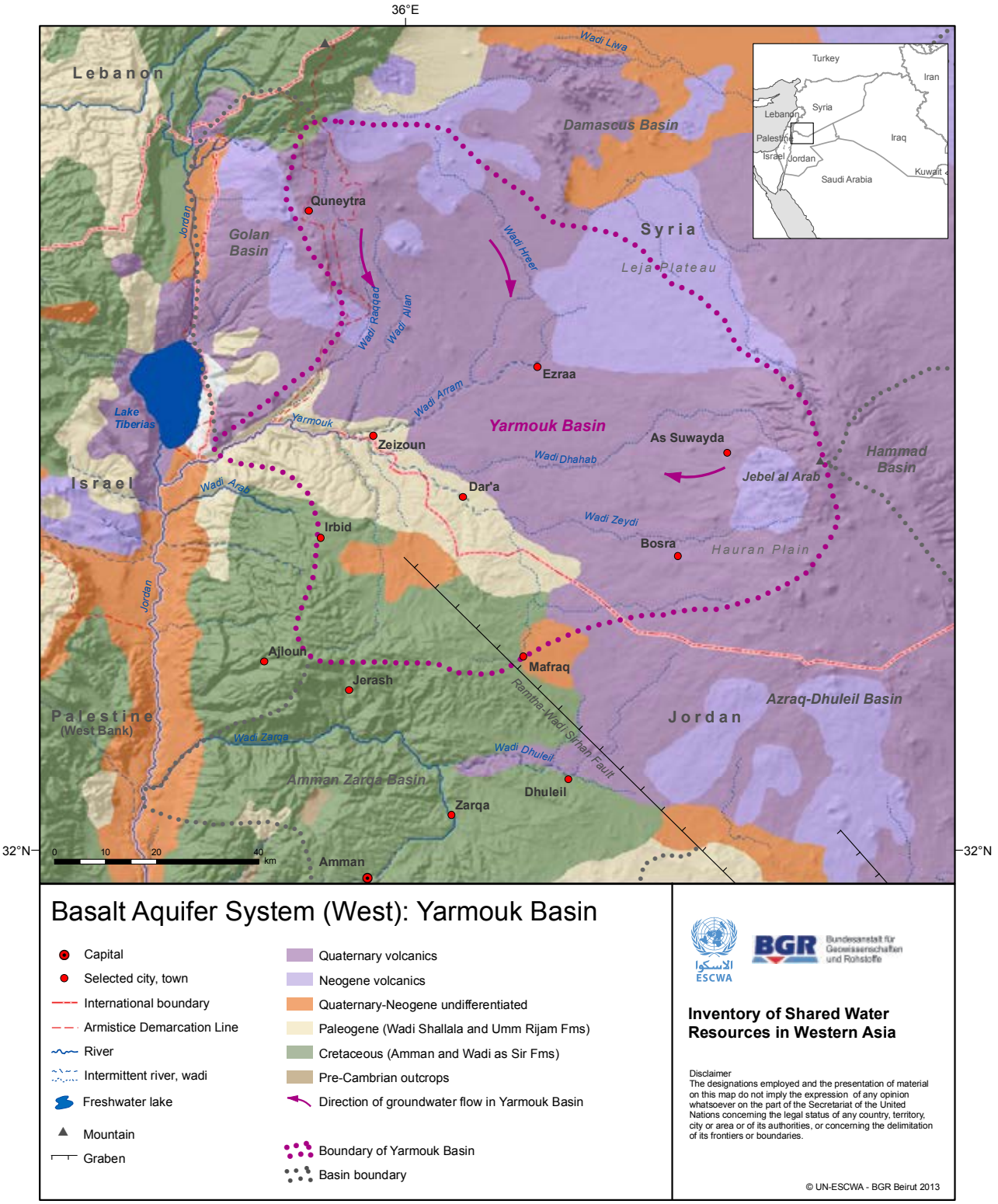
Groundwater flow is generally directed from topographically higher catchments to the major discharge zone around Wadi Hreer-Mzeirib in the Yarmouk Basin, while the western part of the Golan Heights drains towards Lake Tiberias. Groundwater discharge in the Yarmouk Basin appears to be largely maintained by present-day recharge over wide catchment areas, with travel periods of several thousands of years. The main aquifer system in the basin comprises permeable layers in Neogene-Quaternary basalts and the underlying sedimentary rocks (Paleogene and/or Upper Cretaceous formations, depending on the lithostratigraphy of the sequence), which are hydraulically connected with the basalts.

Groundwater and surface water are closely interlinked in this region and the Basalt Aquifer constitutes an important source of water for the Yarmouk River and the Jordan Basin as a whole. Large-scale expansion of groundwater abstraction in some parts of the Yarmouk Basin is likely to have affected natural flow and discharge patterns within a larger radius and may have contributed to the hydrological decline of the Yarmouk River. This has long been a point of conflict between Jordanian and Syrian authorities.

BASIN FACTS

RIPARIAN COUNTRIES	Jordan, Syria
ALTERNATIVE NAMES	-
RENEWABILITY	High
HYDRAULIC LINKAGE WITH SURFACE WATER	Medium (20-100 mm/yr)
ROCK TYPE	Fractured to mixed
AQUIFER TYPE	Unconfined
EXTENT	~7,000 km^2
AGE	Neogene-Quaternary, Paleogene (Upper Cretaceous)
LITHOLOGY	Basalt, limestone
THICKNESS	<100 m - >300 m
AVERAGE ANNUAL ABSTRACTION	..
STORAGE	..
WATER QUALITY	Mainly fresh
WATER USE	Agricultural and domestic
AGREEMENTS	Groundwater-related provisions in the 1987 agreement regarding the utilization of the waters of the Yarmouk River
SUSTAINABILITY	Over-exploitation of groundwater, reduced spring flow in discharge zone, local groundwater pollution

OVERVIEW MAP



Basalt Aquifer System (West): Yarmouk Basin

- Capital
- Selected city, town
- International boundary
- Armistice Demarcation Line
- River
- Intermittent river, wadi
- Freshwater lake
- Mountain
- Graben

- Quaternary volcanics
- Neogene volcanics
- Quaternary-Neogene undifferentiated
- Paleogene (Wadi Shallala and Umm Rijam Fms)
- Cretaceous (Amman and Wadi as Sir Fms)
- Pre-Cambrian outcrops
- Direction of groundwater flow in Yarmouk Basin

- Boundary of Yarmouk Basin
- Basin boundary

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Inventory of Shared Water Resources in Western Asia

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The Basalt Aquifer System in this Inventory

The Quaternary-Neogene basalts of the North Arabian Volcanic Province extend from south-western Syria through eastern Jordan into Saudi Arabia over a total length of around 460 km and with a width of 50-150 km.

They cover an area of approximately 48,000 km^2, of which 11,000 km^2 is located in Jordan, 23,000 km^2 in Saudi Arabia and 14,000 km^2 in Syria. The basalts generally overlie sedimentary formations of Paleogene and Cretaceous ages (Figure 1) and are hydraulically connected with them to form a complex aquifer system that is denoted as the Basalt Aquifer Complex in the Inventory.[1] This volcano-sedimentary complex extends across the boundaries of Jordan, Saudi Arabia and Syria (see 'Overview and Methodology: Groundwater' chapter) to constitute shared aquifer systems in the following basins:

Yarmouk Basin

The basin extends across the border of Syria and Jordan and the aquifer system within the basin is denoted as the Basalt Aquifer System (West) (see current chapter). In the basin, the basalts generally overlie the Paleogene (Shallala-Rijam) formations, except in certain structurally high locations where the Paleogene is missing and the basalts come in direct contact with the Cretaceous (Amman-Wadi as Sir) formations.

Azraq-Dhuleil Basin

The basin[2] extends across the border of Syria and Jordan, and the aquifer system within the basin is referred to as the Basalt Aquifer System (South-East) (see Chap. 22). In the basin, the basalts are hydraulically connected with the Paleogene (Shallala-Rijam) formations in the eastern areas and the Cretaceous (Amman-Wadi as Sir) formations in the western areas to form one aquifer system with both formations.

Wadi Sirhan Basin

The basin extends across the border of Jordan and Saudi Arabia and the aquifer system within the basin is denoted as the Tawil-Quaternary Aquifer System (see Chap. 17). In the basin, the Quaternary-Neogene basalts and alluvium form the upper part of a thick aquifer system that comprises both the Paleogene and Cretaceous (Tawil-Sharawra) formations.

The Basalt Aquifer Complex, which was originally delineated on the basis of surface drainage and morphology, comprises three other basins that are of less relevance as shared aquifers. They are therefore not covered in separate chapters in this Inventory. The **Golan Basin**[3] and **Damascus Basin** lie entirely in Syria, the **Amman-Zarqa Basin** lies entirely in Jordan while the basalts in the **Hammad Basin** are practically dewatered.[4]

Basalt Desert, Jordan, 2005. Source: Robert Bewley, Aerial Photographic Archive for Archaeology in the Middle East.

Introduction

LOCATION

The Basalt Aquifer System (West), hereafter referred to as the Yarmouk Basin, covers wide areas of south-western Syria and a smaller area in north-western Jordan (see Overview Map). It extends from the Jebel al Arab Mountain range in the east over the Hauran Plateau to the foothills of Mount Hermon in the west; and from the Quneytra area in the north to the border area between Jordan and Syria and the Wadi Hreer–Mzeirib groundwater discharge area near the Yarmouk River in the south-west. South of Mount Hermon, the basalt area extends through the Golan Heights to Lake Tiberias (Box 1). To the south-east, it is bordered by the Azraq-Dhuleil Basin, which is shared between Jordan and Syria (see Chap. 22). To the east and north, the basin is bounded by the Hammad and Damascus Basins.

AREA

The morphology of the basin is dominated by the 1,500 m peaks of the Jebel al Arab Mountain range in the east, with the 1,803 m Tell Ghani as its highest peak. The Golan Heights in the south-west reach a maximum altitude of approximately 1,200 m asl. The Hauran Plateau, which adjoins the Jebel al Arab Mountain range in the west, slopes gently to 500 m asl towards the Yarmouk River valley, which cuts into the basalt field to a depth of around 450 m asl. To the west, the Hauran Plateau grades into the Golan Heights, a basalt plateau which descends from an altitude of about 900 m asl on its north-eastern edge to 250 m asl in the Yarmouk River valley in the south. In the west of the Golan Heights, altitudes drop from 700 m asl to 212 m bsl on the shore of Lake Tiberias.

The boundaries of the aquifer system of the Yarmouk Basin coincide approximately with the water divides with neighbouring hydrologic basins (Azraq-Dhuleil, Damascus, Amman-Zarqa, Golan and Hammad Basins). In the south-west, the basin boundary is defined by the limits of the basalt field near the Yarmouk River. In a limited area in the south-west (near Dar'a and Mafraq), the boundary of the Basalt Aquifer is formed by the limit of the extent of the saturated aquifer.

Based on surface topography, the Yarmouk Basin covers an overall area of around 6,900 km^2, of which around 5,150 km^2 are covered in outcrops of basaltic rocks. In parts of the Hauran Plain in Syria, the basalts are overlain by a thick soil cover.

CLIMATE

The climate in the Yarmouk Basin is typically Mediterranean, with cold, rainy winters and dry, warm summers extending from May until October. Average annual precipitation ranges from 500 mm in the Jebel al Arab Mountain range and Golan Heights to 250-300 mm in the Hauran Plain.

POPULATION

The Yarmouk Basin has an estimated total population of around 1.6 million. The Syrian part of the basin has around 1.2 million inhabitants in the governorate of Dar'a, as well as parts of As Suwayda and Quneytra Governorates.[5] In Jordan, the basin extends over parts of the governorates of Irbid and Mafraq, with around 443,000 inhabitants.[6]

OTHER AQUIFERS IN THE AREA

There are no other significant aquifers in the area given that all major aquifers of Quaternary, Neogene, Paleogene and Upper Cretaceous age in the area are, to a varying degree and depending on location, hydraulically connected and considered part of the Basalt Aquifer Complex in this Inventory.

INFORMATION SOURCES

Information for this chapter was mainly derived from a 1996 study,[7] in addition to more recent regional and local publications as listed in the bibliography.

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

The general configuration of the Basalt Aquifer Complex in the Yarmouk Basin can be described as follows:

- The base of the Basalt Aquifer System rises radially from around 200 m asl in the foothill zone of the Jebel al Arab Mountain range to over 500 m asl toward the margins of the basalt field. As a result of the rising aquifer base and descending groundwater surface, the saturated thickness of the basalt decreases from more than 300 m in the foothill zone to less than 100 m on the fringes of the basalt field.
- In several areas, groundwater is found at shallow to intermediate depth above the water table of the main Basalt Aquifer, in particular in the western foothill zone of the Jebel al Arab Mountain range and in the Hauran Plain around the towns of Dar'a and Ezraa.
- A complex system of perched aquifers exists within different basalt flows in the Jebel al Arab Mountain range. No extensive deep aquiferous zones are expected to exist in the deeper subsurface of the Jebel al Arab Mountain range. The core of this mountain range is probably made up of basaltic dikes and sills of the main volcanic feeder zone and by highly disturbed blocks of sedimentary rocks.
- Cretaceous and Paleogene sedimentary formations are exposed in the surroundings of the basalt field, mainly in the Rutba High (along the eastern boundary), the Jordan Uplift (along the western boundary), and the Damascus Uplift to the north.

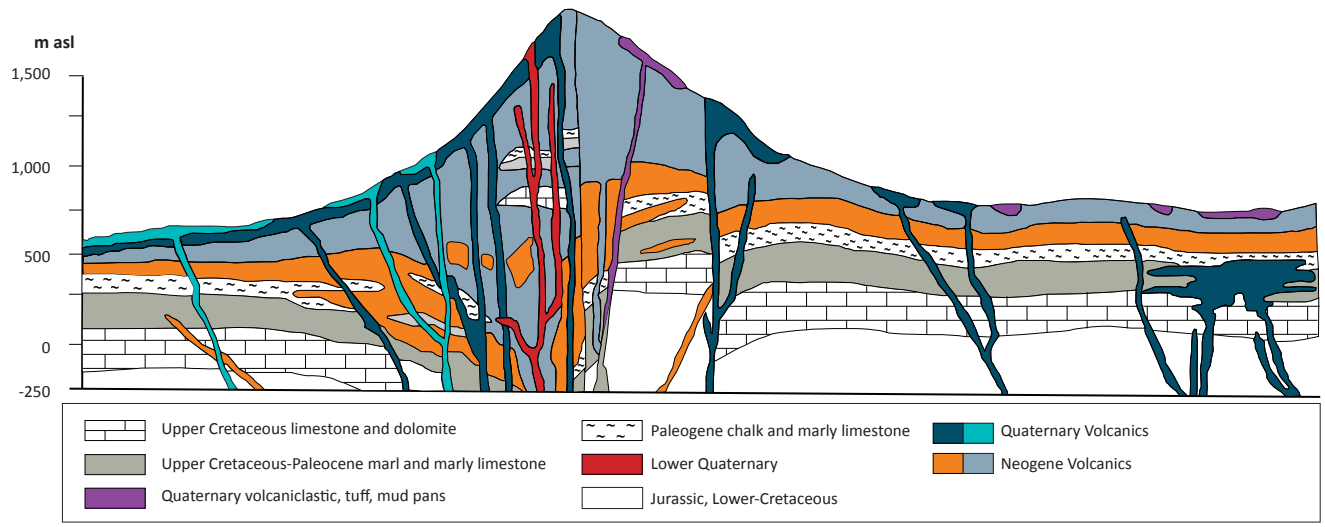
STRATIGRAPHY

The geologic sequence of the Basalt Aquifer Complex in the Yarmouk Basin is mainly composed of Neogene plateau basalts, Quaternary (Pleistocene to Recent) basaltic lava flows and shield volcanoes and carbonate rocks (Upper Cretaceous to Eocene) as indicated in Figure 1 and Table 1. The total thickness of Neogene to Quaternary basalts increases from less than 100 m on the fringes of the basalt field in the Yarmouk area to more than 700 m in the Jebel al Arab foothills.

The **Quaternary** volcanics comprise:[8]

- Basaltic lava flows, which are generally developed as narrow and relatively thin valley fillings in a pre-existing morphological relief.
- Shield basalts, which extend over larger areas and reach a maximum thickness of around 100 m with 15 m thick individual lava flows.
- Basaltic cinder, scoria and tuff.

Figure 1. Schematic geological cross-section through the Jebel al Arab Mountain range



Source: Compiled by ESCWA-BGR based on UN-ESCWA et al., 1996.

Table 1. Lithostratigraphy of volcanic and sedimentary formations in the Basalt Aquifer Complex

PERIOD	EPOCH/STAGE	LITHOLOGY	NAMES OF FORMATIONS IN JORDAN[a]
Quaternary	Upper-Middle Quaternary	Basaltic lava flows and shield basalts	Fahda Vesicular Basalt and Wadi Manasif Basalt formations, mainly in the southern part of the Azraq Basin
	Lower Quaternary	Valley filling lava flows and shield basalts	Hassan Scoriaceous, Madhala Olivine Phyric Basalt, and Abed Olivine Phyric Basalt formations; crops out in wide parts of the Azraq Basin
Tertiary	Pliocene-Miocene	Plateau basalts	..
	Eocene	Chalk, chalky limestone, chert	Wadi Shallala and Umm Rijam Formations (B4/B5)
Upper Cretaceous-Tertiary	Maastrichtian-Paleocene	Marl, chalk, bituminous limestone	Muwaqqar Formation (B3)
Upper Cretaceous	(Campanian-) Turonian-Cenomanian	Limestone, dolomite, marl	Wadi as Sir and Amman Formations (A7/B2)

Source: Compiled by ESCWA-BGR based on UN-ESCWA et al., 1996; Ibrahim, 1993; Selkhozpromexport, 1986.
(a) In Syria the formations are commonly referred to by age (epoch/stage) in combination with lithological characteristics.

The **Neogene**, mainly Pliocene, plateau basalts are composed of single lava sheets, which are crossed by numerous basaltic dikes. Individual lava sheets are generally several metres thick, and may be separated by soil or sedimentary layers. The Neogene basalt is assumed to reach a maximum thickness of about 1,500 m beneath the Jebel al Arab Mountain range.[9] Neogene basalts are exposed mainly in the east of the Yarmouk Basin. In the west of the basin, the Neogene basalts are generally covered by younger Quaternary basalts.

In the Lake Tiberias-Yarmouk area, the basalts overlie terrestrial deposits of lower Pliocene age. The thickness of the Pliocene basalts increases from a few tens of metres around Lake Tiberias to 200 m in Wadi Raqqad. A late Pliocene age sequence of basalt flows with a thickness of 30-200 m extends over wide areas of the Golan Heights. The Pliocene basalts appear to originate mainly from extrusions in the Hauran-Jebel al Arab area, while secondary extrusions (plugs, small volcanoes, fissure dykes) are scattered over the Golan Heights.

Paleogene sedimentary rocks generally underlie the basalts. In a small belt in the south of the Yarmouk Basin, the Paleogene chalks and Upper Cretaceous-Paleogene marls may be missing over a structural high, leaving the basalts in direct contact with underlying Upper Cretaceous limestones and dolomites. The Paleogene is prevailingly represented by marly sediments, which are exposed near Dar'a and underlie the basalts elsewhere across the basin. Their thickness could vary between 0 and 220 m.

Outcrops of **Upper Cretaceous** limestones and dolomites cover the south-western part of the basin and the total thickness of the formations in the area is estimated at 270-360 m or more.

AQUIFER THICKNESS

The saturated thickness of the basalt increases from less than 100 m in the Yarmouk area on the south-western fringes of the basalt field to more than 300 m in the foothill zone of the Jebel al Arab Mountain range. The Paleogene aquiferous rocks may add another 200 m to the total aquifer thickness.

AQUIFER TYPE

The basalts of the Yarmouk Basin constitute a generally unconfined main aquifer; semi-confined conditions occur locally within individual volcanic flows. Perched groundwater bodies exist, particularly in the Jebel al Arab Mountain range, where numerous small springs discharge above low permeability layers within the volcanic rock sequence.

AQUIFER PARAMETERS

Permeable horizons within the Basalt Aquifer Complex comprise 10%-20% of the total saturated thickness of the Basalt Aquifer. Accordingly, transmissivity values of between 3.47×10^{-4} and 1.5×10^{-2} m²/s and permeabilities of 2×10^{-4} to 6×10^{-4} m/s may be assumed (see Chap. 22). Relatively high well capacities, which occur in some areas, may be related to the high transmissivity of the underlying carbonate aquifers, which are hydraulically connected with the Basalt Aquifer.[10]

Transmissivity values from single well tests are reported to range from 2.8×10^{-1} to 1.2×10^{-1} m²/s in the eastern part of the Hauran Plain and the Leja Plateau in Syria. Transmissivity decreases in the western part of the basin.[11]

Well yields are relatively high around As Suwayda in the north-western part of the Jebel al Arab Mountain range, which comprises a complex sequence of aquiferous sections within the basalt with one or two perched aquifer zones above the main Basalt Aquifer. In the area west of the Jebel al Arab Mountain range (Dar'a-Ezraa-Bosra), well yields and specific capacities are low to moderate, but relatively high specific capacities are indicated for a number of wells, in which zero drawdown is observed during operation.[12]

View of Lake Tiberias and the Golan Heights from Jordan, 2011. Source: Tamra Hays.

Hydrogeology - Groundwater

RECHARGE

Favourable recharge conditions exist in areas with mean annual precipitation of more than 300 mm such as the Jebel al Arab Mountain range, the western part of the Hauran Plain and the Golan Heights. Indirect recharge occurs in wadi systems, where seasonal runoff infiltrates. Recharge conditions appear to be relatively favourable on outcrops of Neogene and Quaternary shield basalts with very limited soil cover, e.g. in the Jebel al Arab Mountain range and on the Leja Plateau.

Significant groundwater recharge from present-day precipitation is evident, particularly in the shallow groundwater of the Jebel al Arab Mountain range, the foothills near As Suwayda and in the Wadi Liwa-Leja area north-west of As Suwayda. The following factors indicate recent recharge: [13]

- The immediate response of spring discharge to the seasonal precipitation
- Low groundwater salinity
- Occurrence of perched groundwater
- Significant tritium values

Recharge volumes may be relatively low in parts of the Hauran Plain, where thick soil has developed. In general, direct and indirect recharge in the Yarmouk Basin amounts to 6% of precipitation.[14]

FLOW REGIME

In the Yarmouk Basin, groundwater flows from topographically higher areas to the main groundwater discharge zones at Wadi Hreer-Mzeirib near the Yarmouk River in the south (see Overview Map). However, these natural flow paths may have been altered by agricultural development and the drilling of hundreds of irrigation wells. This section only describes the natural flow paths.

Groundwater flows over the Hauran Plain to the discharge zone from the following locations:

- The western foothill zone of the Jebel al Arab Mountain range in the east/north-east of the basin.
- The narrow hydrologic Wadi Liwa Basin and the southern margins of the Damascus Plain in the north.
- The foothills of Mount Hermon and the eastern part of the Golan Heights in the north-west.

Groundwater temperature and salinity increase along the different flow paths, from around 11.5°C in the foothills of the different mountain ranges to 25°C in the major Yarmouk Springs in the south-west. The common outflow of the Yarmouk Basin at major spring outlets can be verified by groundwater samples collected throughout the basin. The major spring outlets discharge water of different origins: water from the Mount Hermon and the Jebel al Arab foothills is admixed with recharge water from the Hauran Plain.[15] Groundwater flow velocities range from 20 to 60 m/yr in the central Hauran Plain. Flow velocities in the major recharge areas in the Jebel al Arab Mountain range and near Mount Hermon are much smaller (1-7 m/yr).[16] The lowest groundwater ages are found in the Jebel al Arab and Mount Hermon foothills and in the Golan Heights (1,000 years), while higher groundwater ages were registered at the major springs (5,000 years). Groundwater ages of more than 10,000 years were found in the south close to the Jordanian-Syrian border, indicating very low flow velocities and recharge, possibly during the late pluvial phase of the Holocene period.[17] Groundwater from the various perched aquifers in the basalt area leaks into the deeper main groundwater system.

STORAGE

Information on groundwater storage was not available.

DISCHARGE

Major groundwater discharge from the Basalt Aquifer System (West) in the Yarmouk Basin occurs at Wadi Hreer-Mzeirib in the south-west of the basalt field near the Yarmouk River. Mean discharge of spring groups at Zeizoun amounts to 25.2 MCM/yr, while mean discharge of springs at Mzeirib and Chalalate Hreer is 44.2 MCM/yr. Several smaller springs in the area have mean discharges between 3.2 and 10.4 MCM/yr.

The total mean annual discharge of the springs is reported to be 170-177 MCM (see also Table 2).[18] However, the values were registered before intensive groundwater development took place in the basin and may not reflect current conditions.

The springs in the Wadi Hreer-Mzeirib area are mainly located on the boundary between the Basalt Aquifer and underlying marls and marly chalks of Paleogene age. The discharge points are situated at elevations of 380-440 m asl.

Around one hundred springs discharge from the Pliocene and Quaternary basalts in the Jebel al Arab Mountain range. While some larger springs have a discharge of $4x10^{-1}$-$6x10^{-1}$ MCM/yr, most springs are small with a discharge of less than $3.2x10^{-2}$ MCM/yr. Spring discharge in the area shows high seasonal fluctuations and many springs dry up during summer. Spring discharge points are located at altitudes of 1,000-1,600 m asl and generally coincide with boundaries of individual lava flows. According to an estimate[19] and reported discharge summaries,[20] total spring discharge in the Jebel al Arab Mountain range and As Suwayda area is in the order of 3.6 MCM/yr. Spring discharge comprises only about 2% of precipitation in the Jebel al Arab Mountain range and a major portion of the infiltrating rainwater is assumed to leak into the deeper groundwater system.

WATER QUALITY

Groundwater salinity in the eastern areas of the Basalt Aquifer in the Yarmouk Basin is generally low with less than 400 mg/L TDS. Salinity increases towards the west, and TDS values may locally exceed 3,000 mg/L along the boundary of the volcanic-sedimentary terrains (Figure 2). The groundwater in the Basalt Aquifer is prevailingly Na-HCO_3 or Na-Cl type water. Ca-HCO_3 type waters occur in springs in the Jebel al Arab Mountain range.

Significant Tritium Unit values (5-21 TU) are found in the Jebel al Arab Mountain range, in the western Golan Heights and at some locations on the Hauran Plateau. Mean carbon-14 ages of groundwater increase from the Jebel al Arab foothills toward the Hauran Plain and the Yarmouk discharge area. Contemporary recharge is indicated by carbon-14 values in the As Suwayda area and on the eastern Hauran Plateau. In the Yarmouk discharge area, groundwater ages are 4,000-6,000 years.[21]

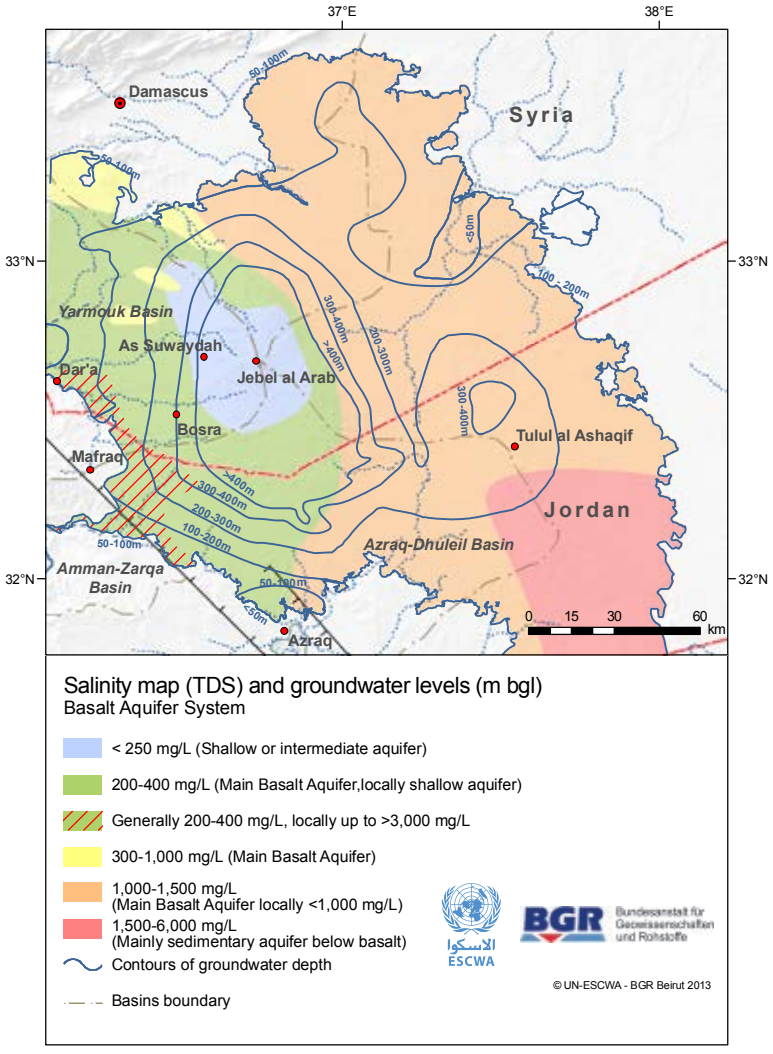
The stable isotope composition of groundwater in the Yarmouk Basin shows a rather homogeneous development from the recharge area in the Jebel al Arab Mountain range through the Hauran Plain to the Yarmouk Spring discharge area. The most negative delta-O-18 values between -6.5‰ and -8.8‰ were found in samples of shallow groundwater in the Jebel al Arab Mountain range. Delta-O-18 values of water from springs in the Mzeirib-Wadi Hreer area vary from -5.5‰ to -6‰.

Table 2. Mean annual discharge of major springs in the Yarmouk Basin

NAME	DISCHARGE (m^3/s)
Mzeirib	1.4
Zeizoun	0.8
Chalalate Hreer	1.4
7 smaller springs	1.6 (total)

Source: Compiled by ESCWA-BGR based on Bajbouj, 1982.

Figure 2. Groundwater salinity and groundwater level map – Basalt Aquifer System



Source: Compiled by ESCWA-BGR based on UN-ESCWA et al., 1996.

EXPLOITABILITY

According to the standardized exclusion criteria used to assess exploitability in this Inventory,[22] the exploitability of the aquifer basin can be described as follows:

- **Depth to top of aquifer** is not a limiting factor in this shallow aquifer system.
- **Depth to water level** exceeds 300 m in the mountainous eastern part of the basin in the Jebel al Arab Mountain range, which limits exploitability (Figure 2).
- **Water quality:** Salinity values in the Basalt Aquifer are usually <1,000 mg/L. This means that water quality does not generally constitute a limiting factor, except perhaps in certain locations in the western areas.

The findings are based on a subset of groundwater quality and groundwater level data for the eastern part of the Yarmouk Basin only[23] and further limitations to exploitability may exist in the western Yarmouk Basin and Golan Heights.

Lake Tiberias, Israel, 2010. Source: Adam Groffman.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

Groundwater is extracted from a large number of drilled wells in the Yarmouk Basin, with wells that are used mainly for agricultural purposes scattered across the western foothills of the Jebel al Arab Mountain range and the Hauran Plateau.

In Jordan, most of the abstraction in the Yarmouk Basin is not from the Basalt Aquifer System itself but from the Upper Cretaceous carbonate aquifer (A7/B2 aquifer), which is partly covered by Pleistocene basalt.[24] Disaggregated abstraction figures for the individual aquifers and locations were not available, and groundwater abstraction from the whole basin in Jordan was around 50-57 MCM/yr during the last decade.[25] In 2010, there were 166 operational wells in the basin, most of which were used for agricultural purposes.[26]

In Syria, total mean annual groundwater use in the basin was 189 MCM for the period 1999-2009,[27] with a maximum of 231 MCM in 2002/2003 (Figure 3).[28] The average surface area irrigated by groundwater during the 10-year period was 21,732 ha, which represents around 60% of the total irrigated area in the basin.[29]

Groundwater abstractions in the basin are assumed to influence the flow of the Yarmouk River. Heavy abstractions in the areas feeding the river as well as large-scale water diversion projects that were initiated in the early 1970s coincide with a significant drop in the river's discharge over the years.[30]

GROUNDWATER QUALITY ISSUES

No information was available regarding groundwater quality and pollution issues in the Yarmouk Basin. It can be assumed that agricultural drainage and wastewater disposal affect shallow groundwater in the basin, leading to locally elevated nitrate (NO_3^-), ammonia (NH_3/NH_4^+) and pathogen levels.

SUSTAINABILITY ISSUES

Detailed information regarding groundwater abstractions and the impact on water levels or spring discharge in the main basalt production areas in Syria was not available. However, the overall water balance for the Yarmouk Basin in Syria is negative for 8 of the 10 years between 1999 and 2009, with an average annual deficit of 72 MCM.[31] The flow of the Yarmouk River also shows a significant decline during that period (see Chap. 6), indicating that groundwater abstraction impacts long-term availability of groundwater reserves and is likely to have negative effects on surface flows in the basin.

Figure 3. Groundwater use and irrigated areas in the Yarmouk Basin in Syria (1999-2009)

Source: Compiled by ESCWA-BGR based on Ministry of Irrigation in the Syrian Arab Republic, 2012.

BOX 1

The Golan Heights

Geographically, the Golan Heights encompass an area of 1,860 km^2, extending from the Jordan River in the west to Wadi Raqqad in the east, from the foothills of Mount Hermon in the north to the Yarmouk River in the south. Morphologically, the Golan Heights belong to the Hauran Plain. The Golan Heights rise from 211 m bsl near Lake Tiberias to 1,350 m asl near the Mount Hermon foothills. Most of the wadis drain towards the west, except for some wadis in the south, which drain to the Yarmouk River. Precipitation varies from more than 1,200 mm in the north (in the vicinity of Mount Hermon) to 500 mm in the south.[a] The Golan Heights are situated in Syria, but have been occupied by Israel since 1967. The area that encompasses the Golan Heights and the slopes of Mount Hermon has an estimated population of 40,400 inhabitants.[b] The region's economy is based on agriculture, industry and tourism.

Geologically, the Golan Heights consist of different basalt sheets which are intercalated with clayey paleosoils. The Pliocene- to Pleistocene-age basalts (Bashan Group)[c] were deposited in the syncline between the Hermon Anticline in the north and the Ajlun Anticline in the south.[d] The deposition of the layers resulted in the creation of a small elevated plateau: the Golan Heights. The feeding zones of the deposited sheet basalts are two volcanic cone belts, which are located in the eastern part of the Golan.[e] The maximum thickness of the basalt layers is 700-750 m, thinning to around 50 m near the Yarmouk River in the south and on the slopes of Mount Hermon in the north. However, estimates vary and some sources also report a maximum thickness of 1,100 m.[f]

Hydrogeologically, the Golan Heights can be roughly subdivided into two different subsurface basins. The western basin, here referred to as Golan Basin (see Overview Map), drains towards the Hula Graben and Upper Jordan River,[g] to which it contributes an estimated 21 MCM/yr.[e] The eastern basin of the Golan Heights belongs to the Yarmouk Basin and drains towards the Yarmouk River where most of it discharges via spring outlets in Wadi Raqqad.[e] However, the location of the water divide is dynamic, not static, and may therefore shift with time depending on the groundwater abstraction in the two basins.

The almost impermeable uppermost Cretaceous chalk and chalky limestone layers (Mt. Scopus Group) underlie the basalt layers. However, in some areas in the north and south, the basalt layers are in contact with the Upper Cretaceous limestone aquifer (Judea Group)[i] and with the Miocene conglomerates (Hordos Fm).[i] The aquifer system is therefore almost completely detached from underlying aquifer systems. According to a 2002 water balance, underlying aquifers in the northern and southern areas may only contribute around 2.5 MCM/yr to the Basalt Aquifer.[j]

More than 200 basaltic springs discharge in the Golan. Most of them are seasonal perched springs with a small discharge.[e] Other larger springs are mainly located on the north-western slopes of the Golan. The springs are referred to as "side springs".[e] Their average annual discharge was 46.7 MCM during the period 1987-2005.[a] Before the occupation of the Golan, only a few wells existed in the area. Abstraction increased gradually from 3x10^{-1} MCM/yr in 1979/80 to around 5 MCM/yr in the mid-1990s and 11.7 MCM/yr in 2000/2001.

Only locally perched aquifers exist in the southern Golan, where groundwater discharges via small local springs.[k] Mean annual recharge rates to the Golan Basalt Aquifer varied from 12% to 16% of total annual precipitation, based on the application of the chloride method at the Golan Side Springs between 2002 and 2004.[l] According to stable isotope analyses, evaporation is higher in the southern springs than in the springs in the middle and northern Golan.[l] Groundwater composition is fairly homogenous throughout the system and shows slight mineralization. The predominant water type is Ca-Na-HCO_3.[k]

(a) HSI, 2006.
(b) Central Bureau of Statistics in Israel, 2009.
(c) Mor, 1986; Heimann, 1990.
(d) Michelson, 1979 in Dafny et al., 2003.
(e) Dafny et al., 2003.
(f) Reshef et al., 2003 and Meiler et al., 2011. A detailed isopach map of the basalt layers can be found in Dafny et al., 2003. More detailed information can be found in Burdon, 1954; Wolfart, 1966; Mor, 1986; Heimann, 1990; Hirsch et al., 2001; Dafny et al., 2003; Shulman et al., 2004 and Dafny et al., 2006.
(g) Siebert, 2005.
(h) Michelson 1972, 1979; Gilead, 1988 in Dafny et al., 2003.
(i) Kafri and Heimann, 1994.
(j) Dafny, 2002.
(k) Dafny et al., 2006.
(l) Brielmann, 2008.

Mount Hermon in the Golan Heights, Syria, 2008. Source: Adel Samara.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no formal water agreements in place for the Basalt Aquifer System (West), which is shared between Jordan and Syria. However, the 1987 agreement concerning the use of the Yarmouk waters contains provisions that indirectly refer to the use of springs issuing from the aquifer.[32]

COOPERATION

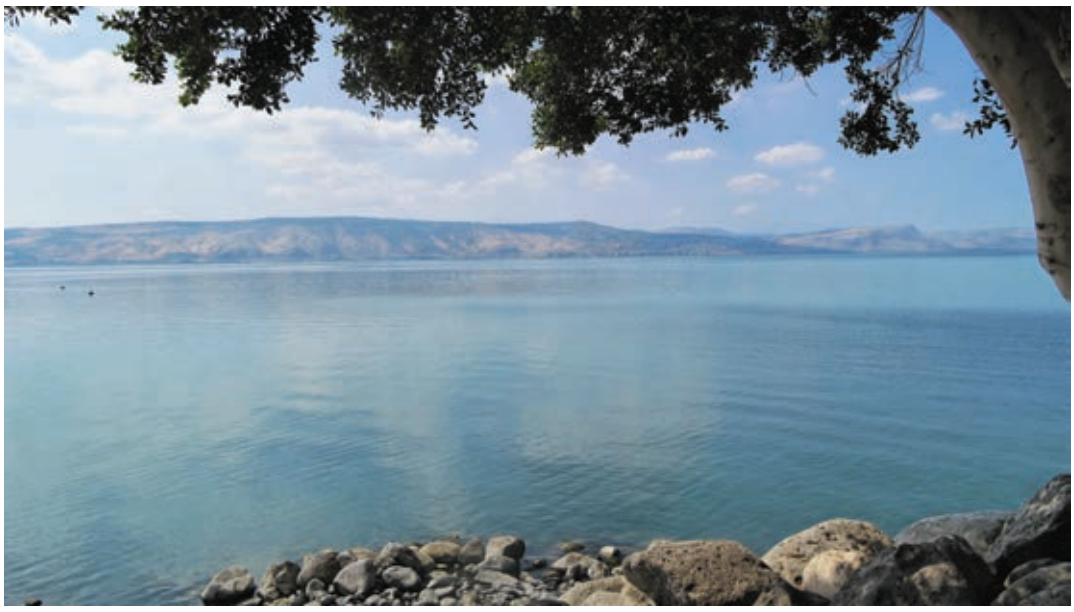
In accordance with the 1987 bilateral agreement, Jordan and Syria established the Jordanian-Syrian Yarmouk River Basin Higher Committee, which brings together representatives from the Jordan Valley Authority and the Syrian Ministry of Irrigation in regular meetings to discuss issues such as floodwater storage, prevention of illegal agricultural activities and the control of unregulated groundwater pumping.[33]

In the early 1990s, ESCWA and BGR facilitated cooperation between the Ministry of Water and Irrigation in Jordan and the Ministry of Irrigation in Syria to investigate and monitor groundwater resources in the Basalt Aquifer System.[34] This process was, however, discontinued shortly afterwards.

In 2009, the two countries commissioned a joint study to evaluate the quantity and quality of water resources in the Yarmouk River Basin, identify the causes of their depletion and propose ways of protecting the basin from pollution and arbitrary pumping.[35]

OUTLOOK

The Yarmouk River Basin has seen a hydrological decline in recent decades as manifested by a marked reduction in discharge and the lack of water in the Wahdah Dam reservoir since its construction (see Chap. 6). This has repeatedly sparked tensions between Jordanian and Syrian authorities and no consensus has been reached as to the causes of the observed changes. However, it is known that groundwater and surface water in the Yarmouk Basin are closely interlinked, and that the Basalt Aquifer plays a central role in its hydrology. A thorough assessment of the history, state and impact of groundwater development in the Yarmouk Basin would therefore be an important reference for the two riparian countries, and in the context of water use in the Jordan River Basin as a whole, to which the basalts of the Yarmouk Basin are hydrologically connected.



Lake Tiberias, Israel, 2010. Source Adam Groffman.

Notes

1. The aquifer system has also been referred to as Jebel al Arab Aquifer based on the name of the mountain range (altitude: ≤1,800 m asl).
2. In the original study of the regional basalt aquifer system (UN-ESCWA et al., 1996), the Azraq and Dhuleil were considered to be separate basins on the basis of surface drainage and morphology. From a hydrogeological perspective, however, the two basins can be merged into one, since a significant part of groundwater in the Dhuleil Basin flows into the Azraq Basin in the area of the main discharge zone.
3. While the Golan Basin is not considered a shared aquifer, most of its basin area has been occupied by Israel since 1967 and the aquifer here discharges into the transboundary Jordan River Basin. Box 1 provides an overview of the Golan Basin.
4. UN-ESCWA et al., 1996.
5. Based on a 2004 population census (Central Bureau of Statistics in the Syrian Arab Republic, 2005) and 2010 estimates (Central Bureau of Statistics in the Syrian Arab Republic, 2011).
6. Based on 2011 estimates by Department of Statistics in Jordan, 2012. Small parts of Ajloun and Jerash Governorates are also included, but these areas are very sparsely populated.
7. UN-ESCWA et al., 1996.
8. Ibid.
9. Krasnov et al., 1966.
10. UN-ESCWA et al., 1996; Schelkes, 1997.
11. Bajbouj, 1982.
12. UN-ESCWA et al., 1996.
13. Ibid.
14. Schelkes, 1997; Wagner, 2011.
15. Droubi, 1991.
16. Kattan, 1996.
17. Ibid.
18. Burdon, 1954; Bajbouj, 1982.
19. Burdon, 1954.
20. UN-ESCWA et al., 1996.
21. Ibid.
22. The following criteria are used to assess exploitability in this Inventory: drilling depth/depth to top of aquifer; groundwater level; and water quality/salinity. For more information on the approach, see 'Overview & Methodology: Groundwater' chapter.
23. The study 'Investigation of the Regional Basalt Aquifer System in Jordan and the Syrian Arab Republic' (1996) covers only the eastern part of the Yarmouk Basin as delineated here. No data was available for the western part, including the Golan Heights.
24. Other main aquifers in the Yarmouk Basin in Jordan are A4, A1, 2 and Kurnub Sandstone (K).
25. Abstractions from the basin amounted to 57 MCM, 55 MCM and 49.9 MCM for the years 2002, 2003 and 2010 respectively (USAID, 2012; El-Naqa and Al-Shayeb, 2009). The safe yield is estimated at 40 MCM/yr.
26. USAID, 2012.
27. This represents around 58% of the total water used.
28. Ministry of Irrigation in the Syrian Arab Republic, 2012. Assuming that groundwater is only used for irrigation in the basin, the groundwater deficit for the period 1999-2009 was 4 MCM.
29. Ministry of Irrigation in the Syrian Arab Republic, 2012.
30. See Chap. 6 for more information on the Yarmouk River.
31. Ministry of Irrigation in the Syrian Arab Republic, 2012.
32. Article VII of the agreement stipulates: "Syria shall retain the right to the use of waters of all springs welling up within its territory in the basin of the Yarmuk and its tributaries, with the exception of the waters welling up above the dam below the 250-metre level..." (The Syrian Arab Republic and Jordan, 1987).
33. See Chap. 6 for more information.
34. UN-ESCWA et al., 1996.
35. Ministry of Water and Irrigation in Jordan, 2011. See also Jordan Times, 2009.

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Chapter 22

Azraq-Dhuleil Basin

Basalt Aquifer System (South)

Basalt Aquifer System (South)

Azraq-Dhuleil Basin

EXECUTIVE SUMMARY

The Azraq-Dhuleil Basin extends over the south-eastern part of the Jebel al Arab basalt field in south-western Syria and north-eastern Jordan, comprising the catchment of the Azraq groundwater discharge area between the Jebel al Arab Mountain range in the north, the north-eastern desert in Jordan and the Azraq Plain.

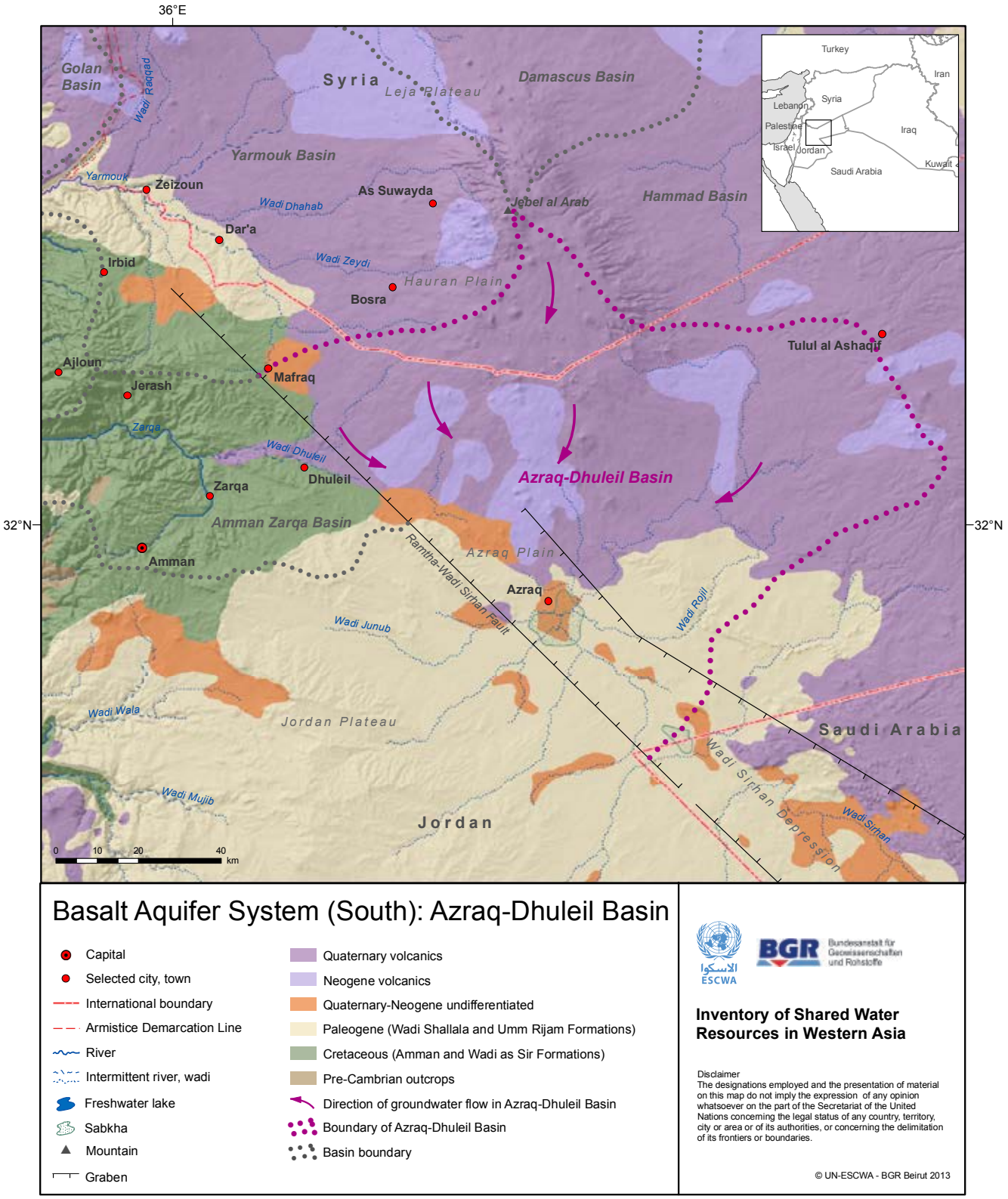
Groundwater in the Basalt Aquifer System of the Azraq-Dhuleil Basin flows from topographically higher parts of the catchment to the major discharge zone in the Azraq area in the south. The groundwater flow regime extends over a combined aquifer system constituted mainly of permeable layers in Neogene-Quaternary basalts and underlying Paleogene chalky limestones. In the Dhuleil area in the west of the Azraq-Dhuleil Basin, the aquifer system also includes Upper Cretaceous limestones and dolomites.

Groundwater discharge appears to be maintained largely by present-day recharge over wide catchment areas with travel periods of more than 20,000 years. Discharge from springs in the Azraq area ceased completely after the creation of a large well field in the area in 1980. Groundwater quality has deteriorated as a result of the infiltration of irrigation return flows in downstream areas where intensive irrigation takes place.

BASIN FACTS

RIPARIAN COUNTRIES	Jordan, Syria
ALTERNATIVE NAMES	-
RENEWABILITY	South: medium North: high
HYDRAULIC LINKAGE WITH SURFACE WATER	Medium to low (2-100 mm/yr)
ROCK TYPE	Fractured to mixed
AQUIFER TYPE	Unconfined
EXTENT	8,500 km^2
AGE	Neogene-Quaternary, Paleogene, Upper Cretaceous
LITHOLOGY	Basalt, limestone
THICKNESS	<100m - >500m
AVERAGE ANNUAL ABSTRACTION	Northern part: 15-20 MCM
STORAGE	-
WATER QUALITY	Mainly fresh, brackish in some areas
WATER USE	Agricultural and domestic
AGREEMENTS	..
SUSTAINABILITY	Groundwater level decline and salinization due to over-abstraction

OVERVIEW MAP



Basalt Aquifer System (South): Azraq-Dhuleil Basin

- Capital
- Selected city, town
- International boundary
- Armistice Demarcation Line
- River
- Intermittent river, wadi
- Freshwater lake
- Sabkha
- Mountain
- Graben
- Quaternary volcanics
- Neogene volcanics
- Quaternary-Neogene undifferentiated
- Paleogene (Wadi Shallala and Umm Rijam Formations)
- Cretaceous (Amman and Wadi as Sir Formations)
- Pre-Cambrian outcrops
- Direction of groundwater flow in Azraq-Dhuleil Basin
- Boundary of Azraq-Dhuleil Basin
- Basin boundary

ESCWA

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

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The Basalt Aquifer System in this Inventory

The Quaternary-Neogene basalts of the North Arabian Volcanic Province extend from south-western Syria through eastern Jordan into Saudi Arabia over a total length of around 460 km and with a width of 50-150 km.

They cover an area of approximately 48,000 km^2, of which 11,000 km^2 is located in Jordan, 23,000 km^2 in Saudi Arabia and 14,000 km^2 in Syria. The basalts generally overlie sedimentary formations of Paleogene and Cretaceous ages (see Figure 1, Chap. 21) and are hydraulically connected with them to form a complex aquifer system that is denoted as the Basalt Aquifer Complex in this Inventory.[1] This volcano-sedimentary complex extends across the boundaries of Jordan, Saudi Arabia and Syria (see 'Overview and Methodology: Groundwater' chapter) to constitute shared aquifer systems in the following basins:

Yarmouk Basin

The basin extends across the border of Syria and Jordan and the aquifer system within the basin is denoted as the Basalt Aquifer System (West) (see Chap. 21). In the basin, the basalts generally overlie the Paleogene (Shallala-Rijam) formations, except in certain structurally high locations where the Paleogene is missing and the basalts come in direct contact with the Cretaceous (Amman-Wadi as Sir) formations.

Azraq-Dhuleil Basin

The basin[2] also extends across the border of Syria and Jordan, and the aquifer system within the basin is referred to as the Basalt Aquifer System (South-East) (see current chapter). In the basin, the basalts are hydraulically connected with the Paleogene (Shallala-Rijam) formations in the eastern areas and the Cretaceous (Amman-Wadi as Sir) formations in the western areas to form one aquifer system with both formations.

Wadi Sirhan Basin

The basin extends across the border of Jordan and Saudi Arabia and the aquifer system within the basin is denoted as the Tawil-Quaternary Aquifer System (see Chap. 17). In the basin, the Quaternary-Neogene basalts and alluvium form the upper part of a thick aquifer system that comprises both the Paleogene and Cretaceous (Tawil-Sharawra) formations.

The Basalt Aquifer Complex, which was originally delineated on the basis of surface drainage and morphology, comprises three other basins that are of less relevance as shared aquifers. They are therefore not covered in separate chapters in this Inventory. The **Golan Basin**[3] and **Damascus Basin** lie entirely in Syria, the **Amman-Zarqa Basin** lies entirely in Jordan while the basalts in the **Hammad Basin** are practically dewatered.[4]

The basalt rock formations in the area of Al Lajat, north of Suweida, Syria, 2009. Source: Adel Samara.

Introduction

LOCATION

The Basalt Aquifer System (South-East), hereafter referred to as Azraq-Dhuleil Basin, extends from the southern border of the Jebel al Arab basalt field in Jordan and Syria to the Azraq Depression along the main Ramtha-Wadi Sirhan Fault System (see Overview Map).

AREA

The morphology of the basin is dominated by the 1,800 m peaks of the Jebel al Arab Mountain range in the north, with altitudes dropping below 500 m in the Azraq Plain (Qaa al Azraq) in the south. Prominent volcanic peaks are scattered throughout the Jebel al Arab Mountain range and the plateaus to the south. In the east, the area around Tulul al Ashaqif constitutes a major mountainous zone in north-eastern Jordan (900 m).

Surface water divides have been used to define the boundary of the Azraq-Dhuleil Basin with neighbouring basins (Yarmouk Basin in the north-west; Amman-Zarqa Basin in the west; and Hammad Basin in the east). In the south-west, the Ramtha-Wadi Sirhan Fault System separates it from the eastern Jordanian limestone plateau, which comprises Mesozoic to Paleogene sedimentary sequences.[5] Based on this delineation, the Azraq-Dhuleil Basin covers an overall area of 8,500 km^2, of which 7,610 km^2 is in Jordan and 890 km^2 in Syria. About 6,450 km^2 is covered in outcrops of basaltic rocks. The area of basalt outcrop is about 6,500 km^2. The basalts are covered by Quaternary sabkha or alluvial deposits in local morphologic depressions, such as the Azraq Plain. Basalts are not present in the southern part of the Azraq-Dhuleil Basin, which drains from the eastern Jordanian Limestone Plateau.

CLIMATE

The Azraq sub-basin is predominantly arid with an average precipitation of 87 mm/yr during the period 1967-1995, most of which occured as storms between January and March.[6] The basalt plateau on the northern tip of the sub-basin forms an exception: precipitation can reach 500 mm on the slopes of Jebel al Arab.[7]

POPULATION

The Azraq-Dhuleil Basin has an estimated total population of 126,900 inhabitants with a low population density. In Syria, the basin falls within a small part of As Suwayda Governorate, with around 43,600 inhabitants in the area.[8] The Jordanian part of the topographic Azraq-Dhuleil Basin has a population of around 83,300 inhabitants, comprising parts of the governorates of Mafraq and Zarqa.[9]

OTHER AQUIFERS IN THE AREA

The Azraq-Dhuleil Basin is underlain by the sandstones of the Kurnub-Ram Formations, which form a deeper aquifer system. Across the basin, the Ajlun aquitard seperates the sandstones from the Basalt Aquifer Complex.[10]

INFORMATION SOURCES

Information for this chapter was mainly derived from a 1996 study,[11] in addition to more recent regional and local publications as listed in the bibliography.

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

The Basalt Aquifer is underlain by aquiferous Paleogene carbonates, which appear to form a combined aquifer system with the basalts in most parts of the basin. In the north-western part of the basin, the basalts directly overlie Upper Cretaceous carbonates to form a joint aquifer.

The Wadi Sirhan Graben system extends to the north-western border of Jordan, across the centre of the Azraq-Dhuleil Basin, where it is known locally as the Azraq Graben or Azraq Depression (see Overview Map). The Ramtha-Wadi Sirhan Fault limited the extrusion of the basalts towards the west, except in the Wadi Dhuleil area. The combined effect of the two major structures has resulted in the creation of a complex groundwater divide. As a result, the flow from the Jebel al Arab area into the eastern areas of the Amman-Zarqa Basin is directed towards the Azraq Plain (see Overview Map).

In the northern part of the basin, the basalts are intercalated with the Wadi Shallala and Umm Rijam Formations, and separated from the Wadi as Sir and Amman Formations by the marls and marly limestones of the Muwaqqar Formation.[12] In the southern areas, the Azraq-Dhuleil Basin is largely covered by the Wadi Shallala and Umm Rijam Formations.

STRATIGRAPHY

The geologic sequence of the basalt complex in the Azraq-Dhuleil Basin is composed of Neogene plateau basalts and Quaternary (Pleistocene to recent) basaltic lava flows and shield volcanoes (see Chap. 21, Table 1). The total thickness of the Neogene to Quaternary basalts increases from less than 100 m on the southern fringes of the basalt field to more than 700 m on the slopes of the Jebel al Arab Mountain range.

Neogene basalts are exposed in the Jebel al Arab area on the northern tip of the Azraq sub-basin and to the east and south-east of this area. Neogene, mainly Pliocene, plateau basalts are made up of numerous lava sheets. Individual lava sheets are generally several metres thick, and may be separated by soil and sedimentary layers. Basaltic dykes cross the sequence of Neogene basalts. The Neogene basalts probably reach a maximum thickness of about 1,500 m beneath the Jebel al Arab Mountain range.[13]

The Quaternary volcanics are more common in the western areas, mainly within the Azraq Graben. They are composed mainly of lava flows and shield basalts. Quaternary lava flows have a total thickness of a few metres to 150 m and fill valleys in a pre-existing morphologic relief. While the Quaternary lava flows are generally narrow and relatively thin, Quaternary shield basalts may cover considerable areas with a thickness of up to 100 m. Occurrences of basaltic cinder, scoria and tuff are scattered over the Quaternary basalt field.

In most areas of the Azraq-Dhuleil Basin, the basalts rest on Paleogene sedimentary rocks. They form the main outcrops in the areas adjoining the basalt field to the west, where the Wadi as Sir and Amman Formations are exposed. To the south, the formations are in the subsurface, separated from the outcropping Wadi Shallala and Umm Rijam Formations by the Ajlun Group. In the Dhuleil area in the south-west of the Azraq-Dhuleil Basin, the Paleogene chalks and Upper Cretaceous-Paleogene marls are missing over a structural high and the basalts lie directly above Upper Cretaceous limestones and dolomites.

AQUIFER THICKNESS

The saturated thickness of the basalt decreases from more than 300 m on the slopes of the Jebel al Arab Mountain range to less than 100 m on the southern fringes of the basalt field. The combined thickness of the Wadi Shallala and Umm Rijam Formations ranges between a few metres in erosional areas to about 500 m in the Azraq Depression.[14] The thickness of the Wadi as Sir and Amman Formation also decreases progressively from about 300 m near the Fuluk Fault to around 100 m in the areas to the west.

AQUIFER TYPE

The Jebel al Arab basalts constitute a generally unconfined main aquifer; semi-confined conditions occur locally within individual volcanic flows. The Wadi as Sir and Amman

Aquifer is unconfined in the Dhuleil area[15] but confining conditions arise towards the east where the main part of the basin is covered by the Muwaqqar Formation. The Wadi Shallala and Umm Rijam Aquifer is mainly unconfined.

AQUIFER PARAMETERS

Up to 50% of the rock sequence in the Jebel al Arab Basalt Complex consists of porous basalts. Horizontal groundwater flow is, however, generally restricted to permeable layers on the boundaries of individual lava flows. Fractures created by cooling of the basalt or by tectonic movements allow for vertical interconnections between the permeable layers. Layers with interconnected porosity may be assumed to comprise 10%-20% of the total saturated thickness of the basalt complex.

Transmissivity values of the Basalt Aquifer System in the Azraq-Dhuleil Basin in Jordan are estimated to range between $5.6x10^{-4}$ and $0.51m^2/s$. Mean discharge rate values in different areas of the Basalt Aquifer System (South-East) are 1-40 m^2/h corresponding with transmissivity values of between $3.47x10^{-4}$ and $1.50x10^{-2}$ m^2/s.[16] The basalt sequence has a thickness of 100-300 m. If a distribution of 20% permeable layers is assumed, transmissivity values can be calculated at around $1.0x10^{-2}$ m^2/s with corresponding permeabilities of $2x10^{-4}$ to $6x10^{-4}$ m/s.

In areas where the basalts form a hydraulically connected aquifer with underlying carbonate rocks, relatively high well capacities are found.[17] In the Azraq and Wadi Dhuleil areas and in the northern desert of Jordan east of Mafraq, relatively high well yields (above $3.5x10^{-1}$ MCM/yr and median discharge rate values of 32 to 39 m^2/h) may be related to an elevated transmissivity of Cretaceous limestones and dolomites underlying the Basalt Aquifer. However, in the Mafraq area itself, no interaction between the basalt and the Upper Cretaceous limestone aquifer exists.[18]

Agriculture in the area of Azraq, Jordan, 2009. Source: David L. Kennedy, Aerial Photographic Archive for Archaeology in the Middle East.

Hydrogeology - Groundwater

RECHARGE

Favourable recharge conditions exist on the southern slopes of the Jebel al Arab Mountain range, where mean annual precipitation reaches up to 500 mm. Relatively high recharge may also occur in sections of wadi systems where runoff is collected from extensive catchments, and on outcrops of Neogene and Quaternary shield basalts which have very limited soil cover. Recharge volumes in some areas appear to be restricted mainly to local indirect recharge in wadi systems, in particular in the arid eastern and south-eastern parts of the Azraq-Dhuleil Basin.

In general, direct and indirect recharge in the Azraq-Dhuleil Basin amounts to around 3% of precipitation, increasing to 6% in the semi-arid northern parts.[19] Total recharge in the Azraq-Dhuleil Basin is estimated at 37.3 MCM/yr. Annual groundwater recharge has been estimated as follows for different parts of the Azraq-Dhuleil Basin:

- 13.5 MCM in the semi-arid northern catchment of the Azraq sub-basin (6% of 150-250 mm over 1,260 km^2).
- 10.8 MCM in the arid eastern catchment of the Azraq sub-basin (2.4 mm over 4,500 km^2).
- 13 MCM in the Wadi Dhuleil catchment (1,320 km^2).

Most samples from bore-holes in northern Jordan (the Mafraq area, the north-eastern desert in Jordan and the basalt area north of Azraq) have an isotopic signature indicating recharge on the slopes of Jebel al Arab and groundwater movement over long distances with retention periods of 6,000 to 16,000 years. In the arid north-eastern parts of the basalt region, bore-hole tests revealed fossil groundwater with groundwater ages of more than 20,000 years and stable isotope composition characteristic of recharge during previous pluvial periods.[20]

FLOW REGIME

Under natural conditions, groundwater in the Azraq-Dhuleil Basin flows southward from the Jebel al Arab Mountain range in Syria to the Azraq discharge zone in Jordan (see Overview Map). Depth to groundwater in the main Basalt Aquifer ranges from more than 400 m bgl in the topographically higher areas to less than 50 m on the southern fringes of the basalt field (see Chap. 21, Fig. 2). Most of the water in the Azraq area originates from the Basalt Aquifer.[21]

In some parts of the Dhuleil area west of the Azraq-Dhuleil Basin, groundwater flow in the basalt and the underlying Upper Cretaceous aquifer may be directed toward the Zarqa River in the west. The groundwater regime is, however, highly disturbed by groundwater extraction.

STORAGE

Information on groundwater storage was not available.

DISCHARGE

The major groundwater discharge area in the Azraq-Dhuleil Basin is situated at Azraq on the southern margin of the basin. Previously, groundwater in the Azraq area in Jordan discharged from four major springs: the freshwater Aura and Mustadhema and the brackish Souda and Qaysiyeh Springs (Table 1). Prior to the development of groundwater resources in the region, spring discharge and evapotranspiration in the Qaa al Azraq, a plain with swamps and salt flats,[22] was 16 MCM/yr. It appears to have been largely sustained by present-day recharge, which occurs chiefly in the mountainous northern parts of the catchment. Spring discharge decreased significantly after 1980 with the establishment of a new well field, which tapped the Basalt Aquifer and Paleogene chalk aquifer upstream of the spring discharge area.[23] The springs are reported to have run dry between 1991 and 1993.[24]

WATER QUALITY

Groundwater salinity in the Basalt Aquifer in the western part of the Azraq-Dhuleil Basin is generally low to moderate (see Chap. 21, Figure 2). TDS values range between 200 and 400 mg/L, while most of the groundwater is Na-HCO_3 or Na-Cl type.

The hydrochemical composition may be related to the low chemical reactivity of the basaltic silicate rocks; solution processes of carbonate and silicate minerals probably contribute to dissolved solids.

Higher TDS concentrations up to several thousand mg/L are found on the south-western fringes of the basalt field, where the basalts form a joint aquifer with underlying sedimentary formations.[25] In the Azraq Plain, high groundwater salinity rates can probably be attributed to the infiltration of irrigation return flow and evaporative salt enrichment.
In the arid south-eastern parts of the Azraq-Dhuleil Basin, groundwater salinity is generally 1,000-1,500 mg/L TDS.

In the Azraq Plain area, groundwater in the shallow aquifer has high salinity levels originating from several sources, including infiltration from the underlying saline Umm Rijam Aquifer[26] and infiltration of shallow groundwater in the plain, which is affected by evaporative enrichment of dissolved substances.[27] The sabkha area of the Azraq Plain contains saline groundwater.

Groundwater salinity in the south-eastern part of the Azraq-Dhuleil Basin is generally more than 1,000 mg/L TDS. In general, the elevated groundwater salinity can be attributed to the arid climate with very low recharge rates, high evaporative enrichment of the limited quantities of infiltrating water, and low rates of groundwater circulation and flushing of aquifers. Freshwater occurrences appear to be restricted mainly to lenses along major wadi courses.

Mean carbon-14 ages of groundwater indicate contemporary recharge on the slopes of the Jebel al Arab Mountain range as compared to the Azraq area, where an increase to between 8,000 and 15,000 years is observed.[28] Delta-O-18 values of groundwater in the Azraq-Dhuleil Basin generally range from -5.5‰ to -6.5‰ and are consistent with a groundwater movement over long distances from the slopes of the Jebel al Arab Mountains towards the Jordanian part of the basalt field. In the areas where intensive irrigation is practised near Azraq and in Wadi Dhuleil, the stable isotope values of the groundwater show a dominant influence of irrigation return flow.[29]

Table 1. Mean annual discharge of major springs in the Azraq area in 1982

NAME	MEAN ANNUAL DISCHARGE (MCM)
Aura	1.5
Mustadhema	0.7
Souda	2.4
Qaysiyeh	5.4

Source: Compiled by ESCWA-BGR based on UN-ESCWA et al., 1996.

EXPLOITABILITY

According to the standardized exclusion criteria used to assess exploitability in this Inventory,[30] the aquifer basin is characterized by limited exploitability in the northern and eastern areas as follows:

- **Depth to top of aquifer** is not a limiting factor in this shallow aquifer basin.
- **Depth to water level** exceeds 300 m in most or all of the main recharging areas in the northern part of the basin (see Chap. 21, Figure 2). Accordingly, exploitability of the aquifer in the Azraq-Dhuleil Basin is limited in Syria and in areas close to the Jordanian border.
- **Water quality:** Salinity varies within the basin, with values of less than 250 mg/L in the Jebel al Arab Mountain range in the north, increasing to over 1,500 mg/L on the eastern fringes of the basin (see Chap. 21, Figure 2). Salinity may limit exploitability, especially in the arid eastern part of the basin.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

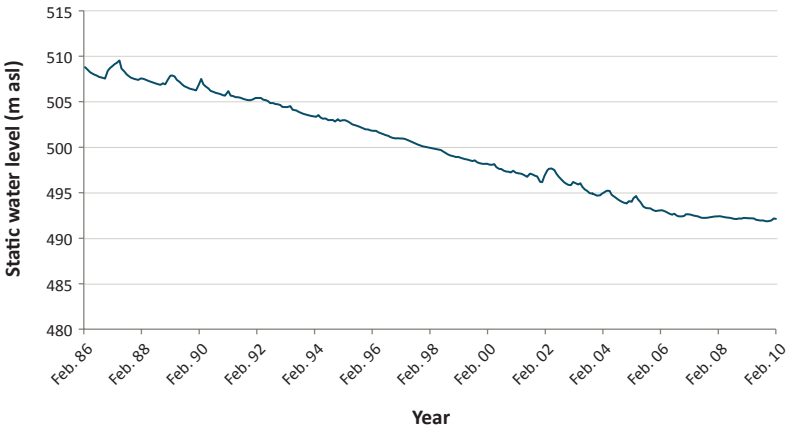
In Jordan, groundwater from the Azraq-Dhuleil Basin is used for domestic and agricultural purposes. The aquifer in the basin is exploited through a large number of drilled wells. The Azraq-Dhuleil Basin currently provides 25% of Amman's potable water.[31] Agricultural wells, which are mainly used to irrigate olive trees, are concentrated in the north-eastern desert east of Mafraq, and in the Dhuleil and Azraq areas in Jordan.[32] Most of the abstraction in the Azraq-Dhuleil Basin in Jordan is not from the Basalt Aquifer, but from the Eocene (B4) aquifer, especially in the Azraq Plain and the southern part of the basin. In Wadi Dhuleil in the south-west of the Azraq-Dhuleil Basin, wells mainly tap the Upper Cretaceous carbonate aquifer (A7/B2 aquifer), which is partly covered by Pleistocene basalt. Disaggregated abstraction figures for the individual aquifers and locations were not available.

While the first wells in Azraq were drilled in the 1930s, irrigated agriculture only took off in the 1960s with the introduction of diesel motor pumps. The introduction of modern irrigation techniques that were already in use in the Jordan Valley led to an agricultural boom in the highlands in the late 1970s and 1980s. In 1980, agricultural water in the Azraq-Dhuleil Basin originated entirely from the springs, which naturally discharged on the surface. However, over the past three decades, the absence of regulations to limit agricultural expansion has led to a sharp rise in groundwater use.[33] In the Azraq region in particular, total agricultural land area has risen from 756.6 ha in 1980 to around 8,803 ha in 2010.[34] In addition, groundwater from the Amman Water Sewerage Authority (AWSA) well field north of Azraq supplies domestic water to Amman, Irbid and Zarqa since the early 1980s.[35]

Total abstraction in the basin nearly tripled after 1980, increasing from 21.6 MCM/yr in 1983 to 58.5 MCM/yr in 2004. As a result, the water table has dropped at a rate of $3x10^{-1}$-$8x10^{-1}$ m/yr[36] (Figure 1), creating serious water quantity and quality problems. Since 2004, some farms have been abandoned as a result of the steep decline in groundwater levels, reduced well productivity and rising salinity – especially around the town of Azraq. However, groundwater over-abstraction continues to be a problem in the basin, with abstractions reaching 215% of the safe yield.[37] In 2009, total annual abstraction from 960 wells in the basin reached 51.16 MCM, of which 27.5 MCM were used for agricultural purposes, 22.9 MCM for drinking water and $7.6x10^{-1}$ MCM for other purposes.[38]

Satellite images of the Syrian part of the Azraq-Dhuleil Basin also show agricultural development, but no information was available regarding wells or abstraction figures.

Figure 1. Groundwater level in observation well F1043 near the AWSA well field in the Azraq Plain



Source: Modified by ESCWA-BGR based on Alraggad and Jasem, 2010.

Azraq Oasis, Jordan, 1997. Source: David L. Kennedy, Aerial Photographic Archive for Archaeology in the Middle East.

GROUNDWATER QUALITY ISSUES

Groundwater quality and sustainability are obviously affected by the high rates of abstraction from the Basalt Aquifer System. In the Dhuleil and Azraq areas in Jordan, heavy groundwater abstraction for irrigation has resulted in soil salinization, deterioration of groundwater quality and depletion of water resources (Figure 1). The drying up of major springs in the Azraq Plain has destroyed a unique desert oasis environment.

In 1994/95 the Jordanian Government decided to pump $5x10^{-1}$ MCM/yr to keep the oasis alive. However, feeding the former oasis with pumped groundwater led to an increase in groundwater salinity in the area, as the hydraulic system of the oasis was reversed from a point of discharge to a point of groundwater recharge. Salts are now actively washed down into the shallow aquifer (Figure 2).[39]

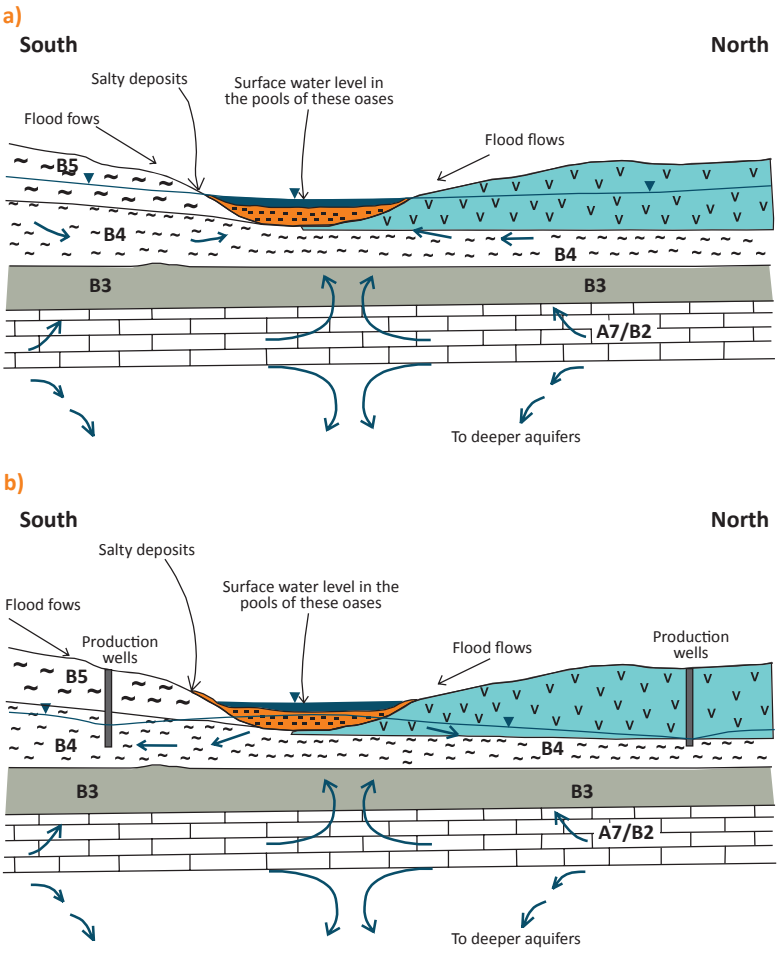
Groundwater exploitation at moderate rates is not expected to significantly affect the resources in distant downstream areas. Operation of well fields with high discharge may, however, have a strong impact on the aquifer in a relatively wide radius.

In Wadi Dhuleil in the south-west of the Azraq-Dhuleil Basin, about 80 production wells are in operation for irrigation and domestic supply. The wells mainly tap the Upper Cretaceous carbonate aquifer (A7/B2 aquifer), which is covered by Pleistocene basalt in part of the area. Groundwater salinity in samples here ranges from 400 to 6,000 mg/L TDS. Mean concentrations of all major ions, except for HCO_3^-, are higher than in other areas of the western part of the Basalt Aquifer System. High groundwater salinity and groundwater quality deterioration is reportedly mainly caused by the rapid recycling of irrigation water. Part of the water applied for irrigation seeps directly into the subsurface without longer retention in the soil zone.

SUSTAINABILITY ISSUES

The over-exploitation of groundwater resources in the Azraq-Dhuleil Basin since 1980 is partly due to uncontrolled agricultural growth and has resulted in a significant drop in water levels, as well as the deterioration of soil and groundwater quality. This has also severely affected the wetlands in the Azraq area, which formed an important environmental site with rich fauna and flora.

Figure 2. Schematic geological cross-sections through the Azraq Oasis: (a) before groundwater abstraction, (b) after major groundwater abstraction



Source: Modified by ESCWA-BGR based on Salameh, 1996.

Agreements, Cooperation & Outlook

AGREEMENTS

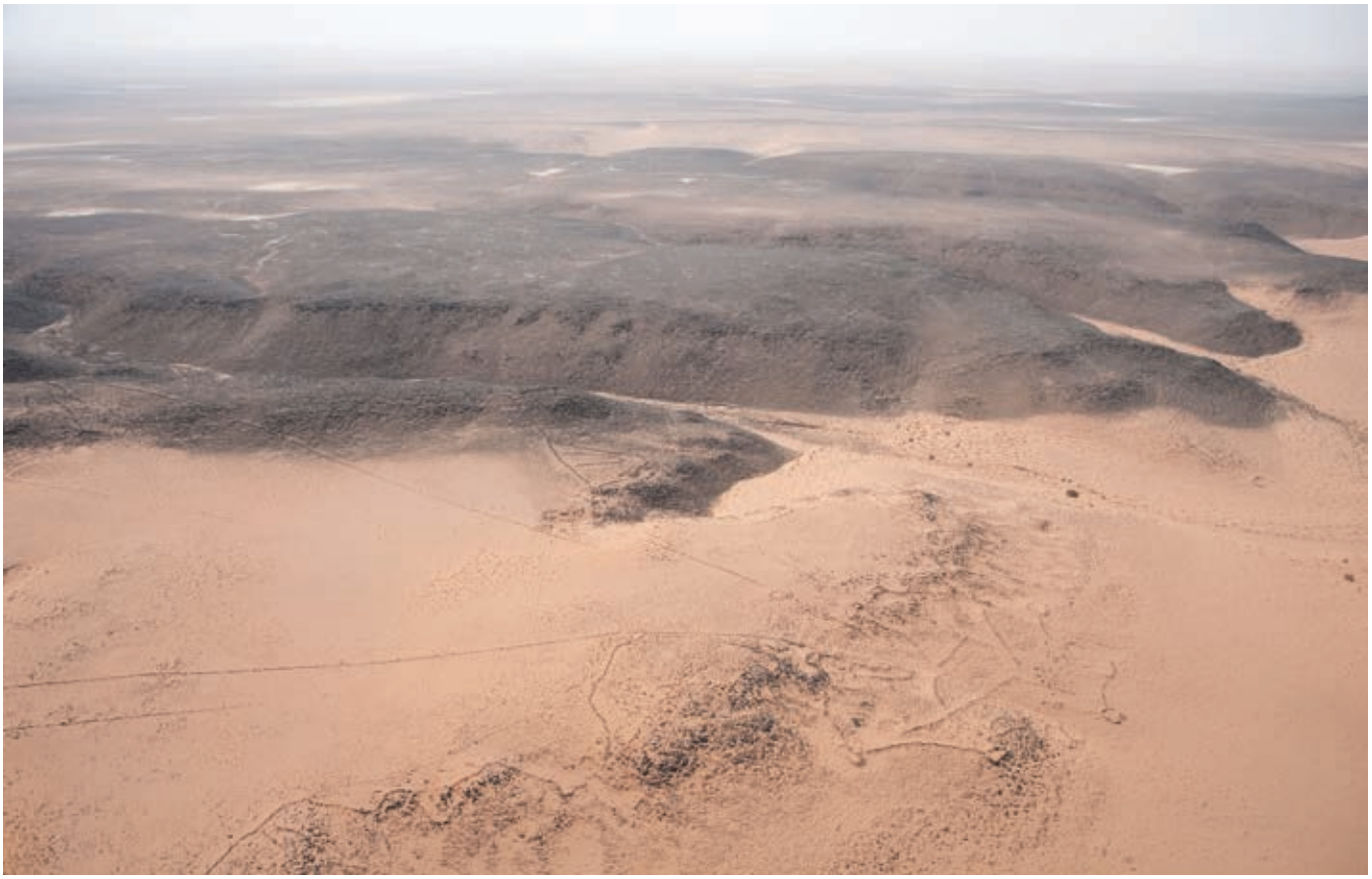
There are no formal water agreements in place for the Azraq-Dhuleil Basin, which is shared between Jordan and Syria.

COOPERATION

In the early 1990s, ESCWA and BGR facilitated cooperation between the Ministry of Water and Irrigation in Jordan and the Ministry of Irrigation in Syria to investigate and monitor groundwater resources in the Basalt Aquifer System.[40] This process was, however, discontinued shortly afterwards.

OUTLOOK

No information was available regarding current or potential transboundary impacts of groundwater use in the Azraq-Dhuleil Basin. It appears that groundwater in the basin is mainly developed in Jordan, where the decline in water levels and rising salinization are important factors that could restrict groundwater exploitation. Farming in the Jordanian Highlands is still quite profitable for some investors, however. Moreover, compared to the Jordan Valley, water quality in the area remains high and it is difficult to reduce support for irrigation due to the strong political ties between farmers and the Jordanian Government. Nevertheless, the government is stepping up its efforts to tackle the over-exploitation of the aquifer. In December 2010, the Jordanian Ministry of Water and Irrigation issued an Amendment to the Groundwater Control Regulation, which outlines an increase in water tariffs for drinking and agricultural water.[41] Other initiatives in Jordan, such as the Highland Water Forum aim to encourage sustainable groundwater management practices in the basin.[42]



Area of Mafraq, Jordan, 2009. Source: Robert Bewley, Aerial Photographic Archive for Archaeology in the Middle East.

Notes

1. The aquifer system has also been referred to as Jebel al Arab Aquifer based on the name of the mountain range (altitude: ≤1,800 m asl).
2. In the original study of the regional basalt aquifer system (UN-ESCWA, 1996), the Azraq and Dhuleil were considered to be separate basins on the basis of surface drainage and morphology. From a hydrogeological perspective, however, the two basins can be merged into one, since part of the groundwater in the Dhuleil Basin flows into the Azraq Basin in the area of the main discharge zone.
3. While the Golan Basin is not considered a shared aquifer, most of its basin area has been occupied by Israel since 1967 and the aquifer here discharges into the transboundary Jordan River Basin. See Chap. 21, Box 1 for an overview of the Golan Basin.
4. UN-ESCWA et al., 1996.
5. The southern part of the Azraq-Dhuleil Basin below the Ramtha-Wadi Sirhan Fault System is excluded from the delineation because groundwater in this part of the Limestone Plateau is not related to the Jebel al Arab Basalt area. Moreover, this groundwater does not constitute a shared resource since it originates and discharges in Jordan.
6. El-Naqa, 2010.
7. Ibid.
8. Based on a 2004 population census (Central Bureau of Statistics in the Syrian Arab Republic, 2005) and 2010 estimates (Central Bureau of Statistics in the Syrian Arab Republic, 2011).
9. Based on 2011 estimates by Department of Statistics in Jordan, 2012. A very small part of Maan Governorate is also included, but this area is very sparsely populated.
10. Figure 4, Margane et al., 2002; El-Naqa and Al-Shayeb, 2009; Al-Mahamid, 2005.
11. UN-ESCWA et al., 1996.
12. Ibid.
13. Krasnov et al., 1966.
14. Margane et al., 2002; El-Naqa, 2010.
15. Al-Mahamid, 2005.
16. UN-ESCWA et al., 1996.
17. Ibid.; Schelkes, 1997.
18. Abu-Jaber et al., 1998; Eraifej and Abu-Jaber, 1999.
19. All recharge figures and calculations in the text based on Schelkes, 1997; Wagner, 2011.
20. Geyh et al., 1985.
21. Abu-Jaber et al., 1998.
22. Also known as the Azraq Oasis and Azraq Plain.
23. In the early 1970s, 54 private wells were dug in the wetland area and abstracted 2 MCM/yr for irrigation purposes (despite the prohibition of unlicensed digging in 1971). By 1984, 327 wells abstracted 8 MCM/yr (GIZ, 2010).
24. UN-ESCWA et al., 1996.
25. Ibid.
26. Abu-Jaber et al., 1998.
27. Salameh, 1996.
28. UN-ESCWA et al., 1996.
29. Ibid.
30. The following criteria are used to assess exploitability in this Inventory: drilling depth/depth to top of aquifer; groundwater level; and water quality/salinity. For more information on the approach, see 'Overview & Methodology: Groundwater' chapter.
31. GIZ, 2010.
32. According to GIZ, 2010, olive trees constitute 51% of agriculture in the highlands, followed by vegetables and stone fruits (respectively 20% and 17%).
33. Al-Adamat et al., 2003.
34. Ministry of Agriculture in GIZ, 2010.
35. El-Naqa et al., 2007. The Amman Water Sewerage Authority (AWSA) began pumping water from the Azraq wetland to Amman in 1981 at a rate of 1.5 MCM/yr. One year later, 15 wells were drilled in the northern part of the oasis to meet domestic water demand in Amman and Zarqa, with an average abstraction of 17 MCM/yr (GIZ, 2010).
36. Water levels in some wells are reported to have dropped by 20 m between 1983-2004 (GIZ, 2010).
37. The safe yield is 24 MCM/yr (GIZ, 2010).
38. GIZ, 2010. Of these, 909 were situated in the Azraq area (865 of these were used for agricultural purposes) and 51 were situated in the northern Badia region in Jordan. Illegal abstraction from the Azraq-Dhuleil Basin amounts to 13 MCM/yr.
39. Salameh, 1996.
40. UN-ESCWA et al., 1996.
41. GIZ, 2010 states that the amendment is awaiting approval by the Prime Minister's Cabinet.
42. The Highland Water Forum is a multi-stakeholder dialogue that aims to build consensus among water users, especially the agricultural community and the authorities, regarding the cause of the decline in groundwater resources and appropriate response measures. It is supported by international donors.

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Chapter 23

Taurus-Zagros

Taurus-Zagros

EXECUTIVE SUMMARY

The Taurus-Zagros Mountain range extends across Iran, northern Iraq and Turkey. Geological formations within this range constitute shared aquifer systems in some areas along the boundaries of these countries. Three such areas are identified and described in this chapter: the Halabja-Khurmal and the Central Diyala Basins between Iran and Iraq, and the Zakho Basin between Iraq and Turkey. Other shared basins may possibly exist but remain unknown because of the complexity of the tectonics in the area.

In the Halabja-Khurmal Basin, groundwater is exploited in the Bekhme (Cretaceous) and Pila Spi (Paleogene) Aquifer Systems. The groundwater originates in the high mountains of Iran and flows towards the Derbendikhan Dam Lake in Iraq. A total annual recharge of 214 MCM occurs in the basin, and natural discharge of groundwater occurs mostly through springs.

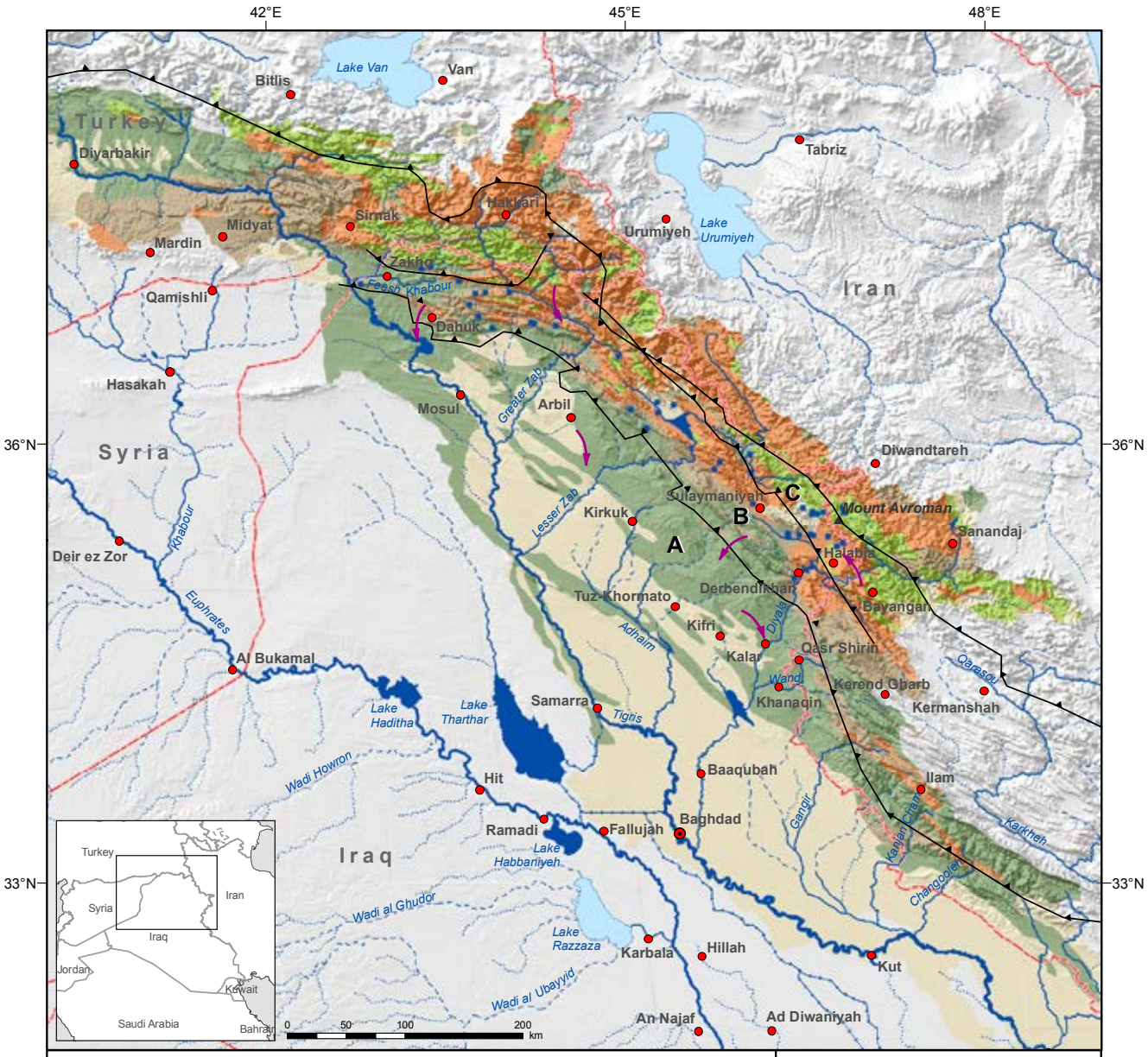
In the Central Diyala Basin, water is abstracted from the Bai Hassan-Mukdadia (Neogene) Aquifer System. A few springs are reported to discharge into this area and recharge is in the order of 50 mm/yr. Groundwater flow is mainly towards the Diyala River and the quality of water deteriorates with depth due to the presence of evaporites.

Both the Neogene and Paleogene aquifer systems are exploited in the Zakho Basin in the north, which receives about 188 MCM/yr of water. A considerable amount of this water is discharged through springs.

BASIN FACTS

RIPARIAN COUNTRIES	Iran, Iraq: Halabja-Khurmal and Central Diyala Basins Iraq, Turkey: Zakho Basin
MAIN AQUIFERS	Bai Hassan, Bekhme, Pila Spi
ALTERNATIVE NAMES	-
SHARED BASINS	Central Diyala, Halabja-Khurmal, Zakho
RENEWABILITY	Medium to high (20-300 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Strong
ROCK TYPE	Bekhme, Pila Spi: carbonate, karstic Bai Hassan: intergranular
AQUIFER TYPE	Semi-confined
EXTENT OF CATCHMENT	Central Diyala: 11,760 km^2 Halabja-Khurmal: 566 km^2 Zakho: 1,960 km^2
AGE	Bai Hassan, Pila Spi: Cenozoic Bekhme: Mesozoic
LITHOLOGY	Shale, limestone, sandstone
THICKNESS	Bekhme: ≤1,000 m Pila Spi: ~1,500 m Bai Hassan: ≥2,500 m
AVERAGE ANNUAL ABSTRACTION	-
STORAGE	-
WATER QUALITY	Fresh (≤1,000 mg/L TDS) except in deeper layers of Central Diyala Basin saline (3,000 mg/L TDS)
WATER USE	Mainly agricultural
AGREEMENTS	-
SUSTAINABILITY	-

OVERVIEW MAP



Taurus-Zagros (Selected Aquifer Systems)

- Capital
- Selected city, town
- International boundary
- River
- Intermittent river, wadi
- Springs 100- >1,000 L/s
- Canal, irrigation tunnel
- Freshwater lake
- Saltwater lake
- Flow direction

- Quaternary
- Neogene (Bai Hassan-Mukdadia Aquifer System)
- Paleogene (Pila Spi Aquifer System)
- Cretaceous (Bekhme Aquifer System)
- Pre-Cretaceous
- Thrust belt
  - **A** Low Folded Zone (foothill zone)
  - **B** High Folded Zone
  - **C** Thrust Zone

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Inventory of Shared Water Resources in Western Asia

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Introduction

LOCATION

The Taurus-Zagros Mountain range extends across Iran, northern Iraq and Turkey in a north-west/south-east direction. Shared aquifer systems exist in three border areas (see Overview Map):

- The Halabja-Khurmal Basin, where groundwater originates mainly in Iran.
- The Central Diyala Basin, with water that originates in Iran and Iraq as part of the Diyala River hydrological system.
- The Zakho Basin, which contains water originating in Iraq and Turkey as part of the Feesh Khabour River hydrological system.

These areas are examined in more detail below.

AREA

The groundwater in the Taurus-Zagros Mountain range forms an integral part of the hydrological system of the Tigris River Basin (see Overview Map and Chap. 3). The northernmost part (Thrust Zone) consists of rugged mountains, mostly over 2,000 m asl, which are intersected by deep valleys. South of the Thrust Zone, long, linear, asymmetrical folds form the High Folded Zone (approx. 900 m asl) and the Low Folded (Foothill) Zone (approx. 100-500 m asl). In this area, groundwater is mainly exploited in intermountain basins[1] that lie between a series of anticlines and synclines. The surficial geology and geomorphic features in the Taurus-Zagros Mountain range is shaped by the course of the Greater Zab River (see Chap. 4), which is controlled by a deep-seated regional fault. East of the Greater Zab, all mountains and valleys have typical linear shapes and are oriented in a north-east/south-west direction, which is referred to as the Zagros direction in this context. West of the Greater Zab, the mountains, ridges and valleys shift to an east-west orientation, known as the Taurus direction in this context.[2]

CLIMATE

The Taurus-Zagros Mountain range is generally characterized by cold, snowy winters and long, dry summers. Precipitation is concentrated in the colder mountain and foothill areas with maxima occurring on the high peaks along the Iran-Iraq border. In general, precipitation rates decrease from north-east to south-west. The region receives practically no precipitation during summer (June-September). The rainy season usually lasts from mid-October to early May, with the highest precipitation occurring in January. Average recorded data from 18 stations in northern Iraq indicates a maximum of 1,466 mm/yr for the period 1958-2002 in the north-eastern mountains and a minimum of 487 mm/yr for the period 1978-1990 in the south-western areas.[3] In western Iran, the annual average precipitation based on data from 140 stations for the period 1965-2000 ranged between 300 and 1,050 mm.[4] Air temperature varies between 10°C and 25°C, with mean annual temperatures of 10°C-15°C in the region of Dahuk, Halabja and Zakho, and 20°C-25°C in the Kirkuk and Tuz-Khormato areas in Iraq. The area of Qasr Shirin in Iran experiences annual average temperatures in the range of 15°C-20°C.[5] Reference evapotranspiration calculated for several stations across northern Iraq was found to be in the range of 1,000-1,700 mm/yr.[6] No data was found for evapotranspiration in Iran or Turkey.

POPULATION

The total population of the three areas where shared groundwater resources occur in the Taurus-Zagros Mountain range is estimated at around 1.44 million, including major towns such as Derbendikhan and Zakho in Iraq; Gharb, Gilan, Qasr Shirin and Sar Pole-Zahab in Iran, as well as small towns in Turkey such as Baskoy and Kapili. More detailed information on population distribution is included in relevant sections below.

INFORMATION SOURCES

With limited data available on groundwater resources in the Taurus-Zagros Mountain range in Iran and no information for Turkey, most of the information in this chapter is drawn from several studies in Iraq, most notably the hydrogeological investigations in northern Iraq published by FAO.[7] The Overview Map was delineated based on various local and regional references.[8]

Overview of Aquifer Systems

MAIN AQUIFER SYSTEMS

Three types of aquifer systems are known to exist in the Taurus-Zagros Mountain range: two in the High Folded Zone and one in the Low Folded Zone as shown in Table 1. The aquifer systems are denoted by the name of the most commonly known formations. A brief description of each aquifer system is given below.

Bekhme Aquifer System

The aquifer system consists of thick and intensively karstified carbonate layers that are often made up of massive 100-500 m thick banks. The Bekhme Aquifer System covers a large surface area and comprises several formations that extend across the High Folded Zone in east-west and north-west/south-east directions (see Overview Map). It contains large groundwater reserves and has a medium to high production of good-quality water. Wells drilled to 100-150 m bgl yield up to 40-50 L/s of water with very little drawdown.[9] In addition, many springs issue from locations where the karstic carbonates come into contact with non-carbonate rocks. A 2001-2002 groundwater monitoring programme[10] recorded an average discharge of 1.24 BCM from 46 springs and spring groups in the Iraqi governorates of Sulaymaniyah and Dahuk, which border on Iran and Turkey respectively (Table 2). Rainwater infiltration was estimated to reach up to 50%, while the aquifer system has a transmissivity of between $1.0x10^{-4}$ and $9.2x10^{-2}$ m^2/s.[11]

Pila Spi Aquifer System

The Pila Spi Aquifer System crops out extensively in the High Folded Zone. However, in the Low Folded Zone it is confined as it is covered by thick Miocene and Pliocene formations and Quaternary sediments. The degree of karstification is similar to that in the Bekhme Aquifer System, but the limestones of these younger formations are often argillaceous, which causes fracture systems to be less well developed.[12] Thus while the Pila Spi Aquifer System may contain relatively less groundwater reserves, the productivity of wells (40 L/s) is comparable with that of the Bekhme Aquifer System. Wells are usually 120-150 m deep except in areas where high artesian pressure prevails and water is struck at around 50 m bgl. An average effective infiltration of 30%-40% of rainfall into the aquifer system was estimated and the range of transmissivity is $4.0x10^{-5}$ to $4.9x10^{-1}$ m^2/s.[13] Table 3 shows that the Pila Spi Aquifer System has a significantly lower average total discharge than the Bekhme Aquifer System in Sulaymaniyah and Dahuk Governorates.

Bai Hassan Aquifer System

The Bai Hassan Aquifer System, which covers most of the Low Folded Zone, consists of

Table 1. Main aquifer systems in the Folded Zones of the Taurus-Zagros Mountain range

ZONE	AQUIFER TYPE	MAIN FORMATION	OTHER FORMATIONS/ DEPOSITS
High Folded Zone	Karst	Bekhme	Qamchuga, Dokan, Kometan, Bekhme, Akra, Sarmord
	Fissured-karstic	Pila Spi	Sinjar, Khurmal
Low Folded (Foothill) Zone	Intergranular	Bai Hassan (Upper Bakhtiari)	Mukdadia (Lower Bakhtiari), unconsolidated sediments (Quaternary)

Source: Compiled by ESCWA-BGR based on Stevanovic and Markovic, 2004.

Table 2. Spring discharge from the Bekhme Aquifer System (2001-2002)

GOVERNORATE	NO. OF SPRINGS/ SPRING GROUPS	TOTAL DISCHARGE (L/s)		
		MEAN	MINIMUM	MAXIMUM
Sulaymaniyah	28	33,019	7,813	72,232
Dahuk	18	6,403	1,861	14,941
Total	46	**39,422** (1.24 BCM)	**9,674** (0.31 BCM)	**87,173** (2.75 BCM)

Source: Compiled by ESCWA-BGR based on Stevanovic and Markovic, 2004.

Table 3. Spring discharge from the Pila Spi Aquifer System (2001-2002)

GOVERNORATE	NO. OF SPRINGS/ SPRING GROUPS	TOTAL DISCHARGE (L/s)		
		MEAN	MINIMUM	MAXIMUM
Sulaymaniyah	12	4,724	1,134	12,766
Dahuk	18	3,119	2,019	9,816
Total	30	**7,843** (0.25 BCM)	**3,153** (0.99 BCM)	**22,582** (0.71 BCM)

Source: Compiled by ESCWA-BGR based on Stevanovic and Markovic, 2004.

heterogeneous unconsolidated materials that are generally highly productive, with the discharge of many wells exceeding 30 L/s. A typical characteristic of this system, however, is the repetition of fine-, medium- and coarse-grained sediments within the same aquifer horizon as a result of which the productivity of wells drilled to the same depth can be highly variable. Artesian conditions prevail in the deeper horizons, especially around the lower reaches of major rivers such as the Diyala, Greater Zab and Lesser Zab, where thick deposits of fine Quaternary materials overlie the Neogene formations. More than 90% of the 2,000-3,000 wells drilled into this system have a total depth of 200 m or less. Many of the wells are no longer operational.[14] An estimated 22%-25% of rainfall infiltrates into the aquifer system and the range of transmissivity is $1.0x10^{-6}$ to $5.3x10^{-1}$ m^2/s.[15] The average total discharge of springs emanating from the Bai Hassan Aquifer System in the Sulaymaniyah and Dahuk Governorates (34 MCM) is almost an order of magnitude lower than the discharge from the Pila Spi Aquifer System during the same period (Table 4).

STRATIGRAPHY

Table 5 briefly describes the formations that contribute to an understanding of shared aquifer systems in the Taurus-Zagros Mountain range. Formation names mentioned in this overview section are mainly found in the literature from Iraq. Different names are generally used in Iran and Turkey and some of them are included in the relevant sections below.

Table 4. Spring discharge from the Bai Hassan Aquifer System (2001-2002)

GOVERNORATE	NO. OF SPRINGS/ SPRING GROUPS	TOTAL DISCHARGE (L/s)		
		MEAN	MINIMUM	MAXIMUM
Sulaymaniyah	2	263	45	673
Dahuk	11	817	262	5,141
Total	13	**1,080** (34 MCM)	**307** (9.7 MCM)	**5,814** (183 MCM)

Source: Compiled by ESCWA-BGR based on Stevanovic and Markovic, 2004.

Table 5. Lithostratigraphy of the aquifer systems in the Taurus-Zagros Mountain range

AGE		FORMATION	LITHOLOGY	THICKNESS (m)	WATER-BEARING CHARACTERISTICS
Quaternary	Pleistocene to recent	-	Gravel, clay and sand	10-100	Hydraulically connected; form one aquifer system in the Low Folded Zone
Neogene	Pliocene	Upper Bakhtiari (Bai Hassan) Lower Bakhtiari (Mukdadia)	Conglomerates and clay-stones, partly sandstones and siltstones	≥2,500-3,000	
	Miocene	Upper Fars (Injana) Lower Fars (Fatha)	Mainly sandstones (Injana) and evaporites (Fatha) with some conglomerate at the base	L. Fars: 400-900 U. Fars: 500	Very low groundwater yield with acidic or salty water
Paleogene	Middle-Upper Eocene	Pila Spi-Gercus	Mudstones, sandstones and shales	65-400	A major aquifer system of fissured-karstic nature in the High Folded Zone
	Paleocene-Eocene	Kolosh-Sinjar-Khurmal	Shales, limestones and dolomites	≥1,000	Sinjar is part of the Pila Spi Aquifer System where it is not separated from the Pila Spi Formation by the flysch deposits of the Gercus Formation
Mesozoic	Cretaceous	Bekhme-Akra-Kometan	Mainly limestones and dolomitized limestones	Few hundreds to ~1,000	A major karst aquifer system in the High Folded Zone

Source: Compiled by ESCWA-BGR based on Stevanovic and Markovic, 2004.

The Halabja-Khurmal Basin

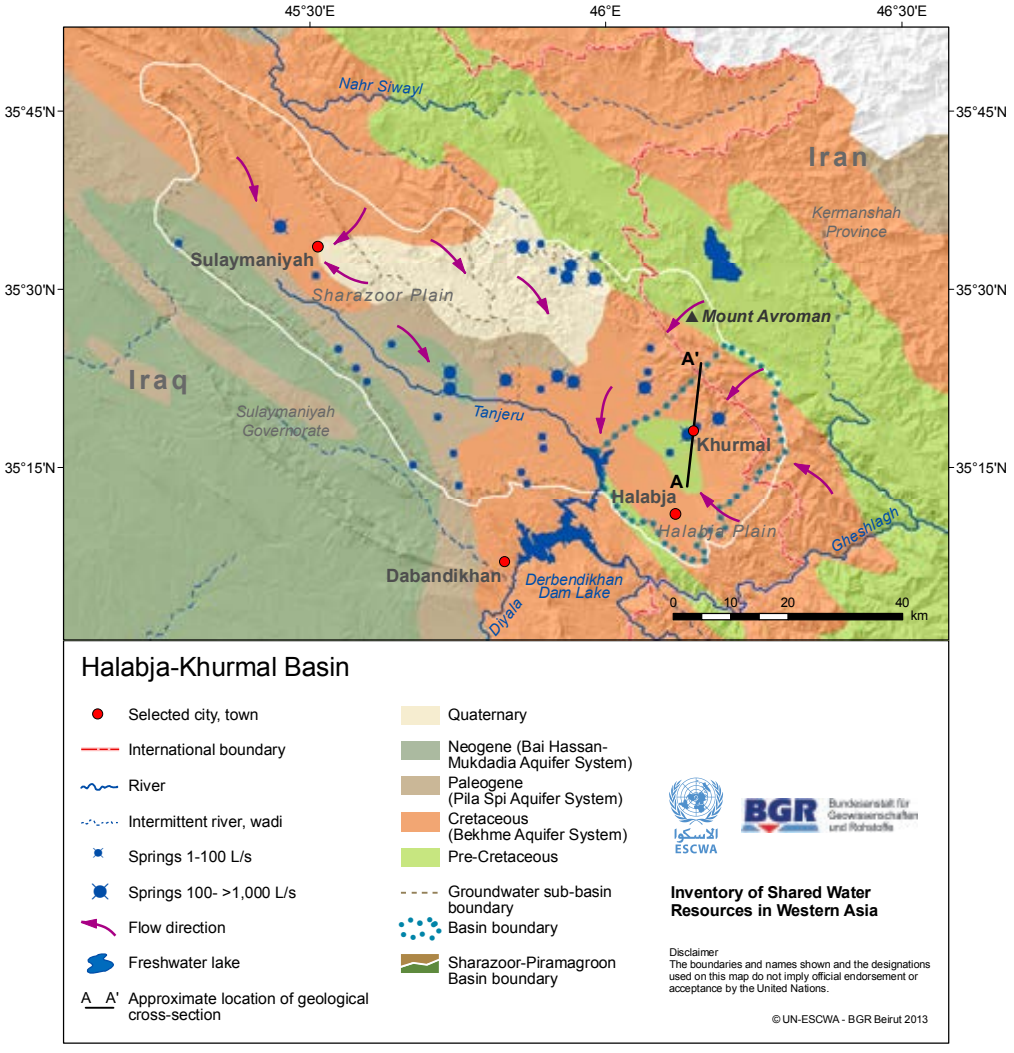
INTRODUCTION

The Halabja-Khurmal Basin is the easternmost of four sub-basins within the Sharazoor-Piramagroon Basin,[16] previously known as the South-eastern Sharazoor Hydrogeological Basin.[17] The Sharazoor-Piramagroon Basin straddles the Iran-Iraq border (Figure 1 and 2), extending across the Iraqi governorate of Sulaymaniyah and the Iranian province of Kermanshah. Due to lack of data, the groundwater boundary of the Sharazoor-Piramagroon Basin in Iran has not been clearly defined.[18] As part of the Sharazoor-Piramagroon Basin, the Halabja-Khurmal sub-basin covers a total of 566 km^2, of which 141 km^2 is located in Iran and 425 km^2 in Iraq.

Mean annual precipitation in the area of the Halabja-Khurmal Basin lies around 675-680 mm (Sulaymaniyah, Derbendikhan),[19] decreasing to 500 mm (Kermanshah) further to the east. The region is characterized by cycles of dry and wet years. Air temperature in the basin ranges from 3°C in January to 32°C in July, with an annual average of 17°C-19°C. To the east of the basin, Kermanshah has a moderate mountain climate. Precipitation falls mostly in winter and the average temperature in the hottest months is around 22°C.

The Halabja-Khurmal Basin has an estimated population of 95,550 inhabitants, who mainly live in the Halabja District of Sulaymaniyah Governorate in Iraq.[20] In Iran, the basin

Figure 1. Overview Map of the Halabja-Khurmal Basin



Source: Compiled by ESCWA-BGR based on Salahalddin, 2007; Stevanovic and Markovic, 2004; Aghanabati, 1993.

comprises small parts of Kermanshah and Kurdistan Provinces, but they are very sparsely populated.

HYDROGEOLOGY

Aquifer characteristics

A wide range of geological units (Late Jurassic to recent deposits) exist in the area, including the three main aquifer systems described above. The area has the following main hydrogeological characteristics:

- Occurrence of karstic and fissured-karstic aquifers (Bekhme and Pila Spi Aquifer Systems) on the edges of the basins.
- Highly productive intergranular deposits (Bai Hassan Aquifer System) often filling the basins.
- Variable permeability and lateral/horizontal changes in lithology of basin layers.

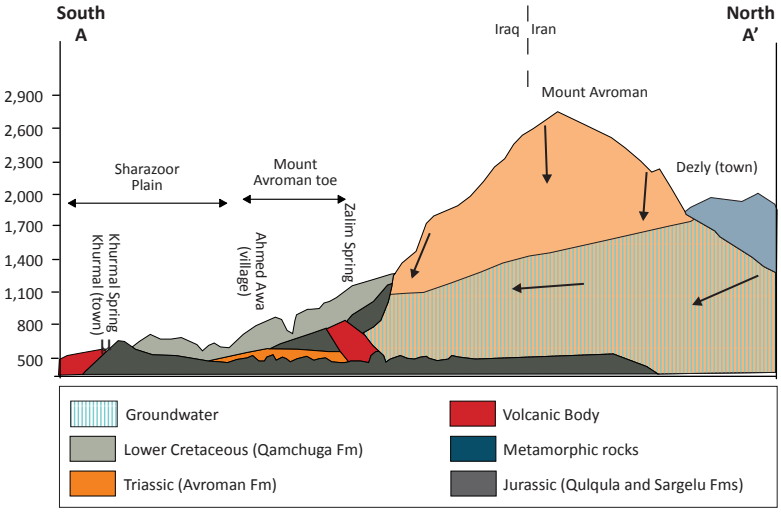
Quaternary deposits overlie the Cretaceous and Paleogene aquifer systems in the Halabja and Sharazoor Plains, creating confined conditions in both systems in this area.[21] Together with the Jurassic formations, the Cretaceous and Paleogene aquifer systems of the Thrust Zone are drained by numerous springs, some of which are of major importance.

Groundwater

Groundwater in most of the Sharazoor-Piramagroon Basin, including the Halabja-Khurmal sub-basin, originates in high mountains in Iran such as Mount Avroman. Groundwater flow more or less coincides with surface water flow and is directed towards the Derbendikhan Dam Lake in Iraq[22] (Figure 1 and 2). A total annual recharge of 214 MCM occurs in the Halabja-Khurmal Basin, mainly via direct infiltration through the exposed rocks.[23]

Natural discharge of groundwater in the Halabja-Khurmal Basin occurs through springs and subsurface drainage. There are two large karstic springs (Zalim and Shiramar) and several smaller ones (Bawakochak, Khurmal, Sargat) in the area. Spring discharge represents the main groundwater outflow in the Halabja-Khurmal Basin. Discharge of the main Zalim Spring during the period 2004-2006 fluctuated between 8.8 and 1.1 m^3/s, with a mean value of 3.9 m^3/s.[24] The presence of aquifer systems drained by up to 400 springs in the neighbouring Nawsud District in Paveh County in Kermanshah Province in Iran has also been reported.[25] Water in the Sharazoor-Piramagroon Basin is generally considered fresh (1,000 mg/L TDS),

Figure 2. Geological cross-section of Mount Avroman and the Zalim Spring



Source: Redrawn by ESCWA-BGR based on Salahalddin, 2007.

Table 6. Groundwater production in the Halabja-Khurmal Basin in Iraq

TYPE OF DISCHARGE	NO. OF WELLS	TOTAL ANNUAL PRODUCTION (MCM)
Springs	-	157
Deep wells	860	16
Shallow wells	230	1.8
Total	1,090	174.8

Source: Compiled by ESCWA-BGR based on Salahalddin, 2007.

with minimum values observed in wells closer to the recharge area in the Halabja-Khurmal sub-basin.

GROUNDWATER USE AND SUSTAINABILITY ISSUES

No information was available on water production and use in the Iranian part of the basin. In Iraq, springs and wells in the Halabja-Khurmal Basin produce 175 MCM/yr. Table 6 shows that about 90% of the water originates from springs. Current water demand is about 157 MCM/yr of which 145 MCM/yr (92%) is used for agricultural purposes.[26]

A report by FAO[27] suggests that optimal exploitation of water resources in the Halabja-Khurmal Basin could be achieved in the following ways:

- Tapping karstic spring water at the edges of the basin through gravity systems and the development of highly productive springs.
- Developing shallow alluvial and terrace aquifers including artificial recharge.
- Deep-well drilling in karstic areas in the foothills or in recent deposits.

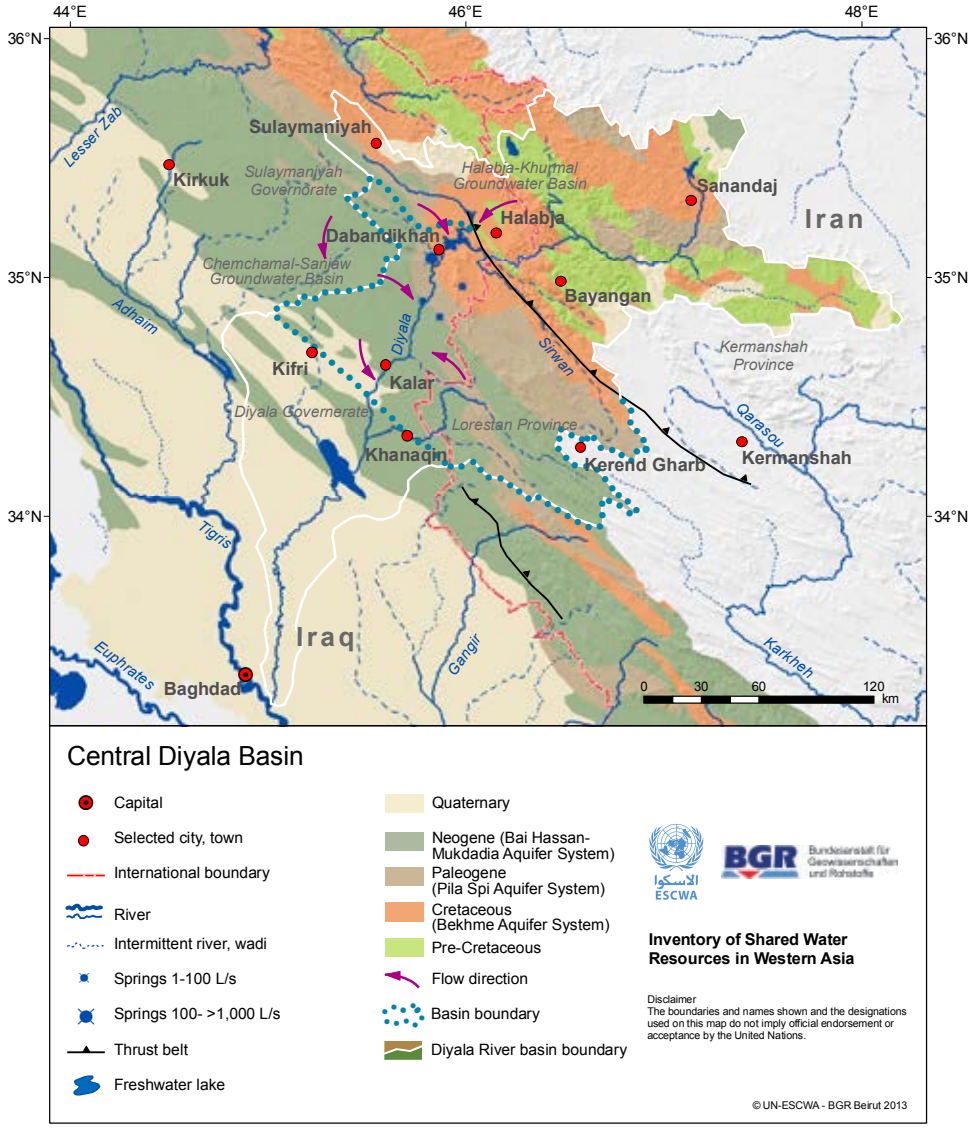
The Central Diyala Basin

INTRODUCTION

The Central Diyala Basin lies mainly in the Low Folded Zone, but also partly in the High Folded Zone along the Iran-Iraq border. It stretches across the eastern part of Diyala Governorate in Iraq and the western part of Lorestan Province in Iran (Figure 3). For the purpose of this chapter, the basin is defined by tentatively extending the groundwater divides of the Halabja-Khurmal and Chemchamal-Sanjaw Basins across the Iraq-Iran border along major thrust faults (northern and southern boundaries, respectively) and the Diyala River Basin (eastern and western boundaries, see Chap. 4). Within the boundary of the suggested delineation, the basin covers a total area of 11,760 km^2, of which 6,350 km^2 are located in Iran and 5,410 km^2 in Iraq.

The climate in the Foothill Zone is semi-arid with hot summers and mild to cold winters. Precipitation occurs mainly between September and May. The Central Diyala Basin around Khanaqin has an average annual precipitation of 330-350 mm.[28] The average annual temperature is 21°C, with highs around 32°C in summer and

Figure 3. Overview Map of the Central Diyala Basin



Source: Compiled by ESCWA-BGR based on Stevanovic and Markovic, 2004; Salahalddin, 2007; Aghanabati, 1993; Sorkhabi, 2012.

lows of 5°C in winter.[29] Total potential annual evaporation was reported to be about 1,750 mm in 2001.[30] The evaporation rate is likely to be higher in the Kalar-Kifri area.

The Central Diyala Basin comprises around 312,300 inhabitants, with around 224,700 people living in parts of Kermanshah Province in Iran,[31] and around 87,600 inhabitants in parts of Sulaymaniyah and Diyala Governorates that lie in the Iraqi part of the basin.[32]

HYDROGEOLOGY

Aquifer characteristics

The main aquifer in this basin is the Neogene (Bai Hassan-Mukdadia) Aquifer System. The Bai Hassan Formation is an aquifer with high potential and sometimes forms a single aquifer with the overlying Quaternary sediments, especially in the southern areas (Kalar). The Mukdadia Formation is also considered an aquifer, though it is less promising. The exploitable saturated thickness of the Bai Hassan-Mukdadia Aquifer System is estimated at 60-200 m in different sub-basins.[33] The aquifer system is basically unconfined with a shallow water table. Confined conditions exist where the overlying Quaternary deposits exhibit high clay content. Differences in lithology often cause semi-confined to confined conditions in the deeper layers. Transmissivity values of 100 m^2/d ($1.2x10^{-3}$ m^2/s) and 350 m^2/d ($4.0x10^{-3}$ m^2/s) were reported in the Central Diyala Basin.[34] However, variable permeability and lateral/horizontal changes in the lithology of basin deposits often result in highly variable productivity.[35] Some springs discharge from the Pila Spi Formation, especially where it is in contact with other formations, but there is no information on the potential and use of the aquifer system.

Groundwater

Major rivers such as the Adhaim, Gangir and Lesser Zab flow through the foothill areas and may contribute significantly to direct and indirect groundwater recharge.[36] In the Central Diyala Basin, groundwater recharge rates were reported to range between 40 and 53 mm (11.8% of an average rainfall of 332 mm[37] and 17.3% of an average rainfall of 308 mm).[38] Both in Iran and Iraq, groundwater flows mainly towards the Diyala River and storage in Iraq has been estimated at between 500[39] and 1,050 MCM[40] in Iraq. Storage in Iran is unknown.

The unconfined upper part of the aquifer is locally drained to the Diyala River. The discharge of the lower confined aquifer system is not well defined but may be connected to the upper part. A few morphological springs are reported to discharge low volumes into the Central Diyala Basin.[41] Similar springs may exist in the Iranian part of the basin. In general, natural discharge of the confined system seems to be limited, indicating possible upward leakage to the upper unconfined system. Good-quality groundwater (<1,000 mg/L TDS) is found along the Diyala River and, in general, salinity increases away from the river. Deep wells contain saline water derived from the Lower Fars (Fatha) Formation but salinity rates generally do not exceed 3,000 mg/L.[42]

GROUNDWATER USE AND SUSTAINABILITY ISSUES

Actual annual abstraction from the confined aquifer in the Central Diyala Basin is estimated at around 6 MCM from 80 wells, with very limited effect on groundwater levels.[43] No abstraction is reported in Iran, but groundwater discharge from qanats[44] can be assumed.[45]

Landscape near Penjwin, Iraq, 1991. Source: Ed Kashi/VII.

The Zakho Basin

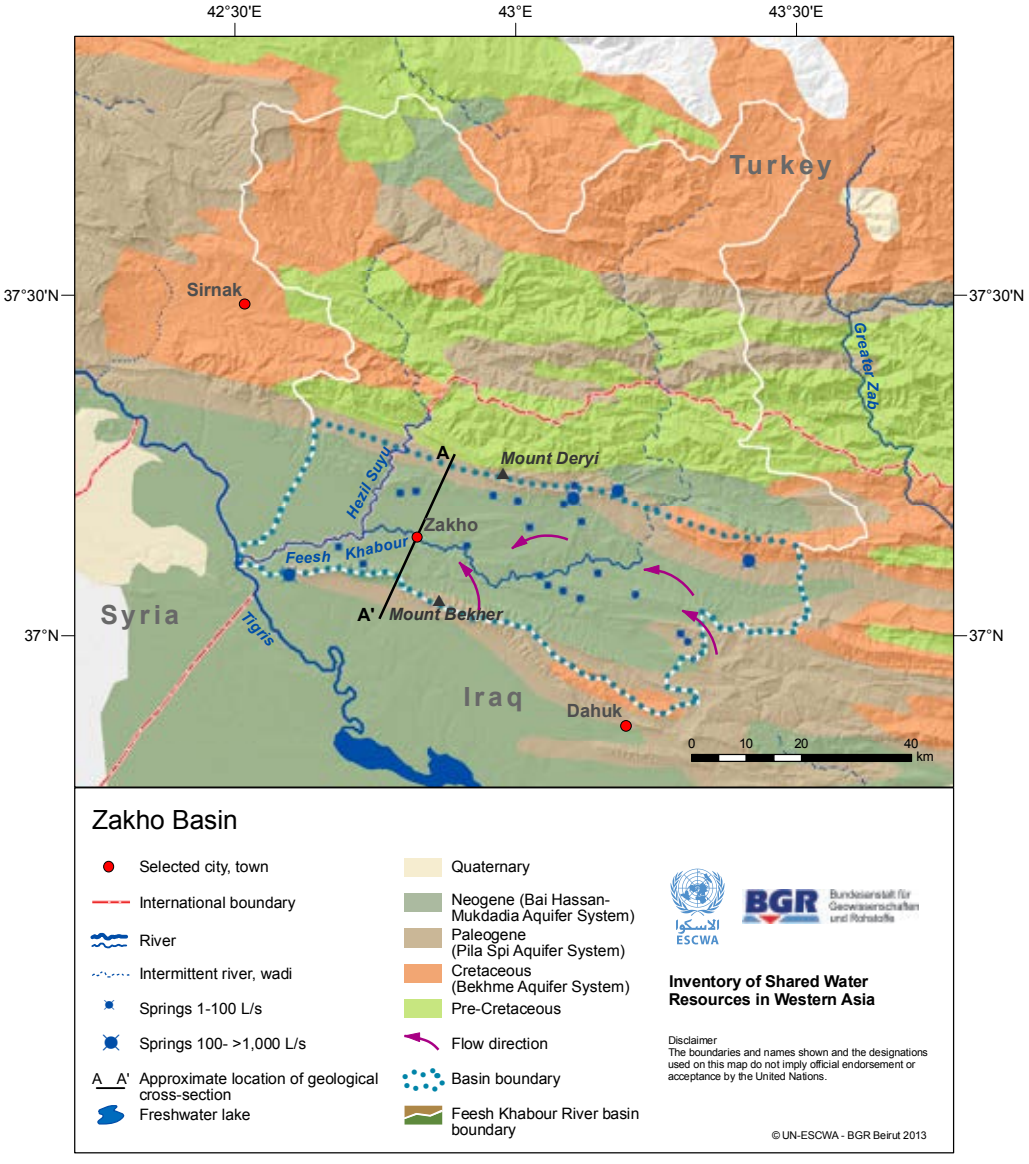
INTRODUCTION

The Zakho Basin stretches across the border between Iraq and Turkey. It constitutes the lower part of the Feesh Khabour River (a Tigris River tributary, see Chap. 4), and is bound from the east and west by the boundary of Feesh Khabour and from north and south by two anticlines, of which one is aligned with the southern border of the river basin. In Iraq, the Zakho Basin lies at an altitude of 500-600 m asl, with the surrounding mountains rising to 1,600-1,800 m asl. The basin is underlain by thick layers of productive recent deposits. Within the boundary of the suggested delineation, the basin covers a total area of 1,960 km^2, of which 1,695 km^2 are located in Iraq and 265 km^2 in Turkey (Figure 4).

Average annual precipitation in the Zakho Basin in Iraq is estimated at 707 mm,[46] with high inter-annual variation. Temperatures range from about 6°C in winter to over 30°C in summer.

The population in the Zakho Basin is estimated at 733,000 inhabitants, with 628,900 people

Figure 4. Overview Map of the Zakho Basin



Source: Compiled by ESCWA-BGR based on Aghanabati, 1993; Stevanovic and Markovic, 2004.

living in Dahuk Governorate in Iraq[47] and the remaining population living in parts of the Sirnak Province in Turkey.[48]

HYDROGEOLOGY

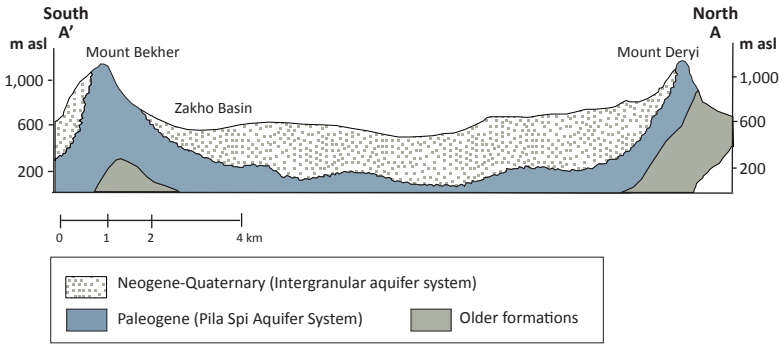
Aquifer characteristics

The upper, dominant water-bearing formations in the Iraqi part of the Zakho Basin are made up of Quaternary deposits and Neogene clastics formations of the Bai Hassan and Mukdadia Formations (Figure 5), and to a lesser extent of Upper and Lower Fars (Injana and Fatha) Formations. They form an unconfined aquifer system with a collective flow type centred on the Khabour River. The system seems to extend briefly across the Khabour and Hezil Rivers into Turkey[49] where it is bordered by a major fault in the north and obscured by younger volcanic deposits to the west of the Tigris River, north-east of Syria. The Paleogene, with its chalky limestone of the Pila Spi Formation, appears only at the axis of the two parallel anticlines that embrace the Zakho Basin. The Paleogene underlies the Neogene clastics at depth and forms a second confined groundwater aquifer system with the fine clastics Gercus Formation.[50] However, the chalky limestone of the Midyat Formation that overlies the Gercus Formation in Turkey appears on the surface further to the north and west, with the Paleogene extent reaching Diyarbakir to the north and Mardin to the west.[51] The older Cretaceous aquifer system, which is widely present in north-eastern Iraq, plunges deep under the Zakho Basin.

Groundwater

In Iraq, the Zakho Basin has a catchment area of about 1,107 km^2. Within the catchment, it is assumed that 31% of the average annual rainfall (707 mm) infiltrates into the ground but only 23% reaches the aquifer systems.[52] This would mean that a total of 188 MCM/yr of water (160 MCM/yr in the intergranular aquifer system and 28 MCM/yr in the fissured-karstic aquifer system) enters the basin as renewable resources.[53] A considerable amount of the recharged volume is discharged through springs, especially those issuing from the fissured-karstic aquifer. A major spring (Deraboon) issuing near the Iraqi-Turkish border at the contact between the Pila Spi Formation and the less permeable overlying Lower Fars (Fatha) Formation is reported to have a discharge of 0.83-1.13 m^3/s (see Overview Map).[54]

Figure 5. Hydrogeological cross-section of the Zakho Basin



Source: Compiled by ESCWA-BGR based on Stevanovic and Markovic, 2004.

GROUNDWATER USE AND SUSTAINABILITY ISSUES

Groundwater abstraction in the Iraqi part of the basin takes place mainly from the interganular Bai Hassan aquifer. In the early 1980s an estimated total of 24.3 MCM of good-quality (<700 mg/L TDS) water had been abstracted (9.5 MCM from deep wells and 12.3 MCM as spring discharge).[55]

As recharge far exceeded abstraction, it was suggested that up to 800 new wells could be drilled in the basin.[56] Additional abstraction could take place as follows:[57]

- Developing the shallow intergranular aquifer in alluvial plains and terraces
- Drilling deep wells in karstic areas in the foothills
- Tapping groundwater from springs

In order to mitigate drought in the area, it was also suggested that wells should be drilled to tap the low yield of brackish water in the Upper Fars-Lower Fars Formations as a back-up reserve.[58]

The city of Dahuk with the Zagros Mountains in the background, Turkey, 2005. Source: Ed Kashi/VII.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place for any of the shared aquifer systems that occur in the Taurus-Zagros Thrust Belt.

COOPERATION

Iraq and Turkey have established a number of technical committees on water issues. However, they mainly deal with surface water issues and Iraq has not discussed shared groundwater management with any of its neighbours. Iran also does not cooperate with Iraq or Turkey over issues of shared groundwater management.

OUTLOOK

The strong interaction between surface water and groundwater in the Taurus-Zagros Thrust Belt entails that future cooperation will have to address conjunctive development and use of the two resources.

Lake Van, Turkey, 2010. Source: Adel Samara.

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34. Al-Jawad et al., 2008; Al-Sudany, 2002; Al Furat Company for Studies and Design of Irrigated Projects, 2002.
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38. Ahmad et al., 2005.
39. Al-Tamimi, 2007.
40. Stevanovic and Iurkiewicz, 2008.
41. Parsons, 1957.
42. Krasny et al., 2006.
43. Ahmad et al., 2005.
44. An underground conduit, between vertical shafts, that leads water from the interior of a hill to villages in the valley.
45. FAO Aquastat, 1997.
46. Stevanovic and Markovic, 2004.
47. Based on Central Organization for Statistics in Iraq, 2010a (2009 estimate) and Iraq Information Portal, 2012.
48. Based on Turkstat, 2010 (2010 census).
49. The Neogene in Turkey is represented by the Beygur and Siirt Formations, while the Midyat is equivalent to Pila Spi (Altinli, 1966).
50. Stevanovic and Markovic, 2004.
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52. Tarmo, 1983, in Stevanovic and Markovic, 2004.
53. Stevanovic and Markovic, 2004.
54. Ibid.
55. Tarmo, 1983 in Stevanovic and Markovic, 2004.
56. Ibid.
57. The thick intergranular (Bakhtiari) sediments that fill the central plain of the Zakho Basin suggest that groundwater exploitation in the basin takes place in a similar manner to the Central Diyala Basin.
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Chapter 24

Jezira Tertiary Limestone Aquifer System

Jezira Tertiary Limestone Aquifer System

EXECUTIVE SUMMARY

The Jezira Tertiary Limestone Aquifer System (JTLAS) comprises two Paleogene Formations: an Eocene (main aquifer) and a Lower Oligocene Formation. It extends from the Jezira Plain on Syria's northern border (Upper Jezira area) into the south-eastern Anatolian Highlands in Turkey.

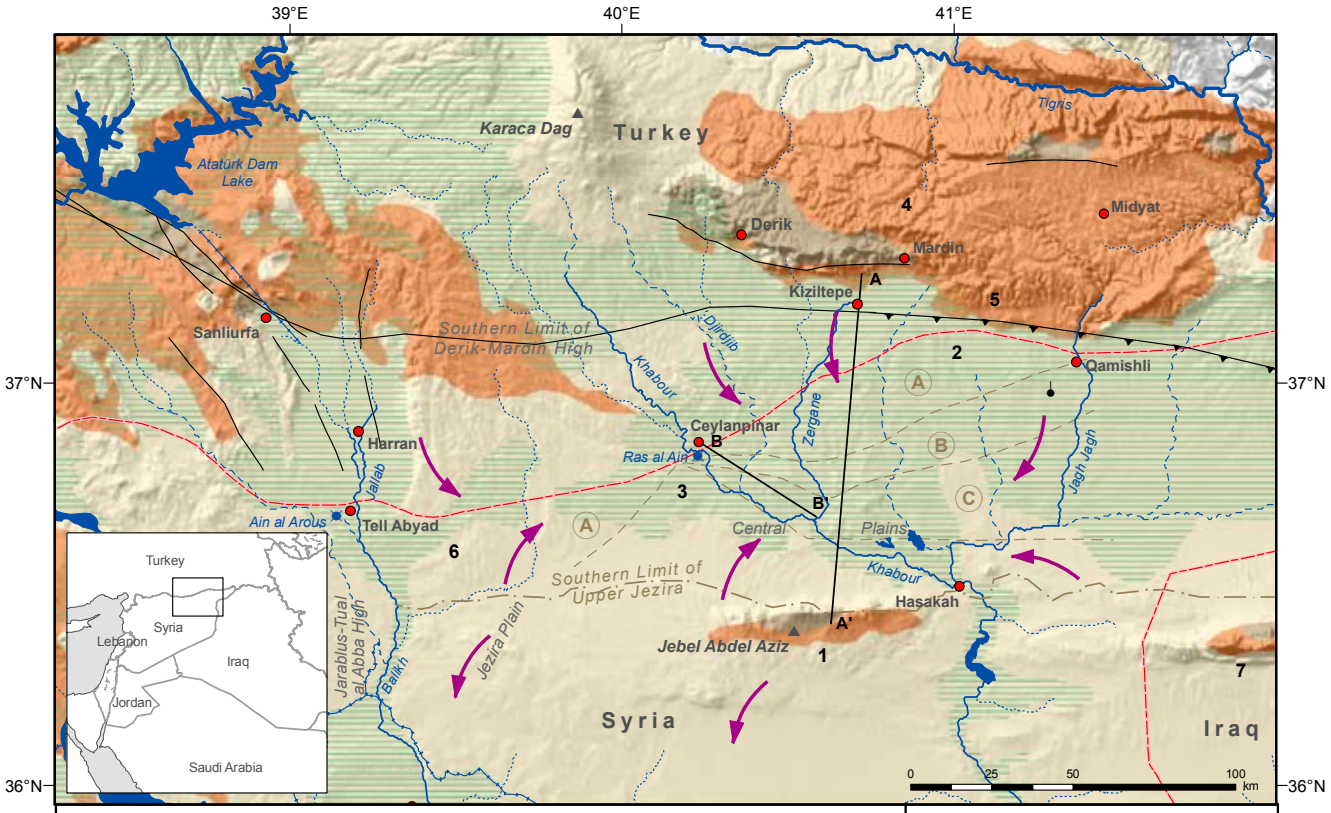
Large volumes of groundwater flow from recharge areas in the highlands to groundwater discharge areas along the Syrian border, where many springs, most importantly the Ras al Ain and Ain al Arous Springs, discharge from the aquifer system. Until approximately 2000, these springs discharged a total volume of more than 1,200 MCM and formed the principal source of surface flow in the Balikh and Khabour Rivers, which are the main tributaries of the Euphrates River in Syria.

In recent years, there has been a significant shift away from rain-fed irrigation to groundwater irrigation in the area and today almost 6,000 wells (around 2,000 in Turkey and 4,000 in Syria) abstract about 3,000 MCM/yr of water from the aquifer system. These high abstraction levels have significantly affected the groundwater regime and led to a dramatic decrease in springs discharge. Thus the springs at Ras al Ain, which used to supply 87% of the total discharge from the aquifer have practically dried up.

BASIN FACTS

RIPARIAN COUNTRIES	Syria, Turkey
ALTERNATIVE NAMES	Turkey: Midyat Aquifer
RENEWABILITY	Medium to high (20 - >100 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Strong
ROCK TYPE	Karstic
AQUIFER TYPE	Confined
EXTENT	14,000 km^2
AGE	Tertiary (Eocene to Oligocene)
LITHOLOGY	Limestone
THICKNESS	200-300 m ≥700 m in the east
AVERAGE ANNUAL ABSTRACTION	3,000 MCM
STORAGE	7,400 MCM
WATER QUALITY	Fresh (220-700 mg/L TDS) to saline (1,400-4,700 mg/L TDS)
WATER USE	Mainly agricultural/domestic
AGREEMENTS	-
SUSTAINABILITY	The springs which used to feed the Balikh and Khabour Rivers have dried up

OVERVIEW MAP



Jezira Tertiary Limestone Aquifer System

- Selected city, town
- International boundary
- River
- Intermittent river, wadi
- Canal, irrigation tunnel
- Spring
- Bore-hole
- Freshwater lake
- Direction of groundwater flow
- Groundwater quality zones:
  - (A) Fresh Ca-HCO_3 type water
  - (B) Brackish $CaSO_4$ type water
  - (C) Saline NaCl-CaCl type water
- Ecocene; Oligocene outcrops of the aquifer system
- Pre-Eocene Formation outcrops
- Approximate subsurface extent of the aquifer system
- Zone of agricultural development (selection)
- A_A' Hydrogeological cross-section
- Faults
- Mountain

Specific features:

1 Jebel Abdel Aziz Anticline
2 Qamishli Anticline
3 Ras al Ain Anticline
4 Mardin Anticline
5 South Mardin Fault Zone
6 Tell Abyad Anticline
7 Sinjar Anticline

ESCWA BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

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Introduction

LOCATION

The Jezira Tertiary Limestone Aquifer System is situated beneath a plateau area, which stretches from northern Syria into south-eastern Anatolia in Turkey. It extends across the Upper Jezira Basin, in the area between the towns of Qamishli, Hasakah and Tell Abyad in Syria, and Sanliurfa and Kiziltepe in Turkey as shown in the Overview Map (see also Figure 1).

AREA

The Upper Jezira Basin lies to the south of the mountains of the Derik-Mardin High between the Euphrates and Tigris Rivers. It comprises plains at altitudes of 350-500 m asl, most notably the Harran, Ceylanpinar and Kiziltepe Plains, which merge into the vast Upper Jezira Plateau. The mountain chain is dominated by the Karaca Dag volcanic massif (altitude: 1,919 m asl), which is adjoined in the west by a zone of hills north of Sanliurfa, and in the east to the highlands between Mardin and Midyat (altitude: 1,000-1,254 m asl). Various streams flow south from the mountain area and converge in the Upper Jezira Plain to form the Balikh and Khabour tributaries of the Euphrates River.

The Jezira Tertiary Limestone Aquifer System covers an area of 14,000 km^2, of which 8,500 km^2 lies in Syria and 5,500 km^2 in Turkey. The following main geo-physiographic features were used to delineate the aquifer system: the Balikh River in the west, the Jagh Jagh River in the east, the South Mardin Fault Zone and the southern limit of the Derik-Mardin High in the north, and the Jebel Abdel Aziz Anticline in the south.

CLIMATE

The southern part of the Jezira Tertiary Limestone Aquifer System lies in a semi-arid climatic zone, while the northern mountainous part reaches into more humid climatic zones. Average annual precipitation varies from around 300 mm in the south to 800 mm at the top of the Karaca Dag Mountains. A mean annual precipitation of 450 mm may be assumed for the catchment area.[1] Precipitation is concentrated during the cool winter season (0°C-10°C). No rain falls during the summer season when temperatures rise between 30°C and 45°C. Mean annual potential evaporation is 1,000-1,300 mm.[2]

POPULATION

In Syria, the Jezira Tertiary Limestone Aquifer System extends over the governorates of Hasakah and Raqqah. A total of 1.2 million people live within the boundaries of the delineated basin, of which 90% live in Hasakah Governorate.[3] In Turkey, the aquifer system extends over the provinces of Mardin and Sanliurfa. A total population of 1.8 million lives in the districts of these provinces that fall within the delineated basin, of which 62% live in Sanliurfa.[4]

OTHER AQUIFERS IN THE AREA

In Syria and in the plains of Turkey, the Jezira Tertiary Limestone Aquifer System is covered by aquiferous Miocene to Quaternary Formations, most notably the Upper and Lower Fars Aquifer System (see Chap. 25). In the Kiziltepe Plain in Turkey, the main exploited aquifer is made up of Pliocene-Quaternary talus and conglomerate deposits.[5] In the Syrian Jezira, the extensive Pliocene-Quaternary Radd Aquifer adjoins the Jezira Tertiary Limestone Aquifer System in the east. Collapse structures which developed in the Miocene Lower Fars gypsum aquifer serve as groundwater discharge funnels from the underlying Jezira Tertiary Limestone Aquifer System.

The Cretaceous Formation that underlies the Jezira Tertiary Limestone Aquifer System is found at great depth (≥1,200 m) and has hydrocarbon indications and saline groundwater, which limit its exploitation and means that it cannot be considered a productive aquifer.[6]

INFORMATION SOURCES

Hydrogeological interest in the Jezira Tertiary Limestone Aquifer System developed mainly because of the discovery of one of the largest karst springs in the world in the Ras al Ain area.[7] Hence most of the information collected on the aquifer system over the past 50 years comes from this area. The Overview Map was delineated based on various local and regional references drawn from both riparian countries.[8]

Hydrogeology - Aquifer Characteristics

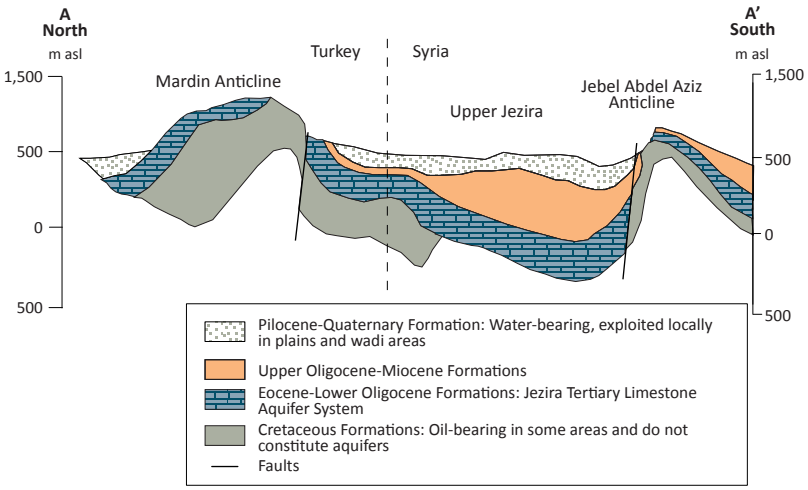
AQUIFER CONFIGURATION

The Jezira Tertiary Limestone Aquifer System is exposed on the surface in the highlands in the northern part of the catchment. The aquifer is covered by volcanic rocks in the Karaca Dag Mountain area and by Miocene to Quaternary sedimentary deposits in the plains to the south. The top of the aquifer system descends from more than 1,000 m asl in the outcrop areas in the highlands to 200-400 m asl in the border area between Syria and Turkey.[9] The aquifer system again appears on the surface in the core of the Jebel Abdel Aziz Anticline on the southern margin of the Upper Jezira. However, this area is assumed to be situated outside the catchment of the Jezira Tertiary Limestone Aquifer System.

The lower boundary of the aquifer system consists of an aquitard of marls and marly limestones of Upper Cretaceous (Maastrichtian) to Paleocene age. The top of the aquifer system is formed by the overlying volcanic rocks in the Karaca Dag Mountain massif and by confining layers of Neogene age in the plain areas. The lateral boundaries are defined by:

- To the north, the South Mardin Fault Zone and the southern limit of the Derik-Mardin Uplift[10] where outcrops of the underlying Upper-Cretaceous-Paleocene aquitard (Pre-Eocene on the Overview Map) are found in some areas.
- To the south, the northern limit of the Sinjar Trough in Iraq,[11] where fault-related structures – most notably the Jebel Abdel Aziz-Sinjar Anticlines – and the general bedding of the geological formations suggests groundwater flow towards the south (see Overview Map and Figure 1).
- To the east, the Jagh Jagh River, where the Paleogene sediments drop down to great depths,[12] suggesting that the river channel may represent a fault.
- To the west, the Balikh River which also seems to represent a fault bordering the Jarablus-Tual al Abba High.[13]

Figure 1. Generalized hydrogeological cross-section along the Jebel Abdel Aziz-Mardin Anticlines

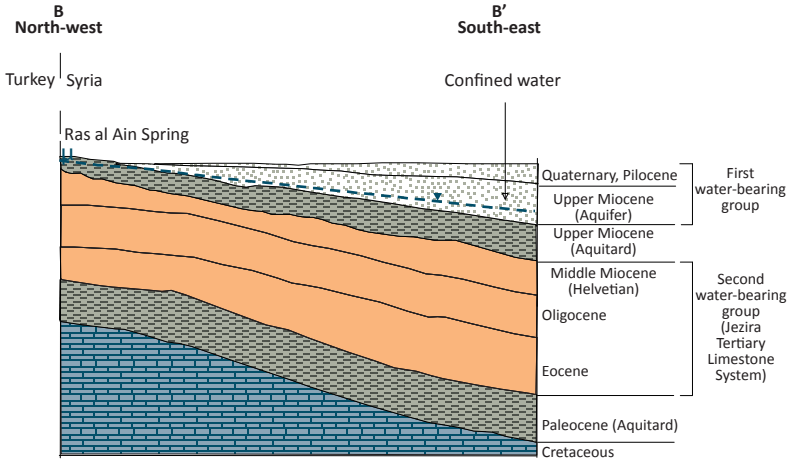


Source: Redrawn by ESCWA-BGR based on FAO and UNDP, 1966.
Note: The figure shows the position of the Eocene Formation (Jezira Tertiary Limestone Aquifer System) with respect to other formations in the Upper Jezira Basin.

STRATIGRAPHY

The Jezira Tertiary Limestone Aquifer System consists of three formations as shown in Figure 2: two karstic formations that constitute the main aquifers and a massive formation in the middle that is water-bearing, mainly in tectonically active faulted areas. A brief description of these formations is given in Table 1.

Figure 2. General stratigraphy of the Ras al Ain area



Source: Redrawn by ESCWA-BGR based on ACSAD et al., 2003.

Table 1. Lithostratigraphy of the Jezira Tertiary Limestone Aquifer System

PERIOD	LITHOLOGY	COMMENTS
Helvetian (Middle Miocene)	Sandstones and limestones with some dolomites; commonly fissured and karstic.	Exposed widely in Turkey and in the Ras al Ain Anticline area where it was tapped by shallow wells.
Oligocene	Massive and marly limestones with some dolomites and marly dolomites.	Usually not water-bearing but locally acts as part of the aquifer system near faults and folds, especially in a narrow belt along the border from Qamishli to Ras al Ain.
Middle to Upper Eocene	Karstic limestone with original fissures and secondary dolomitization.	Main water-producing formation commonly known as the Jezira Tertiary Limestone;[a] denominated as the Midyat Formation in Turkey, where it comprises massive limestones at the base, followed by marls and chalky limestones at the top.

Source: Geyh, 2004; ACSAD et al., 2003; FAO and UNDP, 1966.
(a) Elsewhere in Syria, the Middle to Upper Eocene Formations are known as the Jadala and Sinjar and are placed in the Palmyra Group (Burdon and Safadi, 1963).

AQUIFER THICKNESS

The thickness of the Jezira Tertiary Limestone Aquifer System is generally around 200-300 m in Turkey.[14] In Syria, the thickness of the formations generally increases towards the south (Figure 1) and east where about 570 m of Eocene was penetrated in the Qamishli bore-hole (see Overview Map).[15] The Helvetian Formation usually has a thickness of 50-60 m.[16]

AQUIFER TYPE

In Turkey, groundwater in the Sanliurfa-Harran-Ceylanpinar area was under artesian conditions until about 1970 when the pressure began to drop significantly following intense abstraction. The aquifer system at Ceylanpinar is now unconfined in every location.[17] In Syria, the Jezira Tertiary Limestone Aquifer System is confined in the plain areas in the southern part of the basin, with artesian spring discharge.

AQUIFER PARAMETERS

The large water volumes that used to discharge from the Jezira Tertiary Limestone Aquifer System in some springs indicate high transmissivities in the karst aquifer. However, these high transmissivities are limited to a small radius around the group of springs comprising the Ras al Ain Springs where transmissivity values of 3 and 4 m^2/s were recorded.[18] Transmissivity values generally decrease significantly away from the spring discharge zones toward the east and south where they are most commonly in the range of 0.012 to 0.04 m^2/s.[19] A value of $5x10^{-2}$ was given for storativity.[20]

Hydrogeology - Groundwater

RECHARGE

The main recharge areas of the Jezira Tertiary Limestone Aquifer System are the Derik-Mardin Mountain chain where relatively high precipitation over Quaternary deposits and fractured limestone and basalt outcrops provide favourable conditions for rainfall and runoff infiltration. Most of the recharge occurs during winter and spring when precipitation can infiltrate. In the absence of precipitation data, it was assumed in the 1960s that average annual precipitation in the catchment area was in the order of 450 mm, and that as much as 150 mm of this rainfall would infiltrate over limestones and basalts in the catchment of the Ras al Ain Springs, mainly in Turkey.[21] Furthermore, it was concluded that a recharge area of 8,100 km^2 is required to replenish the annual discharge of the Ras al Ain Springs,[22] which was calculated at an average of 1,219 MCM/yr for the period 1943-1959.[23] Using recent available information, annual recharge in the catchment area[24] is estimated to fluctuate between 9x10^{-1} BCM (for a dry year with 500 mm precipitation) and 1.77 BCM (for a wet year with 800 mm precipitation).[25] This means that the catchment area would receive about 92 mm of recharge during dry years and 180 mm during wet years.

FLOW REGIME

The prevalence of a complex tectonic setting characterized by a number of folds and faults intruded by basaltic flows interferes with the development of a regional groundwater flow direction across the basin.[26] Hence, groundwater generally flows from high areas in the north and south to the low-lying central plains and wadi channel beds (see Overview Map).

STORAGE

The volume of water stored in the aquifer system that feeds the Ras al Ain Springs comprises the majority of the groundwater in the Jezira Tertiary Limestone Aquifer System and has been calculated as 7,400 MCM, or the equivalent of six years of discharge at the average natural rate.[27] Considering that there are several more springs that discharge from the system, the volume of water in storage within the aquifer system is likely to be significantly higher. However, it is not known how much is stored within the Jezira Tertiary Limestone Aquifer System alone.

DISCHARGE

The importance of the Jezira Tertiary Limestone Aquifer System is reflected by the discharge volume of several large springs such as Ras al Ain and Ain al Arous (within the boundaries of the delineated basin) and Ain al Arab (west of the Balikh River).[28] The total discharge of these springs used to exceed 52 m^3/s,[29] but has recently decreased dramatically to about 3 m^3/s.[30] The Ras al Ain Springs used to discharge 45 m^3/s, or 87% of total discharge from the aquifer system, have disappeared completely since 2001 (see also Chap. 2).[31]

On the Jagh Jagh River, springs with a 2-3 m^3/s discharge occur at the south-western foot of the Midyat Plateau in Turkey, upstream from Qamishli.[32] Two large karst springs, the Beyazsu and Karasu Springs, discharge 4.25 m^3/s and 4 m^3/s respectively from the Midyat Aquifer north-east of the Kiziltepe Plain.[33]

The groundwater regime of the Jezira Tertiary Limestone Aquifer System has been significantly altered over recent decades. Intensive groundwater pumping through a large number of wells in Syria and Turkey has resulted in a dramatic drop in the water level in this aquifer system, which has in turn led to a lower total discharge from karst springs in an area of 2,000 km² to the south of the town of Ras al-Ain.[34] During the last 20 years, intensive pumping from wells for irrigation has placed heavy pressure on groundwater supplies in both Syria and Turkey.[35]

WATER QUALITY

The chemical and isotopic compositions of groundwater in the aquifer system show important variations with respect to increasing depth, progressive confinement from north to south, and the geological facies changes. Three main types of groundwater were identified (see Overview Map):[36]

- **Fresh Ca-HCO_3-type water:** Found in springs and shallow wells close to the unconfined-confined limit with a Total Dissolved Solids (TDS) value of 370-720 mg/L and temperatures of 19°C-22.5°C. This type of water occurs in the northern part of the basin (Zone A) where the water percolates and flows in short and shallow paths as in the main spring at Ras al Ain. The isotope data suggests that this group of water is essentially recent meteoric water and that the increase in TDS is related to the evaporation effect.

- **Saline NaCl-CaCl-type water:** This mineralized (1,400–4,700 mg/L TDS) thermal (30°C-38°C) water (Zone C) is drawn from deep wells that tap the confined zone of the aquifer system. It is derived by mixing groundwater from the Jezira Tertiary Limestone Aquifer System with water from the underlying Upper Cretaceous Formation. This is essentially paleo-recharge water, which entered the aquifer system about 10,000 years ago.

- **Brackish CaSO_4-type water:** Admixed water which exhibits medium salinity (700-3,750 mg/L TDS) and temperature (25°C-31°C) and is formed by the mixing of the groundwater in Zones A and C. This type of water is found in both unconfined and confined zones (Zone B) and represents recharge water from both the Pleistocene epoch and recent times.

EXPLOITABILITY

The following criteria were used to delineate the exploitable areas of this aquifer system:

- **Depth to top of aquifer:** The average depth to the top of the aquifer ranges between 100 m bgl and 200 m bgl with the greatest depth occurring in the southern areas near the Jebel Abdel Aziz Anticlines (Figure 1). Hence drilling depth is not a limiting factor to exploitability.

- **Depth to water level:** Depth to groundwater is about 5 m bgl near the Ras al Ain-Qamishli Anticlines and Jebel Abdel Aziz, rising to 40-55 m bgl in the intermediary central plains[37] and in the Kiziltepe Plain to the north. This indicates that groundwater is shallow enough for exploitation.[38]

- **Water quality:** Less than 10,000 mg/L and hence not a limiting factor.

Hence the entire area of the aquifer system as delineated in the Overview Map is considered to be exploitable, although the existence of saline Paleo water in the southern areas of the basin (Zone C) may limit exploitation of the aquifer system in the future.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

In the past, groundwater extraction from the Jezira Tertiary Limestone Aquifer System constituted only a minor source of domestic and irrigation water supply compared to the readily available water from large springs, surface water diverted from the nearby Euphrates River, or abstraction from overlying shallow aquifers. In recent years, however, exploitation of the aquifer system has increased substantially on both sides of the border with approximately equal levels of abstraction in Syria and Turkey.[39]

In Turkey, groundwater investigations in the Sanliurfa-Harran-Ceylanpinar area began in 1955. State Hydraulic Works (DSI) has been drilling wells for domestic water supply since 1957, while it started groundwater exploitation for irrigation purposes in 1967. Recently, DSI started drilling wells for local farmers on contract basis. It was estimated that about 2,000 wells[40] are found in the area with a total abstraction of around 1.38 BCM[41]. Wells in the area have an average depth of about 200 m, reaching 400 m in some cases. Most wells abstract water from the Jezira Tertiary Limestone Aquifer System (Midyat Aquifer in Turkey), but a small number extract from the alluvium.[42] The number of registered bore-holes drilled in the aquifer rose significantly in the last decade and groundwater extraction appears to have increased considerably in the Kiziltepe Plain and adjoining areas in the Syrian Jezira Plain.[43]

In Syria, groundwater in the Qamishli region was exploited from 1955 onward, when preparations were made for the construction of dams on the Jagh Jagh River in Turkey. Soon after, a number of wells were drilled, mainly along river channels to compensate for the reduction in surface water flow. Most of these wells were extracting water from the shallow Plio-Quaternary deposits. Over the years, the number and depth of wells increased and by 2000, 3,797 wells were abstracting 1.59 BCM of groundwater.[44] About 83% of this water (1.32 BCM) is drawn by private wells with the highest abstraction taking place in April and August (Figure 3).

Agricultural land use within the delineated basin has undergone significant change in recent years as rain-fed agriculture was increasingly replaced by groundwater irrigation.[45] The total irrigated land area in Hasakah Governorate in 2010 was officially estimated at 358,000 ha, of which about 45,000 ha were irrigated by rivers and springs, while 313,000 ha were irrigated by wells (see also Chap. 2).[46]

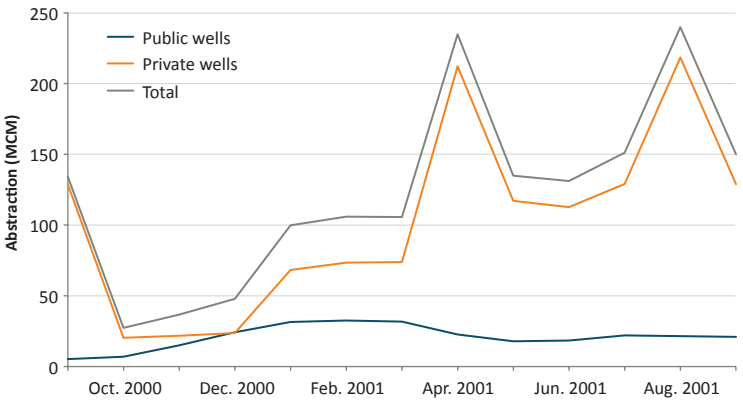
GROUNDWATER QUALITY ISSUES

The overexploitation of the Jezira Tertiary Limestone Aquifer System and intensified land use as part of the Southeastern Anatolia Project (GAP) (see Chap. 1 and 3) in the upper part of the delineated basin suggests that groundwater quality may have been affected. Pollution from pesticides and fertilizers has been suspected.[47] However, no data was available to verify this.

Two main factors indicate that the aquifer system may become a reservoir of deep saline water in the long run:

- Reduced freshwater recharge as a result of increased surface water use in the GAP area in Turkey, as this would allow an increase in the proportion of the deeper saline water in the system.
- Continuous overdraft of fresh bicarbonate water through groundwater mining in Syria and Turkey, which would increase the proportion of deep saline water that enters the aquifer system through mixing.

Figure 3. Monthly distribution of total groundwater abstraction in the Ras al Ain area in Syria (2000-2001)



Source: Compiled by ESCWA-BGR based on ACSAD et al., 2003.

SUSTAINABILITY ISSUES

The large volume of spring water discharged from the aquifer system in the Ras al Ain area has been dramatically reduced as the groundwater level dropped due to heavy groundwater extraction from wells in the adjoining plain areas. Groundwater levels have been dropping at an average rate of 1.68 m/yr for the period 1999-2003 in the Ras al Ain area.[48] The suspension of abstraction from 1,650 wells since 1998 did not result in a groundwater level rise or an increase in spring discharge.[49] This suggests that the aquifer system cannot be sustained without controlled measures to secure freshwater replenishment from the high mountain areas, particularly along the border of the aquifer system.

The spring of Ain al Arous, source of the Balikh River, Syria, 2010. Source: Andreas Renck.

Agreements, Cooperation & Outlook

AGREEMENTS

There are currently no water agreements in place for the Jezira Tertiary Limestone Aquifer System, which is shared between Syria and Turkey. However, the two countries have signed several agreements on the sharing of surface water from major rivers. From the point of view of groundwater, the most important is perhaps the 2009 Turkish-Syrian Strategic Cooperation Council Agreement which states that water is a focal point for cooperation between the two countries with specific emphasis on improving water quality, the construction of water pumping stations and joint dams, as well as the development of joint water policies (see Chap. 1).

COOPERATION

Cooperation between Syria and Turkey on surface water issues did not explicitly mention or take into consideration the need to cooperate over groundwater issues.

OUTLOOK

The present state of the Jezira Tertiary Limestone Aquifer System suggests that while it was reasonable to focus on the Ras al Ain area in the past, a wider and more regional approach to hydrogeological investigation and groundwater resource management woud be more appropriate in the future.

Agricultural fields along the Syrian-Turkish border, Turkey, 2010. Source: Adel Samara.

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1. Burdon and Safadi, 1963.
2. Kattan, 2002.
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4. Turkstat, 2010 cited in City Population, 2010.
5. Günay et al., 1996.
6. Geyh, 2004.
7. Burdon and Safadi, 1963.
8. Aghanabati, 1993; BGR and ACSAD, 1984; FAO and UNDP, 1966; Cater and Gillcrist, 1994; and Brew et al., 1999.
9. FAO and UNDP, 1966, Fig VII-II.
10. Cater and Gillcrist, 1994.
11. Kazmin, 2002.
12. Geyh, 2004.
13. Sawaf et al., 1993.
14. FAO and UNDP, 1966.
15. Burdon and Safadi, 1963; FAO and UNDP, 1966.
16. Geyh, 2004.
17. Gurer, 2008.
18. Geyh, 2004; FAO and UNDP, 1966.
19. FAO and UNDP, 1966.
20. Ibid.
21. Burdon and Safadi, 1963.
22. This means that the headwaters of the Khabour River Basin, which extends across the Mardin High-Basalt Plateau north of the delineated area in the Overview Map (see Chap. 2), would contribute to recharge.
23. Burdon and Safadi, 1963.
24. ACSAD et al., 2003 calculated an area of 9,840 km^2, which is somewhat higher than the 8,100 km^2 previously assumed by Burdon and Safadi, 1963.
25. ACSAD et al., 2003.
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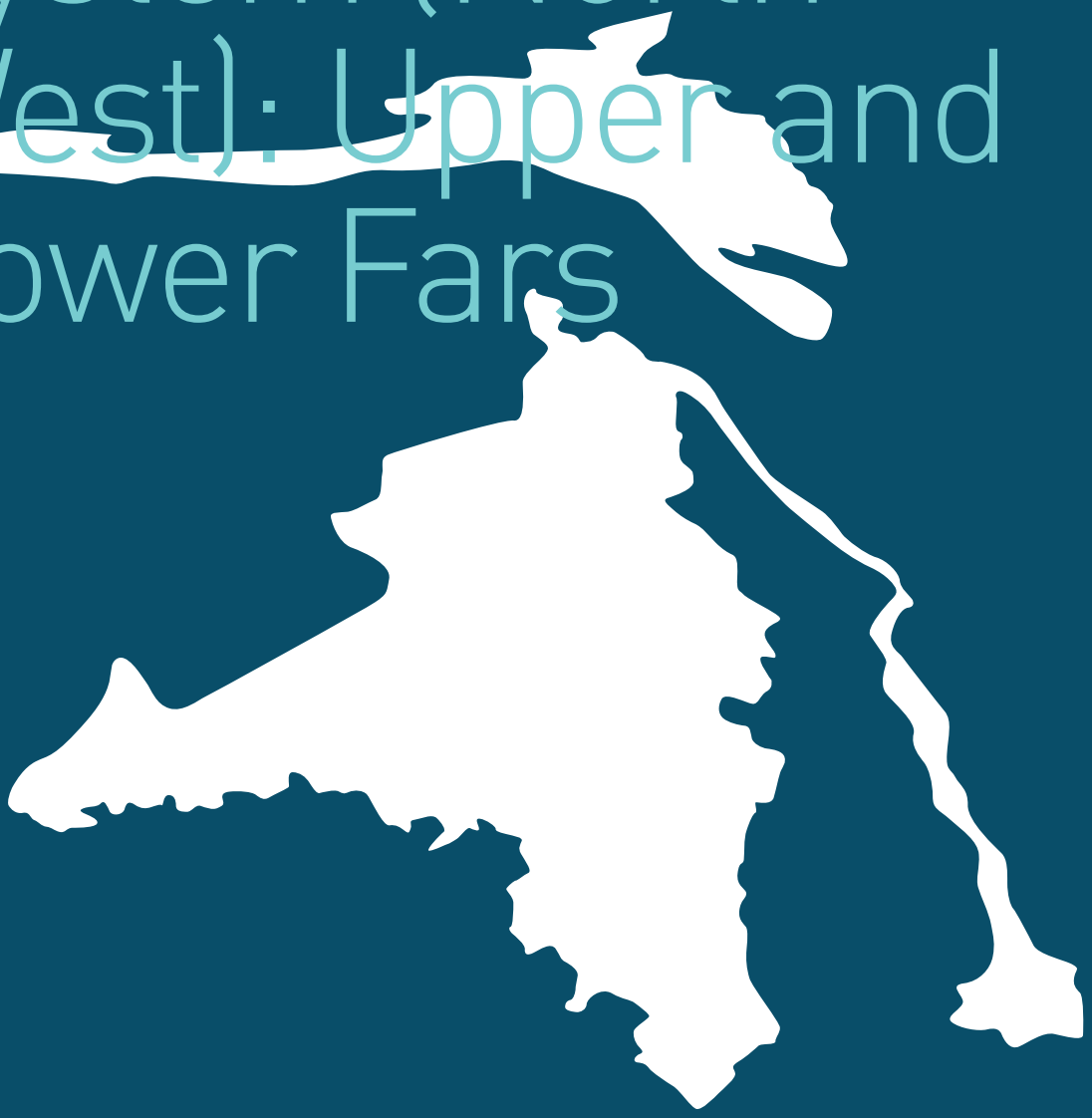
Chapter 25

Jezira Basin

Neogene Aquifer System (North-West): Upper and Lower Fars



Neogene Aquifer System (North-West): Upper and Lower Fars

Jezira Basin

EXECUTIVE SUMMARY

The eastern part of the Upper and Middle Neogene Formations beneath the Mesopotamian Plain constitutes a shared aquifer system between Iraq and Syria. This aquifer system is referred to as the Neogene Aquifer System (North-West), and comprises the Upper and Lower Fars Formations of Miocene age (presently known in Iraq as Injana and Fatha). It consists of a lower part composed mainly of gypsum, and an upper part made up mostly of sandstones and clay.

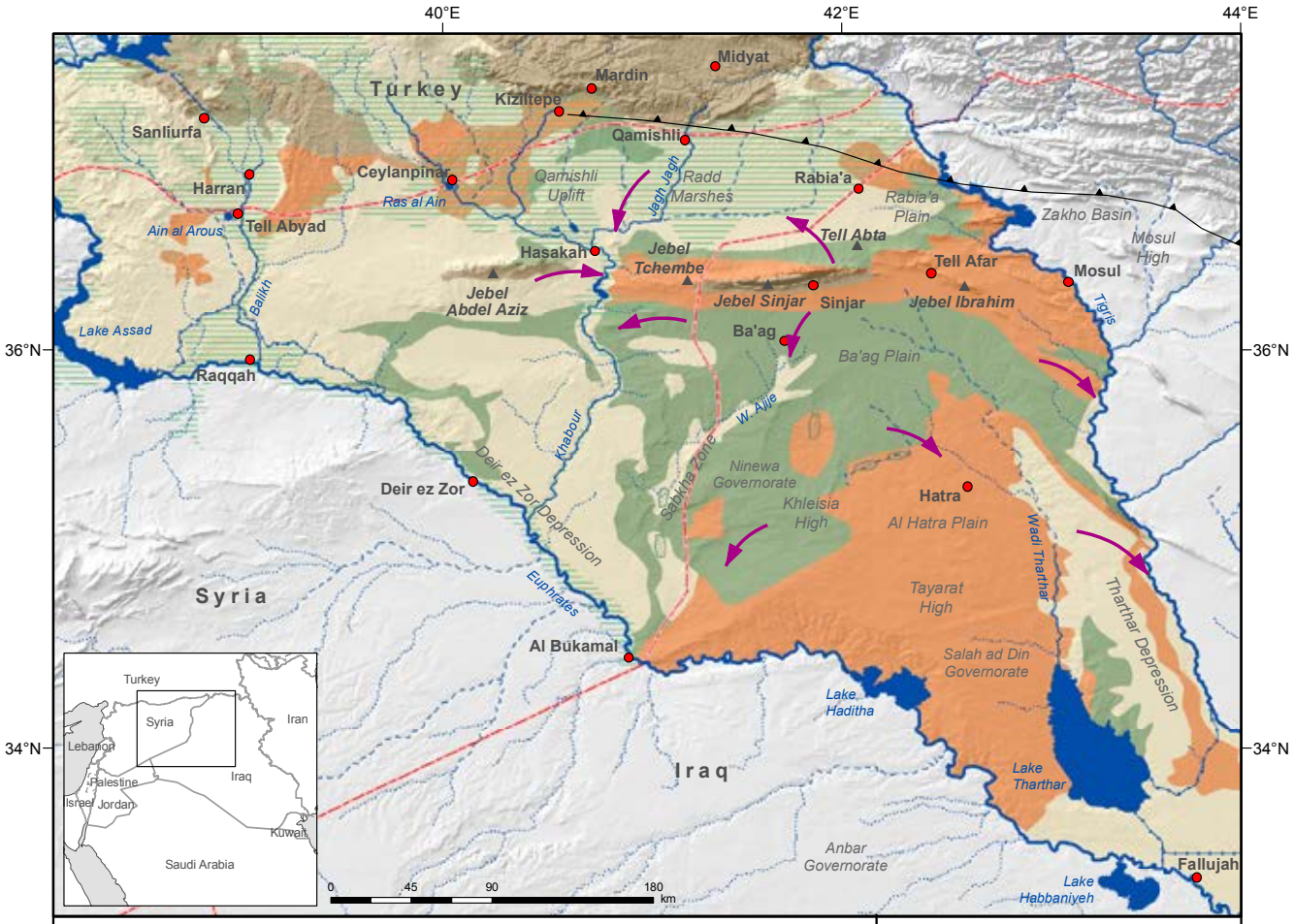
Groundwater flow across the political border is generally directed towards river courses and salt flats. Groundwater in both aquifer parts is generally brackish (4,000-≥20,000 mg/L TDS), with relatively more freshwater in the upper layers (<1,000 mg/L) especially in the northern areas where the aquifer is recharged by precipitation and surface water.

Groundwater is abstracted from wells, in addition to a small number of bore-holes that are concentrated in the vicinity of elevated areas around the Sinjar-Abdel Aziz Mountains. Groundwater use is generally restricted by high salinity levels and low well yields, and water for domestic consumption can only be abstracted from the upper aquifer up to a depth of 25 m bgl.

BASIN FACTS

RIPARIAN COUNTRIES	Iraq, Syria
ALTERNATIVE NAMES	Iraq: Fatha-Injana Syria: Lower and Upper Fars
RENEWABILITY	Medium to High (20 - >100 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Good
ROCK TYPE	Porous
AQUIFER TYPE	Unconfined to confined
EXTENT	65,000 km^2
AGE	Cenozoic (Neogene)
LITHOLOGY	Sandstones
THICKNESS	Generally 500-550 m with a pronounced decrease in thickness north of the Sinjar Uplift
AVERAGE ANNUAL ABSTRACTION	..
STORAGE	..
WATER QUALITY	Most common: brackish to saline (2,000-4,000 mg/L TDS) Recharge areas: ≤ 1,000 mg/L TDS Discharge areas: 5,000 - ≥ 20,000 mg/L TDS
WATER USE	Agriculture and domestic
AGREEMENTS	-
SUSTAINABILITY	Risk of salinization if wells are deepened and/or infiltration of surface water from irrigated areas

OVERVIEW MAP



Neogene Aquifer System (North-West), Upper and Lower Fars: Jezira Basin

- Selected city, town
- International boundary
- River
- Intermittent river, wadi
- Canal, irrigation tunnel
- Freshwater lake
- Sabkha
- Mountain
- Upper Fars Formation outcrop
- Lower Fars Formation outcrop
- Miocene
- Pre-Miocene outcrops
- Approximate subsurface extent of the aquifer formations
- Direction of groundwater flow
- Zone of agricultural development (selection)
- Thrust belt

ESCWA

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

Disclaimer
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

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Introduction

LOCATION

The Upper and Lower Fars Formations also known as Injana and Fatha in Iraq occur across the Mesopotamian Plain in north-eastern Iraq and north-western Syria, in the area situated between the Euphrates and Tigris Rivers known as the Jezira[1] (see Overview Map).[2] The Khabour River in Syria cuts through a narrow ridge,[3] forming a subsurface drain for groundwater from the east and west.[4] The river constitutes the western boundary of the Neogene Aquifer System (North-West) that extends across the Jezira Basin to Wadi Tharthar and Lake Tharthar in Iraq, which form the boundary between two key morphological zones in Iraq.[5]

AREA

For the purpose of this Inventory, the Jezira Basin is defined by the following geo-physiographic features:

- The thrust belt of the Taurus-Zagros system[6] and the Qamishli Uplift,[7] which allow groundwater to flow southward toward the Jezira Basin.
- The Jagh Jagh River, where the Paleogene sediments drop to great depths,[8] suggesting that the river channel may represent a fault.
- The Khabour River, which flows through a gorge into which groundwater discharges from the east and west.[9]
- The Mosul High (or Mosul Uplift), which was active during the deposition of the Lower Miocene age formation and along which the Tigris River flows.[10] It defines the eastern limit of the Western Sinjar Basin,[11] which extends into Syria.
- Wadi Tharthar and Lake Tharthar, which divide two major morphological zones in Iraq: the Alluvial Fans Zone and the Jezira Basin.

The above-mentioned boundaries have been used to calculate the area of the shared aquifer system, which covers around 65,000 km^2, of which 78% (49,000 km^2) lies in Iraq and the remaining 22% (16,000 km^2) in Syria. The Miocene age outcrops cover an area of around 51,000 km^2, which corresponds to around 70% of the total area of the delineated basin (see Overview Map).

The topography of the Jezira Basin is dominated by plains and valleys at altitudes of 340-400 m asl. High ridges between 950 m asl (Jebel Abdel Aziz) and 1,460 m asl (Jebel Sinjar)[12] divide the area into northern and southern parts. The most prominent features in the northern section of the aquifer system are the Rabia'a Plain and the Radd Marshes. The southern section is dominated by the Khleisia-Tayarat Highs and the Deir ez Zor Depression, which are separated by a sabkha zone in the border area.

CLIMATE

The climate in the area of the Neogene Aquifer System (North-West) is arid to semi-arid. Average annual precipitation ranges from 150 mm in the south to 300 mm in the north, increasing to more than 400 mm in the Jebel Sinjar area, where snowfall also occurs. Average annual temperature is 18°C-21°C, while evaporation is estimated at 2,800 mm/yr.[13]

POPULATION

The total population in the delineated basin is estimated at around 4.6 million inhabitants, with around 3.5 million people living in the parts of the basin situated in the Iraqi governorates of Anbar, Ninewa and Salah ad Din[14] and 1.1 million people living in the Syrian governorates of Deir ez Zor and Hasakah.[15]

OTHER AQUIFERS IN THE AREA

The Jezira Tertiary Limestone Aquifer System (Eocene-Oligocene, see Chap.24), which is exploited in the Ras al Ain area, constitutes a potential aquifer, particularly in the vicinity of uplifted areas. The Quaternary deposits also form local aquifers in morphologic depressions and in alluvial fans at the foot of Jebel Sinjar.[16]

INFORMATION SOURCES

Most of the information about the Neogene Aquifer System (North-West) in Syria is drawn from a 1966 survey of groundwater resources in Syria.[17] Information on the Iraqi section of the aquifer system is more recent and specific to the Jezira Basin. The Overview Map was delineated based on various local and regional references drawn from both riparian countries.[18]

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

The Sinjar-Jebel Abdel Aziz Uplift had a significant effect on the development and configuration of the basin in which the Upper and Lower Fars Formations were deposited. North of this structure, the formations are generally thinner and overlain by substantial Pliocene-Quaternary deposits (see Overview Map),[19] while to the south they are significantly thicker and outcropping in plateau areas. The thickest deposits in the aquifer system occur in the vicinity of the Sinjar High.[20]

STRATIGRAPHY

The Neogene Aquifer System (North-West) comprises two formations: the Upper and Lower Fars. They were deposited in a period when the open sea was being irregularly but persistently pushed south-eastward towards the current-day Gulf shoreline. During this period, marine sedimentation was replaced by depositions in saline lagoons, followed at times by freshwater lakes.[21] Table 1 shows the main lithology of the formations in the Jezira Basin. Lateral variations in lithology across the area are described below.

Lower Fars (Fatha)

In the Iraqi part of the Jezira Basin, the Lower Fars consists of several cycles of sedimentation deposited in a shallow lagoonal environment in a semi-closed marginal part of the Gulf Basin, characterized by sabkhas and saline tidal flats with deposition of carbonates and evaporites.[22] The cyclic sequences usually start with massive red claystone or marl, and contain thin limestones and thick layers of evaporites such as gypsum and anhydrite. Eleven such cycles were reported in the southern Jezira area.[23]

In the Syrian part of the Jezira Basin, the formation consists of shale and mudstone, gypsum and marine limestone, indicating the final extension of the open sea into this area. Halite occurs near the centre of the deposition basins.[24]

Table 1. Lithostratigraphy of the Neogene Aquifer System (North-West)

PERIOD	FORMATION	LITHOLOGY
Pliocene-Quaternary	Bakhtiari	Sands, gravels and conglomerates.
Upper Miocene	Upper Fars	Sandstone, marl, clay and gypsum.
Middle Miocene	Lower Fars	Anhydrite, gypsum, interbedded with limestone and marl.
Eocene-Lower Oligocene	Jezira Tertiary Limestone	Limestone with some dolomites and marly dolomites.

Source: Compiled by ESCWA-BGR based on Jassim and Buday, 2006; Brew et al., 1999; Burdon and Safadi, 1963.

Kawkab Mountain in Hasakah Governorate, Syria, 2009. Source: Haitham Alfalah.

Upper Fars (Injana)

In the Iraqi part of the Jezira Basin, the formation conformably overlies the Lower Fars Formation and is characterized by the appearance of siltstone beds. It consists of cyclic alternations of claystone, siltstone and sandstone with a few thin freshwater limestone and gypsum layers. The formation is overlain in some areas by Quaternary deposits, e.g. alluvial fans near Jebel Sinjar and thick soil cover in the Rabia'a Plain.

In the Syrian part of the Jezira Basin, the surface exposure of the Upper Fars is limited in area as it is eroded in uplifted areas around Jebel Abdel Aziz and remains covered by younger deposits in the area of the Khabour River flood

plain. In general, the formation is conformably underlain by Lower Miocene (Helvetian) deposits (Jeribe Formation) made up of sandstone with interbedded siltstone and mudstone.

AQUIFER THICKNESS

The Upper and Lower Fars Formations are easily recognized in the area of Kirkuk in Iraq to the east of the study area, where they reach a combined thickness of 1,240 m.[25] Within the delineated area, the thickness is reduced to 500-550 m as recorded in oil wells along the Iraqi-Syrian border (Figure 1). The most pronounced decrease in thickness is in the areas north of the Sinjar Uplift.

AQUIFER TYPE

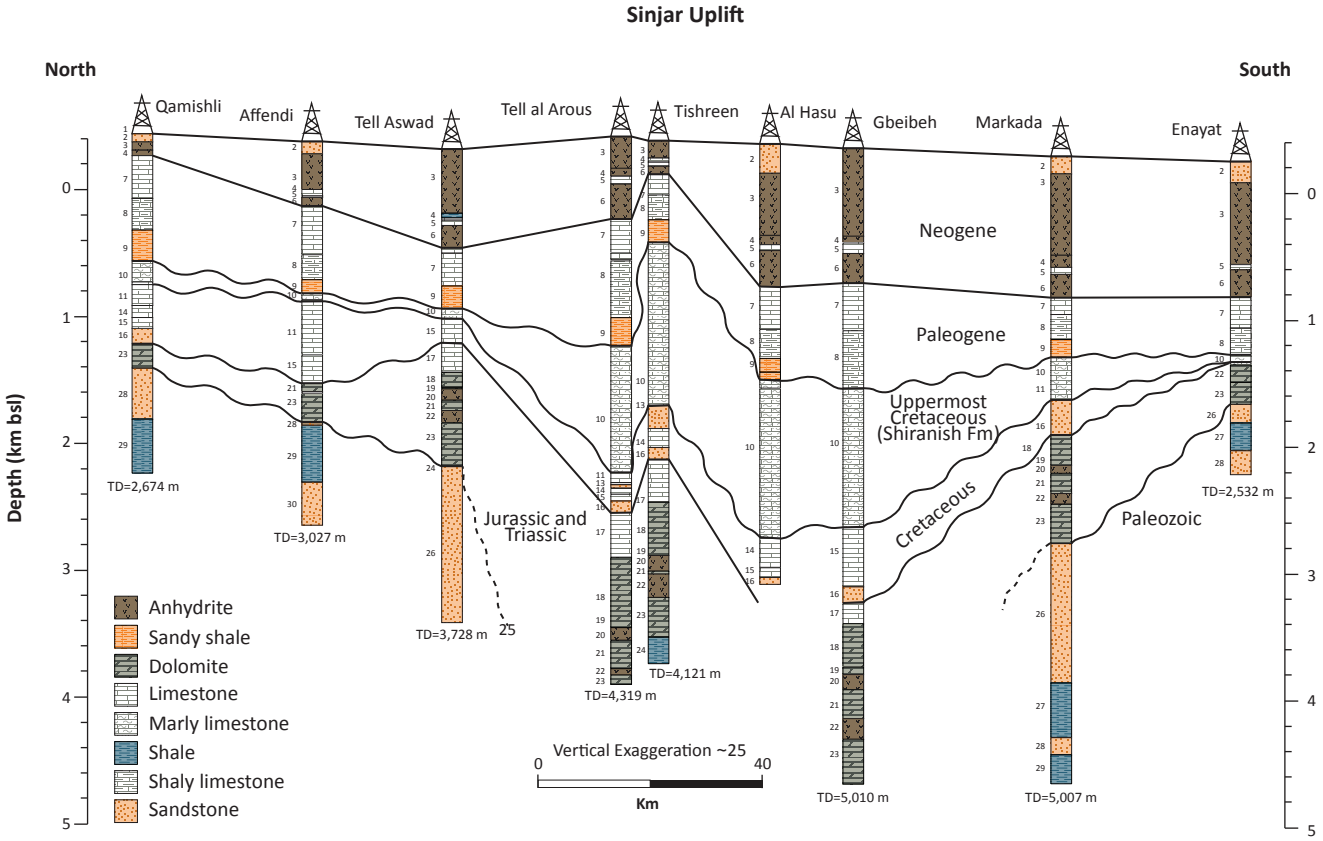
The Neogene Aquifer System (North-West) is unconfined in most areas of the Jezira Basin. The aquifer system is confined in some morphologically lower areas, where it is covered by younger sediments, and in deeper aquiferous sections, which are overlain by impermeable layers. Unconfined conditions prevail in outcrop areas of karstified gypsum and anhydrite beds of the Lower Fars Formation in the southern Jezira in Iraq. Locally, perched aquifers occur in the outcrop areas. The aquifer system comprises karstified and porous sections.[26]

AQUIFER PARAMETERS

In the Iraqi part of the Jezira Basin, hydraulic parameters vary widely due to karstification.[27] A range of $2.3x10^{-5}$ to $1.5x10^{-2}$ m^2/s was reported for the northern areas, with a median value of $4.5x10^{-4}$ m^2/s. [28] Lower values were reported in the Rabia'a Plain, varying from less than $1.2x10^{-5}$ to $1.8x10^{-3}$ m^2/s. Storage coefficients in the Rabia'a Plain are in the order of $5x10^{-4}$.[29]

Bore-hole tests of the aquifer system in Syria indicate a high heterogeneity of gypsum formation. Transmissivity values are reported at $1.6x10^{-4}$ to $8.1x10^{-2}$ m^2/s.[30]

Figure 1. Well correlation section across the western portion of the Sinjar Uplift in Syria



Source: Redrawn by ESCWA-BGR based on Brew et al., 1999.

Hydrogeology- Groundwater

RECHARGE

Three main factors contribute to present-day recharge in the Neogene Aquifer System (North-West):[31]

- The occurrence of rainfall in excess of 250 mm, mainly in the northern areas but also in localized uplifted areas.
- Thick accumulation of alluvial deposits, which allows recharge of the aquifer system after heavy storms, directly from precipitation and indirectly via runoff from the higher areas and surface water from the Khabour River.
- The occurrence of gypsum karstification, especially in areas where the Lower Fars Formation is exposed on the surface.

In the Iraqi part of the Jezira Basin, recharge rates are estimated at 68 mm/yr on limestone outcrops on the northern flank of Jebel Sinjar, and at 14 mm/yr in the soil-covered plain. In the Tell Afar area, which is characterized by low rainfall and a thick cover of silty to clayey soil, recharge is considered to be negligible. Further north in the Rabia'a Plain, an annual average recharge of 53 MCM is reported.[32] On the Ba'ag Plain, recharge of the exposed Upper Fars Formation is estimated at an annual average of around 110 MCM.[33] On the Al Hatra Plain, recharge takes place on the karstified surface of the Lower Fars Formation, mainly through sinkholes, resulting in localized infiltration of around 31.5 mm/yr.[34]

In the Syrian part of the Jezira Basin, groundwater from the overlying Quaternary Aquifer and adjoining Eocene Aquifers seeps into the Neogene Aquifer System (North-West) in the Radd Marshes. About 347 MCM/yr infiltrates into the Pliocene-Quaternary Radd Aquifer.[35] Water from numerous small springs in early Miocene and Eocene aquiferous rocks along the Jebel Abdel Aziz-Jebel Sinjar range re-infiltrates into the Neogene Aquifer System (North-West) through the Quaternary Aquifer. In the Upper Khabour Basin, infiltration takes place at an estimated rate of 50.5 mm/yr, which corresponds to about 18% of the average annual precipitation (282 mm). Overall groundwater recharge to the Upper and Lower Fars Aquifers in Syria has been estimated at 60-90 MCM and 16 MCM in the northern and southern Jezira Basin respectively.[36]

FLOW REGIME

The groundwater flow pattern in this aquifer system more or less follows the steep gradients of the local topography and may not represent a regional groundwater flow system.[37] Groundwater flow in the Lower Fars Formation appears to be karstic, with minor circulation systems directed to morphologic depressions. These depressions act as local groundwater discharge zones to form salt marshes or sabkhas. The overall groundwater flow pattern (see Overview Map) in the area suggests the following:[38]

- North of the Abdel Aziz-Sinjar Uplift, groundwater flow is oriented toward the upper part of the Tigris and Khabour Rivers within the study area and the Radd Marshes.
- South of the Abdel Aziz-Sinjar Uplift, the flow is toward low-lying sabkhas and depressions (Deir ez Zor and Tharthar Depressions), which terminate in the lower part of the Tigris and Khabour Rivers within the study area.

STORAGE

Information on groundwater storage was not available.

DISCHARGE

The main discharge area of the Neogene Aquifer System (North-West) is situated at Wadi Tharthar and Lake Tharthar. Discharge from the Upper Fars Formation provides the base flow in major wadis in the Jezira Basin in Iraq, with a discharge of 0.274 MCM/yr recorded in Wadi al Murra in October 1979.[39] Groundwater from the Lower Fars Formation seeps into local sabkhas along the Hadr-Bekhme Fault. In these sabkha areas[40] and at Jebel Ibrahim in the Tell Afar area, there are many small springs with discharges of around 0.095 MCM/yr. The springs originate in karstified gypsum-anhydrite beds of the Lower Fars Formation, with a total flow rate of 11 MCM/yr.

The largest spring at Tell Afar reportedly had a discharge of 6.3 MCM/yr in 1975.[41]

In the area of Jebel Abdel Aziz, numerous small springs discharge into closed depressions and sabkhas. A number of these springs that rise from the Lower Fars Formation discharge between 31.5 and 63 MCM/yr. There are 35 springs along the Tual al Abta-Jebel Abdel Aziz-Jebel Tchembe range. Relatively high discharge rates are reported for the Khatounye (15.7 MCM/yr), Ain Hol (approx. 9.47 MCM/yr) and Tell Taban (18.93 MCM/yr) Springs.[42]

WATER QUALITY

Groundwater in the Neogene Aquifer System (North-West) is generally brackish to saline and sulphate-type. Fresh bicarbonate-type water with less than 1,000 mg/L TDS is frequently encountered in shallow wells. On average, groundwater salinity in the Upper Fars is lower than in the Lower Fars.

In the Rabia'a Plain, salinity varies from less than 1,000 to 4,000 mg/L TDS in most wells.[43] Further south in the Ba'ag Plain, salinity in wells penetrating the Upper Fars Formation exceeds 4,500 mg/L TDS. Groundwater salinity in the Lower Fars Formation lies in the range of 3,000-5,000 mg/L TDS, increasing to 20,000 mg/L in sabkhas.[44] The following ranges were reported for groundwater salinity in the Jezira Basin in Iraq: less than 500 mg/L TDS in some shallow wells, 5,000-20,000 mg/L TDS in deeper wells, and saline water of more than 30,000 mg/L TDS in playas and salt lakes.[45]

Groundwater in the Lower Fars in the Jezira Basin in Syria is prevailingly brackish Ca-SO_4 water with salinities of about 2,000-4,000 mg/L TDS. At greater depths, groundwater salinity may exceed 10,000 mg/L TDS; fresh HCO_3-type groundwater occurs at a few locations.[46] The situation is similar in the Upper Fars Formation, which contains mainly Ca-SO_4 water with salinities of 2,000-4,000 mg/L TDS increasing with depth to 8,000 mg/L TDS.[47] Some small springs yield HCO_3-type freshwater.

EXPLOITABILITY

The following criteria were used to delineate the exploitable areas of this aquifer system:

- **Depth to top of aquifer:** When not outcropping, the top of the Upper and Lower Fars Formations lie a few hundred metres below the surface. Hence, depth to top of the aquifer is not a limiting factor.
- **Depth to water level:** Depth to groundwater is usually less than 50 m bgl and as little as 20 m bgl as on the Khleisia High.[48] Therefore water level is also not a limiting factor.
- **Water quality:** Groundwater TDS varies widely and can reach 30,000 mg/L, except in shallow depths of 15-25 m where salinity is usually below 1,000 mg/L.[49] Salinity is therefore the main limiting factor to exploitability, both vertically and laterally.[50]

Based on the above, the aquifer system is exploitable within the delineated area up to a depth of 25 m bgl, except in and around sabkha areas where it may not be suitable for exploitation at all.

Kurdistan, northern Iraq, 1991. Source: Ed Kashi/VII.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

In the past, groundwater was abstracted from shallow wells in the Quaternary-Pliocene formations (mostly in the northern areas) and in the Neogene Aquifer System (North-West) around and to the south of the Sinjar-Abdel Aziz Uplift. Drilling of deeper bore-holes occurs where conditions are favourable, such as in the Ba'ag Plain.[51] In general, however, low aquifer productivity and poor water quality restrict the exploitability of the Neogene Aquifer System (North-West), and many wells abstracting from the aquifer system in Iraq have been abandoned due to low discharge.[52] Similarly, withdrawal from the section of the aquifer system in Syria is thought to have been significantly reduced due to salinization, with increased penetration of saline groundwater into the Lower Fars Formation.

The implementation of a number of irrigation projects in the area may help improve groundwater quality as fresh surface water percolates into the aquifer system.
The 60,000 ha Rabia'a Irrigation Project initiated in 1989 in Iraq transfers Tigris River water from Lake Mosul to the Rabia'a Plain. The project uses sprinkler irrigation on an area of 20,000 ha and furrow irrigation on 35,000 ha, allowing for the artificial recharge of groundwater in the Upper Fars Aquifer at an annual rate of about 130 MCM. As a result, the groundwater table has risen up to 4.5 m in certain areas. The infiltration of river water has also slightly improved water quality.[53] The expansion of the irrigated area in the Jezira Basin in Syria following the 1975 construction of Tabqa Dam on the Euphrates River has also led to artificial recharge of the Quaternary Aquifer and the Neogene Aquifer System (North-West).[54]

In the mid-1960s, there were more than 50,000 hand-dug wells and several hundred bore-holes in the northern part of the Jezira Basin in Syria.[55] These wells tap Miocene (i.e. Upper-Lower Fars) or Pliocene-Quaternary Aquifers. The quantity of water extracted from dug wells is generally limited (approx $1x10^{-3}$ MCM/yr), with quantities of up to about $3.6x10^{-3}$ MCM/yr near riverbeds.[56] Groundwater abstraction in Syria has probably decreased considerably in recent years as the relatively freshwater in the upper layers of the aquifer system is likely to have been exhausted.

In the Rabia'a Plain in the Jezira Basin in Iraq near the Tigris River, the Upper Fars Formation forms a key water source, as no other exploitable aquifers exist in the area. At least 66 drilled wells are in use in the plain, with productivity rates ranging between about $9x10^{-3}$ and $5x10^{-1}$ MCM/yr. They are complemented by numerous shallow hand-dug wells.[57] Around the city of Rabia'a, groundwater has low salinity rates and is suitable for human consumption, but in general it is mainly used for agricultural purposes or livestock watering. In the Ba'ag Plain, the Upper Fars Aquifer is exploited through more than 100 drilled wells with discharge rates of around 1.45 MCM/yr.

Further south, hundreds of shallow hand-dug wells and a number of drilled deeper wells exploit the Lower Fars Aquifer, with discharge rates varying between $1x10^{-1}$ and $4.2x10^{-1}$ MCM/yr.[58] The water is mainly used for domestic supply and livestock watering.

GROUNDWATER QUALITY ISSUES

The groundwater in the Neogene Aquifer System (North-West) is not suitable for human consumption in many areas. Groundwater use for irrigation purposes is also restricted because of generally low well yields and elevated salinity. Good-quality water with less than 1,000 mg/L TDS is commonly found in areas with secondary permeability, which is restricted to the upper 15-25 m of the aquifer system.[59] Irrigation with low-salinity water from the Euphrates, Khabour and Tigris Rivers may improve water quality in shallow aquifers.

SUSTAINABILITY ISSUES

Groundwater exploitation in this aquifer system is limited by low aquifer productivity and water quality problems. A number of surface water irrigation projects initiated over recent decades in Iraq and Syria have contributed to artificial recharge of the aquifer.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place for the Neogene Aquifer System (North-West), which is shared between Iraq and Syria.

COOPERATION

The riparian countries do not cooperate over any aspect of water management or use.

OUTLOOK

The quality of water abstracted from wells in the Neogene Aquifer System (North-West) could be improved through the conjunctive use of surface water and groundwater. The construction of large-diameter dug wells would allow for the withdrawal of freshwater from superficial layers, and avoid mixing with brackish water contained in deeper layers. Such an approach could also allow for an increase in the amount of water abstracted from the aquifer system.

Near Aqrah, Iraq, 1991. Source: Ed Kashi/VII.

Notes

1. Jezira means "Island" in Arabic.
2. The formations extend beyond the main channels of the Euphrates and the Tigris. However, the Overview Map in this chapter limits itself to the area between the two rivers.
3. FAO and UNDP, 1966.
4. ACSAD, 1984.
5. The two zones are the Alluvial Fans Zone and the Jezira Basin (Krasny et al., 2006).
6. Kazmin, 2002.
7. Best et al., 1993.
8. ACSAD et al., 2003.
9. ACSAD, 1984.
10. Jassim et al., 1997.
11. As opposed to the Eastern Sinjar Basin which extends to Iran.
12. Kattan, 2001.
13. Al-Jiburi and Al-Basrawi, 2009.
14. Central Organization for Statistics in Iraq, 2012.
15. Central Bureau of Statistics in the Syrian Arab Republic, 2005.
16. Kattan, 2002.
17. FAO and UNDP, 1966.
18. Krasny et al., 2006; BGR-UNESCO, 1998; Robertson, 1987; Kazmin, 2002; Best et al., 1993.
19. Brew et al., 1999; Sawaf et al., 1993.
20. Ibid.
21. Burdon, 1954.
22. Tucker and Shawket, 1980.
23. Maala and Al-Kubaysi, 2009.
24. Burdon, 1954.
25. Jassim and Buday, 2006.
26. Al-Jawad, 1982.
27. Krasny et al., 2006.
28. Al-Jiburi and Al-Basrawi, 2009.
29. Al-Jawad, 1982.
30. FAO and UNDP, 1966.
31. Krasny et al., 2006.
32. Al-Jawad, 1982.
33. Faugere et al., 1976.
34. Jassim and Goff, 2006 .
35. FAO and UNDP, 1966.
36. Ibid.
37. Al-Jiburi and Al-Basrawi, 2009.
38. Figures 1 and 2 in FAO and UNDP, 1966.
39. Al-Jawad, 1982.
40. Krasny et al., 2006.
41. IARNR, 1974.
42. FAO and UNDP, 1966.
43. Al-Jawad, 1982.
44. Jassim and Goff, 2006.
45. Al-Jiburi and Al-Basrawi, 2009.
46. Ponikarov, 1967.
47. Ibid.
48. Krasny et al., 2006.
49. Ibid.
50. See section on groundwater quality issues below.
51. Al-Jiburi and Al-Basrawi, 2009.
52. Krasny et al., 2006.
53. Al-Naif, 2007.
54. Al-Jawad, 1982.
55. FAO and UNDP, 1966.
56. Ponikarov, 1967.
57. Al-Naif, 2007.
58. Al-Jiburi and Al-Basrawi, 2009.
59. Krasny et al., 2006.

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Chapter 26

Dibdibba Delta Basin

Neogene Aquifer System (South-East): Dibdibba-Kuwait Group

Neogene Aquifer System (South-East): Dibdibba-Kuwait Group

Dibdibba Delta Basin

EXECUTIVE SUMMARY

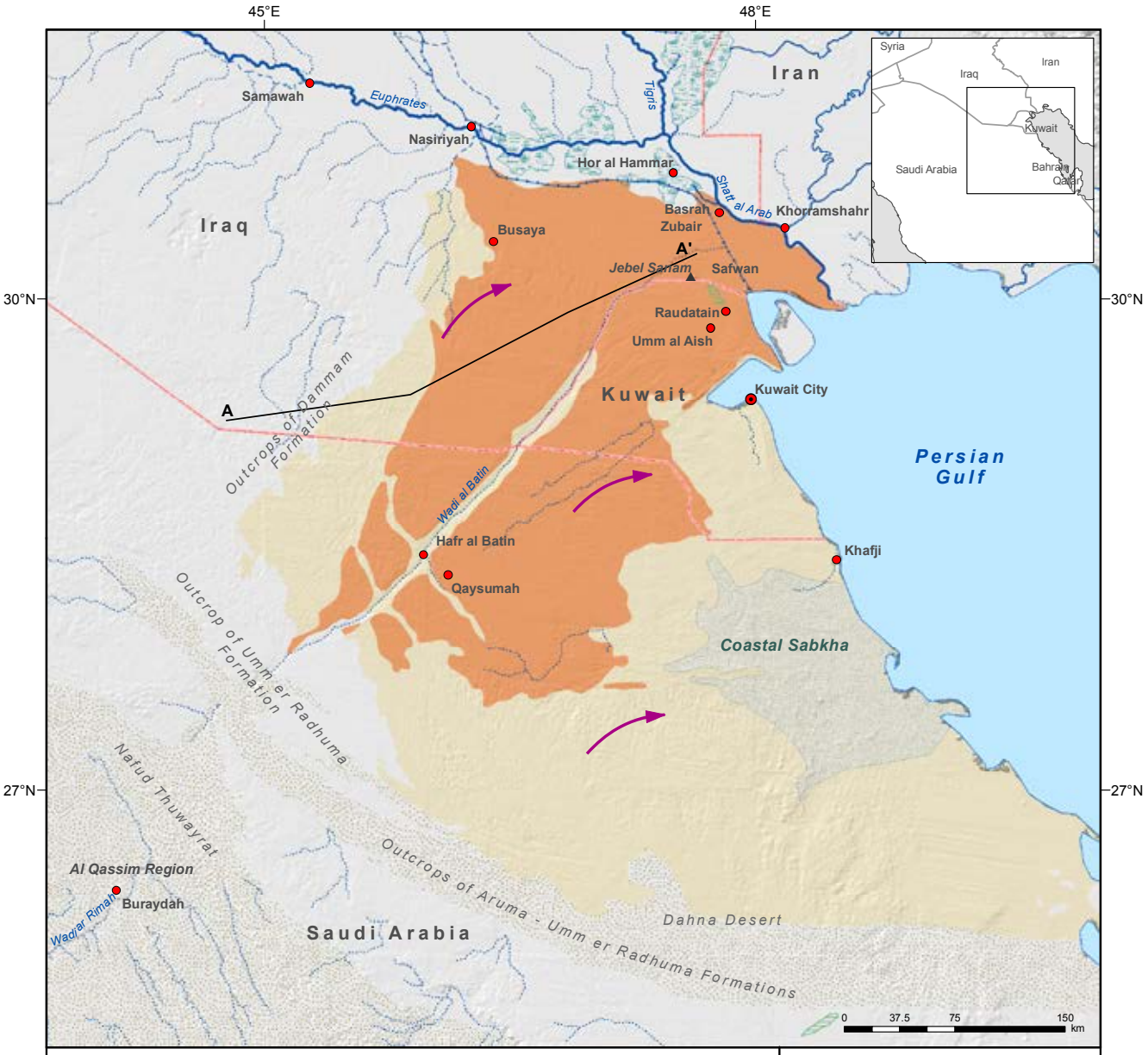
The Neogene Aquifer System (South-East) represents the northern extension of the Neogene Aquifers, which overlie the Paleogene Formations in the north-east of the Arabian Platform. The aquifer system is located mainly within the boundaries of the Dibdibba Delta basin, which is formed by the Wadi ar Rimah-Wadi al Batin that extends from the Arabian Shield in the west to the mouth of Shatt al Arab.

The basin stretches across three countries and comprises three aquiferous formations, known as Dibdibba, Lower Fars and Ghar Formations in Iraq and Kuwait, and Hofuf, Dam and Hadrukh Formations in Saudi Arabia. Groundwater has traditionally been abstracted mainly from the Upper Dibdibba Formation in southern Iraq and Kuwait or the Lower Hadrukh Formation in Saudi Arabia, which are mainly sands and gravels of continental origin. In recent years, abstraction of groundwater from these aquifers seems to be limited by two main factors: dewatering of the Dibdibba Formation, which has become largely unsaturated in several areas, and inversion of downward groundwater flow from the Neogene to the Paleogene Formations in heavy abstraction areas.

BASIN FACTS

RIPARIAN COUNTRIES	Iraq, Kuwait, Saudi Arabia
ALTERNATIVE NAMES	Ad Dibdibba Stony Desert, Ad Dibdibba Alluvial Fan, Dibdibba Plain, Kuwait Plain
RENEWABILITY	Very low to low (0-20 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Medium
ROCK TYPE	Porous
AQUIFER TYPE	Unconfined (central areas), Confined (coastal areas)
EXTENT	153,000 km^2
AGE	Cenozoic
LITHOLOGY	Predominantly sands and gravel
THICKNESS	30-200 m (common range) Max.: 550 m
AVERAGE ANNUAL ABSTRACTION	Iraq: ~370 MCM Kuwait: 88 MCM
STORAGE	Iraq: 1.26 BCM
WATER QUALITY	Brackish to saline (2,500 mg/L to 15,000 mg/L TDS)
WATER USE	Mainly agricultural
AGREEMENTS	-
SUSTAINABILITY	Water level decline and inversion of vertical flow due to over-exploitation

OVERVIEW MAP



Neogene Aquifer System (South-East), Dibdibba-Kuwait Group: Dibdibba Delta Basin

- Capital
- Selected city, town
- International boundary
- River
- Intermittent river, wadi
- Canal
- Sabkha
- Upper Neogene Formation outcrop: Upper Miocene-Pliocene (Dibdibba-Hofuf)
- Lower Neogene Formation outcrop: Lower-Middle Miocene (Ghar-Lower Fars-Hadrukh-Dam)
- Wetlands
- Zone of agricultural development (selection)
- Direction of groundwater flow
- Sand dunes
- A A' Hydrogeological cross-section

ESCWA

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

Disclaimer
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

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Introduction

LOCATION

The term Dibdibba Formation was introduced in 1938 for a type locality in the Zubair area to describe a Late Miocene-Pleistocene Formation, which extends over the Dibdibba Plain from the city of Basrah in Iraq to the northern part of Kuwait and the Wadi al Batin area in Saudi Arabia.[1] The Neogene Dibdibba Formation was deposited in a geographical area known as the Dibdibba Alluvial Fan or Delta.[2] This Inventory uses the term Dibdibba Delta to refer to the basin, while the term Neogene Aquifer System (South-East) refers to the aquifer system in this area. In Kuwait, this Neogene Aquifer System is denominated as the Kuwait Group Aquifer.

AREA

The Neogene Aquifer System (South-East) was formed during the Pleistocene pluvial phases, when a river flowed through Wadi ar Rimah and Wadi al Batin. This wadi system, which is the longest in the Arabian Peninsula, descends from the northern Arabian Shield to the north of the Gulf coast and used to extend further inland during the Pleistocene.[3]

The main part of the Dibdibba Delta basin is occupied by an alluvial fan which slopes north-east from about 400 m asl on its south-western side to 100 m asl on its northern side, with a low gradient of 1-1.2 m/km.[4] Since its formation in the wetter intervals of the Pleistocene, the main wadi has become deeply entrenched into the old alluvial fan, so as to reach Paleogene (Umm er Radhuma Dammam Formations) bedrock in the upper two thirds of the fan. Paleogene bedrocks are also exposed around the fan.

The boundaries assumed for the Dibdibba Delta basin are: the Gulf coast in the east, Paleogene (Dammam and Umm er Radhuma) outcrops in the west (around 350 km in east-west direction), the sand dunes of the Nafud Thuwayrat and Dahna Desert in the south, and the natural marsh systems (Central and Hammar) of the Shatt al Arab Wetlands in the north (around 480 km in north-south direction). The basin extends from the Wadi al Batin area in north-eastern Saudi Arabia into Kuwait and south-eastern Iraq.

For the purpose of this Inventory, the above-mentioned boundaries have been used to calculate the area of the shared aquifer system. The aquifer system covers around 153,000 km^2, of which 71% (109,000 km^2) is in Saudi Arabia, 18% in Iraq (28,000 km^2), and the remaining 11% (approx. 16,000 km^2) in Kuwait. Over 14,000 km^2 of the total area is covered by a sabkha.

CLIMATE

The climate in the Dibdibba Delta basin is arid with an average annual rainfall of around 100 mm. In some wet years, rainfall may exceed 200 mm with limited runoff causing floods in some wadis, in particular Wadi al Batin. More humid conditions prevailed in the area during wetter phases of the Quaternary period, the most recent being between 5,500 and

Khor al Zubair port, Basrah, Iraq, 2012. Source: Earth & Marine Environmental Consultants.

10,000 years ago[5] when the Wadi ar Rimah and Wadi al Batin formed one continuous river system (see Box 1 below).

POPULATION

Several medium-sized towns are situated in the area comprising the Neogene Aquifer System (South-East). The total population in the delineated basin that lies in Iraq is approximately 200,000, while around 2.5 million people live in the area that lies in Kuwait, mainly in urban areas. In Saudi Arabia, about 400,000 people live in the Hafr al Batin area. The total population living in and around the Dibdibba Delta basin can thus be estimated at around 3.5 million, including the population of the smaller villages and nomadic populations.

OTHER AQUIFERS IN THE AREA

The Neogene Aquifer System (South-East) is underlain by Paleogene carbonate aquifers: the Dammam and Umm er Radhuma Aquifers. The Dammam Aquifer provides the main source of brackish groundwater exploited in Kuwait. The Umm er Radhuma Aquifer is situated at great depth in this area, and contains mainly saline groundwater. The upper member of the Neogene Aquifer System (South-East) - the Dibdibba Formation - is overlain by alluvial Quaternary deposits in the area near Basrah and Hor al Hammar in southern Iraq and the northern part of Kuwait. The alluvial sediments are generally unsaturated but can be aquiferous, particularly in the coastal areas.

INFORMATION SOURCES

This chapter mainly uses information from Iraq and Kuwait. In Saudi Arabia, the Neogene Formations are mainly exploited further south-east in the region of Hofuf-Hasa, where they form part of the larger Umm er Radhuma-Dammam Aquifer System that extends to the Aruma Formation in this area.[6] Information on the part of the Dibdibba Delta basin that lies in Saudi Arabia is therefore not available. The Overview Map was delineated based on Mukhopadhyay et al., 1996.

Hydrogeology - Aquifer Characteristics

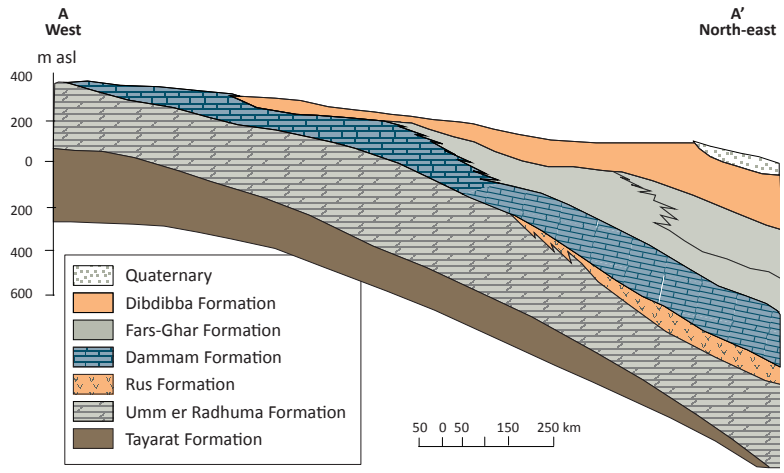
AQUIFER CONFIGURATION

The Neogene Formations rest disconformably over the Paleogene rocks and are overlain by Quaternary sediments at the mouth of the delta (Figure 1) where heavy loads of alluvial materials must have been deposited by both the Euphrates and Wadi ar Rimah-Wadi al Batin river systems.[7] The basin has a gentle slope in the west that becomes more pronounced farther east where the three Neogene Formations were deposited and preserved. Only a thin layer (Dibdibba Formation) can be found in the west.

STRATIGRAPHY

The Miocene sediments that constitute the main part of the Neogene Aquifer System (South-East) were deposited within the Zagros Foredeep, which was formed on the boundary between the stable Arabian Shelf and the Zagros Mountain Uplift. Massive supply of continental to deltaic clastics occurred and shallow marine shales accumulated in the rapidly subsiding Zagros Foredeep.[8] These sediments are thin in the western areas adjacent to the Paleogene outcrops, but quite thick and situated at great depth in the eastern coastal and offshore areas such as the area of Zubair, where they contain oil resources (Figure 1). The Neogene Aquifer System (South-East) has been subdivided into three formations, which are briefly described in Table 1.

Figure 1. Geological cross-section of the Neogene Aquifer System (South-East)



Source: Redrawn by ESCWA-BGR based on Al-Jawad et al., 2001.

Upper Formation (Dibdibba/Hofuf)

The Dibdibba Formation of southern Iraq and Kuwait covers the period from the Late Miocene to Pleistocene and is considered to have a similar fluviatile origin and the same characteristics as the Hofuf Formation.[9] The Dibdibba Formation constitutes a huge gravel fan with mainly coarse gravel and sand deposits, which accumulated during the Pliocene-Pleistocene in a sedimentary basin at the lower end of Wadi ar Rimah. In Iraq, the formation was defined as sand and gravel containing pebbles

Table 1. Lithostratigraphy of the Neogene Aquifer System (South-East)

PERIOD	FORMATION NAME AND GENERAL LITHOLOGY, PER COUNTRY		
	IRAQ	KUWAIT	SAUDI ARABIA
Pliocene	Dibdibba	Dibdibba	Hofuf
Upper Miocene	Continental (fluviatile): gravelly sand, often calcretized with subordinate clays.		
Middle Miocene	Lower Fars	Lower Fars	Dam
	Lagoonal: alternating beds of limestone, anhydrite, gypsum, clay and marls with subordinate sandstone.	Continental (fluviatile): calcretized sandstone.	Coastal (shallow marine littoral with supply of clastics): sandy and silty clay, calcareous marl, fossilferous limestone, sandstone and shale.
Lower Miocene	Ghar	Ghar	Hadrukh
	Continental (fluviatile): sands and gravels, rare clays, anhydritic and calcretic sands.		

Source: Compiled by ESCWA-BGR based on Mukhopadhyay et al., 1996; Alsharhan and Nairn, 1997; Ziegler, 2001.

of igneous rocks, including granite and quartz often cemented into hard grits. In Kuwait, the Dibdibba Formation has been subdivided into two units: a lower unit (Miocene-Pliocene) made up of coarse-grained, poorly sorted, gritty and pebbly sandstone cemented with chalky carbonate,[10] and an upper unit (Pliocene-Pleistocene) composed of gravelly sand and sandy gravel with gypsiferous cement.

Middle Formation (Lower Fars/Dam)

At the end of the Lower Miocene, a transgression of the sea intruded into the area; lagoonal conditions prevailed in the north-eastern corner of the Dibdibba Delta basin and lagoonal evaporitic sediments (Lower Fars) were formed in a considerable thickness.[11] The shallow marine littoral sediments with the terrigenous clastics of the Dam Formation were deposited in the south-eastern part[12] while continental (fluviatile) clastics continued to be deposited over much of the basin during the Middle Miocene, with some interfingering with the Lower Fars towards the east. In Kuwait, the Lower Fars Formation is described as well-sorted sand and sandstone interbedded with silty sand, clay and clayey sand with thin limestone beds and gypsum layers in the lower horizons of the formation.[13] In the area of Wadi al Batin on the Iraq-Kuwait border, the Lower Fars Formation is composed of claystone, marl and limestone.[14]

Lower Formation (Ghar/Hadrukh)

Deposition of this formation occurred under conditions varying from continental to littoral and deltaic.[15] In Iraq, the Ghar Formation consists of sands and gravels with rare anhydrite, clay and sandy limestone interbeds, while in most of Kuwait it is represented by marine to terrestrial coarse-grained, unconsolidated sandstone with a few thin, sandy limestone, clay and anhydrite layers. In southern Kuwait, the Ghar Formation has a gradational contact with the Lower Fars Formation and the two formations constitute an undifferentiated complex.[16] The Hadrukh Formation consists of calcareous to silty sandstones and sandy limestones and coquina beds.[17]

AQUIFER THICKNESS

Bore-hole data indicates that the total thickness of the Neogene Aquifer System (South-East) increases along the Wadi al Batin from 100 m in the south-west to about 550 m near its mouth. On average, the Dibdibba Formation constitutes about 150 m within the aquiferous sequence, with a thickness range of between 30 and 200 m.[18] South-west of the town of Busaya in Iraq, measurements in a water well showed the Dibdibba Formation comprises from its base upward: 21 m of gravelly sandstone, 60 m of medium-grained pink sandstone, and 18 m of calcareous sandstone.[19] The aquifer thickness decreases westward, leaving a large part of the formation unsaturated. The Lower Fars (Fatha) Formation has a minor presence in southern Iraq with a thickness of 40 m, while the Ghar Formation may reach a maximum thickness of 200 m.[20]

AQUIFER TYPE

The Neogene Aquifer System (South-East) is generally unconfined although confined conditions may exist in deeper layers of the aquifer complex. In general, the whole Neogene sequence forms one continuous aquifer system. The upper tens of metres of the sequence are unsaturated in many areas, especially west and north of the Wadi al Batin channel.

AQUIFER PARAMETERS

Hydraulic parameters of the Neogene Aquifer System (South-East) vary widely according to lithologic variations and saturated thickness. In general, higher aquifer productivity is found in the central gravel plain of Wadi al Batin with relatively thick and coarse sediments, while the aquifers in the flood plain areas may contain higher clay contents and have a lower productivity. The range of transmissivity values recorded in Kuwait increases from less than 1.15×10^{-4} m^2/s in the south-west to 1.73×10^{-2} m^2/s in the north-east for the aquifer system as a whole.[21] Similarly, a range of transmissivity values between 3.35×10^{-4} and 2.49×10^{-2} m^2/s is reported from Iraq.[22] The highest transmissivity value (2.95×10^{-2} m^2/s) was recorded for the unconfined Dibdibba Formation around Safwan.[23] The storage coefficient of the aquifer system was found to range between 1.8×10^{-2} and 8×10^{-2} in the southern part of Kuwait, where the aquifer system is unconfined, and about 1×10^{-4} in the northern part where it is confined.[24] The highest value (2×10^{-1}) was recorded in the Safwan-Zubair area in Iraq.[25]

Hydrogeology- Groundwater

RECHARGE

The aquifer system is fed by an extensive watercourse (Wadi ar Rimah-Wadi al Batin) that extends hundreds of kilometres into the Arabian Shield. Sources of recharge therefore are not only the rainstorm events within the Dibdibba Delta but also, and perhaps more importantly, the surface and subsurface flow of freshwater in this watercourse since the Pleistocene time.

Isotope data suggests that the Neogene Aquifer System (South-East) was recharged during more humid and cooler periods 20,000-30,000 years ago[26] and 5,500-10,000 years ago.[27] The occurrence of recharge under the present climatic conditions, though highly irregular, has also been observed, mainly in areas where karstic features developed in the Neogene-Paleogene Formations (mainly the Umm er Radhuma Formation). Recharge through this formation in the central Gulf region (82,100 km^2), which incorporates the entire Saudi part of the Neogene Aquifer System (South-East), ranged from nil to 2,706 MCM over the period 1952-1978.[28] The average recharge for this period was 547 MCM (6.7 mm/yr).

Variations of recent recharge during dry and wet years have reportedly ranged between 2.2 and 12 mm/yr for the Dibdibba Formation in Iraq.[29] The range of recharge values observed in southern Iraq (from 0.25 mm/yr in the western area to 26 mm/yr in the Safwan area)[30] may indicate a significant decrease in recharge in the south-west/north-east direction.[31] Estimates of natural annual groundwater recharge computed for the Iraqi part of the Dibdibba Plain vary between 30 and 90 MCM.[32]

In topographic depression areas in northern Kuwait (Raudhatain and Umm al Aish), occasional rainstorms cause freshwater ponding that infiltrates and forms freshwater lenses floating over the brackish water. In these areas, an average annual recharge of 850,000 m^3 has been estimated. Annual recharge to the entire aquifer system in Kuwait was estimated to be in the order of 58.5 MCM. The recharge rate included recharge from infiltration, subsurface inflow, and upward leakage from the Paleogene Dammam Aquifer.[33]

FLOW REGIME

In the northern areas, where the ground slopes from about 270 m asl in the extreme south-west to the lowlands of Iraq, groundwater flows towards the Shatt al Arab. In the southern part, the ground surface drops towards the Gulf through a series of discontinuous scarps, plateaus and plains, and groundwater flow is slightly deflected to the east. The elevation of the water table in the Neogene Aquifer System (South-East) descends from 130 m asl in the upstream area at Wadi al Batin and in southern Kuwait, to less than 5 m asl in the discharge zone.[34] At the downstream end of the aquifer system along the coast and the Shatt al Arab Depression, the groundwater is in direct contact with the sea or leaks into overlying Quaternary sediments and salt flats. Parallel to the Gulf coast in Kuwait, a belt of saline water forms a boundary to the brackish water of the Dammam Aquifer, causing an upward flow of groundwater into the overlying Neogene Aquifer System (South-East). The groundwater ultimately discharges from the Neogene Aquifer System (South-East) and through overlying Quaternary deposits into the sea and evaporation flats in the coastal area.

STORAGE

It is estimated that the Neogene Aquifer System in the Dibdibba Delta basin may hold around 11 BCM of groundwater,[35] which is about 10% of what has been estimated for the Negoene Aquifers as a whole in the Arabian Peninsula.[36] However, a large part of the Dibdibba Delta is now unsaturated. The uppermost exploited brackish water horizon in the Safwan-Zubair area, which has a saturated thickness of nearly 20 m, has storage of 1.26 BCM.[37] No other estimates were recorded in the literature.

DISCHARGE

Natural discharge from the Neogene Aquifer System (South-East) occurs mainly in the Gulf coastal area and the Shatt al Arab lowlands, through evaporation from shallow water tables and seepage into overlying Quaternary sediments, riverbeds and sabkhas.

WATER QUALITY

The groundwater in the Neogene Aquifer System (South-East) is generally brackish to saline with high lateral and vertical variations. Groundwater salinity increases horizontally along the flow path, as well as vertically across the different lithological units of the aquifer system.

In southern Iraq, two salinity layers can be distinguished in the Dibdibba Formation, separated by consolidated silty clay beds. The upper horizon has Electrical Conductivity values between 2,400 and about 11,000 µS/cm, with an average range between 2,500 and 7,000 µS/cm.[38] Lower salinity values of about 1,000 mg/L TDS are found in morphologic depressions, where present-day recharge occurs.[39] The salinity contained in the second layer normally exceeds 15,000 mg/L. The separation between the two layers with different salinity may be related to low permeability layers or to a transitional salinity increase, with less saline water floating above water with higher salinity. The cause of the high salinity in the deeper horizons of the aquifer may be a connection with seawater or leakage from deeper carbonates (Upper Eocene Dammam Formation), which contain saline groundwater in this part of Iraq.[40]

In Kuwait, the overall salinity of the aquifer system ranges from 4,000 mg/L in the south-west of the country to 18,000 mg/L and higher in the north-east. An exception are the freshwater lenses in the Upper Dibdibba Formation in the Raudhatain and Umm al Aish Depressions, formed by the infiltration of runoff from infrequent rainstorms.[41] Relatively high boron (B^{3+}) concentrations between $9x10^{-1}$ mg/L and 2.5 mg/L are found in wells in the Dibdibba Formation in Iraq.[42]

EXPLOITABILITY

The Neogene Aquifer System (South-East) comprises a shallow aquifer system with water levels at relatively shallow depth. In some areas, the groundwater level is situated below the Dibdibba Formation and this unit is unsaturated. Exploitability depends mainly on the saturation level and water quality. Both of these parameters seem to be most favourable along the eastern bank of the Wadi al Batin and near the mouth of the delta where freshwater leakages from shallow lenses may occur. Areas along the coast, especially on the north-eastern tip of the Dibdibba Delta, are expected to be least suitable for exploitation.

Khor al Zubair port, Basrah, Iraq, 2012. Source: Earth & Marine Environmental Consultants.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

In southern Iraq, the aquifer system has been exploited through a large number of – mostly hand-dug – wells in the area west of Basrah, mainly from the Upper Dibdibba Aquifer. An official survey found that nearly 5,000 wells were in use in this area in 1998.[43] Annual groundwater abstraction for agricultural purposes was estimated at around 370 MCM in the 1980s.[44] A substantial part of the extracted water returns back to groundwater through the permeable pebbly sand soils (a return flow of about 84%).[45]

In Kuwait, exploitation of the Neogene became significant in the mid-1980s with a noticeable shift to the drilling of bore-holes that tap both the Neogene and the Dammam Formation below it. Abstraction from the Neogene and the Dammam Formation reached 91.6 MCM and 118.9 MCM respectively in 1988.[46] Annual abstraction from both the Neogene and the Dammam was estimated at 88 MCM in the 1980s, excluding extraction from private wells.[47] This groundwater exploitation resulted in:

- Vertical leakage from the Neogene Aquifer System downward into the Dammam Aquifer has been reversed.
- A 191 MCM/yr reduction in the groundwater storage in the Neogene Aquifer System (South-East), including 30.8 MCM/yr from the Dibdibba Aquifer.
- A 26% drop in the volume of outflow from the aquifer system. The draw-down in the Neogene Aquifer System (South-East) resulted in a 5-20 m drop in the water table in the border area between Kuwait and Saudi Arabia.[48]

GROUNDWATER QUALITY ISSUES

Groundwater in the Dibdibba Delta Basin is not suitable for human consumption with the exception of limited freshwater lenses near Raudhatain and Umm al Aish in northern Kuwait and in the Sabriah and Barjisiyah oilfields near Zubair in southern Iraq. The two freshwater lenses in Kuwait may have been polluted by oil spills during the second Gulf War in 1991.

SUSTAINABILITY ISSUES

The hydraulic connection with the Paleogene system – in particular the Dammam Aquifer – may influence the sustainability of the Neogene Aquifer System (South-East). Reversal of the hydraulic gradient downward and the flow of groundwater from the Neogene into the Dammam Aquifer have been observed for more than 20 years. This could represent a major risk to the productivity of the Neogene Aquifer System (South-East).

BOX 1

The Wadi ar Rimah-Wadi al Batin System

Extending across north-eastern Saudi Arabia, south-eastern Iraq and much of Kuwait,[49] the Rimah-Batin Wadi System is the longest wadi system in Arabia.[50] It is one of three[51] great west-east through-draining wadis on the peninsula[52] and used to be made up of major perennial rivers during the Late Pleistocene epoch.[53] Extending over a distance of about 970 km[54] from the Arabian Shield north-eastward to the southern part of Iraq, the system drains an area of about 174,400 km^2.[55] It crosses the borders of three countries: Iraq, Kuwait and Saudi Arabia. The Wadi ar Rimah-Wadi al Batin formed the Dibdibba Plain,[56] which is a sheet gravel blanket. The courses of Wadi ar Rimah and Wadi al Batin are now separated by the sand dunes of Nafud Thuwayrat. The Wadi ar Rimah system drains an area of over 112,000 km^2 and, although its lower course is largely sand filled, it still carries water in the wadi course. Wadi al Batin has a modern channel with some perennial water as well as many shallow ephemeral distributaries that fan out across the broad nose of Dibdibba Alluvial Fan.[57]

SEDIMENTOLOGICAL PROPERTIES

The landscape around Wadi ar Rimah consists of a wide flat pediplain on which coarse- to fine-grained Quaternary sediments have accumulated, mainly in eroded pediments and alluvial fans. The nature of the alluvial fans depends mainly on the kind of outcropping rocks. In granitic terrains, the fine-grained detritus allows only a low gradient of the slopes, whereas sharp terrace edges in areas of crystalline schists are mostly cut into the rocks.[58] The wadi channels are filled by fine clastic material with a high percentage of gypsum, while thin gravels, sands and fanglomerate-like sediments cover the older, smoothly eroded pediments.[59] The Wadi al Batin area is a 7-10 km wide alluvial fan with a relief of up to 57 m.[60] The surface is covered with gravel ridges (up to 20 m high) and inter-ridge depression erosional patterns.

HYDROLOGICAL FEATURES

The Wadi al Batin and Wadi ar Rimah were connected during the Quaternary wetter phases (until about 5,500 years ago) to constitute a major river system[61] that comprised two rivers separated by a highly faulted and fractured area covered by avalanches of wind-blown sand.[62] The carving of the wadi across the peninsula suggests the prevalence of a period of rainfall considerably greater in magnitude than any such periods during the Pleistocene.[63] Evidence that fluvial flow was available much more frequently and with a greater volume than today includes the well-defined Wadi al Batin Valley which is cut deep enough to uncover the underlying Tertiary Formations and the elevated terraces of older gravel.[64]

HYDROGEOLOGICAL CHARACTERISTICS

The Wadi ar Rimah-Wadi al Batin System (Figure 2) is a clear example of the concentration of groundwater by fractures where, in this case, the pathway of two old rivers is traced by a fault zone.[65] The lateral change in geology beneath the wadi system also appears to have a significant effect on its hydrogeological characteristics. West of the Buraydah-Unayzah area, the Basement allows increased surface runoff and evaporation, and decreased infiltration; hence no recharge from present precipitation occurs and shallow groundwater is only found in localized areas. The hydrogeological situation changes in the Buraydah-Unayzah area and further east, where present-day recharge occurs and the productivity of wells increases as a result of water circulating through joints and pore volumes in sedimentary rocks.[66]

Table 2 shows the exploitable amount of groundwater stored in the Rimah-Batin Wadi System. The water is found even under the part of the system covered by sand,[67] which is believed to have been a major source of water for the aquifers in the Al Qassim region.[68]

The water level is generally around 20 m bgl and wells abstracting water are commonly lowered to the fractured part of the Basement or the Saq Sandstones and other sedimentary formations, with generally higher salt content in the upper zone. The groundwater has a highly variable degree of mineralization. The general salinity range was reported to be 1,000-8,700 mg/L TDS.[69] However, values of up to 41,000 mg/L TDS have been found in localized areas beneath the wadi bed.[70] Extremely high nitrate levels up to 570[71] and 1,000 mg/L NO_3^- have been reported in some areas.[72] Isotope data indicates that the salt content of the water increases with the resident time of the water, mainly through the process of tertiary evaporation and recycling.[73]

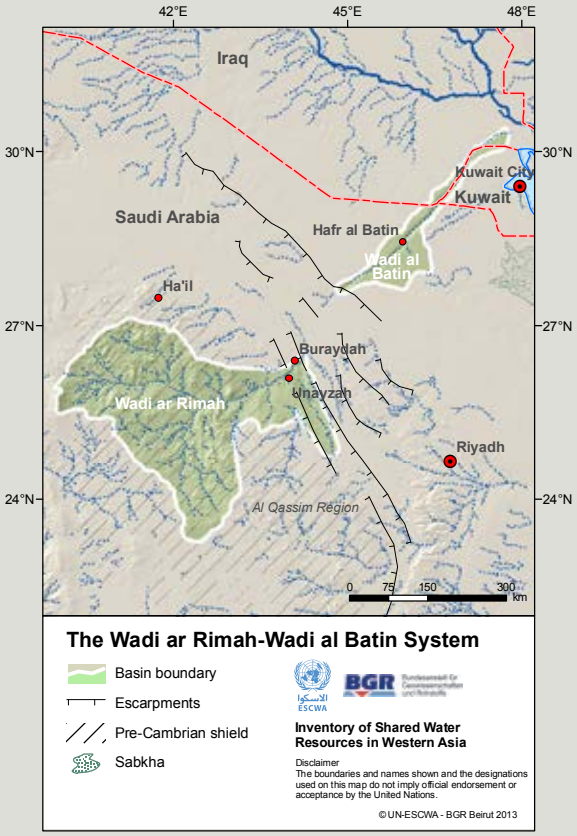
GROUNDWATER USE

Historically, three oasis towns in Saudi Arabia have survived on the shallow groundwater in this area: Buraydah, Unayzah and Hafr al Batin.[74] Further east, the shallow groundwater is heavily abstracted from the gravels of the Dibdibba Alluvial Fan, which was deposited by the Wadi al Batin. The isotopic composition of freshwater (500-1,800 mg/L TDS) perched in the Dibdibba Formation indicate that this is present-day recharge water.[75] This water forms a key source of groundwater for populations in the area of Raudhatain and Umm al Aish in Kuwait.

SUSTAINABILITY AND MANAGEMENT ASPECTS

The fertile arable lands created by runoff in the Wadi ar Rimah have allowed for agricultural development since the early 20th century in the upstream areas of the Rimah-Batin Wadi System, mainly around the towns of Buraydah and Unayzah.[76] Similarly, agricultural development in northern Kuwait and south-eastern Iraq depends heavily on the runoff in Wadi al Batin. In both of these areas, the shallow fresh groundwater is underlain by very saline water. Upconing of saline water already occurs[77] and poses a major risk to the sustainability of this alluvial system.

Figure 2. The Wadi ar Rimah and Wadi al Batin catchment area



Source: Compiled by ESCWA-BGR based on Sowayan and Allayia, 1989.

Hafr al Batin area, Saudi Arabia, 2007. Source: Drh104.

Table 2. Generalized hydrogeological information on the alluvial sediments in the Wadi ar Rimah-Wadi al Batin area

CATCHMENT AREA[a] (km²)	STORAGE (MCM)	POTENTIAL ABSTRACTION CAPABILITIES (MCM/yr)	GROUNDWATER ASSESSMENT	WATER QUALITY
174,400	4,000	20	Shallow supplies are available; some irrigation.	Generally poor; specific conductivity 2,000-5,000 µS/cm.

Source: Compiled by ESCWA-BGR based on Ministry of Agriculture and Water in Saudi Arabia, 1984.

(a) Data shown in the table is from source reference. Edgell, 2006, states an area of 112,000 km² for the catchment. This Inventory used GIS ArcMap Application to calculate an area of 114,000 km².

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place for the Neogene Aquifer System (South-East), which is shared between Iraq, Kuwait and Saudi Arabia.

COOPERATION

No information was available regarding cooperation between the riparian countries on the aquifer system.

OUTLOOK

The quantity and quality of available groundwater in the Neogene Aquifer System (South-East) suggest that it could sustain agricultural development in the central gravel plain, along the eastern bank of Wadi al Batin and near the mouth of the delta. On the plain itself, the aquifer system may have some potential as a source of recharge to the underlying Paleogene Formations, especially where the two aquifer systems are used as a common source of groundwater.

Kuwait, 2011. Source: Cajetan Barretto.

Notes

1. Alsharhan and Nairn, 1997, p.443.
2. Edgell, 2006.
3. Holm, 1960 cited in Edgell, 2006.
4. Ibid.
5. Edgell, 2006.
6. Tokhais and Rausch, 2008.
7. Edgell, 1997; Bakiewicz et al., 1982.
8. Ziegler, 2001.
9. Ibid.
10. Mukhopadhyay et al., 1996.
11. Ibid.
12. The Dam Aquifer does not extend beyond the area of Hasa (Edgell, 1997) and, hence, may not be part of the Neogene Aquifer System in the Dibdibba Delta basin.
13. Mukhopadhyay et al., 1996.
14. Al-Mashadani, 1995.
15. Alsharhan and Nairn, 1997; Ziegler, 2001.
16. Mukhopadhyay et al., 1996.
17. Ziegler, 2001.
18. UN-ESCWA and BGR, 1999.
19. Jassim and Buday, 2006.
20. Jassim and Goff, 2006.
21. Mukhopadhyay et al., 1996.
22. Al-Jawad et al., 1989.
23. Haddad and Hawa, 1979.
24. Mukhopadhyay et al., 1996.
25. Haddad and Hawa, 1979.
26. Pike, 1985 and Quinn, 1986 cited in Mukhopadhyay et al., 1996.
27. Edgell, 2006.
28. Faulkner, 1994.
29. Al-Mashadani, 1995.
30. Haddad and Hawa, 1979.
31. Assaf and Al-Suhail, 2001.
32. Al-Jawad et al., 2001.
33. Barrat et al., 1992.
34. Mukhopadhyay et al., 1996.
35. Al-Jawad et al., 2001.
36. Al Alawi and Abdulrazzak, 1993.
37. Al-Jawad et al., 2001.
38. Hassan et al., 1989.
39. Al-Jawad et al., 1970.
40. Parsons, 1957; Al-Jawad et al., 1970; Al-Rawi, 1983.
41. Mukhopadhyay et al., 1996.
42. Haddad and Hawa, 1979.
43. Al-Jawad, 1999.
44. Hassan et al., 1989.
45. Haddad and Hawa, 1979.
46. Mukhopadhyay et al., 1996.
47. This average dropped significantly as a result of much lower abstraction rates during the 1990-1991 Gulf War (UN-ESCWA and BGR, 1999).
48. Barrat et al., 1992.
49. Edgell, 2006.
50. Ibid.
51. The other two are Wadi as Sahba in central Arabia and Wadi ad Dawasir further south. The lower courses of all three wadi systems are now largely sand filled (Edgell, 2006).
52. McClure, 1978.
53. Edgell, 2006.
54. Ibid.
55. Ministry of Agriculture and Water in Saudi Arabia, 1984.
56. Powers et al., 1966.
57. Ibid.
58. Hotzl et al., 1978.
59. Ibid.
60. Al-Sulaimi and Pitty, 1995.
61. Edgell, 2006.
62. El-Baz, 2010.
63. McClure, 1978.
64. Anton, 1984.
65. El-Baz, 2010.
66. Hotzl et al., 1978.
67. Edgell, 2006.
68. El-Baz, 2010.
69. Moser et al., 1978; Sowayan and Allayia, 1989.
70. Sowayan and Allayia, 1989.
71. Ibid.
72. Moser et al., 1978.
73. Ibid.
74. El-Baz, 2010.
75. BGR et al., 1999.
76. Sowayan and Allayia, 1989.
77. Ibid.

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The Inventory of Shared Water Resources in Western Asia is the first UN-led effort to comprehensively assess the state of transboundary surface and groundwater resources in the Middle East. The United Nations Economic and Social Commission for Western Asia (ESCWA) and the German Federal Institute for Geosciences and Natural Resources (BGR) developed the Inventory as a desk study, while working in close consultation with ESCWA member countries, as well as regional and international experts. The Inventory follows a standardized structure, with 9 surface water chapters and 17 groundwater chapters that systematically address hydrology, hydrogeology, water resources development and use, international water agreements and transboundary water management efforts. The chapters cover all rivers and groundwater resources shared between Arab countries in the Middle East. Boasting 60 new maps and over 200 figures, tables and boxes with recent, comprehensive data series, the Inventory provides an up-to-date view of the state and evolution of shared water resources in Western Asia.

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