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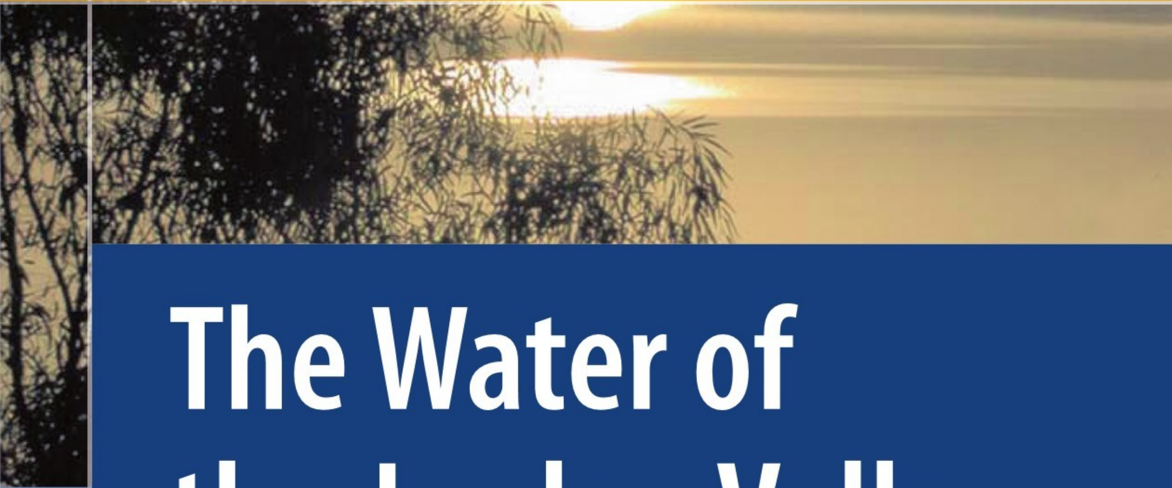

The Water of the Jordan Valley

Scarcity and Deterioration of Groundwater and its Impact on the Regional Development

Springer

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Sunset over the Dead Sea. View from Jordan towards the Judea Mts., Israel.
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THIS BOOK IS DEDICATED TO ALL PEOPLE LIVING ALONG THE JORDAN VALLEY IN HOPE THAT THE STUDIES CARRIED OUT IN THIS AREA OF SEVERE WATER SHORTAGE WILL CONTRIBUTE TO THEIR WELFARE, PROSPERITY AND TO THEIR PEACEFUL COEXISTANCE.

Preface

The long Jordan River, Dead Sea and the Arava/Araba chain of valleys compose together a segment of a global system termed The Syrian-African Rift which extends over 1/6 of the earth's circumference. Therefore, since the early 19th century this particular region became the target of multidisciplinary interest.

The Dead Sea-Jordan Valley Rift is not only an important geological and geographical feature but is of primary importance for the understanding of global zoological, botanical and anthropological migration processes. The prehistoric forefathers migrated 1.3 millions years ago through this Valley from Africa towards Europe and southern Asia. Among other places they settled south of Lake Tiberias and religious traditions, which evolved in this region which was once very prosperous, regarded this area as the mythical Paradise.

Unfortunately over long periods, the illusion of Paradise vanished and the valley became a pathway of armies - ancient Egyptians marching northwards and Assyrian and Babylonians going southwards. Later, the Valley was overrun by many others who wandered along this narrow border between green lands and desert.

During the present times, the political mosaic around the Jordan Valley is very complicated and - for a long time - did not facilitate free, easy and open dialogue neither between people nor between scholars and scientists. Nevertheless, the present book is the result of long and fruitful cooperation between scientists from Germany, Jordan, Israel and the Palestinian Authority. This may be the beginning of a new era of understanding and mutual help.

This is the first time when this complicate area has been studied by scientists from all riparian countries and without being hindered by territorial or by political limitations. This enabled us to create a complete, even 3-dimensional image of the area and solve hydrogeological issues which bothered all specialists in the area for many decades. One may say that following the studies described in the book, there is a clear picture as to all water bodies – fresh and saline - reaching the Jordan Valley and of their mutual interaction.

A most important achievement of the Project is the attenuation or even complete dissipation of suspicions between the riparians as to water resources. Moreover, its results indicate that in the study area, there is no negative transboundary influence which could have been caused by the utilization of local water resources. The joint and concerted scientific investigations are a tangible contribution to an atmosphere of cooperation not only in the domain of research but also in the ongoing exploitation of regional water resources. Throughout the duration of the investigations, all participants shared the feeling that they are contributing to the welfare of all inhabitants of the Valley and that the gradual progress of this concerted scientific effort, promotes the building of bridges joining the hitherto divided peoples of the area.

The Jordan Valley is in desperate need of additional water resources and we all hope that the results of our studies will enable to meet these acute demands. We all hope that the students and young researchers trained within the framework of the Project, will contribute to the development of additional water resources and to their rational management so as it should not be a Land of Lost– but a Land of Reborn Paradise.

The German-Israeli-Jordanian-Palestinian Joint Research Program on Water Resources Evaluation for a Sustainable Development in the Jordan Rift Basin was funded by the Federal Ministry of Education and Research, Germany, and by the Ministry of Science, Culture and Sport, Israel. Besides the financial support, the logistic assistance and the supply of information by Mekorot Co. and the Ministry of Water and Irrigation, Jordan, are greatly acknowledged. The Helmholtz-Centre of Environmental Research - UFZ, Germany, and the Geo-Research Center Potsdam, Germany, promoted the program by their man-power in field and laboratory work. The program was attended by special funds for PhD students from the four countries. All members of the international group acknowledge the financial support for publication of this volume received from the German Federal Ministry of Education and Research. Specifically, the editors thank Dr. H. Werz and Dr. C. Siebert for their assistance in editing the various contributions.

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1 Introduction

1.1 Scope and goals

H. Hötzl, A. Flexer, M. Haddad, E. Salameh

The lower Jordan Rift Valley is a large geotectonic feature bordered by a deep-seated fault system that creates an elongated and narrow basin. Three nations are neighbouring and sharing this basin and its margins: Jordan, the Palestinian Authority and Israel. The area has great potential for agricultural development being the natural greenhouse for a widespread region. The scarcity of water due to arid conditions is, however, the limiting factor for profitable growth. With the exception of Turkey and of Lebanon, the Middle East is an area deficient in water with yearly average natural recharge which is much lower than in Europe.

There are several major drainage basins in the Middle East, i.e., of the Euphrates, the Tigris, the Nile, Orontes, Litani, and of the River Jordan. The basin of the latter extends over Lebanon, Syria, Jordan, Israel and the Palestinian Authority. As it is a transboundary basin, neither country may independently dispose of its waters and is usually at the mercy of other riparians even if their political relations are not the best. Moreover, west of the River Jordan, groundwater basins are also transboundary and have to be shared by different political entities such as Israel and the Palestinian Authority

In the Jordan Valley, in which the studies presented in this book were carried out, rainfall is low, irregular, and often torrential. Most of it runs off without penetrating into the subsurface and replenishing groundwater. This delicate hydrological situation occurring in a complicate hydrogeological setting is often taken out of equilibrium due to overexploitation. Other results of the disturbance of the hydrological equilibrium are acute processes of natural salinization conditioned by the occurrence of brines and of saline groundwater bodies. Anthropogenic pollution is an additional factor for the deterioration of water resources and for their increasing deficiency. During the last two decades, the countries of the Jordan River basin are facing one of the most severe environmental problems which is the result of the retreat of the Dead Sea. This is manifested by diminishing groundwater resources, decreases in the discharges of springs, and formation of sinkholes along the shoreline causing the collapse of roads and of tourism facilities and the loss of agricultural areas

During the last century this area was ruled by different authorities such as the Ottoman Empire, the British Mandate, the Jordanian Kingdom, and by Israel and by the Palestinian Authority. In view of the fact that water flows across political boundaries, the present study investigates the water resources occurring to the east and west of the river Jordan disregarding any administrative or political boundaries. We all believe that water in general and the waters of the Jordan basin in particular, can play a significant role in building peace and ensuring that riparian neighbors work together to achieve together beneficial goals. Prince Hassan bin Talal from Jordan defined our strivings in a very precise manner …"Water, so essential to life, is a means to extinguish fires, not to ignite them…".

In order to improve the knowledge on available water resources a multidisciplinary research project with German, Israeli, Jordanian, and Palestinian counterparts was carried out for the sustainable utilization of aquifer systems in the Jordan Rift in the years 1997–2004. Scientists and engineers from universities, research institutions, and commercial companies of all enlisted countries joined their skill and experience. It has allowed close continuous and collegial cooperation between partners of all parties, even under the most difficult political circumstances. The main fields of activity included: hydrogeology and database management, water quality, salinity and salinization processes, vulnerability studies, quantitative modeling of groundwater flow and solute transport processeses.

This project supported by the German Ministry of Education and Research seems to be one of the most important catalysts for future cooperation among the riparian countries of the Dead Sea and of the Jordan River. This free choice of scientists to cooperate in such a project, should find the strong support it deserves. Jordan, Israel, and Palestine with the assistance and help of German scientific institutes and the support of the Federal Government of Germany would strengthen their commitment to peace, when they cooperate to find the solution for the upcoming regional deficiency in water resources and its socio-economic implication. Such an exercise in regional cooperation could encourage these countries also to overcome other, more ideologically based conflicts.

1.2 Regional setting

A. Flexer, J. Guttman, M. Haddad, H. Hötzl, E. Rosenthal

1.2.1 Topography

The project domain is located within the Jordan Rift Valley and encompasses an area of approximately 5,000 km^2. It extends from the Lake Tiberias in the north to the Dead Sea in the south. It is limited on the east by the mountainous crest along the axis Irbid-Amman-Madaba (Jordan) and in the west by the mountainous crest along the axis Bardala-Faria-Ramallah-Jerusalem and Hebron (Israel and Palestine).

The lower Jordan Valley is 8–15 km wide and extents over a length of 100 km. Its elevation decreases from -200 m msl in the north, to -415 m msl at the Dead Sea. The Jordan River flows all along the valley, from Lake Tiberias in the north to the Dead Sea in the south (Fig 1.2-1). In the past the river carried a considerable amount of freshwater to the Dead Sea. However, at present its flow consists of only a small amount of high salinity water. To the east, the valley is outlined by the Jordanian Rift escarpment. Its elevation goes up to +1200 m msl and the slopes, extending in the cross-section over a distance of 20 km, decline flexure-like with increasing gradient to the west. The slopes are deeply incised by numerous wadis. The valley-floor is limited to the west by the fault-escarpments of the Hebron and Judea Mountains. The elevation increases to +900 m msl and generally, the slopes are milder as compared with the Jordanian side. They too are deeply cut by several important wadis.

Due to the rather inhospitable dry and hot conditions, there are only few larger urbanised areas down in the valley. The largest city is Jericho, situated close to the Dead Sea. In the west, the larger settlements such as the cities of Hebron, Jerusalem and Ramallah, are located along the bordering mountain crest. In the east the cities of Madaba, Amman and Salt are in a comparable situation.

Fig. 1.2-1. Satellite-Mosaic of the Near East region with the Dead Sea and Jordan Rift Valley as a part of the Aqaba-Syrian transform fault. Modified after image source: http://parstimes.com/MODIS/. (Abreviations of city names: A: Amman, Aq: Aqaba, E: Elat, J: Jerusalem)

1.2.2 Climate

The lower Jordan Valley is mostly arid (precipitation rates of 50–150 mm/yr and potential evaporation rates of up to 2600 mm/yr). Replenishment from rainfall occurs mainly along the western and eastern margins, with precipitation rates of 600–800 mm/yr and potential evaporation rates of up to 1900 mm/yr.

In the Jordan Rift Valley there is a close correlation, both on regional and local scale, between physiographic features, geological structures and climate. Three different climatic zones prevail in the study area:

- *Mediterranean climate zone*: This type of climate prevails along the highlands with precipitation rates of 600–800 mm/yr, and potential evaporation rates of about 1600–1900 mm/yr.
- *Arid climate zone*: This type of climate prevails in the Jordan Valley. Precipitation rates range from 50–150 mm/yr, and the potential evaporation rates reach 2,600 mm/yr.
- *Semi-arid to Mediterranean climate zone*: Between the arid zone of the Jordan Valley floor and the Mediterranean zone along the highlands, a transitional zone prevails along the slopes extending from the highlands to the Jordan Valley. This zone receives average precipitation rates ranging from 200–300 mm/yr, with average potential evaporation rates of 1,900–2,400 mm/yr.

The amount of groundwater recharge into the aquifer and surface runoff depends on factors such as rainfall intensity, duration, evaporation and on the sizes and rock types of the catchments areas.

- *Precipitation*: Water resource in the Jordan Rift Valley depends directly on the amount of precipitation (rain and occasionally snow) in the mountainous areas. Rain falls between October and April. The wettest months are January and February.
- *Temperature*: The average annual temperature in the mountainous region of the West Bank is 17°C and 23–28°C in the Jordan Valley. In the mountainous region of Jordan, the average annual temperature decreases to 18°C.
- *Relative humidity*: The average relative humidity in the West Bank varies from 50–70%. Down in the Rift Valley it varies between 20–30% and in the mountain region of Jordan it range from 35–40%. The minimum humidity is recorded in June, while the maximum occurs in January.

- *Evapotranspiration*: No direct evapotranspiration measurements are available in the Jordan Valley. Annual evaporation rates of 1,900 mm/yr are typical in the highlands, while down in the valley they reach 2,600 mm/yr.

1.2.3 Introductory remarks on geology and hydrogeology

The study area is part of the Dead Sea Rift system (a segment of the East African-Red Sea Rift System). The Rift Valley faults are the major structures that affect the geology and hydrology of the Rift Valley.

The regional lithologic column contains carbonates, cherts, chalk, gravels, sandstones and evaporites which range in age from Triassic to Holocene. The ancient formations of Triassic to Turonian age are composed mainly of limestone, sandstones and marl layers and crop out in the highland areas on both sides of the Jordan Rift. As a result of the creation of the Rift Valley, the oldest formations of Triassic to Lower Cretaceous age are exposed on the eastern side of the Rift. Within the Jordan Rift Valley the sediments consist mainly of Quaternary gravel, sand, clay and evaporites. A more detailed description of the geology is given in chapter 2.1.

The Jordan Rift Valley is a topographic low acting as the drainage basin for groundwater originating both from the eastern and the western mountain aquifers bordering the Rift basin as well as from ephemeral streams and floods generated in the surrounding mountains.

Due to the irregular pattern of replenishment in many parts of the arid zone, most water resources are groundwater from local aquifers. Their storage capacity is of crucial importance. Two groundwater systems can be identified:

- The regional mountain aquifers, including the Judea Group aquifer on the western side of the rift and the Ram, Zerka, Kurnub and Ajlun Groups on the eastern side of the Rift.
- The Jordan Valley aquifer system, where the water is pumped from gravels and from sand beds.

The replenishment of the mountain aquifers occurs essentially on the outcrops of their formations. The replenishment of the Jordan Valley system is manifold: precipitation, base flows, flash floods, return-flows from irrigation and upward seepage from deeper aquifers (mainly on the eastern side of the Rift).

The predominant elements governing the flow regime are the anticlinal and synclinal structures crossing the entire area and the intensive fault system that form graben, horsts and step structures. They dictate the groundwater flow patterns, the distribution of salinity and the size and shape of the replenishment areas. The dense faulting system allows hydraulic connections between the upper and lower aquifers.

The hydrogeology of the Jordan Valley itself is still ambiguous, first because of the complexity of the Rift system and associated faults and second, because the entire rock mass is covered under young sedimentary fill. Interpretations of available seismic sections reveal several conspicuous structural and stratigraphic features, which are of considerable hydrological importance. A preliminary seismic interpretation indicates the occurrence of several deep-seated salt bodies. The interpretation of salinity distribution and of the chemical composition of brines show that these salt bodies are one of the factors causing salinization of groundwater in the Rift Valley and along the foothills. Several wells located along the mountain edges are pumping brackish water which is the mixing product of freshwater and of the saline end-members.

Due to the ever-increasing population in the main cities located on the hills on both sides of the Rift, substantial amounts of raw sewage are created. These flow through the wadis to the Jordan Valley (Fig.1.2-2). The wadis are incised into the aquifer rocks and allow hydraulic connections between the sewage and the groundwater causing contamination events in many wells located along the foothills and particularly at the outlets of the wadis to the Jordan Valley. When wells are contaminated by sewage, they have to be shut down until the contamination disappears. This means that such a well cannot supply water to customers and therefore water shortage increases. It becomes crucial particularly if this happens during the peaks of seasonal water demand.

The springs that are outlets of the phreatic aquifers are traditionally an important water source of many villages in the region. Most of the springs emerge along the banks of the wadis in proximity to the sewage flowing in the wadis. The springs are highly sensitive to contamination and to the deterioration of their water quality. This occurs also in the shallow phreatic aquifers of the Rift Valley as a result of leakage of sewage, irrigation return flow and leaching of salt crusts that exist in the section. These deteriorations cause numerous water supply problems. Water that only one decade ago could be used directly for drinking and for agriculture, has to be mixed with less saline water (if such is available) nowadays. Reservoirs such as the Kafrain Dam contain water deteriorated by eutrophication processes with all the resulting impacts on downstream irrigation projects.

Therefore, there is a high demand for waste-water treatment plants and for responsible reuse of treated effluents.

1.2.4 Environment

On both sides of the Jordan Valley natural forests and afforested lands cover parts of the upper reaches of the catchments area. Irrigated agriculture is practiced along the wadi courses, whereas the high rainfall areas are used for rain-fed agriculture. Natural rain-fed plants are used for grazing.

Desertification is increasing in the lower parts of the escarpment slopes which are covered by hard rocks and rock debris and are barren of any vegetation. The floor of the Valley is covered by desert pavements with reg and sand sheets. At the outlets of wadis to the Valley as well as around springs, natural vegetation cover is common. Further eastwards and mainly due to irrigation, the valley plain becomes progressively covered by agricultural land.

The environmental scenery is governed by the presence of urban centres and of industrial areas. The cities are located along the mountain crests (the axis of the major anticlines that build the mountains).

The population growth in the area puts real threats on the development of agriculture. For instance, the Jordan Valley with its tributary wadis is the most important agricultural area in the West Bank. This is due to water allocation from groundwater wells and springs. The area has a good potential for fertile soil and is suitable for agricultural communities. However, the development of this sector is affected by water quality. The shallow aquifers and springs such as Ein Sultan in Jericho become more and more deteriorated due to cesspits and waste-water disposal system such as open sewage channels which facilitate infiltration of pollutants into the shallow aquifers.

The main activity of the people in the Valley is agriculture. Fertilizers and pesticides are applied rather generously; for example, 15,000 metric tons are applied every year in Israel and the West Bank. When applied from the air, the effect of pesticides on natural ecosystems adjacent to agricultural land is particularly evident. Fertilizers are also applied through irrigation water. Fertilizers reach aquatic ecosystems causing eutrophication and also contaminate ground water. In some of the aquifers the concentration of nitrate in the water reaches 130 mg/l.

Agriculture and urban development requires water-resource development. The impact caused by increase in agriculture has a stronger negative effect on biodiversity than the urban development. The development of agriculture and urban areas and the infrastructure connecting them (e.g., roads and pipelines) adversely affect biodiversity. Therefore, changes in the agricultural land use are necessary. The recent reduction in cotton production in Israel, for example, not only saves water but also reduces the pesticide damage to aquatic and other ecosystems. Thus, water drawn from wadis and aquifers for agriculture, contaminates and alters ecosystems. Because dry-land ecosystems are limited not just by water but also by nutrients, the enrichment of fertilizers "escaping" from desert agriculture may dramatically change the functioning and structure of these ecosystems.

Human activities that affect water quality in the Jordan Rift Valley include the followings (Fig.1.2-2):

- Discharge of inadequately treated effluent from municipal treatment plants,
- Discharge of untreated domestic and agricultural wastes,
- Extraction, use, and disposal of low-quality groundwater,
- Leachates from solid waste landfills,
- Run off from urban drainage,
- Fertilizer and pesticide residues, and
- Drainage of wetlands.

1.2.5 Socio-economic aspects

The main economic activity both in the Palestinian, Jordanian and Israeli communities at present and in the foreseeable future, is agriculture. The Jordan Valley has great potential for agricultural development, being a natural greenhouse. In the coming years, Palestinian and Jordanian towns and villages expect fast growth rates. This will result in additional demand for freshwater, which can only be supplied by reducing the amount of available water for agriculture in the Jordan Valley. On the other hand, the volumes of sewage will increase and, after adequate treatment, could be used for the agriculture in the Valley. Waste-water treatment is almost inexistent and most of the sewage flows in the wadis and rivers of the area, thus causing serious environmental problems and high risks of aquifer pollution.

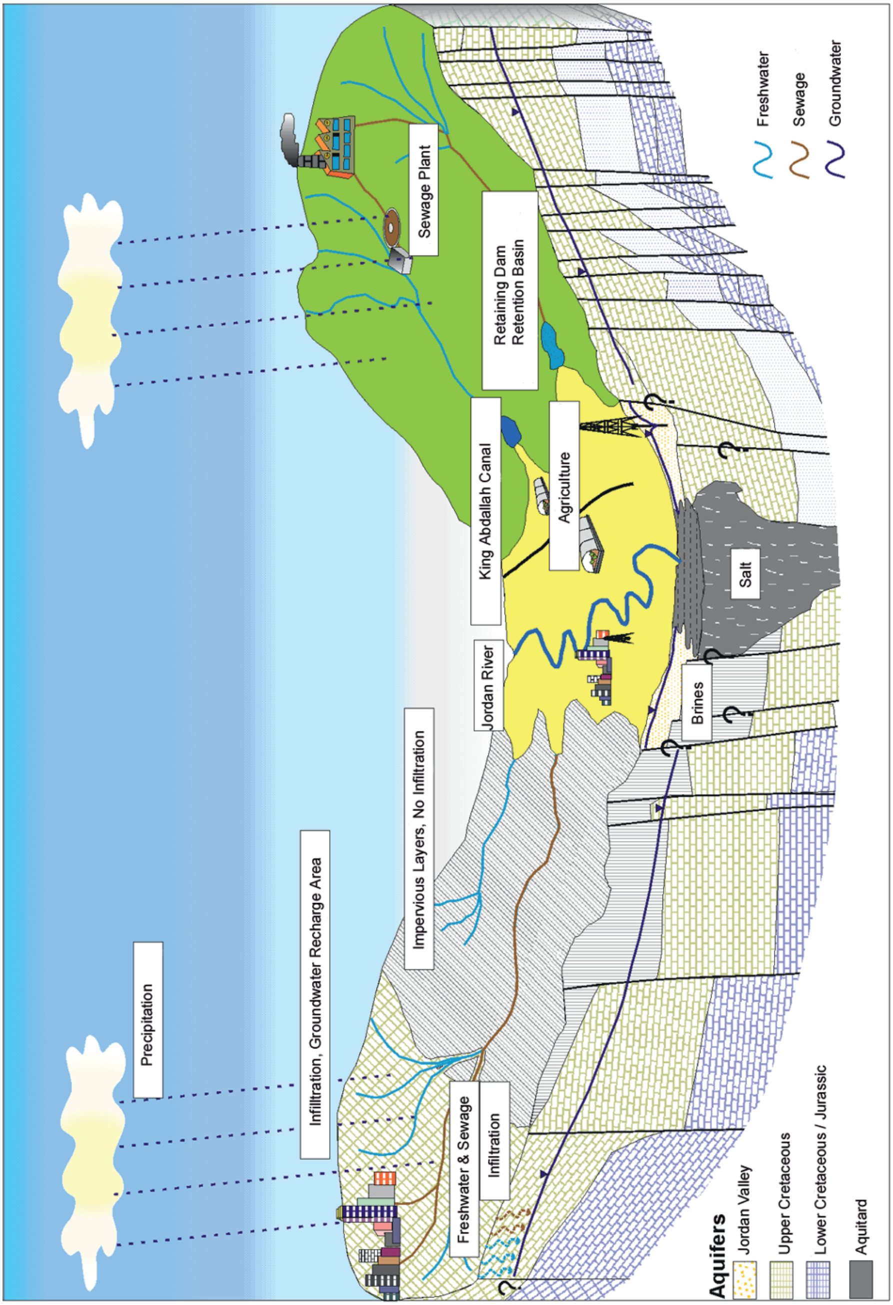

Fig. 1.2-2. Main components of the hydrogeological system in the lower Jordan Valley (after Sauter and Toll, unpubl.)

Joint industrial ventures are being planned in the region. All these activities depend on the availability of relatively large quantities, of high-quality water which, as of yet, are unavailable. Large portions of groundwater resources, which constitute the major source of water in the area, are of a relatively high salinity, which makes them unsuitable for urban- and for most of traditional agricultural uses. The water demand is expected to rise significantly but the expected supply is far from satisfying it. New prospect for future economic development is tourism. Here too, freshwater is a precondition for its large scale development. It is clear that additional freshwater resources are needed. Import of freshwater from other regions in the following 10–20 years is clearly unfeasible, since the neighboring areas also suffer from severe hydrological deficits. Due to their prohibitive costs (of both desalination and transport) so are also the prospects of import of desalinated seawater. These are the reasons which encourage the need to explore possibilities and options for increasing the sustainable exploitation of groundwater in the area - fresh, saline residual waters alike - for the benefit of all the populations in the region.

1.2.6 Current status of water exploitation

The total amount of water produced in the western part of the area amounts to 100 Mm^3/yr: 70 Mm^3/yr from wells of both the Judea Group and alluvial aquifers and 30 Mm^3/yr from springs. Production wells are located in two well fields: (i) in the hills, at the vicinity of the urban agglomerations, along the eastern edge of the mountain slopes, and (ii) in the Jordan Valley (Jericho, Marj Naja). There is considerable advantage of drilling in the mountain area in the proximity to the main urban concentrations. However, the disadvantages are deep water levels, low discharge and quick influences of drought periods on the water level and on exploitation possibilities.

In the mountain areas east of the Jordan River the aquifer conditions are much more inappropriate and restricted due to the outcrop of the main aquifer (Ajlun Group) in the high altitude and due to the close watershed to the eastern Basin. The lower aquifers lack recharge areas and the waters are more or less brackish. The intercalated mighty and marly aquitard abets the fast discharge of surface flow into the deeply carved wadis. Therefore, the water production is mainly based on (i) seasonal surface water from the wadis partially stored in reservoirs (120 Mm^3/yr), (ii) treated and untreated waste water of about 65 Mm^3/yr discharged into the wadis and reservoirs and thereby indirectly used for irrigation, (iii) spring and well water from the upper aquifer of about 80 Mm^3/yr, and (iv) few deep wells tapping the lower aquifers with a still small amount of brackish water.

In the lower Jordan Valley and along the margins of the mountain ranges usage of shallow wells is limited by salinization. In order to avoid the rise in salinity, pumping (hourly and yearly) had to be reduced. This reduction has caused the loss in supply of large amounts of freshwater. In the shallow aquifers there is a constant degradation of water quality as a result of the migration of saline water into the freshwater bodies, of the irrigation return flow and leakage of raw waste water.

On the Jordanian side about 130 Mm^3/yr of the Yarmouk River are deviated by the King Abdullah Canal and distributed along the lower Jordan Valley for municipal and irrigation use.

1.2.7 Geographic nomenclature

The study area extends over a region populated by a diversity of people, cultures, religions, languages, dialects and customs. During the last 100 years the area was administered by different political authorities, each of them left behind its imprints on the geographic nomenclature of the area.

The papers assembled in this book were written by authors from different national entities in the area and Germany. Each such entity preserves zealously their geographic terms. This produces a long series of local names which at first sight seem to be different but are actually synonymous. Therefore, a reader which is not familiar with these regional characteristics may suspect editorial inconsistencies or even negligence, which is not the case. Moreover, the rules of transliteration of local Hebrew and Arabic names into English are not identical in the three national entities residing in the area.

The editors took in consideration the sensitivities and decided not to impose one system of geographical terms and to respect each national tradition. We read critically all the papers and in those cases in which divergent nomenclature could cause confusion, necessary corrections and changes were made while preserving the original national terminology.

We would like to present several commonly encountered examples (A = Arabic name; H = Hebrew name; E = English translation):

Geographic terms

En (H)	Ein (A)	Spring (E)
Nahal (H)	Wadi (A)	Ephemeral stream (E)

Different names for the same locations

Lake Tiberias, Lake Kinneret, Sea of Galilee

Different transliterations of same location names
Qilt, Qelt
Feschkha, Faschkha Fashkha, Fescha,
Zerka, Zarka, Zerqa, Zarqa
Mitspe, Mitzpe
Nezer, Netzer
Salt, E-Salt
Fasail, Fatzael, Fazael, Pezael
Yorqeam,Yorkeam, Yorqe'am
Arava Valley (H), Araba Valley (A)

2 State of the Art

2.1 Geology

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2.1.1 Geology and tectonic setting

The geologic setting of the Eastern Mediterranean and the Levant consists of the triple junction of the African, Arabian, and Anatolian plates, bounded by the Cyprian Arc, the Peri-Arabian Ophiolitic crescent and the Dead Sea Transform.

Israel, Palestine and Jordan are located along the northern and northwestern margins of the Arabian-Nubian continental craton that is a part of the African-Arabian Plates. It comprises a series of rigid blocks composed of a complex assemblage of Precambrian igneous, metamorphic, and sedimentary rocks. During Cambrian to Holocene time, regional geologic conditions were dominated by the interaction between this rigid continental mass and the oceanic areas extending to the north and northwest which produced the stratigraphic sequence that has so far been observed in the surface and subsurface geological record of the study area. This interaction between the Arabian Craton and adjacent oceanic areas is controlled by:

- Alternating advance and retreat of shallow epicontinental seas on the Arabian Craton in response to cratonic subsidence/emergence and eustatic sea level changes
- Opening and closing of the Neotethys, accompanied by faulting and volcanism
- Convergence and development of an Alpidic folding system: the Levantid folds or the (Senonian-Eocene) Syrian Arc fold System
- Regional uplift and fracturing of the Arabian-African Plate, isostatic readjustments and Dead Sea stress field activity since Oligocene, the opening of the Red Sea, the Dead Sea Transform, and Palmyride thrusting and folding (Flexer et al. 2005)

The area subdivides into a number of tectonic provinces. These provinces are defined in the geological sense, i.e., as zones with common geophysical, seismological, structural, and sedimentary characteristics. In most cases a typical morphological character expresses a tectonic province. The area can largely be divided in the sense of the five classical morphotectonic units of the Middle East as suggested by Picard (1937), (Fig. 2.1-1):

1. The Arabo-Nubian Massif, consisting of Precambrian terrain devoid of sedimentary cover.

2. The Tabular Zone, consisting of a thin sedimentary cover on a relatively thick continental crust that has been relatively stable during and since the Paleozoic. It has been subjected to slow, epeirogenic, long-wave time-wise oscillations which brought about rhythmic advances and retreats of the sea along its margins. During the Paleozoic and the greater part of the Mesozoic, these generated a typical platform sedimentary cover of mature clastics (primarily sandstones) on a flat continental landscape, or

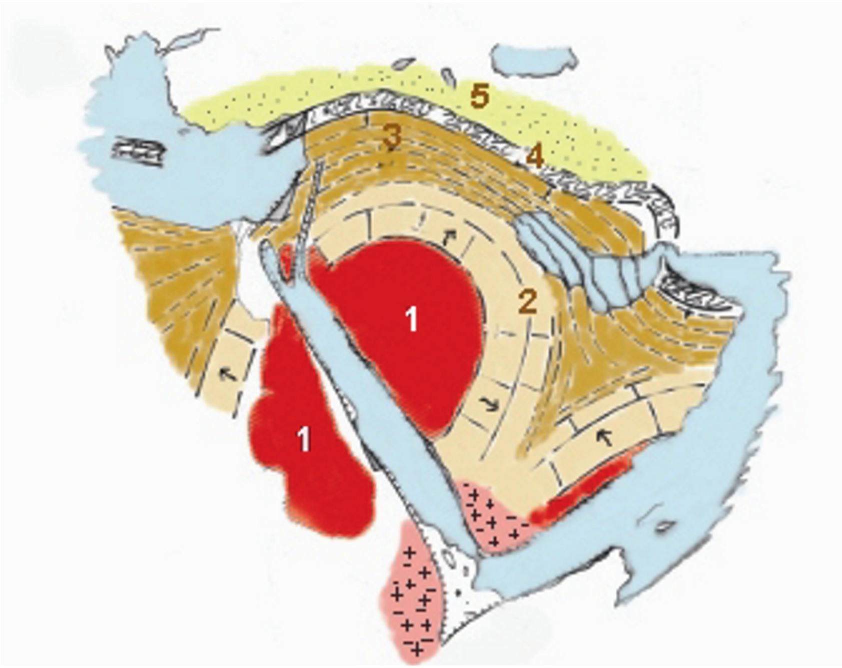

Fig. 2.1-1. The legendary morphotectonic scheme of the Middle East originally plotted by Picard (1937). The numbers present structural units with an unique relief expression: (1)The ancient Arabo-Nubian Massif with an uneven topography; (2) the Tabular Zone, a sedimentary flat highland; (3) the valleys and range topography of the Folding Belt; (4) the high mountainous view of the Alpine Orogenic Belt; (5) the Flat Median Plateau extending between the mountain belts.

carbonate-shale sequences in shallow epeiric seas. An accentuation of earth movements took place in Late Triassic and in Late Jurassic-Early Cretaceous times.

3. The valley-and-range topography of the Folding Belt consists of the Levantid folds of the Syrian Arc. The simple folding zone is characterized by a flat S-shaped band of folds that extends from northwestern Sinai, through Israel and Lebanon into Syria. The common characteristic of this tectonic province is the presence of generally normal concentric folds which were developed in the sedimentary cover. Most of the folds are strongly asymmetric, a feature generally attributed to the presence of basement-controlled, deep-seated reverse faults. Starting in the Coniacian, the Levantid compression decomposes into transversal faulting with strike-slip components and vertical displacements, and in reverse faulting with asymmetric folding. These compressional pulses re-occurred until the Early Miocene, post-Oligocene deformation, decomposed into folding and sinistral strike-slip movements, possibly in both combinations. In Mt. Hermon, the compressional deformation, though present from the Senonian, reached its peak only after the Oligocene, as in the Palmyrides (Chaimov et. al. 1990).

4. The Alpine Orogenic Belt thrusted over the African-Arabian Plates. The belt, characterized by a chain of high mountains, starts in the Kyrinia Range in Cyprus and continues eastwards to the Taurus chain in Turkey and to the Zagros Mountains in Iran.

5. Median blocks (Anatolian and Ionian masses). These are Paleozoic blocks that were consolidated after the Hercynian Orogeny and behaved as massifs during the Alpine Orogeny.

2.1.1.1 Tectonics

Plates and plate boundaries

The area of the Eastern Mediterranean countries can be subdivided geologically into three plates: the African Plate, the Arabian Plate and the Eurasian Plate (Fig. 2.1-2).

The Arava-Dead Sea-Jordan Rift Valley is the plate boundary which separates the Arabian Plate from the African Plate. It should be pointed out that since the Miocene this boundary has developed as a major left-lateral transform fault zone (Fig. 2.1-2) in response to the culmination of the major collision of the African-Arabian and Eurasian Plates. During most of the Phanerozoic era, the African-Arabian Plates were united and consisted of the Arabian-Nubian Massif or Craton.

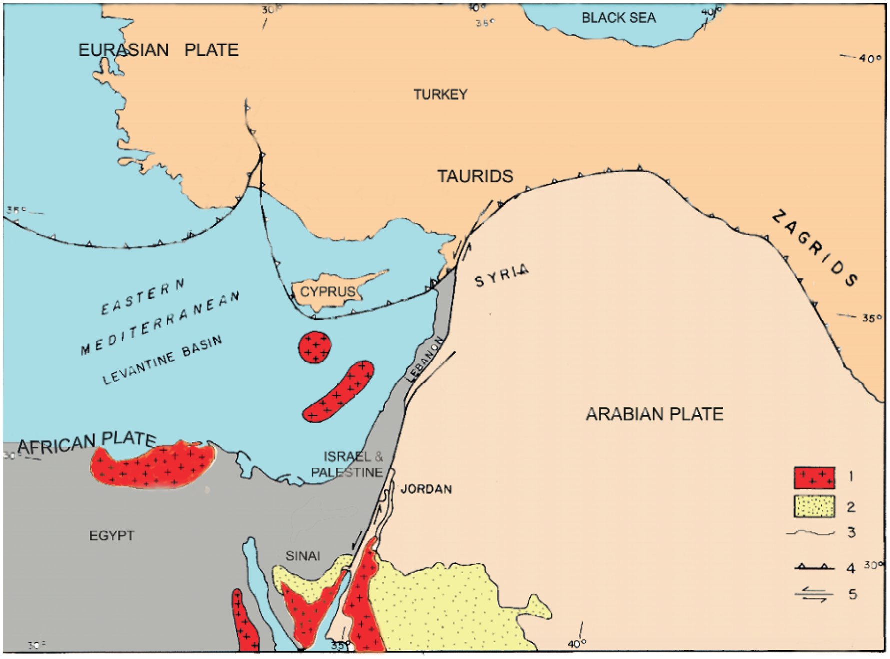

Fig. 2.1-2. Plate-tectonic pattern of the Levant highs (modified after Hirsch et al. 1995):

1. African-Arabian Precambrian crystalline
2. African-Arabian Paleozoic sediments
3. Present day coastline
4. Eurasian Plate thrust front
5. Dead Sea transform

Interplay and collision of plates

The strongly interwoven geological and tectonic history of the Levant is punctuated by periods of subsidence and uplift which are subdivided into phases (Hirsch et al. 1995):

The early geological history of the Levant as part of the ancient Gondwana continent was a build-up of a basement composed of accreted terranes, consisting of plutonics, volcanics, ophiolites and metasediments. It was consolidated by Late Precambrian Pan-African orogeny, including the Menderes, Eratosthenes and Arabian-Nubian massifs, prior to regional peneplanation.

The Paleozoic history of the Levant is one of domal uplifts during the Late Devonian, Permian and post-Permian, which resulted in the erosion of much of the Paleozoic deposits. Hardly anything is left of the Ordovi-