COMPREHENSIVE Assessment of water management in agriculture

Research Report 9

Historical Transformations of the Lower Jordan River Basin (in Jordan): Changes in Water Use and Projections (1950-2025)

Rémy Courcier, Jean-Philippe Venot and François Molle

International Water Management Institute

MREA

The Comprehensive Assessment of Water Management in Agriculture takes stock of the costs, benefits and impacts of the past 50 years of water development for agriculture, the water management challenges communities are facing today, and solutions people have developed. The results of the Assessment will enable farming communities, governments and donors to make better-quality investment and management decisions to meet food and environmental security objectives in the near future and over the next 25 years.

The Research Report Series captures results of collaborative research conducted under the Assessment. It also includes reports contributed by individual scientists and organizations that significantly advance knowledge on key Assessment questions. Each report undergoes a rigorous peer-review process. The research presented in the series feeds into the Assessment's primary output—a "State of the World" report and set of options backed by hundreds of leading water and development professionals and water users.

Reports in this series may be copied freely and cited with due acknowledgement. Electronic copies of reports can be downloaded from the Assessment website (www.iwmi.org/assessment).

If you are interested in submitting a report for inclusion in the series, please see the submission guidelines available on the Assessment website or send a written request to: Sepali Goonaratne, P.O. Box 2075, Colombo, Sri Lanka.

Dialogue on Water, Food and Environment

Comprehensive Assessment outputs contribute to the Dialogue on Water, Food and Environment Knowledge Base.

Comprehensive Assessment Research Report 9

Historical Transformations of the Lower Jordan River Basin (in Jordan): Changes in Water Use and Projections (1950–2025)

Rémy Courcier
Jean-Philippe Venot
and
François Molle

Comprehensive Assessment of Water Management in Agriculture

The Comprehensive Assessment (www.iwmi.cgiar.org/assessment) is organized through the CGIAR's System-Wide Initiative on Water Management (SWIM), which is convened by the International Water Management Institute. The Assessment is carried out with inputs from over 100 national and international development and research organizations—including CGIAR Centers and FAO. Financial support for the Assessment comes from a range of donors, including the Governments of the Netherlands, Switzerland, Japan, Taiwan, Sweden (through the Swedish Water House) and Austria; EU support to the ISIIMM Project; the OPEC Fund; FAO; Challenge Program on Water and Food; World Bank in support of Systemwide Programs and the Rockefeller Foundation. Cosponsors of the Assessment are: FAO; the Ramsar Conventions and the CGIAR.

The authors: Rémy Courcier was formerly head of the MREA (French Regional Mission for Water and Agriculture) of the French Embassy in Amman; Jean-Philippe Venot was formerly a master student at the 'Institut National Agronomique de Paris-Grignon' working with MREA. He is now a PhD student with the International Water Management Institute; François Molle is a Principal Researcher at the Institut de Recherche pour le Développement (IRD), France, currently seconded to the International Water Management Institute, Colombo, Sri Lanka.

This report is the result of a comprehensive study of water resource development and use in the Jordanian part of the LJRB developed through to a collaboration between the French Regional Mission for Water and Agriculture of the French Embassy in Jordan (MREA) and the International Water Management Institute (IWMI), within the framework of the Comprehensive Assessment of Water Management in Agriculture.

This document greatly benefited from comments made by Peter McCornick and R. Orthofer on its earlier versions. The authors thank Aida Jridi and Rebhieh Suleiman for their earlier contribution in gathering quantitative data. The authors also gratefully acknowledge the help and support given by Susan Taha, Naief Seder, Youssef Hassan, Philip Magiera and Jochen Regner.

Courcier, R.; Venot, J. P.; Molle, F. 2005. *Historical transformations of the lower Jordan river basin (in Jordan): Changes in water use and projections (1950-2025).* Comprehensive Assessment Research Report 9. Colombo, Sri Lanka: Comprehensive Assessment Secretariat.

/ *river basins / water use / water resources development / history / water use efficiency / hydrology / water policy / water balance / land use / Jordan* /

ISSN 1391-9407
ISBN 92-9090-609

Please send inquiries and comments to: comp.assessment@cgiar.org

Contents

Summary

The Lower Jordan river basin (LJRB), defined as a hydrological entity, is a region of prime importance for the Hashemite Kingdom of Jordan: this area includes 83 percent of the total population of Jordan, and most of the main industries in the country, 80 percent of irrigated agriculture, and receives 80 percent of the national water resources. During the last 50 years, because of a demographic boom and generalized economic development, the Jordanian part of the LJRB has experienced an intensive and rapid process of mobilization of its rare water resources.

This report presents a qualitative and quantitative assessment of the history of water resources mobilization and uses within the LJRB. It illustrates the gradual “artificialization” and “complexification” of this river basin from a situation around 1950, where only 10,000 hectares were irrigated, groundwater was untapped and abundant water flowed to the Dead Sea, to the current situation where 46,000 hectares are irrigated and all surface resources are tapped and committed, and groundwater is being severely mined. Both the Jordan valley and the highlands, on the one hand, and agriculture and cities, on the other, are now interconnected and interdependent.

Presently, the available water resources in the LJRB are renewed at a rate of 705 million cubic meters per year (Mm^3/yr including 155 Mm^3/yr of groundwater and 550 Mm^3/yr for surface water). The total amount of water withdrawn within the basin reaches 585 Mm^3/yr (i.e., 83% of the renewable surface and groundwater), including 275 Mm^3/yr in groundwater abstraction (i.e., a gross overdraft of the aquifers of 120 Mm^3/yr) and 310 Mm^3/yr of surface water diversion (including 60 Mm^3/yr of treated wastewater). The basin also imports each year 30 Mm^3 of groundwater and 45 Mm^3 of surface water. The rest flows uncontrolled to the Dead Sea (215 Mm^3/yr).

Patterns of water use reflect changes in the wider economy. Extensive rain-fed agriculture in the highlands increased before the mid-1970s but later declined with the change in the economy and the growth of cities. The most intensive part of the agriculture sector (cultivation in the highlands and the valley, oriented to the export of vegetables and fruits) is affected by changes in relative competitiveness with regard to other regional producers and also by changes in market prices. Population growth, also linked to the wider political situation in the Middle East, increased pressure on the water resources. Because of the unquestionable priority given to domestic water use and the large share of the agricultural water use, the future of irrigated agriculture is uncertain. The most questionable part of agricultural use is the low-profitability olive trees planted in the desert plateau that make up half of the highland irrigated area and which consume about one-fourth of the total high-quality groundwater abstracted for agricultural purposes in the LJRB. The resulting depletion of the aquifers is likely to jeopardize their use for domestic water supply as they become saltier.

Intensive agriculture in the valley relies on surface water uses and is likely to remain stable, even if its water supply is reduced in quantity and quality. Banana cultivation yields high economic benefits but these benefits are artificial, due to protective customs duties. The likely future disappearance of these duties due to World Trade Organization (WTO) agreements, and a redefinition of allocation or of water prices might encourage a shift towards less-water-intensive crops, such as date palm trees in the south of the valley.

Such a reorientation and other measures necessary to achieve better water management are faced with some sociopolitical difficulties within the Jordanian society. Only a global

awareness of the problems that Jordan faces could mitigate these difficulties and allow for the implementation of the measures needed. Another aspect of the transformations that have occurred in the LJRB is the shift in water policy. Calls for demand management have been only partially incorporated or implemented, mainly for sociopolitical reasons. The prevailing mid- and long-term solutions are eventually typical capital- and technology-intensive supply augmentation projects, namely large-scale interbasin transfers and desalinization. This may be seen as the lasting dominance of the engineering-based approach but this also shows that however desirable they may be, demand-management options may only alleviate the actual situation without providing long-term solutions.

The quantitative analysis of these evolutions has shown that most of the indicators (such as depleted fraction, processed fraction of water resources) varied sharply between 1950 and 1975, on account of both a growth in rain-fed and irrigated agriculture, and the quasi interruption of the flows coming from the Upper Jordan. In the following 25 years, water use became unsustainable because of overdraft of the aquifers (and concomitant reduction of the flow in the Yarmouk). While around 2,700 Mm^3 of surface water and rainfall enter the basin each year on average, only 200 Mm^3/yr reach the Dead Sea. The difference is depleted (effectively used), 18 percent of it in irrigated fields, 18 percent in rain-fed areas, and 3 percent in municipal and industrial uses, the remaining 61 percent being evaporated either in grassland and forest, or in desert areas. Overdraft of aquifers and competition for water can only be rebalanced through some contraction of irrigated agriculture, together with an increase in the use of treated wastewater and in interbasin transfers.

Lower Jordan River Basin (in Jordan): Changes in Water Use and Projections (1950–2025)

Rémy Courcier, Jean-Philippe Venot and François Molle

Introduction

Due to both scarcity of water resources and an important demographic boom[1] and despite a high degree of infrastructural development, the per capita water allocation which was at 3,600 m^3/year and per person in 1946 has sharply decreased: water availability in Jordan has been estimated at only 163 m^3 of renewable blue water[2] per capita per year (according to the Ministry of Water and Irrigation Master Plan 2004), a quantity expected to further decrease down to 90 m^3/year/person in 2025 (Ferragina 2000; Abu-Sharar 2002).[3] At the same time, the average domestic consumption only reaches 94 liters per capita/day (lpc/day) nationwide (THKJ 2004).

In this situation of extreme scarcity, irrigated agriculture, which significantly contributed to the development of Jordan during the years 1970–1980s (Elmusa 1994; Nachbaur 2004), uses two-thirds of the available water resources. Its future is thus questionable. In order to sustain agricultural development as well as to meet the increasing urban and industrial needs linked to demographic growth and economic development, Jordan has reached a point where it overexploits its water resources.

In the 2000s, while available renewable resources are evaluated at around 860 Mm^3/yr at the country level (Scott et al. 2003), with 335 Mm^3/yr of uncontrolled surface water, a total of 845 Mm^3 are abstracted annually (i.e., 98% of the renewable resources), of which 585 Mm^3/yr in the Lower Jordan River Basin (LJRB) (computation according to MWI [Ministry of Water and Irrigation] records and the THKJ 2004). This is possible only because of reuse of water and of the overexploitation of aquifers, which causes a drop in the water table[4] and the degradation of groundwater resources, since overexploitation leads also to an increase in salt concentration within the aquifers (notably in the case of the Azraq oasis, in the east of the country).

Collaboration between the French Regional Mission for Water and Agriculture of the French Embassy in Jordan (MREA) and the International Water Management Institute (IWMI), within the framework of the Comprehensive Assessment of Water Management in Agriculture, allowed the development of a comprehensive study of water use in the Jordanian part of the LJRB. The aim of the present report is to develop a qualitative and

[1]The population of Jordan increased from 0.58 million in the early 1950s to 2.13 million in 1979 to finally reach 5.33 million in 2003 (that is essentially linked to the decrease in infant mortality and to the transfer of Palestinian populations).

[2]That is, annual surface runoff and aquifer recharge.

[3]In comparison, the World Bank generally considers that 500 m^3 per capita per year constitute “the poverty threshold” below which it is necessary to mobilize new water resources. Despite all the difficulties in defining and considering relevant thresholds (see Molle and Mollinga 2003), Jordan—with such a level of water availability—will always be at the bottom of the table.

[4]Averaging, for example, 0.5 meters a year in the Amman-Zarqa groundwater basin (ARD 2001; Chebaane et al. 2004).

quantitative outlook of the history of water resources mobilization and use within this basin. After 50 years of accelerated development, uses of the resources have reached an unsustainable level. Because of the rapidity and intensity of the changes observed, the LJRB appears as a good illustration of the complexity of water management in a developing country faced with a situation of extreme water scarcity.

The section on “Main Features of the Lower Jordan River Basin in Jordan”provides an overview of the basin’s main features. The section on “History of Water Resources Development” recounts the development of the basin and details both the changes in water use and the wider context of agricultural and societal change. And the section on “Situation in the 1950s: Pre-exploitation Phase” parallels this analysis by a calculation of the terms of the basin water accounting and allows a better quantification and characterization of the transformations that occurred. The conclusion recaps the main lessons learned.

Main Features of the LJRB in Jordan

General Presentation

The Jordan river is an international river which drains a total area of about 18,000 km^2. Its three headwater tributaries originating from the slopes of Mount Hermon drain the Upper Jordan river basin and flow southward into Lake Tiberius. They are the Hisbani, coming from Lebanon, the Banias, coming from Syria and the Dan coming from the Syrian Golan Heights, occupied by Israel since 1967. Apart from some irrigated agriculture north of Lake Tiberius, almost all water from the three tributaries is collected in the lake, which acts now as a freshwater reservoir currently used almost exclusively by Israel. The outflow of the Jordan river from Lake Tiberius is virtually blocked and only consists of some saline springs and wastewater, as we will see later.

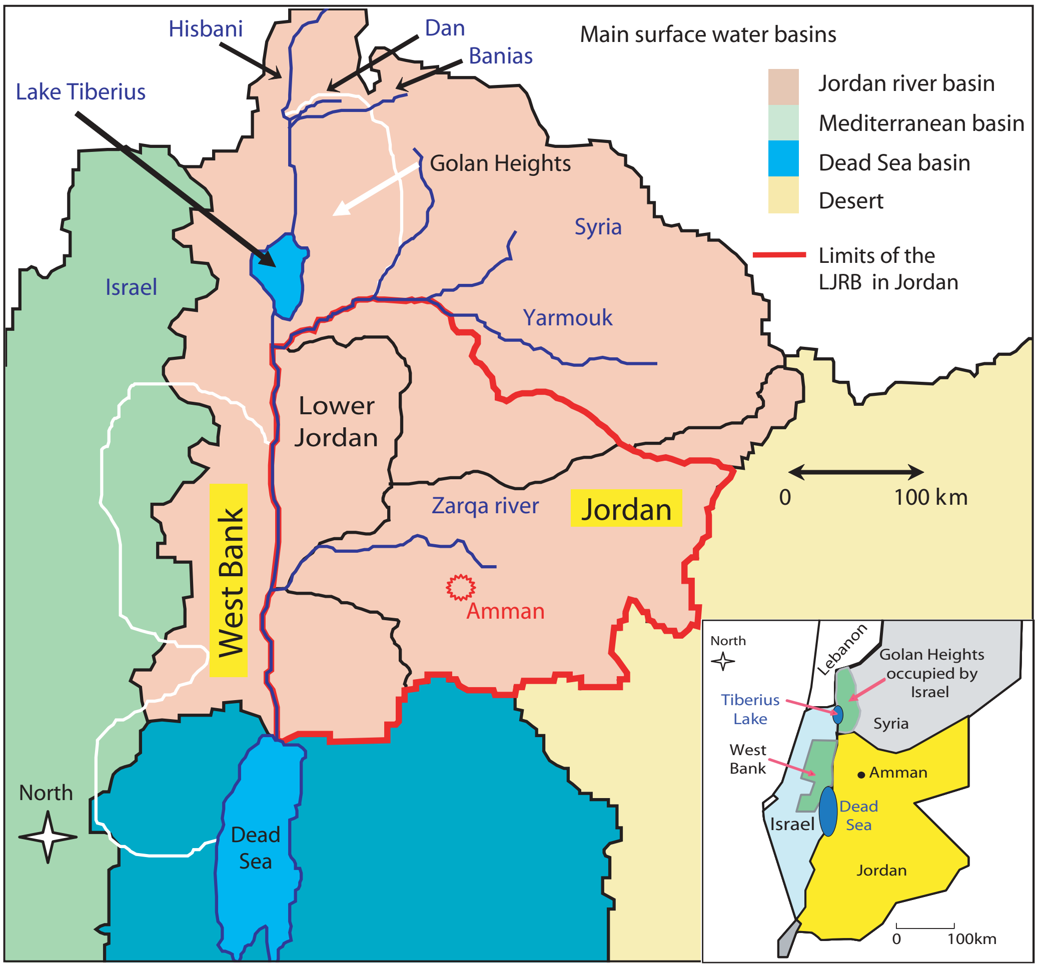
The Jordan river flows southward in a nearly 130-km-long longitudinal depression named the Jordan valley before discharging into the Dead Sea. The valley results from a continental rift located between the Mediterranean and the African plates, which led to a lowering of the floor down to 400 meters below sea level.

Ten kilometers downstream of Lake Tiberius, the Lower Jordan river receives the water from its main tributary, the Yarmouk river. Originally, this river coming from the northeast of Syria contributed almost half of the Lower Jordan river flow, the other half coming from the Upper Jordan river. Several temporary streams of lesser importance named “side-wadis,” with the exception of the larger Zarqa river, come from the two mountainous banks and feed the Lower Jordan river. Prior to water development projects, the original flow of the Jordan river into the Dead Sea varied between 1,100 and 1,400 Mm^3/yr. (Klein 1998; Al-Weshah 2000; El-Nasser 1998.)

Our study focusses on the Jordanian part of the LJRB, without considering issues related to water sharing between the riparian states of the Jordan river. The Yarmouk river (and the Upper Jordan) are thus considered as giving inflows to this basin. Moreover, the other streams draining to the Dead Sea from the south and from Israel are also not analyzed and taken as mere contributions to the basin.

What will be referred to as the LJRB in what follows represents 40 percent of the entire Jordan river basin but only 7.8 percent of the Jordanian territory (cf., figure 1). The basin so defined is nevertheless the wettest area in Jordan and supplies 80 percent of the national water resources. It is a region where 83 percent of the population is concentrated and where the potential

FIGURE 1.
Limits and drainage area of the LJRB (pink) and its extent in Jordan (red line).



for economic development is at its highest. Moreover, irrigated agriculture, which uses 70 percent of the national water resources, is also mainly concentrated in this area, as we will see later.

Physical Setting

The basin, like the country, is divided into two main areas: the Jordan valley and the remaining part referred to here by the term "highlands."

The highlands are composed of a mountain range running alongside the Jordan valley and of a desert plateau extending easterly to Syria and Iraq. About 30 km wide, with an altitude reaching 1,000 m above sea level, the mountains, which consist of sedimentary rocks—essentially limestone—are incised by several side-wadis (or lateral intermittent streams) draining surface water to the Jordan river. These mountains receive around 400 to 600 mm of rain per year with a peak in January-February and are the rainiest areas of the country (figure 2). Snowfall can be observed where the altitude exceeds 700 m. Historically, they were covered with forests (essentially composed of Mediterranean conifers), but now they are mostly rangelands with occasional olive trees and stone-fruits trees.

The plateau has an average altitude of 600 m and is mainly used to grow cereals near the mountain, in the area where main urban agglomerations (Amman, Irbid, Al-Baq'ah, Jerash, and Ajloun) are concentrated and where rainfall is still sufficient. Eastward, precipitations become scarcer (between 200 and 300 mm/year), and only nomadic Bedouin livestock farming can be found.

The Jordan valley is a 130 km stretch between the Yarmouk river in the north and the Dead Sea in the south; it is the northern part of the Jordan rift valley, extending from Lake Tiberius in the north to the Red Sea in the south, over a total length of 360 km. Its altitude varies from 200 m (in the north) to 400 m (in the south) below sea level. The valley can be considered as a natural greenhouse: temperature increases by around 1°C as the altitude decreases by 100 m. Temperatures are thus moderate during winter (between 15°C and 22°C on average between November and March) and reach some record levels during summer, commonly exceeding 45°C during the day in the months of June, July and August. The climate is semi-arid in the north (precipitations of 350 mm/year) and arid in the south (50 mm/year near the Dead Sea).

The Jordan river flows in a 30 to 60 m deep gorge through a narrow alluvial, fertile plain locally called "Al Zhor" (cf., figure 3) from 200 m to 2 km wide; it can be flooded during some exceptional events. The rest of the valley, called "Al Ghor" in Arabic, is a fertile area formed by colluviums coming from neighboring mountains and lying on alluvial sediments of Lake Lisan, which covered the area 14,000 years ago. Gently sloping (1.5 to 2.5%) from the mountains, it is 20 km wide in the south, narrows down to 4 km in the middle, and finally widens to 10 km in the north. In these two areas, soils are deep and of good quality but, because of the climate, only a steppe and some grassland existed before the reclamation of the valley, with the notable exception of small areas irrigated by the side-wadis and springs.

FIGURE 2.
Rainfall distribution in the LJRB (adapted from EXACT 1998).

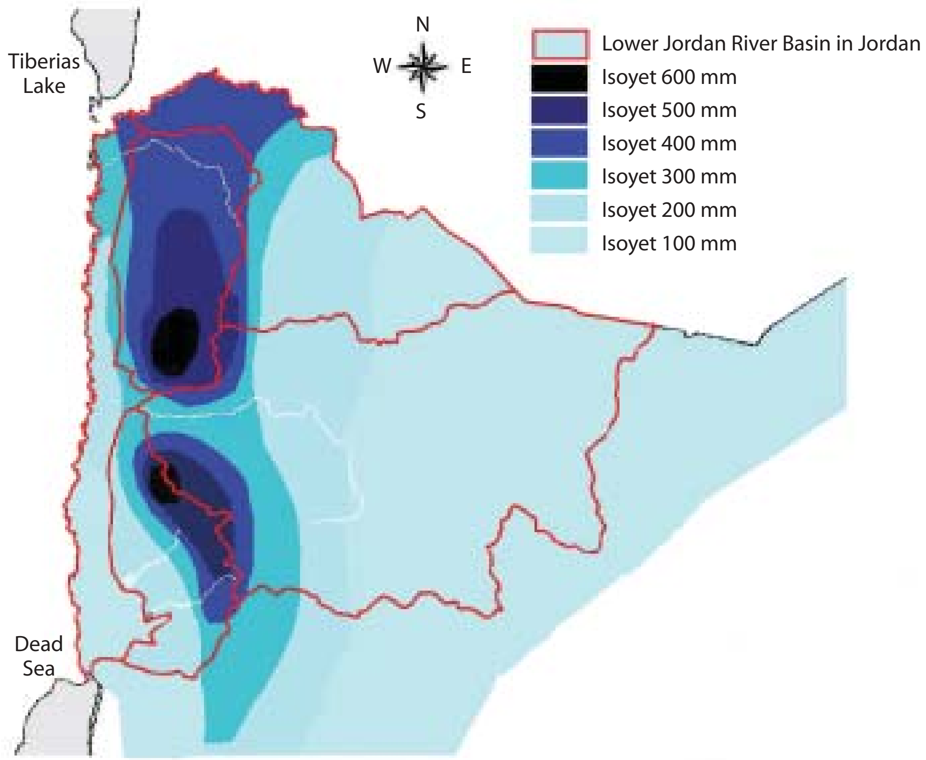
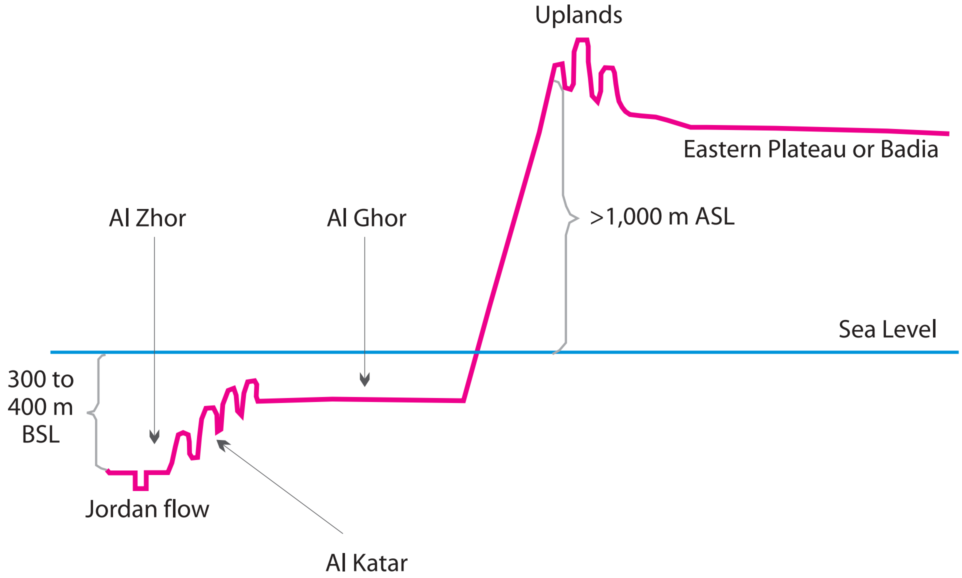


FIGURE 3.
Topography of the LJRB in Jordan.



History of Water Resources Development

General Remarks and Methodology

This report presents a synthesis on the following issues:

- The water resources of the LJRB. (The hydrology of the basin will also be presented.)
- The evolution of the development and use of these water resources from the 1950s to the mid-2020s (we will use 2025 as a reference date).
- The corresponding evolution of the water accounting for the basin.

This report is based on four successive charts illustrating the situation of water use at four different points in time: 1950 (which can be considered as an initial "predevelopment" state), 1975 (for which a complete study of the hydrological situation of Jordan is available)[5] and 2000 for which most of the figures presented are available because of many studies done recently on the water sector in Jordan. Last, the year 2025 is used as a time horizon for projections and discussions on future trends. We will particularly focus on water resources, and the process of mobilization and utilization of these resources for each of the four different periods. We will also try to link these changes to more general transformations observed during the period studied.

The figures presented in the historical description are expressed in Mm^3/yr and have generally been rounded up to 5 Mm^3/yr. Moreover, we used average figures referring to 5 to 10 years around the date indicated on the charts (1950, 1975, 2000 and 2025). These figures were extracted from a comprehensive list of references (presented in appendix 1). With this method, we do not consider the year-to-year variability that can affect the water balance. Although this variability is important in terms of management, we are focusing here on long-term evolutions characterized by average balances.

[5]Carried out by the Jordanian MWI with the support of German cooperation.

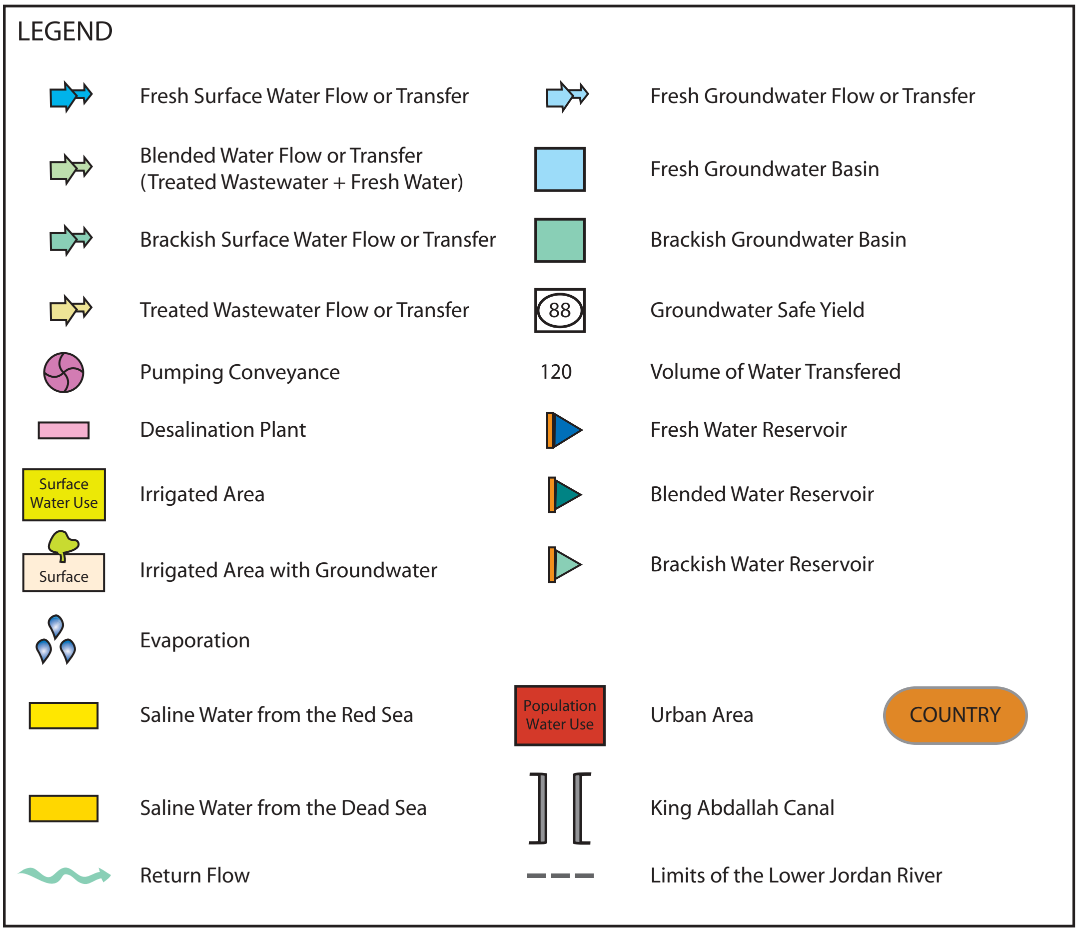
In our representations of water flows, we used arrows to represent natural river flows and water transfers from one place to another. The bigger the flow/transfer the larger the arrow. Water quality is also suggested, with a variation from freshwater (blue) to wastewater (green) or saline water (yellow). We used rectangles to represent groundwater basins and their capacity as well as geometrical shapes to represent the irrigated areas. Again, the larger the water resources/ irrigated areas the bigger the rectangles and other geometrical shapes. We do not distinguish between river base-flows and winter runoff flows ("floods"). The legend presented in figure 4 shows all the symbols used on the charts presented in this report.

Hydrology of the LJRB

We will present in this section the natural or theoretical hydrology of the Jordanian part of the LJRB prior to any kind of water development.

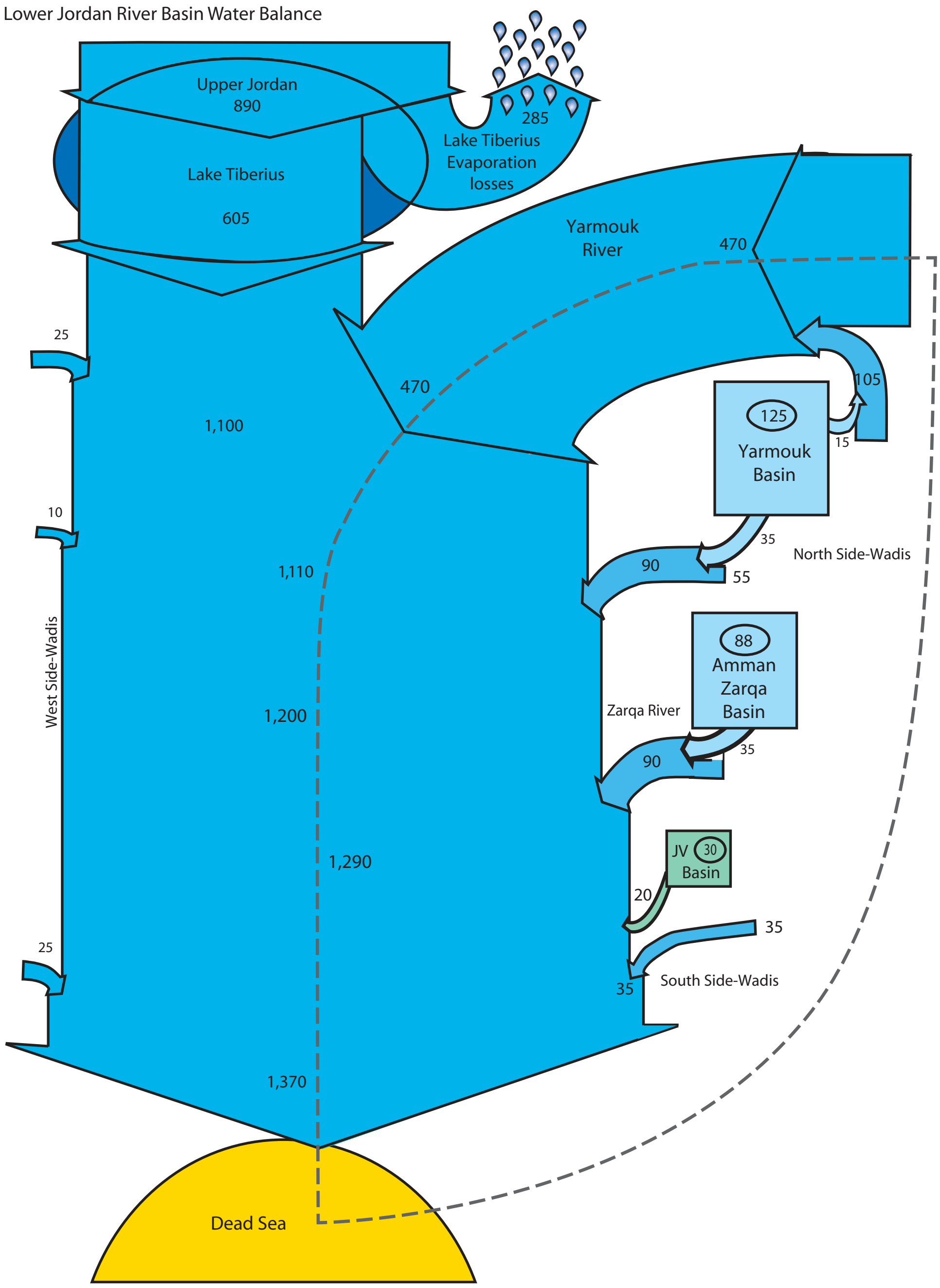
Total precipitation in Jordan is estimated at 8,500 Mm^3/yr (of which about 2,200 Mm^3/yr fall within the LJRB); in crude terms, 85 percent of this precipitation is evaporated (50% of this evaporation being beneficial since processed either by irrigated or rain-fed crops, 5 percent flows into the rivers and the remaining 10 percent infiltrates to recharge the aquifers [El-Nasser 1998]). Figure 5 describes the natural hydrology of the basin.

FIGURE 4.
Legends used in the charts.



Note: The charts indicate the total safe yield of each aquifer. These values do not always correspond to the Jordanian safe yield (corresponding to the sustainable rate of groundwater exploitation within Jordan) since some of the groundwater basins are not entirely located in Jordan.

FIGURE 5.
LJRB: Hydrology.



Surface Water

Surface water in the basin mainly comes from Lake Tiberius (natural reservoir collecting water from the Upper Jordan), the Yarmouk, the Zarqa rivers as well as other side-wadis incising the mountains.

- The Upper Jordan hydrological flow into Lake Tiberius has been estimated at 890 Mm^3/yr and the evaporation within the lake at 285 Mm^3/yr. The outflow thus averaged 605 Mm^3/yr before the 1950s (Klein 1998). The bulk of this resource is now diverted by Israel to its National Water Carrier.

- The Yarmouk river is the main tributary of the Lower Jordan river and represents the main share of Jordan's surface water. The Yarmouk watercourse is fed by springs and wadis mainly originating in Syria. The annual flow of the Yarmouk river evaluated at the confluence of the Lower Jordan river was 440 to 470 Mm^3/yr for the period 1927–1954 (Salameh and Bannayan 1993). (We have used 470 Mm^3/yr in our charts.)

- Before reaching the Dead Sea, the Jordan river is fed by several side-wadis. To get clearer representations, we have chosen to pool them in three groups: the northern side-wadis, the southern side-wadis and the Zarqa river, which contribute 90, 30 and 90 Mm^3/yr respectively (Baker and Harza 1955).

- The contribution of smaller flows of side-wadis located on the West Bank (Israel and Palestinian territories) is also taken into consideration.

These flows are indicated in figure 5, which depicts natural flows in the (hypothetical) absence of any use or diversion. It can be used as a backdrop to assess historical transformations.

Groundwater

The Yarmouk and north side-wadi basins. (125 Mm^3/yr; Salameh and Bannayan 1993.) For the sake of simplifying the charts, these two groundwater basins have been pooled together into a unique aquifer replenished by water infiltrating in the northern mountains (and are represented by a unique rectangle entitled "Yarmouk basin" on the charts).[6]

The mean total annual usable recharge[7] of this aquifer has been estimated at 125 Mm^3/yr. According to THKJ (2004), the net recharge of the part of the Yarmouk basin located within Jordan is 35 to 40 Mm^3/yr. The side-wadi basin is annually replenished by 30 to 40 Mm^3/yr (cf., figure 6). In addition, the latter receives 25 Mm^3/yr of underground transfers from the Yarmouk basin (Salameh 1990), which are part of the north side-wadis base-flow.

The Jordan Valley Basin (30 Mm^3/yr). The aquifer of the Jordan valley receives 30 Mm^3/yr through direct infiltrations coming from the Jordan river, the valley area and neighboring hills (THKJ 1977; Salameh 1993), out of which 15 to 20 originate within Jordan (THKJ 2004). Unlike the other basins, the water here is slightly brackish or salty and some hot springs can also be found.

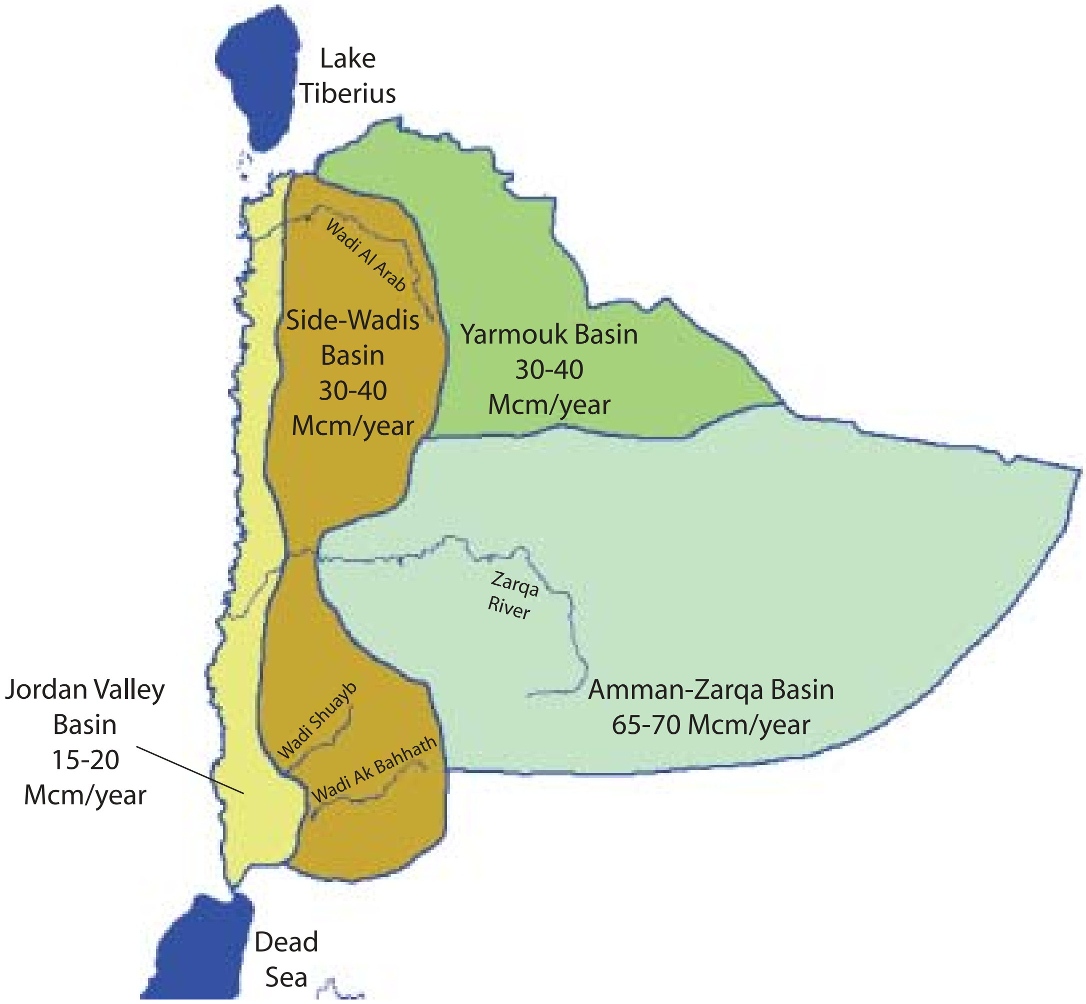
The Amman-Zarqa Basin (88 Mm^3/yr). Of this groundwater basin 85 percent is located within Jordan (the remaining 15% lying in Syria) and it represents the most important groundwater reservoir of the LJRB. It can be divided into two parts; the first one in the east receives the infiltrations from the rainy area of the Djebel Druze in Syria; the second part receives infiltrations from the mountains around Amman. The annual usable recharge of the entire basin reaches 88 Mm^3/yr, including 70 Mm^3/yr within Jordan (Salameh and Bannayan 1993; ARD/USAID 2001; Chebaane et al. 2004). THKJ (2004) indicates a recharge between 65 and 70 Mm^3/yr (cf., figure 6).

---

[6]Moreover, the southern part of the side-wadis aquifer is also not represented on the charts (because of limited abstraction occurring there). In the last section of this report, however, quantitative water balances distinguish between the Yarmouk and the northern and the southern parts of the side-wadis aquifers.

[7]We define the "usable recharge" as the direct recharge minus the baseflow. See footnote 22 for discussion on this definition.

FIGURE 6.
Groundwater basins in the LJRB in Jordan.



Situation in the 1950s: Pre-exploitation Phase

Historical Background

The Jordan basin is considered one of the cradles of humankind. Around 6,000 B.C., owing, among other things, to a climate probably less arid than today, domestication of crops and animals allowed the development of the first cities city (Jericho). Since then, the Jordan valley has seen fluctuating periods of development, stagnation, and decline as well as several successive political upheavals. The region has thus been successively under the control of the Arameans, the Edomites, the Greeks, the Romans, the Byzantines (Umayyad), the Ottomans and the British. We can, for example, mention a prosperous period around 700–800 B.C. when the Umayyad used the entire Jordan valley to grow sugarcane, before production in the south of Italy came to dominate the market. On the other hand, the Ottoman period (900–1920 B.C.) was one of stagnation for a province located at the empire's margin (Abujaber 1988; Lancaster 1999). The United Kingdom's (Balfour Declaration 1917) and the international community's (through the League of Nations) support to the establishment of a Jewish state opened the way to radical modifications of the water resources regime in the Jordan basin. In this context, and mainly during the British mandate (1931-1946), a beginning of development was thus observed. Several studies of hydraulic development (irrigation and hydroelectricity) and several attempts to an amicable sharing of water resources between the riparian parties saw the light[8], but they were applied only much later and partially, due to the political instability of the region.

By 1950, the main changes caused by the creation of the Israeli State, namely its access to the Upper Jordan water resources and the displacements of the Palestinian populations, had already taken place but it was still too early to sense their consequences on the effective use of water resources. We, therefore, present the situation of the basin as it could be observed before the creation of Israel critically changed the situation.

Until the 1950s, the Jordan valley was only sparsely populated and was mainly dependant on a subsistence agricultural production limited by natural conditions which had become drier than before. It is estimated that in 1939 the Trans-Jordan population amounted to 325,000 inhabitants who, in their great majority, made a living from agriculture in the uplands and from pastoralism in the eastern desert (Lancaster 1999). Cities located in the highlands were still not very developed. Amman's population, for example, was only around 100,000 while Irbid, which is today the largest city in the north of Jordan, had a population of only 25,000 (Baker and Harza 1955). Bedouins traditionally used the valley during winter where they could find the forage needed for their herds. They were cultivating wheat, barley, maize and some vegetables, irrigating them from the Yarmouk river and from other side-wadis. During summer, they left with their herds to the fresher mountains where they met the "fellahin" (sedentary population), cultivating olive trees and cereals.

The techniques used at that time to develop water resources (small dams and earth or masonry canals) allowed domestic water supply and the irrigation of small areas located along the side-wadis. In the highlands, direct use from springs and from tanks collecting local rainfall also allowed this double use (Khouri 1981; Lancaster 1999). The cities were supplied by neighboring springs. The first instances of dams and groundwater pumping were observed during the 1940s but these two options remained limited and their development took place only during the 1960s. This was triggered by the first roads (built during the British Mandate), which resulted in traditional self-sufficiency-oriented agriculture being shifted slowly towards market-oriented production of the cities.

Figure 7 illustrates the situation regarding water resources on the territory then called Transjordan, as well as their utilization before the creation of the State of Israel which dramatically altered these conditions.[9]

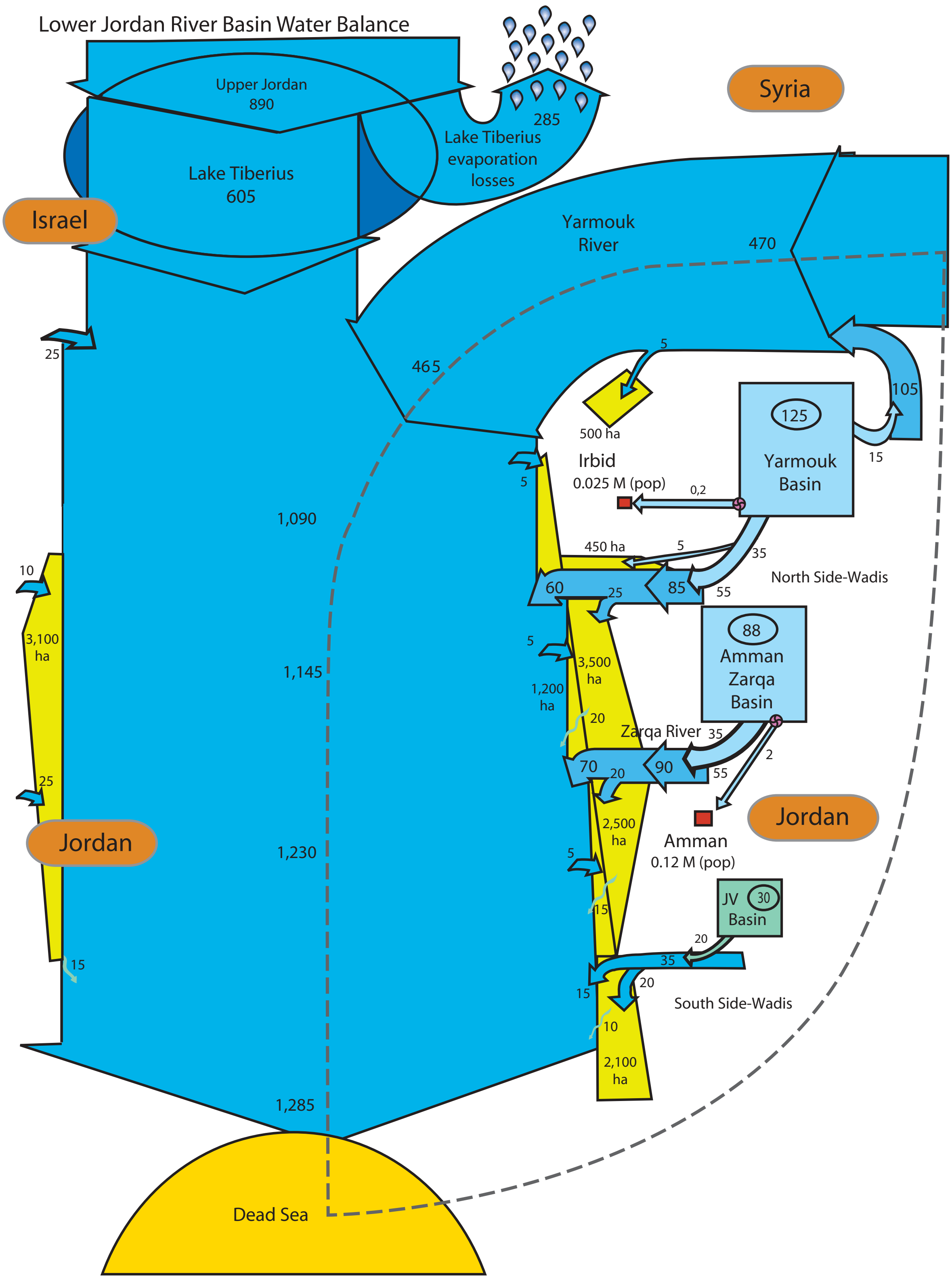
Water Resources and Uses in the 1950s

- Cities are essentially supplied by neighboring springs.
- Surface water coming from the Yarmouk river, the side-wadis and the Jordan river itself allows the irrigation of small areas located along these rivers (around 13,000 ha using 125 Mm^3/yr [Baker and Harza 1955] i.e., 9 percent of the Lower Jordan river flow) and in the alluvial fans of the valleys.
- No significant groundwater exploitation is observed.

[8]For example: The Henriques study (1928), the Ionides study (1939), The Lowdermilk Plan (1944), the Cotton and Arab Plans in 1954, The Johnston Plan and the Harza-Baker study in 1955.

[9]The State of Israel was established by the United Nations in 1948 and, until 1967, the West Bank was under Jordanian administration, the eastern bank of the Jordan river being known as the Kingdom of Transjordan.

FIGURE 7.
Water resources development in the LJRB around 1950, before the development of major diversion schemes.



Situation in the Mid-1970s: The Exploitation Phase

Historical Background: Changes Since 1950

In the wake of the 1948–1949 war following the creation of the State of Israel, a first huge influx of Palestinian refugees (around 450,000 persons [El-Nasser 1998]) constituted a major challenge for a country which had just begun its economic development. In 1967–1968, after the 6-day war of June 1967, an additional 400,000 “displaced persons” immigrated to Jordan (Haddadin 2000). The demographic boom (there were 450,000 inhabitants in Jordan before 1948 and 2 million in 1975 [De Bel-Air 2003]) resulting from these “transfers of population” and from a decrease in infant mortality, is undoubtedly a crucial factor in explaining the extremely rapid development of the LJRB’s water resources.

On the other hand, the international community, which had backed the creation of the State of Israel, also strongly supported the economic development of Jordan in order to alleviate social tensions due to population displacements and to promote “stability” within the region. Because of this, the financing of large facilities quickly allowed the development of irrigated agriculture in the Jordan valley as part of a larger socioeconomic development process. In the Jordan valley, the construction between 1958 and 1966 of a main 69 km-long concrete canal—King Abdullah Canal (KAC)[10]—a land reform allowing the constitution of thousands of small intensive farms, the construction of several roads, some urbanization projects and the development of basic social services allowed the settlement of people and the development of modern production of fruits and vegetables (JVA 1988).[11] Within a few years, the traditional agricultural-cum-livestock model of the nomadic Bedouins had been replaced by a modern market-oriented agriculture developed by small entrepreneurial farmers, which could supply growing cities and produce a substantial surplus, which was exported all around the Middle East (Elmusa 1994; Nachbaur 2004; Venot 2004a). This evolution can be explained by several factors, such as the agricultural know-how of the Palestinian refugees, some capitalistic investments made by large Jordanian families, support from international aid and the favorable market conditions both in Jordan and in the Middle East. During this period, in the highlands, the rapid development of cities and of irrigated agriculture was accompanied by growing groundwater exploitation. Development of irrigated agriculture was due to, on the one hand, several effective actions taken by the Government of Jordan aiming, since the 1950s, to settle the nomadic tribes of the area and, on the other, to various private initiatives during the 1960s and the 1970s, fueled by the emergence of new techniques allowing groundwater exploitation (petrol and electric pumps, drilling of bore holes, etc.,). Furthermore, potable water supply in the cities expanded through the development of public wells in and around urban areas. In cities located near main springs, the tapping of local aquifers through wells allowed a strong increase in the exploitation of local resources. On the other hand, for some cities, interbasin water transfers from distant aquifers were needed and implemented. For example, transfers from the Azraq oasis (located outside the LJRB) supplied water to the cities located in the north of the basin. The later increase in these transfers compounded the dramatic increase of private agricultural wells depleting this shallow aquifer, contributing to the drying up of this wetland.

[10]Initially named East Ghor Canal.

[11]A troubled period between 1967 and 1971 interrupted this process. The 6-day war caused the exodus of the entire population located in the valley to the highlands and it was only after 4 years of internal instability within Jordan and the departure of the Palestine Liberation Organization (PLO), that the Government of Jordan relaunched, on a larger scale, its development projects in the Jordan valley.

Water Resources and Uses in the Mid-1970s

In 1977, the Ministry of Water and Irrigation (MWI) published, in collaboration with the German Cooperation, a global assessment of water resources in Jordan after a first phase of substantial exploitation. This study is the basis of our presentation of the water resources (cf., figure 8), their utilization in the middle of the 1970s, and of the changes that occurred since the 1950s.

- Israel developed its use of the Upper Jordan river water resources. In the late 1950s the Israelis increased the level and capacity of Lake Tiberius, the only major reservoir of the area, by raising the level of the Degania dam (built in 1932 under 1921-Rutenburg concession). Together with some local uses, Israel pumped from Lake Tiberius nearly 440 Mm^3/yr (PASSIA 2001) and started to transfer this water through its National Water Carrier (NWC) to cities along its Mediterranean coast and to some irrigated schemes down to the Negev desert, southwest of the Dead Sea. The outflow from Lake Tiberius thus decreased from 605 to 70 Mm^3/yr (Klein 1998), reaching the LJRB only during winter flood flows.

- In addition, in order to preserve the quality of Lake Tiberius water, mainly used as a reservoir of potable water, Israel diverted saline springs from the north of the lake to the Lower Jordan river downstream of the lake. At the same time, Israelis pumped water from the Yarmouk downstream of the intake of the Jordanian KAC in order to fill the lake as well as to serve nearby irrigated schemes (70 Mm^3/yr)— (PASSIA 2001).

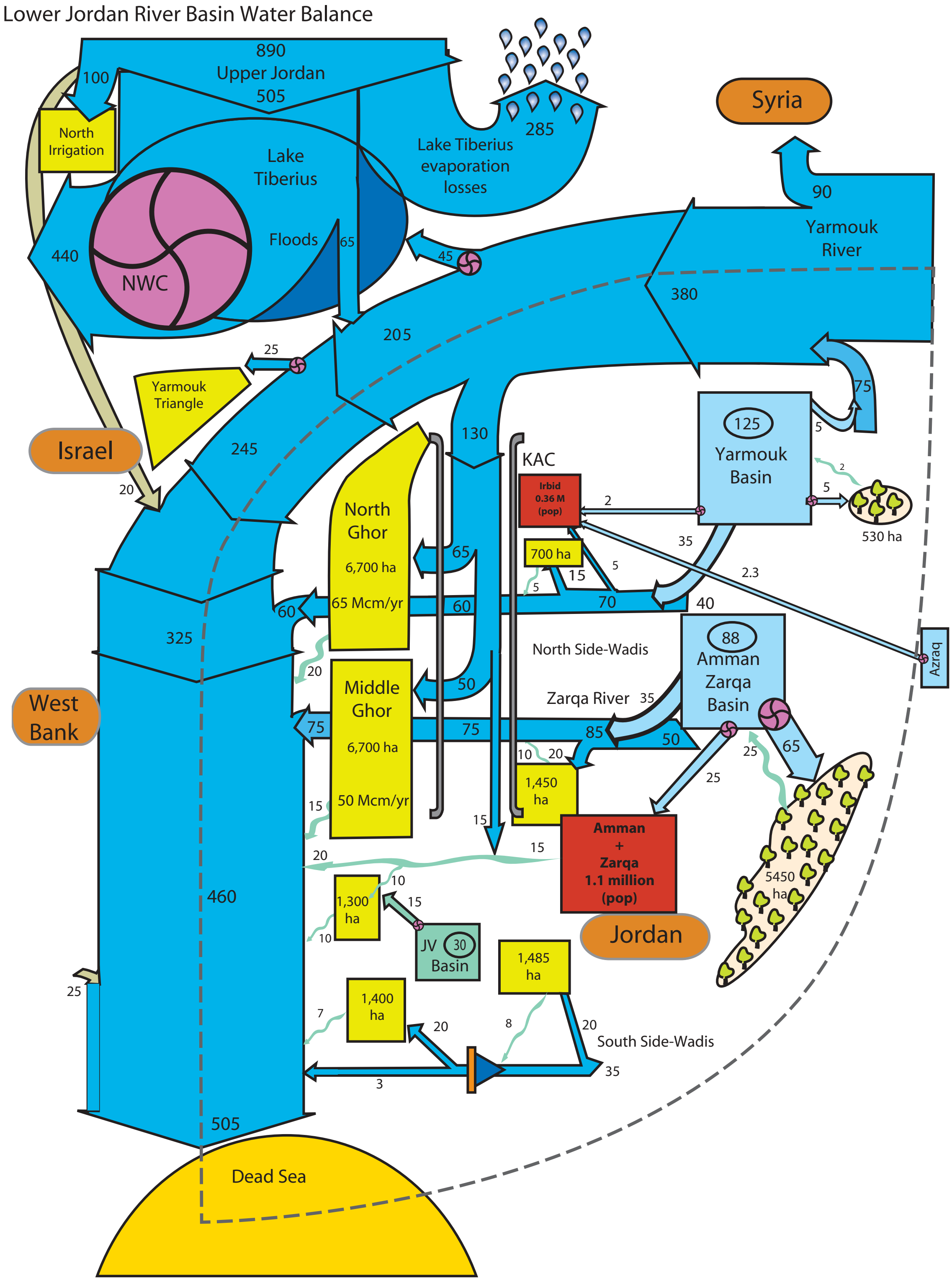
- In Jordan, irrigated agriculture developed on a large scale. In the northern and middle parts of the Jordan valley, 13,500 hectares were irrigated by using 115 Mm^3/yr (THKJ 1977) coming from the KAC. In the south, water from several side-wadis and pumping from the aquifers allowed the irrigation of around 4,200 hectares with 55 Mm^3/yr (THKJ 1977). In the highlands, 2,150 hectares were also irrigated (35 Mm^3/yr) in the side-wadis and the Zarqa river valleys, while around 5,900 hectares were irrigated with groundwater within the Yarmouk and the Amman-Zarqa basins (respectively depleted by 5 and 65 Mm^3/yr)—(THKJ 1977).

- The period is also characterized by the strong development of urban areas such as Amman-Zarqa (population of 1.1 million), and Irbid (population of 0.36 million), which then used 30 Mm^3/yr of groundwater (THKJ 1977).

- At the same time, Syria also started to develop its use, essentially agricultural, of the upper Yarmouk river (90 Mm^3/yr [Hof 1998]) ultimately reducing the flow of the Lower Yarmouk to the Jordan river to 380 Mm^3/yr (cf., figure 8).

- These diversions are done along the rivers and no reservoir is yet built on the main tributaries of the Lower Jordan river. Because of these combined water uses in Israel, Syria and Jordan, only one-third (505 Mm^3/yr) of the historical flow of the Jordan river still reaches the Dead Sea.

FIGURE 8.
Water resources and uses pattern in the LJRB in the mid-1970s.



Situation in the 2000s: Growing Scarcity Problems

Historical Background: Changes Since 1975

The exploitation of the water resources increased sharply between 1975 and 1995, but no change was apparent in the way water resources were managed even if, in the beginning of the 1990s, some evidence suggests that awareness of a "water crisis" was developing among the users.

In the Jordan valley, irrigated agriculture was greatly expanded through the construction of several hydraulic facilities (doubling of the length of the KAC, construction of secondary canals for this new section, implementation of a pressurized water distribution network, storage dams on the Zarqa river and other side-wadis). All these investments, mainly financed by international aid during three decades, have been estimated at US$1,500 million (Suleiman 2003; Nachbaur 2004). Moreover, because of new techniques of production (greenhouses, drip irrigation, plastic mulch, fertilizer, new varieties, etc.,) the availability of the Egyptian labor force, and of market opportunities, at least until the first gulf war, irrigated agriculture in the Jordan valley enjoyed a boom in production and economic profitability described by Elmusa (1994) as the "Super Green Revolution."

The particular climate of the Jordan valley allows many small entrepreneurial farmers to produce vegetables almost all year long (and especially during winter) as well as some fruits withstanding the heat in summer (citrus and bananas).

At the same time, in the highlands, vegetables and Mediterranean fruits can be produced all summer long. On these desert plateaus, private wells have actually provided "unlimited access" to good-quality groundwater resources.[12] Big and dynamic entrepreneurs have made massive investments allowing the development of an irrigated agriculture which supplies Jordan and the Gulf countries with fruits and vegetables during summer.[13] In addition, some well owners also grow orchards of olive trees, which represent now more than half of the irrigated area in the highlands (8,170 hectares on a total irrigated area of 14,785 hectares [Venot 2004b]). These orchards seem to reflect the pursuit of social prestige rather than mere economic profitability. These plantations are, in fact, hardly profitable (Venot 2004c); nevertheless, they contribute greatly to depletion of the aquifer (by about 30 Mm^3/yr i.e., one-fourth of the agricultural groundwater abstraction of the LJRB in Jordan [Venot 2004b]) and to its salinization, jeopardizing, therefore, the present low-cost-domestic use which already amounts to the usable recharge rate of the aquifer (ARD and USAID 2001; Chebaane et al. 2004). This water use, developed by some entrepreneurs who do not depend on their agricultural activity, lends itself to criticism in the present situation of extreme scarcity, just like the artificially

[12] We will see in the following section that groundwater quality is now declining in some places (in particular in older irrigated areas near urban centres [ARD 2001]), due to overexploitation of the aquifer.

[13] The small and middle-size Palestinian-Jordanian entrepreneurs constituted the main driving force of the rapid development of fruit and vegetables production in the Jordan valley. In the highlands, the development of irrigation was also due to some Palestinian-Jordanian entrepreneurs but investments have been higher (as well as the economic return [see Venot 2004]). To explain this process, it is useful to remember the mainly rural origin of the displaced populations, the Palestinian agricultural knowledge, the technology transfers from Israel, the willingness of the displaced populations to develop their activity of production, the existence of important marketing-networks linked to Palestinian communities settled in the Gulf countries and, finally, the capital investment in the agriculture sector by these communities.

maintained and very profitable banana production using large amounts of good-quality water in the Jordan valley.[14]

During the same period, in order to ensure the supply of potable water to growing cities, it was necessary to both multiply the number of wells in the surroundings of the cities (between 1975 and 2000, the number of wells used for domestic purposes in the city of Amman increased from 6 to 12 [see Darmane 2004]) and mobilize new resources to be transferred to the cities. Therefore, in addition to the 22 Mm^3 pumped every year in the municipality, Amman now receives 32 Mm^3/yr from other wells, of which one-third comes from aquifers outside the LJRB (Darmane 2004).[15] Added to this water coming from the highlands, another huge transfer brings water from the KAC, in the Jordan valley, to Amman. This transfer, initiated at the end of the 1980s, has been developed after the massive immigration of Jordanian-Palestinians who were working in the Gulf countries and were forced to leave and to come back to Jordan after the first Gulf war (1991).[16]

This transfer (now reaching 50 Mm^3/yr; JVA Water Resources Department records 2004) makes up one-third of the water supplied to Amman and represents one-third of the water diverted to the KAC. As irrigation in the south of the Jordan valley was already developed (around 3,000 ha), this transfer was made possible only because of the concomitant gradual development of the treatment of wastewater from Amman. Effluents are collected in the King Talal Reservoir (KTR, capacity of 80 Mm^3 [THKJ 2004] and built in 1977) and mixed with freshwater coming from the Zarqa river itself. This blended water has actually replaced the freshwater initially used to irrigate the middle and the south of the Jordan valley (see records of JVA-Water Resources Department).[17] This transfer is facilitated by a favorable topographical situation, allowing a low-cost transfer of treated wastewater from the cities to irrigated areas.

Until the mid-1990s, water was considered as a "sleeping resource" to be found and mobilized by ever-effective and efficient new techniques. The fuzziness around the sharing of water resources between the riparian countries of the Jordan basin fueled the impression that new resources could become available in the future. However, with more comprehensive hydrological knowledge and the 1994 Peace Treaty that fixed the repartition of water resources between Israel and Jordan, these countries and the donors realized that the situation was more critical than formerly envisioned. This influenced water policymaking towards more sustainable management of the resource.

[14]The cultivation of banana in the Jordan valley (1,350 ha) uses around 46 Mm^3/yr of which 30 Mm^3 are of best quality (banana is highly sensitive to salt) and could be used at low cost for domestic purposes. The remaining 16 Mm^3 are brackish or desalinated water (Venot 2004) from the Jordan Valley aquifer. This cultivation has mainly been developed by some influential tribes traditionally established in the valley, which have long controlled springs and wadis and claim historical rights to these sources. It is today by far the most profitable crop grown in Jordan, with one of the highest water productivity (ARD 2001), but this profitability is largely artificial, due to protective customs barriers which keep the local price of banana at a level higher than the international market price. With the entry of Jordan to the WTO in 2000, these customs duties are likely to be dropped (even if no schedule has been negotiated yet) threatening the economic profitability of this crop (Venot 2004).

[15]The main part of these "water imports" is coming from the Azraq oasis, a Ramsar site located 80 km from Amman (outside the Lower Jordan basin). Continuous and increasing abstraction since the mid-1970s has led to a dramatic drop in the water table level and to the almost complete disappearance of this ecosystem. Moreover, there are other transfers from the Dead Sea basin.

[16]This new transfer of population was due to the particular position of King Hussein of Jordan and the PLO leader Yasser Arafat, both of whom had expressed their support to Saddam Hussein and to the invasion of Kuwait.

[17]At the same time, the construction of the Karamah dam in the south of the Jordan valley in the mid-1990s (completed in 1997) has proved to be a failure ($ 77 million [Nachbaur 2004]). The reservoir was meant to store excess runoff in the rainy season for further reuse in the valley; it actually constitutes a sink, since the water reaching it is too saline to be used in agriculture, because of both salty groundwater infiltration and neighbouring highly saline soils. The water is thus not kept in the reservoir but released to the Jordan river.

Unsustainable Exploitation and Reorientation of Water Policies

Improved knowledge of each aquifer shows that the volumes pumped each year were, and still are, generally much higher than the mean usable recharge of these aquifers. At the same time, the first abandoned areas irrigated with groundwater from desert aquifers (e.g., in Wadi Dulheil and Azraq) clearly show the risks and the problems resulting from an overexploitation of these water resources. Abstraction now largely exceeds both the annual usable recharge by rainfall water and also the total recharge when percolation losses from users are added (cf., section under Refining Water-Use Categories, p. 43). As a result there is a quick drop of the water table as well as an increase in salt concentration in some of these aquifers. Observations have shown that this increase can be due both to the intrusion of brackish or salty water coming from more saline neighboring aquifers and to salts mobilized by return flows from irrigated areas (JICA 2004).

In addition, demographic growth and the improvement in the living standards of the entire population led, and will continue to lead, to a strong increase in the demand for municipal water, which is now reaching 94 lpc/day (average for the country) (THKJ 2004).[18] This will require the development of new water resources.[19] Furthermore, the costs (investment, operation and maintenance [O&M]) of urban water supply have strongly increased (Abu-Shams 2003; Darmane 2004). In order to meet the growing needs of the urban population, it is now necessary to resort to energy-consuming transfers over longer distances and to elevate water several hundred meters (1,200 m from the Jordan valley up to the highlands or from 200–600 m in deep wells), to develop water reuse (McCornick et al. 2002), and establish desalination plants (see Scott et al. 2003).

Moreover, it is worth noting that agriculture, which enjoyed very favorable conditions during the 1970s and the 1980s, and which was strongly supported by the government because it allowed rapid and economically viable local development and the settlement of nomadic populations, uses today a large share of national water resources. Agriculture employs 5 percent of the labor force, produces only 3 to 4 percent of the Gross Domestic Product (GDP), but indirectly contributes to nearly 29 percent of the GDP (Ministry of Planning 1999), when all agriculture-related activities are computed. The sector makes up 65 percent of the national water use (i.e., 511 Mm^3/yr in 2002, including 71 Mm^3/yr of treated wastewater [THKJ 2004]). This is a common situation due to the large amount of water needed for crop production and to the relatively undeveloped nature of the other sectors, but these percentages signal that, because of the overall limited amount of water available, more inter-sectoral transfers are forthcoming.

Faced with such problems and the evidence of a growing overall scarcity, the Government of Jordan, supported by international partners strongly involved in the water-sector's investments, has tried to critically reorient its water policy. The main lines of this new policy are:

Institutions and Policies

- Official publication of the government priorities and objectives in the Jordan's Water Strategy Policies of 1995 and 1997: where priority is given to potable water, then to industrial use and finally to irrigation water.

- The concentration of the responsibilities for the public management of the entire sector within the MWI (Ministry of Water and Irrigation).

[18]Darmane (2004) presents a figure included between 115 and 150 lpc/day for the capital Amman.

[19]Prospective presented in THKJ (2004) has been done to allow a municipal water consumption of 150 lpc/day.

Supply Augmentation

The planning of a set of new projects aiming at mobilizing the last available resources: dams, transfers, reuse, and desalination.

Actions Aiming at Reducing Agricultural Water Consumption

- Freezing of well-drilling authorizations in 1992.
- Initiation of a control of water pumped from aquifers (installation of water meters in 1994 and groundwater-control by law in 2002, establishing a taxation on the volume pumped).
- Modernization of the irrigation systems in the Jordan valley (shift from a distribution system by open channel to an underground pressurized network, completed in 1996).
- Replacement of freshwater used in irrigation with blended treated wastewater coming from the KTR in order to irrigate the middle and the south of the Jordan valley.
- Since 1998, a reduction of the annual water quotas allocated to farmers in the Jordan valley has been introduced, according to the quantity of the resources available in the country each year.
- Compensation by the government to farmers for letting their land fallow in order to reduce the demand for and the consumption of irrigation water in the Jordan valley during dry years (1,000 ha for a value of US$ [hereafter, $] 0.4 million in 2001).
- Development of applied research and technical assistance to farmers (American, German and French cooperation, among others).

Actions Aiming at a Better Management of Urban Water Supply

- Rehabilitation of the network of Greater-Amman (investment of $250 million in the 2003–2006 period) in order to reduce the large leakages which amounted to 30 percent of the water delivered.
- Transfer of the management of urban water supply for Amman city to a private company in an attempt to improve distribution and control over the network, and to increase bill recovery (reduction of unaccounted-for water). The reliability of the distribution has considerably increased as well as the percentage of bill recovery, but losses are still very high because of the dilapidated state of the network.

Water Resources and Uses in the 2000s

The main modifications that occurred between the middle of the 1970s and the 2000s are shown in figure 9 and include the following:

- Reduction of the water coming from the Yarmouk and reaching the LJRB. During the 1980s, 35 middle-size dams were built in the Upper Yarmouk basin in Syria. Direct pumping in the rivers and wells for agricultural and urban purposes has developed significantly. The Syrian utilization of the Yarmouk has thus more than doubled within the period to reach 200 Mm^3/yr (El-Nasser 1998). The Yarmouk flow, before its partial diversion into the KAC and to Israel, reaches 270 Mm^3/yr (THKJ 2004), of which about 110 Mm^3/yr flow uncontrolled to the Lower Jordan river.

- In 1994, Jordan and Israel signed a peace treaty, defining the sharing of common water resources. The prevailing Israeli utilization of the Yarmouk water (local use and diversion by pumping to Lake Tiberius in winter) was recognized and remains unchanged (70 Mm^3/yr)—(El-Nasser 1998; Hof 1998). Moreover, Israel pumps 25 Mm^3/yr in winter from the Yarmouk and gives back the same amount to the KAC during the year, which allows a certain degree of regulation of the canal inflow.[20] Moreover, according to the treaty, Israel, after desalinating the 20 Mm^3/yr coming from saline springs and presently diverted to the Lower Jordan river, should transfer 10 additional Mm^3/yr to Jordan. Another 50 Mm^3/yr of freshwater should also come from common projects to be defined. These two points have not been implemented yet and in compensation, Israel has been transferring 20 Mm^3/yr (added to the 25 Mm^3/yr returned in summer) of freshwater from Lake Tiberius to Jordan since 1998 (Peace Treaty between Jordan and Israel 1994; Beaumont 1997).

- Extension to the south of the KAC by 18 km between 1975 and 1978 and by 14.5 km in 1988. Only an additional area of 3,400 hectares has been newly irrigated, thanks in particular to the use of blended freshwater/wastewater (50 Mm^3/yr of such water are now used in the southern Jordan valley [JVA-records], i.e., one-third of the water used in the south of the valley, this amount is increasing each year). Due to lack of water, an area of 5,100 hectares, already equipped with an irrigation network, is still not put to use.

- Optimization of the efficiency and of the control of the distribution of water to irrigated farms, through the construction of an underground pressurized pipe network.

- Building of dams on the Zarqa river and other side-wadis in order to control the surface water and irrigate new schemes. Little water still reaches the Jordan river in winter.[21]

- While groundwater use was already significant in the mid-1970s, most deep wells (85%) were dug between 1975 and 1992 (BGR-WAJ 1994). Agricultural

[20]However, it is worth noting that this part of the treaty raised some problems since the water pumped by Israel from the Yarmouk in winter is of very high quality, while the water returned from Lake Tiberius to the KAC in summer is, on the contrary, of poor quality.

[21]The total capacity of the reservoirs is evaluated at 165 Mm^3 (THKJ 2004).

groundwater use in the basin would thus reach 109 Mm^3/yr in the 2000s (records of the MWI-Water Resources Department for the year 2003) to irrigate around 15,000 hectares.[22]

- Urban population within the basin has been multiplied roughly by 2.5 in 25 years (1975–2000—THKJ, DoS 1978, 2003). Urban groundwater use (domestic and industrial water) has, in parallel, grown fivefold to now reach 150 Mm^3/yr (records of the MWI-Water Resources Department).

- Within this amount, 20 Mm^3/yr come from neighboring basins located at 50–100 km of the large urban areas of the LJRB in Jordan.

- Since the beginning of the 1990s, a set of pumping stations allow the transfer of 50 Mm^3/yr from the middle of the valley to Amman.

- Total groundwater exploitation in the basin officially reaches 240 Mm^3/yr (to which 30 Mm^3/yr of groundwater imports from other basins must be added), compared with an annual usable recharge of 160 Mm^3/yr. This means an overexploitation rate of 150 percent on average on the LJRB (MWI-records), which seems to be an under-evaluation of the actual figure (our calculations based on a local abstraction of 275 Mm^3/yr gave a rate of 180%, see footnote 22).

Decline in quality and quantity of the water reaching the Dead Sea has reduced its inflow to only 20 percent of the historical flow of the Jordan river. Only the Yarmouk river and some side-wadis, mainly in the north of the basin, still feed, in winter, the Lower Jordan river. In addition, this latter only receives polluted and salty water (water from saline springs diverted by Israel, drainage waters from the irrigated perimeters and wastewater from Israeli colonies and Palestinian and Jordanian villages or cities).

---

[22]The volumes presented here are official figures from the MWI for the year 2003 and are split amongt the different basin as follow: 58 Mm^3/yr for the Amman-Zarqa basin, 29 Mm^3/yr for the Yarmouk basin; 18 Mm^3/yr for the Jordan valley basin and 4 Mm^3/yr for the side-wadis groundwater basin. These figures may, however, be questioned due to, among other things, the unreliable functioning and readings of the water meters installed on the agricultural wells.

Field surveys (Venot 2004), crop requirement evaluations (FAO 1977; THKJ 2004) as well as the estimation of irrigated areas in the highlands of the basin (Venot 2004) lead to an estimate of total agricultural groundwater abstraction in the Amman-Zarqa and the Yarmouk basins of 75 and 35 Mm^3/yr respectively (i.e., 110 Mm^3/yr [Venot 2004]). For the Amman-Zarqa basin, ARD (2001) and Chebaane (2004) present a comparable figure of 70 Mm^3/yr for agricultural groundwater abstraction within this basin. Since no other figures concerning the Jordan valley and the side-wadis basin are available, we will consider THKJ (2004) figures.

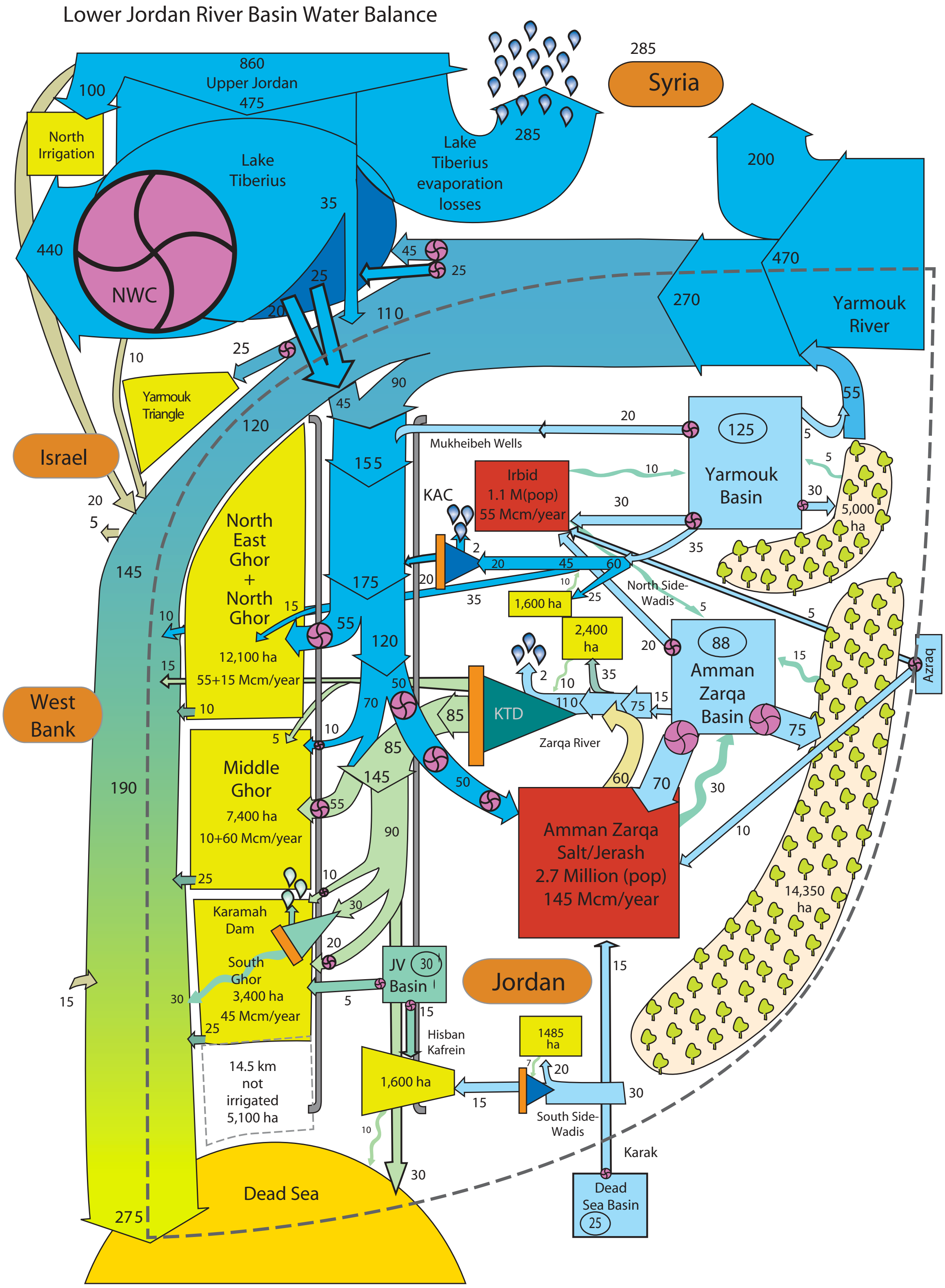
Considering the figures given for M&I abstraction as accurate, these new evaluations of agricultural abstraction and the annual recharges presented in THKJ (2004), the effective overexploitation of the Amman-Zarqa aquifer would thus represent 250 percent of the annual usable recharge instead of the 216 percent announced, and this overexploitation would reach 117 percent instead of 100 percent of the annual recharge of the Yarmouk basin (return flows not considered in this calculation). This leads to an overall abstraction of 180 percent for the entire Lower Jordan basin (abstraction of 275 Mm^3/yr).

However, these rates of overabstraction are calculated based on the ‘usable recharge’, i.e.; the recharge by rainfall minus the baseflow. If we now consider return flows from irrigation (efficiency of 80%) and cities (efficiency of 70%), the abstraction decreases respectively to 161 percent and 85 percent of the annual usable recharge of the Amman-Zarqa and Yarmouk basins. This evaluation leads to an overall abstraction equivalent to 120 percent of the annual usable recharge of the LJRB (abstraction of 185 Mm^3/yr).

Notes: 1. The definition of the overdraft based on annual recharge is problematic. Part of the recharge returns to the surface through springs or baseflow and abstractions at the level of the recharge are likely to have severe impact on these flows. The notion of safe yield is very fuzzy and not employed here. We compare here abstractions with the usable recharge but this does not mean that a rate of 100 percent is optimum or sustainable. Much uncertainty remains on the water balances since aquifers are not in a static state of equilibrium and the dynamics of aquifer de-stockage, as well as their impact on base flows, cannot be fully predicted.

2. If we consider that the 20 Mm^3/yr abstracted from the Mukheibeh wells are abstracted from the Yarmouk aquifer, the balance of this aquifer is more worrying since overabstraction would reach 169 percent and 135 percent, with and without computing the return flows.

FIGURE 9.
Water resources and uses in the LJRB in the 2000s.



Emerging Problems in 2000-2025 and Expected Evolutions

This section presents the main problems the Jordanian water sector is now facing, as well as their possible consequences for the near future. It also mentions some issues which are not yet of immediate concern but which will have to be addressed in the future. The following issues are to acquire increased relevance by the year 2025:

- The *physical scarcity* of water resources.
- *Population growth*. The rapid increase in water needs (due to an improvement in living standards and to a still high demographic growth of 2.8% [THKJ, DoS 2003]),[23] notably in urban needs (the cities concentrate nearly 80% of the population [THKJ, DoS 2003]).
- *Growing cost of supply*. The ever-increasing costs of the necessary mobilization of supplementary water resources, supported until now by the government[24] and international aid (expensive dams, long-distance transfers, elevation costs, desalination, etc., see Kolars 1992; GTZ 1998; Nachbaur 2004) but which may have, in the next decades, to be increasingly borne by the population (the present financing being unsustainable in the long term), with possible impact on the poorest households of the Jordanian society (see Darmane 2004 for some clues in the Amman's area).
- *Groundwater control*. The overexploitation of aquifers and the decline of their quality. Irrigated agriculture, in particular, leads to a deterioration in their quality (induced salinization, nitrates, etc.,) and thus jeopardizes the possible future use by cities of this high-quality and low-cost water. At the same time, little is really done to substantially decrease groundwater agricultural use in the private wells located in the highlands (abstraction limits have never been respected and too many licenses had been issued until 1992 [ARD 2001; Venot 2004b]).
- *Growing vulnerability to droughts*. The unchallenged policy of transferring increasing freshwater volumes from irrigated agriculture to urban uses, affects the stability of the agriculture sector. During dry years (2000 to 2002), for example, the Jordanian government froze the quantity of water reserved for cities, while drastically reducing the amount allocated to agriculture in the Jordan valley.
- *Modernization and maintenance*. Several measures have, however, already been taken to improve the management of water in the country. This includes, for example, modernization and physical improvement of the networks, reduction of the volumes of water unaccounted for,

[23] Even if a slowdown in population growth is now perceptible, the DoS presents an average of 2.9 percent for the period 1997-2003, that puts Jordan among the 12 countries with the highest population growth rate in the world. The natural growth rate (immigration excluded) is evaluated at about 2.4 percent. On the other hand, a figure of 3.6 percent is often referred to (El-Naser 1998; JRVIP 2001; Al-Jayyousi 2003), to evaluate total population growth in Jordan during the same period (which puts Jordan just after the Gaza Strip in terms of total population growth).

[24] The cumulated deficit of the Jordanian water sector corresponding to the amount of money invested (construction of water facilities, subsidies on water prices, etc.), due to public deficit, has been evaluated by the World Bank (1997) at $476 million in 1995 and has been increasing since then at an average rate of $90 million/year (i.e., 0.9% of the GDP) (Central Bank of Jordan quarterly reports).

transfer of Amman water supply and wastewater collection to a private company (Darmane 2004).[25] Such privatization would also probably bring benefits to the irrigated schemes of the Jordan valley now managed by a public service. However, partly because of the highly subsidized water prices, expected benefits are probably too low for a private company to invest in such a venture. In addition, as seen earlier, modern techniques allowing high efficiency of distribution always incur high O&M costs, which have to be borne either by users or by the government. However, until now, for both urban and irrigation supply, emphasis has been placed in obtaining international funding for implementing modern systems, while O&M recurring costs have been disregarded. The financing of O&M has always been minimal (and mainly borne by the public sector), resulting in degradation. There is a clear need for closely considering the O&M of these systems, notably if their efficiency is to be maintained.

- *Health and environmental hazards*. Apart from the problem of unsustainability associated with the overexploitation of the aquifers, other environmental problems have to be underlined. These include health hazards linked to a generalized use of treated wastewater in agriculture, the decrease in the Dead Sea level (one meter per year during the last decade [1995-2004]), the disappearance of the Azraq oasis, as well as the contamination of groundwater and surface water.

The future of irrigated agriculture raises a complex set of technical, social and economic questions:

- *Redefine agriculture in the highlands*. Irrigated agriculture in the highlands has mainly developed during the last three decades because of large private investments (minimum of $200,000 per farm of 20 hectares on average for the well, pump, irrigation system, fences, houses and often orchards). The 500 to 1,000 investors concerned belong to the high society (deputies, senators, entrepreneurs, sheikhs, etc.,) their social importance and their influence on government decisions suggest that all the measures aiming at reducing their water use will be conflict-prone and will take long to implement.

- *Degradation of water quality*. The situation in the southern Jordan valley, which receives blended fresh/treated wastewater from Amman instead of freshwater coming from the north (now transferred to the capital), is expected to be extended to the whole Jordan valley during the next decade (see McCornick et al. 2002; MWI/JVA 2002; MWI/WAJ 2004). A degradation of the agricultural water quality will follow and will generate a complex array of problems: workers' and consumers' contamination, soil degradation, clogging-up of irrigation system emitters, disappearance of certain sensitive crops (strawberries, beans, citrus, etc., [FORWARD 1999; Grattan 2001; McCornick et al. 2002]), consumer's lack of confidence in the quality of the products, drop in prices, and loss of some export markets. On the other hand, effluents from the cities (and notably from the Amman-Zarqa urban areas) negatively impact the quality of surface water, creating problems for agricultural areas, notably along the Zarqa river (ARD 2001).

[25] Recently, some drawbacks concerning the process of privatization have been noticed at the national level. For example, it is likely that a public company will replace the private one in charge of the management of Amman's water utilities after 2006 (when the current contract will be over), while another is to manage the water supply in Aqaba. At the same time, several privatizations projected have been delayed (notably the one concerning the privatization of JVA in the northern directorate).

- *Declining profitability*. While allocation of freshwater to the Jordan valley has already decreased, prices of water have increased (even if they still remain very low)[26] but yet never constituted, until now, a real handicap for agricultural production in the Jordan valley. Marketing actually constitutes the main problem faced by producers (ASAL 1994; World Bank 1999). Jordanian irrigated agriculture has mainly developed during a period (1975–1990) of strong regional demand for fresh products. These products could be sold for high prices because of the payment capacity of the gulf countries (oil booms of 1973 and 1979) and of the lack of real competition, notably in winter (production in the valley) and in summer (production in the highlands). At this time, the necessary investments (greenhouses, irrigation systems, wells, equipment, etc.,) assured a handsome return within a few years (Venot 2004c) and a lot of investors invested in agricultural activities because of a profitability that was among the highest in all economic sectors. After 1985, the quick development of production in Jordan and in the region (citrus in Syria, vegetables in Syria, Lebanon and Gulf countries) led to a drop in prices and in the profitability of investments (Nachbaur 2004; Venot 2004b). Moreover, the first Gulf war of 1991 worsened this situation since the Gulf markets, which constituted a major outlet for Jordanian products (THKJ, DoS records) were lost (Fitch 2001; Jabarin 2001) as a result of the Jordanian support for the invasion of Kuwait by Iraq. The profitability of the Jordanian agriculture sector has thus decreased since the beginning of the 1990s and this decrease might become more pronounced in the near future, strongly affecting farms' profitability and farmers' revenue.

- *Threat to the trade balance*. Because of particular climatic conditions, irrigated agriculture has allowed the development of an important production of fruits and vegetables, and their exports now represent, on average, 12 percent of the value of Jordanian exports (MoA 2001). Due to the strategic social and economic nature of these agricultural exports, any reduction of the production will raise macro-economic questions. If imports of cereals (sometimes defined as "virtual water" [Allan 2002]) have never been a controversial issue in Jordan,[27] maintaining the export of high-value crops produced in the Jordan valley seems essential to stabilize the trade balance,[28] which shows a sharp deficit in a country with only a few natural resources (potash and phosphates of the Dead Sea) and with an economy mainly based on services.

- *Vegetable/fruit local markets*. Moreover, Jordanians are big consumers of fresh vegetables (tomatoes, cucumber, eggplant, zucchini, onion, etc.,) all year long. Therefore, it is necessary to maintain a production oriented towards the local market, notably in the Jordan

[26]Water fees in the Jordan valley amount to $0.02/m^3 of water supplied, i.e., about one-third of the O&M costs of the network.

[27]In areas where rain-fed cereals can be grown, possible improvements in term of yields and volume are very limited. On the other hand, the development of irrigated cereals has always been limited, the preference being given to vegetables and fruits.

[28]Based on figures of the Department of Statistics, exports coming from the Jordan valley account for 66 percent of the total vegetables and for 40 percent of the total fruits exported from Jordan; the rest is exported from the highlands.

valley.[29] Every drastic reduction in local production would actually lead to an increase in the local prices of these common products. If this could have a (limited) positive impact on the profitability of agriculture it will also negatively affect the budget of the poorest families.

- *Free trade*. Jordan has favored the development of new economic sectors (tourism, services, and industry) and signed several agreements,[30] which could lead during the next decade to a reappraisal of the profitability of certain agricultural productions still protected in Jordan (e.g., bananas and apples).

- *Impact on labor force*. Another important social problem is the fact that two-thirds of the workers in the agriculture sector are migrants, mainly coming from Egypt, and that the majority of the entrepreneurs are of Palestinian origin. It allows some groups of the Jordanian society to argue that the social impact of a drastic reduction of irrigated agriculture would only have little impact on the "Jordanian society." [31]

- *The illusion of cheap water*. Up to now, public agencies have never implemented the laws aiming at a reduction of agricultural groundwater abstraction by private wells (quotas, taxes if the quota is exceeded, etc.,) while this could have been possible because of the generalization of water meters on the wells from 1994 onwards.[32] Owners of private wells in Jordan consider that they own the resources they use and, through their political influence, manage to obviate the government measures which could affect them. In addition, because of the lack of fines for the use of private wells [33] and of highly subsidized water prices in the Jordan valley, farmers only bear a limited share of the abstraction and exploitation costs of water, strengthening the illusion of the availability of low-cost water.

Projections by the Mid-2020s

Scenarios Considered in Our Projections at the 2025 Horizon

Several investment and reform projects have been floated in order to meet and to satisfy the increasing urban water needs within the country during the next 25 years. Some of them have already been initiated (2004) or are in their final phase of implementation or definition. We present here a projection for 2025 considering projects that are already implemented or under way (in 2004) and those that seem to be the most likely implemented in the near future (see figure 10).

Construction of the Last Reservoirs. The last reservoirs which are likely to be built (along the side-wadis) are generally far from consumption

[29]Intensive irrigated agriculture in the Jordan valley seems to us to be less questionable than in the highlands mainly because it uses renewable surface water. Some problems of irrigated agriculture in the Jordan valley have however to be considered, including water pollution by nitrates and soils degradation (Orthofer 2001; Orthofer and Loibl 2002).

[30]The WTO, Jordan-UE Agreement, Great Arab Free Trade establishing a free trade area between the Arab states and several bilateral agreements, notably with the USA and Israel.

[31]This discourse opposes the "true Jordanian society" composed of inhabitants of the former Transjordan (east bank of the Jordan river) to foreigners (Egyptian, Syrian migrants) and Palestinians (either refugees, displaced or even with the Jordanian nationality).

[32]The example of the Underground Water Control By-Law No. (85) of 2002 is noteworthy since it is the first attempt to make the farmers pay for the water they abstract above a certain limit. Even if the expected decrease in agricultural abstraction is to be limited, the first bills have been sent to farmers on the April 1, 2004, opening the way to an effective water taxation (Venot 2004).

[33]Two-thirds of the licenses issued until 1992 included clauses on abstraction limits at 50,000 or 75,000 m^3/year/well (Fitch 2001) which have never been enforced.

centers, smaller and expensive, with the exception of the Jordanian-Syrian dam (Unity or Wehdah dam) whose construction has been delayed by the opposition of the Israelis until the Israeli-Jordan Peace Treaty of 1994.

In our projections, we consider the construction of the Wehdah dam (also called Unity dam; storage of 110 Mm^3 annual inflow of 85 Mm^3/yr [THKJ 2004]) which began in April 2004, as well as the construction of smaller storage facilities on the remaining non-controlled side-wadis and on neighboring rivers located out of the basin (Wadi Mujib, 35 Mm^3/yr).[34]

The consequence will be a nearly complete disappearance of the Lower Jordan river flow (Wehdah dam) as well as lateral flows (Mujib dam) reaching the Dead Sea, and the availability of new freshwater resources diverted mostly to cities (according to the governmental plans: 60 Mm^3/yr for Irbid and the other northern cities and 65 Mm^3/yr for Amman-Zarqa).

Consequently, the volumes diverted to irrigated agriculture within the Jordan valley will remain stable but the regulation of the KAC's flow and the flexibility allowed by the Wehdah dam will allow an improved fine-tuning of irrigation supply, but might also have an impact on soil salinization (McCornick et al*.* 2001).[35]

Development of Long-distance Interbasin Transfers. In the Jordanian situation of extreme scarcity, large transfers have long been envisaged (transfer of freshwater from Lebanon, Iraq and Syria; transfer of saline water from the Mediterranean Sea to the Dead Sea [GTZ 1998]) but these transfers have never been implemented because of the regional political instability and of their very high costs in terms of investment and O&M.

On the other hand, transfers within the basin and from neighboring basins, located in Jordan, are already developed (transfers from the Azraq and the Dead Sea) and should, in the mid-term, decline because of the general overexploitation of these basins.

In our projections for the 2025 horizon, we have considered, as part of a policy aiming at reducing the overexploitation of the renewable aquifers, that the transfers from the Azraq and southern basins (Dead Sea basin notably) could be discontinued or reduced (as presented in THKJ 2004).

On the other hand, a large transfer from the fossil aquifer of Disi, located about 300 km south of Amman, is envisaged and a Build Operate and Transfer (BOT) scheme is presently considered.[36] It is foreseen that 50 Mm^3/yr could be transferred to Amman in a 50-year period while the present (2000) private utilization of the Disi aquifer for local agricultural irrigation in the midst of the desert (50 Mm^3/yr MWI-Water Resources Department records) would be stopped or at least strongly decreased (and limited to fruit trees). The governmental decision to exploit this strategic fossil aquifer illustrates the severity of the problems to be solved in Jordan in the short term.

Finally, all the new projects (desalinization plants, new dams, and water reuse) would also need high investments in terms of pipes, pumping stations and other facilities allowing the transfer of water.

---

[34]The construction of this dam was completed in 2004.

[35]The management of the canal water depends essentially on the Yarmouk flow: some wasting of water generally occurs in winter when the crop requirements are low and the resources abundant (but uncontrolled flows in winter can also be useful for leaching the soils in off-seasons as shown by McCornick et al. [2001]). On the other hand, there are periods when water is lacking, notably at the end of the spring and the beginning of autumn when farmers' needs are high. The control of the Yarmouk flows by the Wehdah dam will allow a more "on-demand" management, which should both allow meeting agricultural needs and optimizing the resources use.

[36]The Government of Jordan is now studying the different offers received from private companies but recent evolutions seem to show that none of these offers is satisfactory. It is thus possible that the idea of a BOT scheme will be given up and that the government will invite tenders for this huge water transfer.

Development of Brackish and Seawater Desalinization. In 2004, an important desalination plant of the brackish groundwater of the Jordan valley (Deir Allah, 15 Mm^3/yr [MWI 2002]) was implemented and is already supplying Amman with 10 Mm^3/yr.

Some others smaller reverse-osmosis plants have also been developed during the years 2000-2005 in areas where groundwater is brackish, in order to supply cities with potable water as well as to develop agricultural activities in the south of the Jordan valley (private facilities, essentially for banana cultivation). We consider in our projections that these plants will be still in use in the mid-2020s.

We also consider in our projections some large projects of desalination of saline springs (Zara-Maïn, 35 Mm^3/yr under construction [MWI 2002]) and of brackish aquifers in the Jordan valley (Hisban, 10 Mm^3/yr to be developed within the next decade). Moreover, we consider that Israel, in compliance with the 1994-Peace Treaty, will desalinate the 20 Mm^3/yr it now dumps into the Jordan valley and will transfer half of this volume to Jordan.

The Red Sea-Dead Sea Project (Red-Dead). This project consists of the huge transfer of seawater from the Dead Sea to the Red Sea (difference in altitude of 400 meters, distance of 180 km). It is intended to stabilize the Dead Sea level (see evolution of the water level in figure 11) by transferring into it a volume close to that historically brought by the Jordan river (between 800 and 1,000 Mm^3/yr). A bigger transfer is, in fact, planned (1,500 Mm^3/yr in total) in order to supply the main cities of Jordan, Palestine and Israel with some seawater which would be desalinated on the shores of the Dead Sea using the electricity produced because of the natural difference in altitude (Harza 1998).

In addition, the tourist activity in the area is to be strongly developed due to the importance of the site for the main monotheist religions and to the medicinal value of the Dead Sea mud. The project would, therefore, also benefit this activity and allow its development. The capital required is estimated at $1,000 to 1,500 million for the seawater transfer, and at $3,500 million for the desalinization and freshwater transfer facilities (Harza 1998). The magnitude of these investments as well as the involvement of the three political entities concerned (Israel, Jordan, Palestinian territories) requires regional collaboration and a strong support from the international community. The project, in fact, has been presented, for the first time, by a bipartite committee (Jordan and Israel) during the Earth Summit for a Sustainable Development in Johannesburg in 2002. The World Bank has been appointed to draft the term of references for the feasibility study by a tripartite committee (Jordan, Israel and Palestinian Authority) and the study is seen by the international community as a means to contribute to the Peace Process in the region.

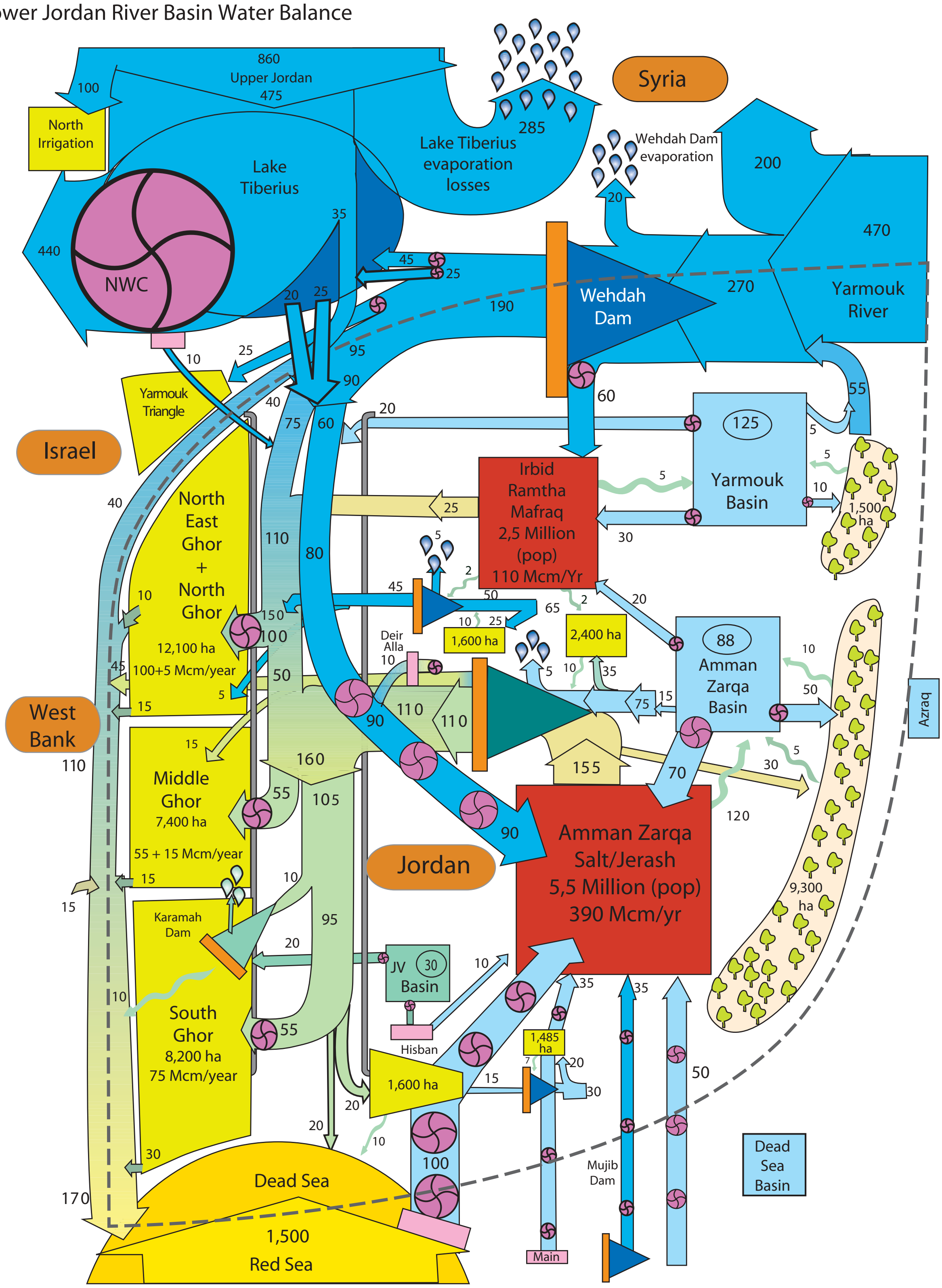
Due to the scope of the project and to the time needed for its implementation, we have considered in our projection for 2025 that only the first step would be implemented with the production of 100 Mm^3/yr of desalinated water (against a prevision of 570 Mm^3/yr of desalinated water for Jordan at the last stage of the project [Harza 1998]).

In spite of its high costs (desalination, elevation and transfer), this technical solution is already the main option considered today to solve or at least to alleviate the freshwater scarcity problem in Jordan in the mid- and long-term.

Expansion of Treated Wastewater Use in Irrigated Agriculture. It is forecasted that in 2025 Amman will produce twice as much wastewater as in 2000 (100 Mm^3/yr). In our projections, we consider that this wastewater, blended in the KTD with freshwater coming from the Zarqa river, will be used in the south of the valley (allowing, therefore, irrigation of all the area which can be potentially irrigated) and in the highlands mainly for industrial purposes (25 to 30 Mm^3/yr as mentioned in the THKJ 2004) around wastewater treatment plants, instead of using freshwater from aquifers.

FIGURE 10.
Projected situation of water use patterns by the mid-2020s.

Lower Jordan River Basin Water Balance



We also considered that 25 Mm^3/yr of treated wastewater would be available in the northern cities of Jordan and would be blended in the KAC with water coming from the Yarmouk in order to irrigate the schemes of the northern Jordan valley (McCornick et al. 2002).[37] This would counterbalance the increasing freshwater transfers from the Jordan valley to Amman that have been estimated at 90 Mm^3/yr in the mid-2020s.

Reduction of Agricultural Groundwater Use. In order to reach a sustainable level of groundwater exploitation (88 Mm^3/yr in the Amman-Zarqa basin, for example, [see ARD 2001; MWI-Water Resources Department]), it would be necessary, at the current level of urban uses, to stop all agricultural groundwater use.

This scenario is highly improbable since it seems unlikely that from a role of producer-exporter of fresh products in summer, Jordan will become a net importer of these products during this period of the year. Moreover, the importance of the sociopolitical impacts of such a shift suggests that the policies needed to reduce irrigated agriculture in the highlands (and notably the export-oriented one) will be delayed and only partially implemented.

On the other hand, the increase in the aquifer salinity could lead, in the mid to long term, to a reduction of irrigated agriculture in the highlands since some of the crops planted (grapes and apples) are salt-sensitive and would thus become nonviable (Grattan 2001).

In our projection to 2025 we have envisaged an average scenario for the entire society, whereby the irrigated areas would be reduced by two-thirds in the Yarmouk basin and by 30 percent in the Amman-Zarqa basin by 2025 (1,500 and 9,300 ha, consuming 10 and 50 Mm^3/yr of groundwater, respectively, to which must be added 30 Mm^3/yr of treated wastewater in the Amman-Zarqa basin).[38]

Hints for Future Policies

Supply Augmentation: Reopening the Basin. Until now, meeting the water needs of the Jordanian society, which has one of the lowest per capita domestic water consumption in the world (94 lpc/day [THKJ 2004]), has been done because of an ever-increasing development of water production and use. Diverse technical solutions were successively implemented: earth and masonry canals, dams, pumps, canalization and pressurized irrigation networks, deep wells, long distance transfers, increasing use of marginal quality water (brackish and treated wastewater) and desalination.

Today, some technical solutions allowing an increase in water supply are still available but these options have very high investment and operational costs. The epitome of these solutions is the project of transferring seawater from the Red Sea to the Dead Sea. This project should allow, in the long run, to eventually increase by one half the total available freshwater resources in Jordan and to replenish the Dead Sea with seawater. A total of 810 Mm^3/yr would be desalinated for domestic purposes but the production costs of this water (delivered to Amman) would, however, be at least five times higher than the present costs of potable water, because of the huge facilities to be built.

Because of the regional political situation, and as it has always been the case, the investments needed will probably be facilitated by international aid or funding agencies. However, the O&M costs of such facilities would certainly

[37] THKJ (2004) in this Scenario 1 presents that 230 Mm^3/yr of treated waste water will be available in 2020 in Jordan while 155 Mm^3/yr will be reused both in industry (30 Mm^3/yr) and in irrigation (125 Mm^3/yr) (the remaining being lost in transfer and storage).

[38] It is worth noting the decrease in agricultural groundwater abstraction projected in the next 20 years is very limited and does not allow a return to a sustainable rate of groundwater abstraction. For example in the Amman-Zarqa basin, the abstraction is projected to reach about 140 Mm^3/yr i.e., 207 percent of the annual recharge of this aquifer. To reduce further the present agricultural abstraction, stronger measures would have to be enforced, notably to limit the areas planted with irrigated olive trees which presently consume about 30 Mm^3/yr (for about 8,170 ha).

have to be borne by the water users and not only by the government which has already strongly subsidized the sector at the cost of an ever-increasing public deficit.

Sectoral Competition. Irrigated agriculture consumes two-thirds of the national water resources (THKJ 2004) and competes with the domestic and industrial uses, which are the priority of the government (HKJ/MWI 1997b). This competition might be more crucial for agriculture than for the M&I sector, since the latter is indeed being given priority, with an increasing part of the Yarmouk flow transferred to the highlands. The competition manifests itself not so much in terms of present allocation (since a diminution of the water used by agriculture in the valley or in the highlands would not readily increase supply to M&I uses), but rather in terms of future use. The actual overdraft of the aquifers decreases the resources potentially available for future urban use and implies that more costly alternative resources must be tapped.[39] Groundwater overuse within the basin also causes degradation of the groundwater resources both in the short term (direct pollution due to infiltration of pesticides and fertilizers as shown by JICA (2004) and in the long term (salinization of water due to a decline of water tables) and thus jeopardizes future low-cost use for domestic purposes.

Another aspect of this sectoral competition is the growing vulnerability of agriculture to climatic vagaries. As the residual water user, agriculture in the valley bears the brunt of the variability in supply, as priority is given to cities in time of drought. Compensation measures for fallowing land or in case of reduced supply need to be considered in order to avoid financial and livelihood breakdowns. This would be tantamount to recognizing a water right for the valley and would help weather the impact of reallocation.

Reorientation of Agriculture. Jordan's continued protection of its banana production, and its support to "luxurious" irrigation of olive trees with high-quality water in desert areas, incur a cost to society and may obstruct the development of alternatives crops that might yield higher aggregate benefits (e.g., date palm in the valley, which has the advantage for being a low water consumer, and relatively salt-resistant crop [Grattan 2001; McCornick et al. 2003] and highly profitable [Venot 2004c]). Moreover, the price of water remains also quite low for both agricultural and urban uses: only one-third of the O&M costs is recovered in the valley (government subsidies). Taxing the use of groundwater in the highlands might also be instrumental in reducing aquifer overdraft (Venot 2004c).

Until now, except for the public schemes in the valley, irrigated agriculture in Jordan has developed through private investments with no public subsidies, excluding the reduction of energy costs. However, public intervention is needed to partly reorient irrigated agriculture towards more socially and economically adapted productions, instead of preserving the gains of some influential social groups. This intervention could have the form of some compensation for: a) giving up the production of some fruits (olives); b) a support to modernization of irrigation and cropping techniques; c) an increase in groundwater fees; d) a suspension of protection from customs and subsidies on electricity for agricultural pumping; and e) a buy-out of wells. Such measures, however, are likely to be delayed due to sociopolitical deadlocks recurrently blocking governmental decisions. Most of the measures presented here have been considered in national policies for at least 10 years or recommended by several studies (HKJ/MWI 1997b, HKJ/MWI 1998b, 1998c, 1998d; ARD 2001; JICA 2004) but they have not yet been implemented, or only partially implemented with mixed results.

Demand Management. Raising awareness of water problems and encouraging conservation are

[39]It must be said, however, that even a drastic curtailment of groundwater use by, say, 30 Mm^3/yr would only ease the problem of urban use for a decade or so but would not radically alter the longer-term picture.

a must. Although the awareness of water problems has greatly increased within the Jordanian society in the past few years, these problems are still insufficiently comprehended by the majority of the population, which still often focuses on the consequences of the creation of the State of Israel on Jordanian water resources. These consequences are only one of the underlying factors of the Jordanian water crisis but, acting as an emotional catalyst, they hide some of the deeper internal causes, ignored or even denied by the entire society.

An issue that commonly comes along with water scarcity is that of efficiency in water use. Unaccounted for water, which includes losses by leakage, was around 50 percent and is supposed to have been reduced to around 30 percent in Amman, after network rehabilitation and better management. Demand in urban areas can also probably be partly managed with a rise in prices. Agriculture is also often designated as a wasteful user and low efficiencies of irrigation networks are reported. The following section looks at aspects of water use at the basin level by calculating the terms of the water accounting for the different periods, and concludes by a reflection on irrigation and water use efficiency. However desirable demand management may be, it is also necessary to acknowledge that its scope is too limited to provide long-term solutions to water scarcity.

Water Accounting of the LJRB: Historical Trends

The description of the transformation of the LJRB given in the preceding section can now be paralleled by a more quantitative accounting of the resulting (im)balance between supply and demand. The water-accounting exercise presented here draws on the categories of water balance proposed by Molden (1997) and summarized in appendix 2. The net inflow includes rainfall, basin transfers into the basin, and possible net overdraft of the aquifer and reservoirs. This total inflow is partly transformed through evapotranspiration of crops (irrigated, rain-fed and also natural vegetation) and water bodies, and through municipal and industrial (M&I) processes. The balance flows outside the basin (surface or underground flows): one fraction is committed to downstream use and the remaining uncommitted part is considered usable (if it can be put to use through better management of existing facilities) or not usable (e.g., uncontrollable flood flows).

These definitions are somewhat problematic when applied to the Jordan basin. If we consider the environmental flow needed to maintain the level of the Dead Sea as a “commitment,” then the basin has been having a deficit of around 540 Mm^3/yr since the early fifties (figure 11), at the time Israel diverted the Upper Jordan river and reduced it to a trickle of water. The remaining flow to the Dead Sea is mostly limited to the Yarmouk and side-wadis, resulting in a gradual and constant drop in the water level of the Dead Sea (figure 11). On such a basis, if we consider this environmental flow as one use among others the basin accounting points to an extreme overcommitment, with 540 Mm^3/yr adding to a net overdraft of approximately 32 Mm^3/yr to make up a shortfall greater than all the water used by irrigated crops in the basin. Although this does correspond to reality, considering such a shortfall would distort our water balances to the point of making them meaningless. We have chosen here to consider that there is no commitment of the waters entering the Dead Sea, which is, therefore, considered as a sink. Any freshwater or brackish water flowing into it is, therefore, considered as uncommitted nonusable water.[40]

In such conditions, the meaning of “available water” tends to lose its significance because it is equal to the water depleted, i.e., to the renewable water minus the flow to the Dead Sea. We have, therefore, chosen to use two more meaningful variables: “renewable blue water” is the sum of surface water, aquifer recharge, and imports from both groundwater (distant aquifers) and surface water (desalinated water from the Red Sea). “Controlled renewable blue water” is the “renewable blue water” from which the part of the Yarmouk water that flows undiverted to the Jordan river is deducted, as well as brackish flows from Israel to the river, both resources which are of no use and cannot be controlled (and, therefore, may or may not be disregarded).

Molden (1997) defines water depletion as a use or removal of water from a water basin that renders it unavailable for further use (the depleted fraction being the share of the water which is depleted, often expressed in percentage of the net or gross inflow). Water depletion is a key concept for water accounting, as interest is focused mostly on the productivity and the derived benefits per unit of water depleted. It is extremely important to distinguish water depletion from water diverted to a service or use, as not all water diverted to a use is depleted. Water is depleted by four generic processes (Molden 1997):

- *Evaporation*: Water is vaporized from surfaces or transpired by plants (rain-fed or irrigated).
- *Flows to sinks*: Water flows into a sea, saline groundwater, or other location where it is not readily or economically recovered for reuse.
- *Pollution*: Water quality gets degraded to an extent that it is unfit for certain uses.
- *Incorporation into a product*: Through an industrial or agricultural process, such as bottling water or incorporation of water into plant tissues.

The water accounting of the basin for the year 2000 is based on the data appearing in figure 9 and land-use data combining remote sensing data (HKJ/MWI/GTZ 2004)[41] and official statistics. Flow data for years 1950 and 1975 are those appearing in the flow charts presented earlier. For these two periods, land-use patterns have been interpolated from the 2000 data, using figures for the total cultivated area and historical descriptions of land use (notably Baker and Harza 1955; THKJ 1977; Khouri 1981; Elmusa 1994).

We first give a detailed accounting of the water flows in 2000 (current situation) and then observe historical changes in land use and in the components of the water balance.

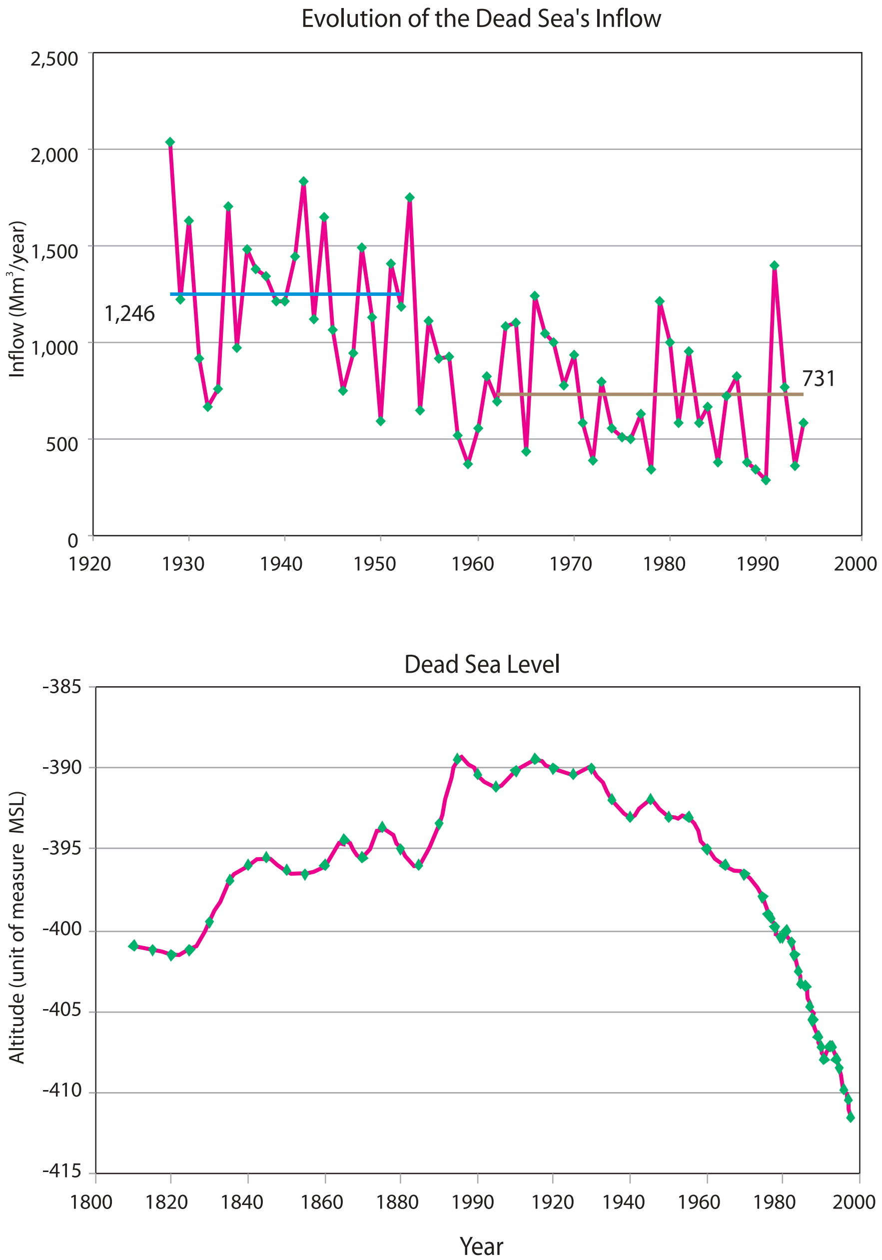
Water Accounting in 2000

Figure 12 first provides the depleted fraction (expressed in percentage of the net inflow) for each subbasin (see subbasins map in appendix 3 and the diagram of subbasins in appendix 4). We can see that, in the Jordan valley (hydrological subbasin) only half of the net inflow is depleted. This is due to the high amount of uncontrolled water since, at the moment, out of the 200 Mm^3/yr “imported” from the upper Yarmouk basin, only 90 Mm^3/yr can be controlled and diverted to the KAC, the remaining 110 Mm^3/yr flowing uncontrolled to the Dead Sea.

[40]Alternatively, one may consider this remaining outflow to be committed to environmental preservation: this does not change the calculation of the available water within the basin since we consider there is no uncommitted-usable water. Water reaching the Jordan river is of too low quality to be used.

[41]Land-use raw data are drawn from the Water Sector Planning Support Project (WSPSP, MWI/GTZ). It is the result of a GIS-analysis of two LandSat images dated August 1999 and May 2000, respectively.

FIGURE 11.
Historical evolution of the annual water inflow and level of the Dead Sea.



Source: "upper" panel from Arab Potash Company (personal communication) and "lower" panel from Harza (1998).

On the other hand, very little water flows out of the other subbasins and part of this water (especially in the Amman-Zarqa basin) is made up of return flows from cities.

Overall, the Lower Jordan basin consumes 86 percent of its net inflow (i.e., rainfall, interbasin transfers and lateral groundwater flows) through evaporation and processes. We can further distinguish as follows:

- *Beneficial depletion* refers to evapotranspiration from both irrigation and rain-fed agriculture as well as M&I uses.

- *Low-beneficial depletion* refers to evaporation from natural vegetation and forest.

- *Non-beneficial depletion* refers to evaporation from bare land, deserts, and water bodies.

In the LJRB the beneficial depleted fraction accounts for 22 percent of the net inflow, the low beneficial depleted fraction for 6 percent, and the non-beneficial depleted fraction for the remaining 59 percent.

Figure 13 shows these three categories (beneficial, low-beneficial and non-beneficial fractions) in more detail and in relative terms (% of the total depleted fraction). It illustrates that beneficial depletion (corresponding to the sum of the four "'process" fractions) is higher in the valley where it reaches approximately 76 percent of the total depleted fraction, and lower in the Zarqa basin where it only represents 31 percent of the total depleted fraction, while the non-beneficial evaporation/use (bare land and water bodies) is highest because of its large desert area. The low-beneficial depleted fraction corresponds to forests and grasslands mostly grazed by sheep and is highest in the mountain area (north and south-wadis basins).

With the exception of the valley, where it amounts to 63 percent of the total depleted fraction (cf., figure 13), the share of the irrigation process (crop ET, irrigated), which stands for water depletion in irrigated agriculture, remains limited (7, 7, 9 and 14%, respectively, of the total depleted fraction in the north wadis, south wadis, Yarmouk and Amman-Zarqa basins). On the entire Lower Jordan river basin, irrigation process accounts for 18 percent of the total depleted fraction.

Finally, over 40 percent of the rainfall which is depleted in the basin is lost with no benefit whatsoever (mainly through evaporation of bare land).

The figure also shows that despite all the allocation conflicts between the cities and agriculture, the share of M&I uses[42] (process drinking and process industry on figure 13) is negligible, representing only 3 percent of the total depleted fraction in the LJRB, but rises to 14 percent when compared with irrigation depletion.

The importance of irrigation is better demonstrated by figure 14. The depleted fraction in irrigated agriculture makes up 45 percent of the "beneficial" depleted fraction, on the entire LJRB that is, irrigation almost equates rain-fed agriculture although irrigated areas are three times smaller than rain-fed ones (cf., figure 15).

Irrigation depletion is particularly high in the Jordan valley subbasin where it reaches 84 percent of the beneficial depleted fraction.

In terms of fraction of the net inflow, however, the share of the irrigation fraction drops down to 15 percent basin-wide (but remains very high in the valley at 28%), due to the significance of the low-beneficial and non-beneficial depletion.

Evolution of the Terms of the Water Balance in the LJRB

From a situation in the 1950s when few of the surface water and groundwater resources were put into use, to the current situation of overexploitation, the terms of the water balance have presumably varied from one extreme to the other and the examination of these changes is likely to be very instructive.

Changes in Land Use

The first notable evolution is that of land use. Irrigated areas increased from around 10,200 hectares in 1950 to 24,900 hectares in 1975, and to 45,800 hectares at present (cf., figure 15), including both schemes in the valley and groundwater-based agriculture in the highlands. This total area is projected to decrease by

[42]The depleted fraction in M&I uses is taken as 30 percent. This is higher than values corresponding to industrial and human consumption but includes the depleted fraction of outdoor uses such as city gardens, car wash, etc.

FIGURE 12.
Percentage of the net inflow depleted (i.e., depleted fraction) on the Lower Jordan basin and subbasins, base year 2000).

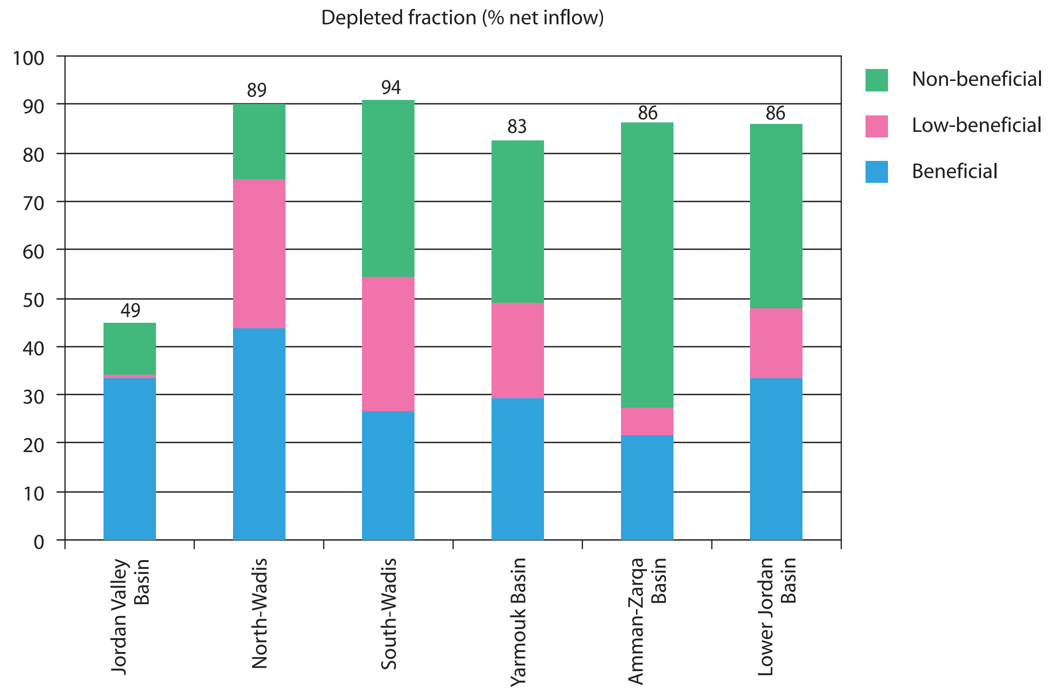


FIGURE 13.
Categories of depleted fractions (Lower Jordan basin and subbasins, base year 2000).

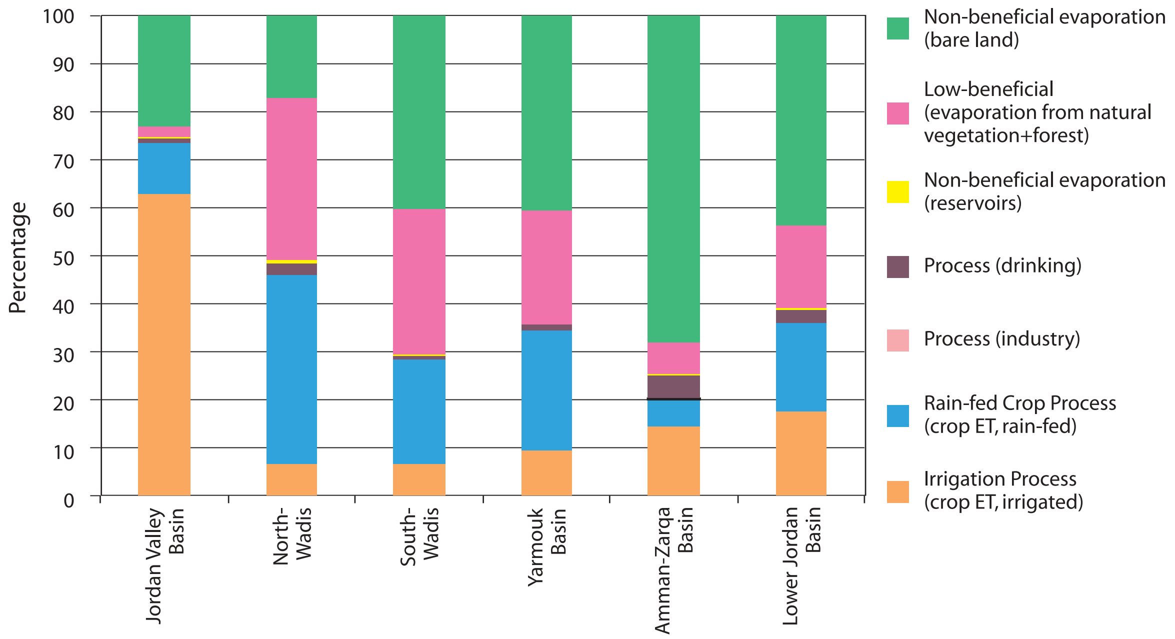
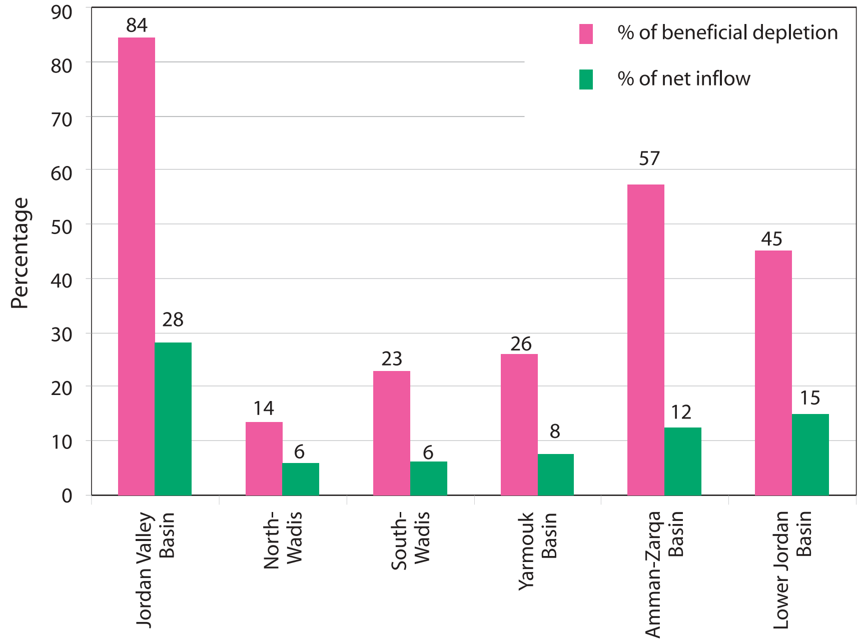
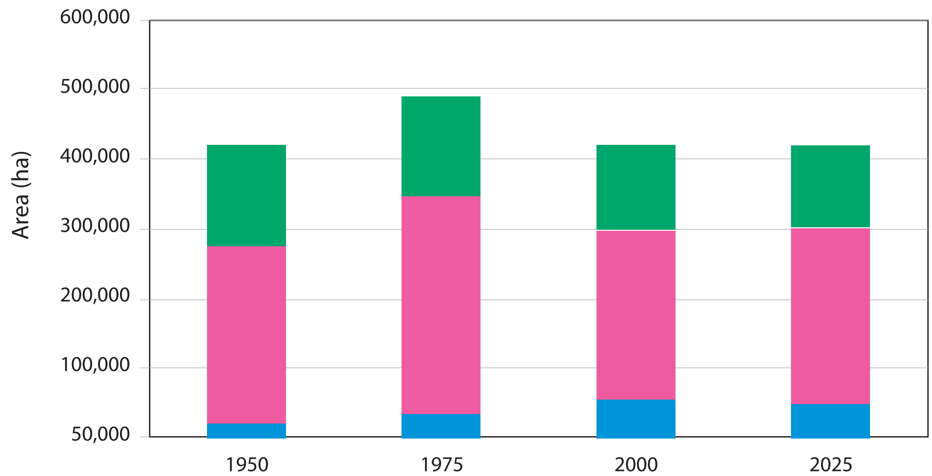


FIGURE 14.
Water depleted in irrigation (irrigation fraction) in each subbasin, as percentage of beneficial depletion and net inflow.



about 10 percent in the next quarter century and to reach about 41,400 hectares: a relatively limited decline due to a decrease of irrigated agriculture in the highlands, partly counterbalanced by an increase in the Jordan valley.

Rain-fed cropping areas have significantly increased in the 1950–1975 period (from 108,000



	1950	1975	2000	2025
Natural vegetation (ha)	145,398	118,847	114,182	122,864
Rain-fed crops area (ha)	271,209	334,924	260,577	269,259
Irrigated area (ha)	10,250	24,902	45,812	37,389

to 165,000 ha), with cereals providing work and food to a growing population. This extensive type of agriculture later declined, with a shift in the economy towards nonagricultural activities. The natural vegetation (forests and grasslands) contracted and expanded in line with these changes. It decreased from 155,000 hectares to 109,000 hectares between 1950 and 1975 because of the large expansion of rain-fed agriculture, and later increased by about 5,000 hectares, and is expected to further increase (to about 123,000 ha), following a decrease in the irrigated area in the highlands.

Figure 16 shows the evolution of the cropped area between 1950 and 2025 and differentiates between the Jordan valley and the highlands (defined as the sum of the four subbasins that are the north wadis, the south wadis, the Yarmouk and the Amman-Zarqa basins).

The figure highlights the structural differences existing between the Jordan valley and the highlands. Cropped areas are much larger in the highlands (total area of 143,900 ha) than in the Jordan valley (total of 32,300 ha) which reflects the large areas of rain-fed cereals and olive trees planted in the highlands (total of 121,100 ha).

In the valley, irrigated crops have always constituted a large share of the total cropped area. From 1950s onward, irrigated areas have continuously increased from 9,300 hectares in 1950 (31% of the total cropped area) to 16,100 hectares in 1975 (56% of the total cropped area), and to 22,970 hectares at present (71% of the total cropped area), with projections for the year 2025 at 27,300 hectares (75% of the total cropped area). At the same time, rain-fed areas (limited to cereals) have continuously decreased (21,000, 12,700 and 9,300 ha in 1950, 1975 and 2000, respectively). This last figure is projected to remain unchanged by the year 2025.

In the highlands, rain-fed areas (both cereals and olive trees) are predominant and mainly located near the side-wadi basins. We can see from figure 16 that areas with cereals strongly increased between 1950 and 1975 and then decreased during the last 25 years, while rain-fed olive trees (mainly located in the north side-wadis and south-side wadi basin as well as along the wadi Zarqa) increased significantly between 1975 and 2000 (from 16,900 to 49,300 ha).

Irrigated areas are now comparable to those in the valley (22,800 ha in 2000) but their expansion occurred in the early 1980s, much later than in the valley. Moreover, they only represent now 16 percent of the total cropped area (against 1% and 5.5% in 1950 and 1975, respectively). In our projections we considered that irrigated areas in the highlands will decrease by 38 percent within the next 20 years, both in absolute (to 14,200 ha) and in relative terms (to 10.5%), while rain-fed areas will remain stable at about 121,100 hectares.

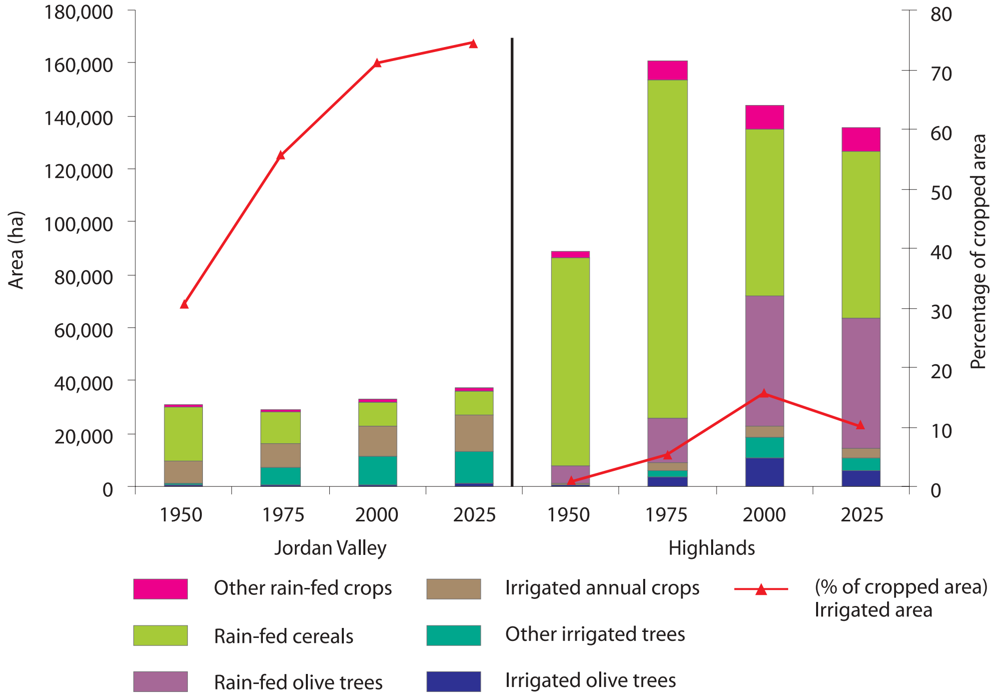
Figure 16 clearly shows the importance of irrigated orchards in the highlands and their dramatic increase: irrigated olive trees increased from 420 hectares in 1950 to 3,900 hectares in 1975, and it has reached about 11,000 hectares as at present, i.e., almost half of the irrigated areas in the highlands (the other half consists of vegetables and stone fruit trees), of which 8,170 hectares are located in the midst of the desert (Venot 2004b).

Evolution of the Water Balance in the LJRB

The net inflow into the basin moved from over 3,300 Mm^3/yr in 1950 to around 2,600 Mm^3/yr in the following periods, because of the diversion of the Jordan river by Israel and growing abstraction of the water of the Yarmouk river by Syria.[43] Deducting rainfall water directly evaporated from crops and bare soil, Figure 17 focuses on the renewable blue water and shows a similar drop by 50 percent, with a slump at 671 Mm^3 in 2000 and a subsequent increase by 23 percent projected for 2025, because of water imports. The

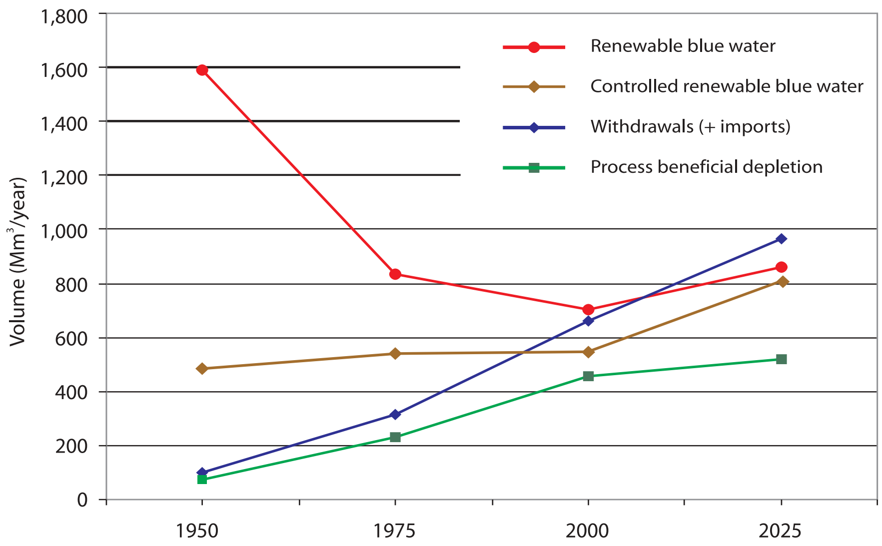
[43]The net inflow appears stable between 2000 and 2025: The increase in imported water is compensated by less groundwater use and losses in the Wehdah dam.

FIGURE 16.
Crop- and region-wise evolution of cropped area in the LJRB.



controlled renewable blue water (CRBW) is significantly lower, since uncontrolled and/or brackish flows from the Yarmouk or Israel are discounted. The expected increase in 2025 mirrors the imports and the larger share of the Yarmouk diverted by the Wehdah dam. Strikingly, withdrawals (gross diversions of surface water plus abstracted groundwater) now amount to 127 percent of CRBW (i.e., 660 Mm^3/yr) because of groundwater overabstraction and multiple diversions (return flows from wadi-irrigation or from Amman are reused downstream).

FIGURE 17.
Evolution of net inflow and available water in the Jordanian part of the LJRB.



Withdrawals have continuously and dramatically increased in the last 50 years: they were at 101 Mm^3/yr in 1950 (20 percent of the CRBW), at 314 Mm^3/yr in 1975 (58 percent of the CRBW), and at 660 Mm^3/yr in 2000. They are expected to reach 970 Mm^3/yr in 2025. In 2000, only 315 Mm^3/yr ends into the Dead Sea and this amount decreases to 165 Mm^3/yr if we do not consider the (still uncontrolled) flow from the Yarmouk and from Israel to the Jordan valley.

The figure also shows the evolution of the process beneficial depleted fraction (in irrigated and rain-fed agriculture, and in M&I), which almost equates CRBW in 2000 (effective rainfall and aquifer overdraft are coincidently close to the nonconsumed part of CRBW) and levels off in 2025 (increase in M&I compensated by a decrease in highland irrigation).

Aquifers began to be overexploited during the last quarter of the century (the groundwater budget still presented a positive balance of 51 Mm^3/yr in 1975), the situation being now worrying since the overdraft reaches 32 Mm^3/yr. A net positive balance of 83 Mm^3/yr on the entire LJRB in Jordan is expected to be reached during the next quarter of the century (with the assumption of 30% decrease in highland agriculture, and an increase in the return flows associated with the use of water imported from other basins [including the Red-Dead project]).

The evolution of the depleted fraction, distributed over three categories (process/ beneficial, low-beneficial, and non-beneficial depletion), is given in figure 17. It can be seen that the biggest change occurred in the 1950–1975 period, when the total beneficial depletion increased dramatically from 391 to 756 Mm^3/yr (or from 21% to 37% of the total depleted fraction). This happened when cropped areas increased and when the net inflow was curtailed by the diversion of the Upper Jordan river by Israel. This trend continued in the last quarter of the century and took the beneficial depleted fraction to 39 percent of total depletion (867 Mm^3/yr) (partly due to the overexploitation of aquifers). At the same time, the depleted fraction (expressed in percentage of the net inflow) increased from 58 percent to 86 percent and will continue to increase up to 92 percent in the next 25 years.

Figure 18 also illustrates that the non-beneficial depleted fraction stayed (and will remain) roughly constant since 1950, while its relative share continuously decreased because of the expansion of the cropped area (both rain-fed and irrigated) contributing to the beneficial depleted fraction.

Figure 19 zeroes in on the irrigation fraction, i.e., the percentage of water depleted in irrigated agriculture as a percentage of the total beneficial depletion and of the net inflow. It indicates a quite dramatic increase from 2 percent of the net inflow in 1950 to around 18 percent at present (making up 45% of the beneficial depleted fraction). Again, these figures are expected to decline, under the assumption that highland irrigated agriculture is to be reduced and that more water is imported for cities. It is interesting to note that the shares of both the valley and the highlands in the irrigation depletion fraction are almost identical (not shown). This is due to comparable irrigated areas in these two regions of the basin.

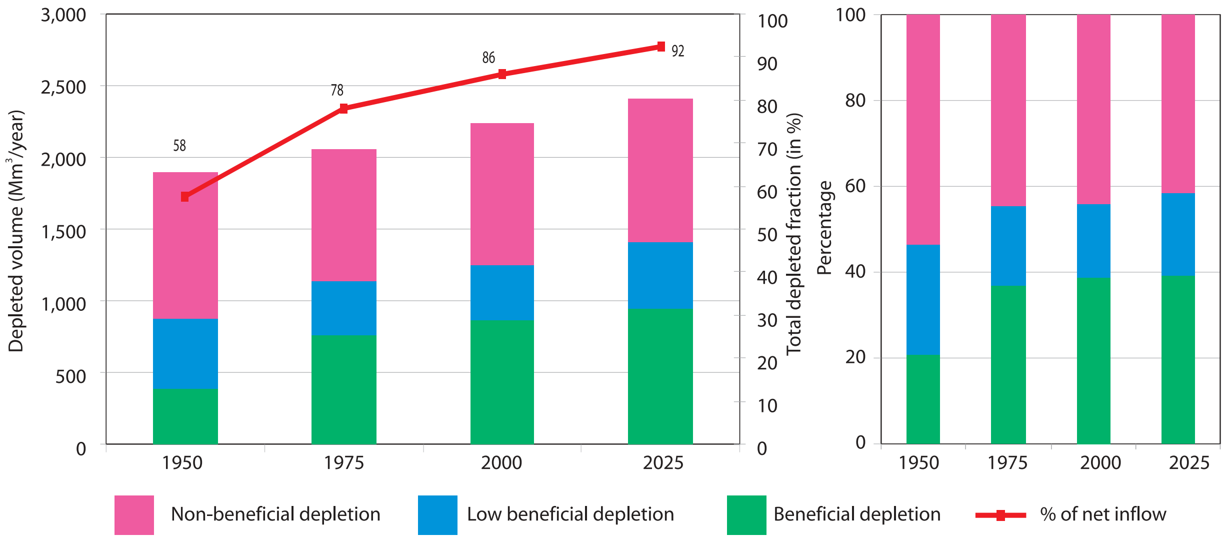
Table 1 provides details of all the terms of the water accounting for the whole LJRB as well as for its five subbasins.[44] Appendix 3 also

[44]It has been hypothesized that the Mukheibeh wells, located in the Yarmouk basin and used to supply the KAC with some 20 Mm^3/yr of additional freshwater (it is expected that this water will be used for drinking purposes in 2025), abstract water from the Yarmouk aquifer. Following Salameh (1990) and Salameh and Bannayan (1993), we have computed a groundwater flow of 25 Mm^3/yr from the Yarmouk aquifer to the north side-wadi basin. As a result, the balance of the Yarmouk aquifer shows a substantial overdraft (-13 Mm^3/yr) while, on the contrary, the aquifers of the side-wadis show a yearly net gain of 22 Mm^3/yr (in the north side-wadis).

Note: All data refer to the situation *circa* 2000. Figures for inflows, outflows and different indicators of water depletion are given in Mm^3/yr; fractions are given as percentages. Data are based on the chart presented in figure 19 and are drawn from a comprehensive list of figures presented in appendix 6. All numbers have been rounded.

Most of the numbers given for subbasins are summed up to obtain the figure corresponding to the entire LJRB. However, transfers between subbasins do not add up at the basin level because some of the transfers are internal to the basin. Water is moved from one reservoir to another without affecting the global water balance of the basin.

FIGURE 18.
Evolution of depleted fractions in the LJRB (nominal values and percentage).



provides a flow chart for each of the subbasins, indicating the rainfall, ET fraction, groundwater net balance, imports and exports for the year 2000, while appendix 6 shows the terms of the water balance for each subbasin.

Note on Water Use Efficiency

These basin-level figures prompt some reflections on the question of efficiency in water use. Groundwater-based irrigation efficiency in the

FIGURE 19.
Changes in the fraction of water depleted in irrigation (irrigation fraction) expressed as a percentage of beneficial depletion and available water.

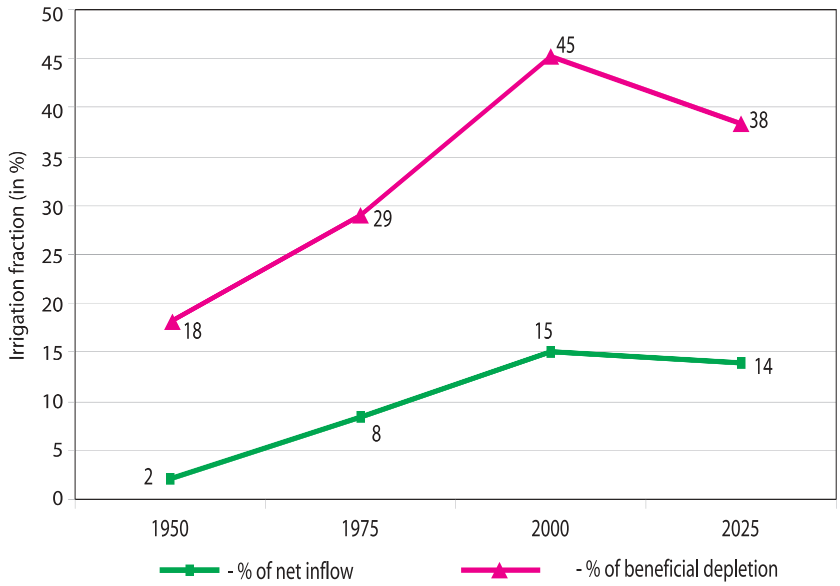


TABLE 1.
Details of water accounting for the Jordan river basin and each subbasin.

		Jordan Valley Basin	North-Wadis	South-Wadis	Yarmouk Basin	Amman-Zarqa Basin	LowerJordan Basin
Inflow	Direct rainfall	190	460	253	530	801	2,235
	Import/inflow from other basins	477	17	0	9	75	310
	Lateral groundwater flows	0	25	0	0	28	28
	Gross inflow	667	502	253	539	904	2,573
	Storage change Reservoirs	0	0	0	0	0	0
	Soil (groundwater depletion)	0	22	–0.1	–12.5	–41	–32
	Net inflow	667	481	254	552	944	2,605
Depletion Beneficial	Irrigation Process (crop ET, irrigated)	188	29	15	42	117	391
	Rain-fed crop Process (crop ET, rain-fed)	32	170	50	114	46	413
	Process (industry)	0	0	0	0.2	2	2
	Process (drinking)	3	11	2	5	40	61
	Non-beneficial evaporation (reservoirs)	1	2	0.2	0	2	5
	Non-beneficial evaporation (bare land)	69	74	93	185	557	978
	Low-beneficial (evap., from nat.veg+forest)	6	147	70	108	53	385
	Total depleted	299	434	231	455	816	2,235
Outflow	Committed water	0	17	18	52	13	0
	Non-committed water (usable)	0	0	0	0	0	0
	Non-committed water (nonusable)	318	30	5	0	35	318
	Export to other basins	50	0	0	45	80	52
	Total outflow	368	47	23	97	128	370
Renewable blue water (RBW)							705
Controlled renewable blue water (CRBW)							545
Aquifer net overdraft		0	22	0	–13	–41	–32
Indicators	Depleted fraction percentage of net inflow	45	90	91	82	86	86
	Process fraction percentage of net inflow	33	44	27	29	22	33
	Process fraction percentage of depleted water	74	48	29	36	25	39
	Low-beneficial depletion (non-process) percentage of net inflow	1	31	28	20	6	15
	Low-beneficial depletion (non-process) percentage of depleted water	2	34	30	24	7	17
	Non-beneficial depletion (non-process) percentage of net inflow	11	16	37	33	59	38
	Non-beneficial depletion (non-process) percentage of depleted water	23	18	40	41	68	44
	Irrigation Process (crop ET irrigated) percentage of beneficial depletion	84	14	23	26	57	45
	Irrigation Process (crop ET irrigated) percentage of depleted water	63	7	7	9	14	18
	Irrigation Process (crop ET irrigated) percentage of net inflow	28	6	6	8	12	15

Note: Unit of measure is Million m^3

highlands has increased in the last two decades, with an almost complete shift from surface water irrigation to micro-irrigation (Elmusa 1994; THKJ 2004). This, in many cases, has allowed the discharge obtained from each well to be "spread" over a larger area (Venot 2004c), bringing more benefit to the farmer but resulting also in more evapotranspiration and less return flow to the aquifer, thus compounding the net overdraft. As mentioned earlier, there is evidence that percolation losses from irrigation in the highlands return to the aquifer and are, therefore, not significant in terms of net water balance or savings. (Secondary benefits from improved efficiency come from reduced pumping costs.) Areas irrigated by diversion of wadis along the main valleys also have high efficiencies because return flows are quickly reintegrated to the main stream.

In the valley, the shift to micro-irrigation owes more to the intensification of agriculture than to water scarcity per se since it started 20 years before talks of a water crisis emerged. Cultivation of vegetables under plastic mulch that controls weeds competing with vegetables makes micro-irrigation necessary and also allows better application of water and "fertigation." Other more extensive crops (notably citrus) as well as part of the banana crop are still irrigated by gravity but the defined JVA-quotas[45] keep application losses to a minimum since quotas are less than full crop requirements. In the long term, adoption of micro-irrigation in the valley is beneficial because it allows a reduction of allotments and because the return flow is little used: surface runoff quickly flows to the Jordan river, where it mixes with brackish water and is not diverted further downstream; part of the percolation losses is drained by the Jordan river and the main part replenishes the Jordan valley aquifer but the use of this aquifer is limited since only the upper part of this aquifer is not too brackish and can be used for non-salt-sensitive crops (also note cases of desalination for banana cultivation in the southern part of the valley). Therefore, gains in efficiency are desirable when they limit runoff to the Jordan river, but with a possible impact on downstream groundwater users.

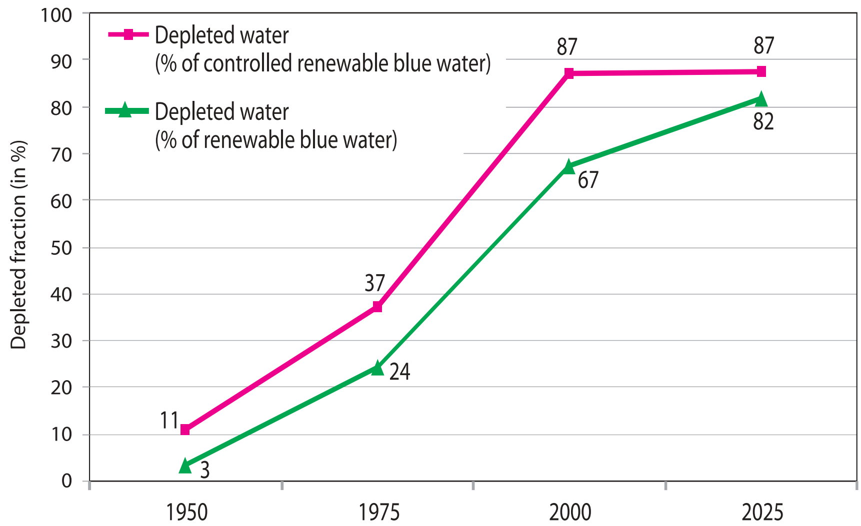
However, water use efficiency at the plot level is already rather high (it is generally taken at 80% for drip irrigation; see THKJ 2004) and possible on-farm savings are, therefore, limited. More significant gains will be realized at the basin level when the Wehdah dam will allow managers to control water in the Yarmouk and distribute it throughout the year according to real requirements. Even this benefit is partly unclear because the current benefits of excess water availability in KAC (in months when flows in the Yarmouk are abundant) in terms of salt lixiviation are not well known and might be understated (McCornick et al. 2001).

Appendix 7 provides additional water accounting indicators which allow us to evaluate the overall efficiency of water use in the basin, considered as a system. This efficiency has continuously increased since the depleted fraction expressed both in percentage of RBW (3% in 1950; 24% in 1975; 67% in 2000) or in percentage of the CRBW (11% in 1950; 37% in 1975; and 87% in 2000) has sharply increased. These efficiencies are expected to further increase to 82 percent and 87 percent, respectively, by 2025 (figure 20).

This underlines the fact that the LJRB is a closed river basin, where almost no water resource is left to be mobilized and used. It is noteworthy that the process of closure has been very rapid since the development of the basin dates back only to the early 1950s and is fast approaching completion. With the caveat regarding our earlier assumption on environmental flows, the basin efficiency stands around 90 percent at present.

[45]5,110 m^3/ha/year for vegetables, 9,990 m^3/ha/year for citrus, and 13,200 m^3/ha/year for bananas (according to the new rules of the JVA Water Resources Department [see Venot 2004]) to which must be added some extra amounts from private water sources (wells), community water sources (wadis), and exceptional supply requested from the JVA. However, these quotas are defined in terms of mm/day and are both constraining in some months and not fully used in others (Petitguyot 2003).

FIGURE 20.
Basin management efficiency.



In other words, there are very few prospects to alleviate the Jordanian water crisis by technical improvement aiming at increasing water use efficiency since overall, at the basin scale, this efficiency (volume of depleted water expressed in percentage of the volume of water withdrawals) already reaches 72 percent. This does not mean that saving water through improved fine-tuning of irrigation supply in the valley or through water-saving technology does not need to be considered, but it does set a drastic limit to what can be achieved through conservation means.

Refining Water-Use Categories

A limitation of the water accounting is that the water use (withdrawals) category pools together four different kind of water sources that are groundwater, surface water (controlled by dams), stream water (uncontrolled flows that are diverted), and efficient rainfall (used by irrigated and rain-fed crops)—(Molle 2003). These categories of water are not equivalent because the degree of control we have on these four resources varies highly (in decreasing order in the above list).

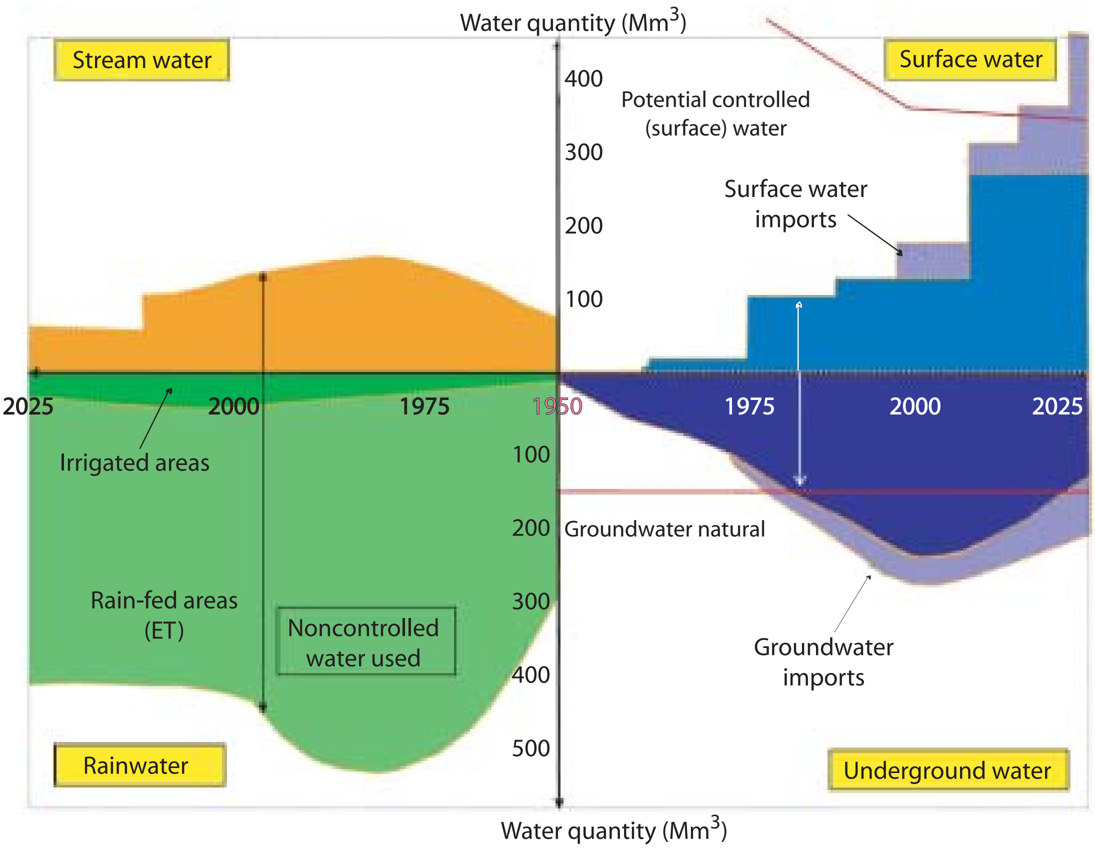
It is, therefore, instructive to disaggregate water use into these four categories and to plot these fractions against time. By so doing, we obtain a view of both their relative importance and time dynamics, as illustrated in figure 21.

Figure 21 first shows that rainfall on rain-fed crops constitutes the major category of beneficial water, even in such arid conditions.[46] It is due to the large extent of rain-fed crops within the basin (cf., figure 15). It is also striking that groundwater use (gross abstraction) in the LJRB now appears as a source of greater magnitude than (controlled) gross diversions of surface water (275 Mm^3/yr against 120 Mm^3/yr in 2000), although this will be reversed when the Red-Dead project is in operation.

Surface water follows the construction of the dams, while stream water includes side-wadis and Yarmouk diversions: this term increased with the construction of the KAC (supplied by water diverted from the Yarmouk) but decreases as dam construction shifts water from the stream water category to the surface water category.

[46]While all other three quadrants show gross withdrawal values, the rainfall quadrant shows the fraction used by the plants only. If we consider total direct rainfall the difference would be even more considerable (for example, 912 Mm^3 in 2000).

FIGURE 21.
Four-quadrant diagram presenting water withdrawal trends in the LJRB from 1950 to 2025 according to several water "categories."



The total natural recharge of the aquifers (158 Mm^3/yr for the LJRB, as evaluated by THKJ [2004]) is indicated in the "groundwater quadrant." The notion of safe yield as the level of abstraction that does not impact on existing users or ecological sustainability is very fuzzy. In general, water pumped from the aquifer incurs both a "de-stockage" of the aquifer itself and a reduction in the base-flow and spring discharge. Current hydrogeological knowledge does not allow us to establish an accurate balance of all these flows, all the more because both recharge and abstraction fluctuate in time. While abstraction is often compared to natural recharge (or some value of safe yield), recharge by return flows of urban and agricultural uses is often not considered despite their magnitude.

The total return flow through percolation of groundwater use in the LJRB is currently estimated at 89 Mm^3/yr[47] against 153 Mm^3/yr[48] for the natural recharge (calculated as direct recharge by rainfall plus possible lateral flow minus base-flow) and will reach 168 Mm^3/yr in 2025 compared with a total expected abstraction of 237 Mm^3/yr pointing to the fact that it is imperative to take such flows into account, although more

[47]This figure is an evaluation of the authors assuming that agricultural irrigation efficiency is about 80 percent (figure largely used in the literature: Al-Weshah 2000; ARD 2001; THKJ 2004), and that the efficiency of urban water supply reaches 70 percent (Abu-Shams 2003; Decker 2004) and will increase to 80 percent by the year 2025.

[48]It is worth noting that the annual recharge considered here is lower than the one presented in the THKJ 2004 by about 39 Mm^3/yr. Estimates of overabstraction will therefore be higher than in THKJ 2004.

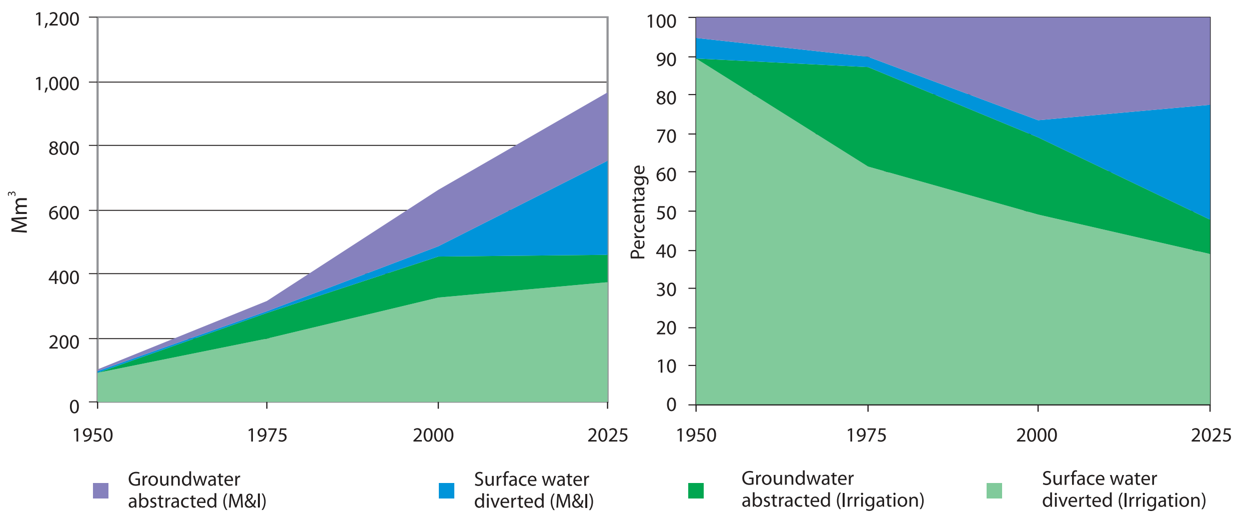
information on their dynamics is needed.[49] Not taking into account such return flows leads to evaluating of current abstraction at 180 percent, against 119 percent in the opposite case. The difference is even sharper for the projections for the year 2025 when expected net abstraction will only represent 45 percent of the overall groundwater recharge, but 155 percent if we disregard return flows (cf., appendix 8).

This shows how numbers can vary depending on the hypotheses made and how they may support very contrasting conclusions and lead to different policies. We underline here that the increase in water use allowed by interbasin transfers of freshwater and pumping from the KAC could, by the way of their return flows, counterbalance the present overabstraction of the aquifers, at least locally.[50] The impact of water imports on groundwater recharge is crucial but often overlooked. This conclusion must, however, be considered very carefully: more studies on the characteristics of both the aquifers and return flows from different uses are needed to develop an accurate groundwater budget and to refine quantitative assessments. It must also be emphasized that the figures on net abstraction highly depend on the evaluation of the annual recharge.

It is useful to emphasize that the four categories distinguished in figure 21 are not, and cannot be, "waterproof," in the sense that some pumped groundwater, for example, can return to the aquifer, make its way to the river as base-flow, be stored and/or diverted again to other uses. The interconnectedness of the hydrological regime and the reuse of some fraction of water flows make it impossible to disaggregate water flows and stocks into fully independent categories.

The concomitant decrease of inflow (due to upstream diversions by Israel and Syria), later partly compensated for by imports from other

FIGURE 22.
Evolution of sectoral water use (nominal values and percentage).



[49]Return flow from cities (leakage, percolation from outdoor uses and sewers, etc.) and agriculture (now reduced because of the generalization of micro-irrigation) are not well known. It is possible that some fraction is taken up by evapotranspiration (capillarity and phreatophytes) but studies on water quality identifying a high level of nitrates near agricultural wells (JICA 2001) point to a significant return flow to the aquifer. The time lag for the transfer from the surface to the aquifer is also not well known.

[50]A limitation of our approach is that water budgets are done at the subbasin level. High groundwater return flows in the Amman region may not replenish the aquifer uniformly. Moreover, there is also a question of water quality, since return flows replenishing aquifers will be of lower quality.

basins, and increase in total withdrawals have reduced the nondiverted fraction of “stream water” to almost nil: from 1,335 Mm^3/yr in 1950 to 489 Mm^3/yr in 1975 and to 252 Mm^3/yr at present; the projected value for 2025 is 163 Mm^3/yr. This is once again, an illustration of the rapid closure of the Jordan river basin in the last 50 years. Very little water remains unmobilized and the basin can hardly be developed further without interbasin transfers that will play a major role in the future.

Sectoral Water Use

We may also investigate the evolution of sectoral water use over the last 50 years. Figure 22 provides a striking representation of how agricultural withdrawals (gross river diversions plus groundwater abstraction) have leveled off since the mid-1970s. In contrast, M&I withdrawals reached 31 percent in 2000 and are expected to go up to 52 percent in 2025. This evolution will reproduce something similar to that what is observed in Israel, where agricultural water use remains, by and large, stable but increasingly relies on treated wastewater, while M&I uses benefit from increases in supply and eventually supersede agriculture. The share of groundwater in M&I is dominant but this situation will also be inverted with the supply of the Red-Dead project.

Table 2 indicates how these withdrawals relate to population change, with the annual growth between 2000 and 2025 being computed at 2.8 percent per year. With industrial withdrawals estimated at 37 and 80 Mm^3 in 2000 and 2025, respectively, for the entire Jordan, municipal per capita daily endowments were at 127 l/capita/day in 2000[51] and will rise up to 184 l/capita/day in 2025, due to an increase in supply through imported water. These values are slightly higher than those considered in the 2004 Master Plan (THKJ 2004). Low values for 1950 and 1975 indicate the higher weight of rural areas and perhaps improper knowledge and computing of M&I diversions at the time.

TABLE 2.
Evolution of per-capita withdrawals in the LJRB.

Year	1950	1975	2000	2025
Population (1,000)	498	1,539	4,283	7,261
Irrigation withdrawals (Mm^3/yr)	90	275	445	485
M&I withdrawals (Mm^3/yr)	10.5	41	205	507
Per capita total withdrawals (m^3/yr)	202	205	152	137
Per capita M&I withdrawals (m^3/yr)	21	27	48	70
Per capita M&I withdrawals (l/c/day)	58	73	131	191
Per capita municipal withdrawals (l/c/day)			127	184

[51]This value corresponds to the whole Lower Jordan basin and is lower than the average for Amman (115 l/capita/day).

Conclusion

This report illustrates the gradual "anthropogenization" and "complexification" of a river basin over a time span of 50 years. It describes a quite striking transformation from a situation around 1950, when only 10,000 hectares were irrigated, groundwater was untapped and abundant water flowed to the Dead Sea, to the current situation when nearly all surface resources are tapped and committed and groundwater is being severely overexploited. Both the valley and the highlands, on the one hand, and agriculture and cities, on the other, are interconnected and interdependent. This interdependence manifests itself in terms of water quantity and also more and more in terms of water quality. For example, freshwater is pumped in the highlands and from distant aquifers to supply the city of Amman, which depletes some fraction but returns the bulk of it as wastewater, although of reduced quality. This wastewater is treated and sent to the irrigation schemes in the valley; drainage water has a higher salt content and eventually reaches the Dead Sea. This path, from highland aquifers to the Dead Sea illustrates the growing difficulties in terms of sustainability, water quality and allocation.

The quantitative analysis of historical evolutions has shown that most of the water accounting indices varied sharply between 1950 and 1975, on account of both a growth in rain-fed and irrigated agriculture, and the quasi interruption of the flows coming from the upper Jordan. In the following 25 years, water use became unsustainable because of an overdraft of the aquifers (and concomitant reduction of the flow in the Yarmouk, diverted upstream by Syria). At present, circa 2000, while around 2,600 Mm^3/yr of surface water and rainfall water enter the basin on average, only 317 Mm^3/yr reach the Dead Sea. The balance is depleted, 18 percent of it in irrigated fields, 18 percent in rain-fed areas, and 3 percent in M&I uses, while the rest is evaporated by natural vegetation and bare lands. However, if we restrict ourselves to the renewable blue water (i.e., surface runoff and groundwater annual recharge), 67 percent of this volume appears to be depleted through beneficial use and this percentage springs up to 87 percent if we disregard the uncontrolled flow of the Yarmouk to the Jordan valley. This clearly illustrates the continuing process of water mobilization and consumption registered in the Jordan river basin during the last 50 years. At present the basin is closed, as almost all the water is mobilized and depleted. Because of the reuse of water and of current groundwater overdraft, withdrawals amount to 127 percent of controllable blue water.

It is also important to note that these high percentages of controlled and depleted volumes are obtained although we made the drastic assumption that flows to the Dead Sea were uncommitted (and non-usable). By considering the Dead Sea as a sink we have ignored the massive environmental and economic costs resulting from the continuous drawdown of its water level. The justifications in terms of culture, religion or tourism industry conjured up to justify the investment in the Red-Dead project, and give a measure of what these costs might be. It is thus necessary to recall that the closure of the Jordan basin is described here in a context where environmental considerations have de facto be written off as a result of the diversion of the upper Jordan by Israel.

Shifting patterns of water use have also reflected changes in the wider economy. Extensive rain-fed agriculture in the highlands increased before the mid-1970s as a necessity to provide food and work to a population swollen by the migration of refugees, but later declined with the change in the economy and the growth of cities. The most intensive part of the agriculture sector developed mainly during the 1970s and 1980s (cultivation of vegetables and fruits, first in the valley and then in the highlands, mostly for export). It is now affected by the increasing use of wastewater but above all by changes in relative competitiveness with regard to other regional producers, by changes in market prices, and by wider regional geo-politics: population growth is also linked to the wider political situation in the Middle East and strongly influences pressure on water resources. It is likely, however, that this intensive agriculture will remain stable, even if it sees its water supply reduced in quantity and quality.

The study has identified two “anomalies” in the agricultural sector. Citrus orchards in the valley and olive trees in the highlands are conspicuous by their low profitability and water productivity. They fit the strategies of urban absentee owners who are interested by the social prestige or the culturally positive image attached to agriculture (and by shady gardens in the countryside to spend their weekends) rather than by direct profit (Lavergne 1996). Both these crops consume high-quality water which could be used for cities. The irrigated area in the highland is now controlled but its reduction remains an important policy objective, since local aquifers are critically overexploited. Banana cultivation in the valley owes its record profitability to custom duties on imports rather than to its intrinsic value, and it also incurs an economic cost to society.

These anomalies notwithstanding, it must be acknowledged that the Wehdah dam will bring controlled blue water resources at the level of 94 percent of the total blue water, that irrigation efficiency has now been drastically improved through micro-irrigation, that percolation losses in highland agriculture largely return to the aquifer, and that consequently the scope for water savings both at the local and basin levels is much reduced. Although control of leakage in the Amman water supply network and further efficiency gains in the valley are desirable, they will not radically alter the fact that a ceiling has been reached and that demand-management options may only alleviate the actual situation without providing long-term solutions. That prevailing mid- and long-term solutions are eventually typical capital- and technology-intensive supply augmentation projects, namely large-scale interbasin transfers and desalination, may therefore not be only the sign of a lasting dominance of the engineering approach. This may also partly explain why calls for demand management have been only partially incorporated or implemented, the opposition from vested interest groups only contributes in raising the political costs of policy options that provide only limited potential. The reallocation of water to the M&I sector (ultimately, the valley is expected to mostly receive and use treated wastewater) and the subsequent reopening of the basin through water transfers and desalination is also observed in Israel and might signal a wider evolution of arid countries.

Appendix 1

Sources of Water Accounting

Shemas	Data Issue	Data	Source
		Figure	* indicates figures chosen in our charts and round off to 5 Mm^3/year
Hydrology	Surface Waters		
	Upper Jordan flow into lake Tiberius	840	Goffen and Gal. 1992.
		900	Soffer. 1994a.
		870	Klein, M. 1998.
		890*	Internet: http://www.unu.edu/unupress/unupbooks/80858e/
			80858E06.htm
	Evaporation in lake Tiberius	283*	Klein, M. 1998.
		210	GTZ. 1998.
		270	Internet: http://www.unu.edu/unupress/unupbooks/80858e/
			80858E06.htm
	Natural outflow of lake Tiberius	605*	El-Nasser, H. 1988.; Salameh, E.; Bannayan, H. 1993.
		590	Klein, M. 1998.
		600	Beaumont, P. 1997.
	Yarmouk river natural average flow (all tributaries)	455	Al-Jayyousi, O. 2001.
	Variability of the evaluations we are presenting for the		
	Yarmouk river flow are mainly linked to the period during	438	Khori, R. 1981.
	when the measurements have been done. We can	480	Hof, F. C. 1998.
	observe the figure of 470 Mm^3/year has the highest	300	Qaisi, K. 2001.
	frequency and we choose it as the historical flow of the	475	Klein, M. 1998.
	Yarmouk river before any water development projects.	170-440	Al-Jayyousi, O. 2001.
	The following tables will present lower figures according	400	Internet: http://www.unu.edu/unupress/unupbooks/80858e/
	to the Yarmouk water use of the period considered.		80858E06.htm
	- do -	470*	Baker and Harza. 1955.
	- do -	467	Salameh, E.; Bannayan, H. 1993.
	Lower Jordan river flow into the Dead Sea	1,100-1,400	Klein, M. 1998.

		1,400	Al-Weshah, R. A. 2000.
		1,400	Jaber and Mohsen. 2001.
		1,350	El-Nasser, H. 1988.
		1,850	Internet: http://www.unu.edu/unupress/unupbooks/80858e/ 80858E06.htm
		1,250-1,600	Mimi and Sawalhi. 2003.
		1,500	http://www.fsk.ethhz.ch/encop/13/en13-ch1.htm#Surface_water_resources
		1,850	http://www.gefweb.org/Projects/Pipeline/Pipeline_6/ Jordan_water_Quality.pdf
		1,450	Baker and Harza. 1955.
		1,370*	Our evaluation.
	North (eastern) side-wadis flow in the Lower Jordan river (natural flow)	55+35= 90*	THKJ.1977. (Potential surface water resources map); Baker and Harza. 1955.
	Zarqa river flow in the Lower Jordan river (natural flow)	90*	THKJ. 1977.; Baker and Harza. 1955.
		92	Baker and Harza. 1955.
	South (eastern) side-wadis flow in the Lower Jordan river (natural flow)	30	THKJ. 1977. (Potential surface water resources map); Baker and Harza. 1955. Total flow in which 22 Mm^3/year are groundwater base flow.
		35*	THKJ. 2004.
	North (western) side-wadis flow in the Lower Jordan river (natural flow)	25*	Orthofer, R. 2001. Calculation according to Baker and Harza. 1955.
	Middle (western) side-wadis flow in the Lower Jordan river (natural flow)	10*	Orthofer, R. 2001. Calculation according to Baker and Harza. 1955.
	South (western) side-wadis flow in the Lower Jordan river (natural flow)	25*	Orthofer, R. 2001. Calculation according to Baker and Harza. 1955.
		30	Baker and Harza. 1955.

	Total western side-wadis flow in the Jordan river	58*	Baker and Harza. 1955.
	Groundwaters		
	Yarmouk basin safe yield	127*	El Nasser, H. 1991.; Salameh and Bannayan. 1993.
	Yarmouk basin flow drained from Jordan into the Yarmouk river (drainage water)	105*	El Nasser, H. 1991.; Salameh and Bannayan. 1993. (in which 15 Mm³/year of base flow).
	Jordan valley basin flow drained to the Jordan valley (drainage water)	22*	THKJ. 2004.
	Amman Zarqa basin safe yield	88*	El Nasser, H. 1991.; Salameh and Bannayan. 1993.
	Amman Zarqa basin flow into Zarqa river (drainage water)	35*	El Nasser, H. 1991.; Salameh and Bannayan. 1993.
	Jordan valley basin safe yield (east bank)	20*	Salameh, E.; Bannayan, H. 1993. (30 Mm³/year for the entire Jordan valley basin, recharge occurring on the west bank considered).
	Jordan valley basin flow into the Jordan river	20*	THKJ. 1977. (Potential surface water resources map).
	For information: Water drained from the west bank aquifers to the Jordan valley	125 100	http://www.gci.ch/GreenCrossPrograms/waterres/gcwater/jordan.html http://law.onzaga.edu/borders/water.htm
		100-150	http://www.mena.gov.ps/part340_m.htm
1950s	Volume of water are in Mm³/year ; population in inhabitants and areas in hectares (ha)		* indicates figures chosen in our charts and round off to 5 Mm³/year
	We only present figures which differ from the preceding table		
	North (eastern) side-wadis flow into the Lower Jordan river	60*	THKJ. 1977. (Natural flow remained unchanged).
	Zarqa river flow into the Lower Jordan river	70*	THKJ. 1977. (Natural flow remained unchanged).
	South (eastern) side-wadis flow into the Lower Jordan river	15*	THKJ. 1977. (Natural flow remained unchanged).
	Jordan river flow reaching the Dead Sea	1,285*	Our evaluation.
	Surface of the northern plots irrigated in the Jordan valley with water from the Yarmouk river	1,500	Interview M. Avedis Serpekian (JVA) October, 2003.
		500*	Baker and Harza. (1955).
	Surface of the middle plots irrigated in the Jordan valley with water from the northern side-wadi (east)	1,000 3,500*	Interview M. Avedis Serpekian (JVA) October, 2003. Barker and Harza. 1955. (7,000 ha are classified as irrigated land but

			cropping area registered is evaluated at around 50 % of this area).
	Surface of the middle plots irrigated in the Jordan valley with water from the Zarqa river	1,000 2,500*	Interview M. Avedis Serpekian (JVA) October, 2003. Barker and Harza. 1955. (5,000 ha are classified as irrigated land but cropping area registered is evaluated at around 50 % of this area).
	Surface of the southern plots in the Jordan valley from the southern wadis (east)	1,000 2,100*	Interview M. Avedis Serpekian (JVA) October, 2003. Barker and Harza. 1955. (4,200 ha are classified as irrigated land but cropping area registered is evaluated at around 50 % of this area).
	Surface of irrigated plots in the Jordan valley with water from the side-wadi (west)	3,100*	Baker and Harza. (1955).
	Surface irrigated in the Zhor	1,200*	Baker and Harza. (1955).
	Surface irrigated along side-wadis with water from the springs in the North	450*	Baker and Harza. (1955).
	Water used to irrigate the northern plots in the Jordan valley is from the Yarmouk river	5*	Our evaluation.
	Water used to irrigate the northern plots in the Jordan valley is from the northern wadis (east)	30*	(25+5) Our evaluation.
	Water used to irrigate the plots located on the West Side of the Jordan river	35*	Our evaluation.
	Water used to irrigate the middle plots in the Jordan valley is from the Zarqa river	20*	Our evaluation.
	Water used to irrigate the southern plots in the Jordan valley is from the southern wadis (east)	20*	Our evaluation.
	Water used to irrigate side-wadis plots in the north (east) is from Yarmouk basin	5*	Our evaluation.
	Water used to irrigated plots in the Zhor is from the Jordan	15*	Our evaluation.
	Water from the Yarmouk basin to Irbid municipality	0.2*	Our evaluation.
	Water from the Amman-Zarqa basin for Amman municipality	2*	Our evaluation.
	Population of Amman-Zarqa	120,000*	Baker and Harza. (1955).

	Population of Irbid	25,000*	Baker and Harza. (1955).
1975s	Volume of water is in Mm^3/year; population in inhabitants and areas in hectares (ha)		* indicates figures chosen in our charts and round off to 5 Mm^3/year.
	We only present figures which differ from the preceding table		
	Upper Jordan natural flow into lake Tiberius	600	Al-Weshah, R. A. 2000.
		660	Internet: http://www.unu.edu/unupress/unupbooks/80858e/80858E06.htm
		770	Klein, M. 1998.
		790*	Internet: http://www.unu.edu/unupress/unupbooks/80858e/80858E06.htm
	The Israeli water abstraction from Upper Jordan Huley Valley	100*	Klein, M. 1998.
		100*	http://www.unu.edu/unupress/unupbooks/80858e/80858E06.htm
	Yarmouk flow after Syrian pumping	380*	Our evaluation.
	Natural outflow of lake Tiberius	70	ANTEA-BRL. 1995.
		60	Hof, F.C. 1998
		70	Klein, M. 1998.
		65*	Our evaluation-Average figure.
	Yarmouk basin flow drained from Jordan into the Yarmouk river (drainage water)	75*	El Nasser, H. 1991.; Salameh and Bannayan. 1993. (in which 5 Mm3/ year of base flow).
	The Syrian water abstraction from Yarmouk river	90*	Hof, F.C. 1998. Calculation according to the 1987s treaty between Syria and Jordan and the Johnston Plan (1955).
	The Israeli water abstraction from Yarmouk river to	45*	El-Nasser, H. 1998.
	the lake Tiberius		
	Israeli water abstraction from the Yarmouk river to the	25*	El-Nasser, H. 1998.
	Yarmouk Triangle		
	Total Israeli exploitation of water from the Yarmouk river	70*	El-Naser, H. 1998.; Hof, H.C. 1998.
		65	http://www.passia.org/publications/bulletins/water-eng/pages/water04.pdf
		100	Al-Jayyousi, O. 2001.

		70-100	http://www.transboundarywaters.orst.edu/projects/casestudies/ jordan_river.html
	The Israeli water abstraction from lake Tiberius to the National Water Carrier	420-460*	Internet: http://www.passia.org/publications/bulletins/water-eng/pages/ water04.pdf
		420-450	http://www.fsk.ethhz.ch/encop/13/en13-
			ch1.htm#Surface_water_resources
		450	http://www.gefweb.org/Projects/Pipeline/Pipeline_6/ Jordan_water_Quality.pdf
		450	Beaumont, P. 1997.
		405	Klein, M. 1998.
	Irrigation return flow from Israel	40	Internet: http://www.passia.org/publications/bulletins/water-eng/pages/ water04.pdf
		45*	20 in the north + 25 in the south (Orthofer, R. 2001.)
	Water diverted from the Yarmouk river to the KAC	130*	Hof, F.C. 1998.
		90-110	http://www.passia.org/publications/bulletins/water-eng/pages/water04.pdf
		100-105	Al-Jayyousi, O. 2001.
		100-110	Qaisi, K. 2001.
		135	JVA personal communication.
		125	THKJ. 1977.
	Lower Jordan flow after the KAC diversion and after Israeli pumping	245*	Our evaluation.
	Lower Jordan flow reaching the Dead Sea	505*	Our evaluation.
		325	THKJ. 1977.
	Northern Ghor irrigated area	6,700*	THKJ. 1977. (Map of Location and acreage of irrigated areas).
	Middle Ghor Irrigated Area	6,700*	THKJ. 1977. (Map of Location and acreage of irrigated areas).
	Surface of the southern plots in the Jordan valley	4,185*	(1300+1400+1485) THKJ. 1997.
	Irrigated area along the northern wadis	700*	THKJ. 1977. (Map of Location and acreage of irrigated areas).
	Irrigated area along the Zarqa river	1,450*	THKJ. 1977. (Map of Location and acreage of irrigated areas).

Irrigated area in the Yarmouk basin	530*	THKJ. 1977. (Map of Location and acreage of irrigated areas).
Irrigated area in the Amman-Zarqa basin	5,450*	THKJ. 1977. (Map of Location and acreage of irrigated areas).
Water from KAC to northern Ghor	65*	THKJ. 1977. (Map of Water for irrigation, average year conditions).
Water from KAC to middle Ghor	50*	THKJ. 1977. (Map of Water for irrigation, average year conditions).
Water pumped from Jordan valley basin to irrigate southern Ghor	10*	THKJ. 1977. (Map of Water for irrigation, average year conditions).
Water from wadis to irrigate southern plots in the Jordan valley	20*	THKJ. 1977. (Map of Location and acreage of irrigated areas).
Water from wadis to irrigate areas along the northen wadis	15*	THKJ. 1977. (Map of water for irrigation, average year conditions).
Water from the Zarqa river to irrigate areas along the Zarqa river	20*	THKJ. 1977. (Map of water for irrigation, average year conditions).
Northern side-wadis discharge	75*	THKJ. 1977.
Northern side-wadis flow into the Lower Jordan river	60*	Our evaluation.
Zarqa river natural discharge	85*	Khori, R. 1981.
Zarqa river flow in the Lower Jordan river	75*	Our evaluation.
Water from the southern side-wadis flow into the Jordan river	3*	Our evaluation.
Water from northern wadis is utilized for municipal and industrial uses in Irbid	3.5	THKJ. 1977.
Water pumped from the Yarmouk basin to irrigate farms in the Yarmouk basin	5*	THKJ. 1977.
Water pumped from the Yarmouk basin for municipal and industrial uses in Irbid	2,3*	THKJ. 1977.
Water pumped from the Amman-Zarqa basin to irrigate farms in the Amman-Zarqa basin	65*	THKJ. 1977. (Map of water for irrigation, average year conditions).
Water pumped in the Amman-Zarqa basin for municipal and industrial uses in Amman-Zarqa	25*	THKJ. 1977. (Map of water for irrigation, average year conditions).
Water pumped from Azraq for municipal use in Irbid	2,3*	THKJ. 1977.
Population of Amman	1,100,000*	THKJ. 1977.

	Population of Irbid	360,000*	THKJ. 1977.
2000s	Volume of water are in Mm^3/year; population in inhabitants and areas in hectares (ha)		* indicates figures chosen in our charts and round off to 5 Mm^3/year.
	We only present figures which differ from the preceding table		
	Upper Jordan natural flow into lake Tiberius	475	Internet:http://www.passia.org/publications/bulletins/water-eng/pages/water04.pdf
		520	Al-Jayyousi, O. 2001.
		475*	Our evaluation.
	Natural outflow of lake Tiberius	35*	Orthofer, R. 2001.
	The Israeli water from Yarmouk river according to the	25*	Jordan-Israel Peace Treaty. 1994.
	Peace Treaty, 1994		
	Winter concession to Israel from Yarmouk river	25*	Peace Treaty. 1994.
	The Jordanian water abstraction from lake Tiberius according to the Peace Treaty, 1994	50*	Peace treaty. 1994. Not yet received.
	Syrian water abstraction from Yarmouk river	200*	El-Nasser, H. 1988.
		160	Internet: http://www.passia.org/publications/bulletins/water-eng/pages/water04.pdf
		180	ANTEA-BRL. Schema directeur indicatif de gestion des resources en eau du basin du Jourdain
		170	Al-Jayyousi, O. 2001.
		220	Hof, F. C. 1998. And http://jordanembassyus.org/112298002.htm
		130-180	Klein, M. 1998.
		160-170	Beaumont, P. 2002.
	The Israeli water abstraction from Yarmouk river to The lake Tiberius	70*	45+25 El-Nasser, H. 1998.; Hof, F.C. 1998.
	Flow of water in the Yarmouk river after Syrian pumping	240-280	GTZ. 1998.
		270*	THKJ, 2004 and Internet: http://www.jordanembassyus.org/112298002.htm

Lower Jordan flow after the KAC diversion and after Israeli pumping	120*	Our evaluation.
Saline pumping from the Jordan river to Israel	7*	Orthofer, R. 2001.
Diversion of saline water from Israel to the Jordan river	30*	Orthofer, R. 2001. (20 +15 Mm^3/year in the north and 15 Mm^3/year to be rejected in the south of the Jordan valley).
Lower Jordan flow reaching the Dead Sea	400	Al-Weshah, R. A. 2000.
	220-250	Klein, M. 1998.
	100-200	Orthofer, R. 2001.
	250-300	Salameh, E.; Bannayan, H. 1993.; Al-Jayyousi, O. 2001. (+ 15 Mm^3 of drainage water from Amman Zarqa basin).
	315*	Our evaluation (in which 275 Mm^3/year are coming from the Jordan river).
Zarqa river natural discharge	60*	Salameh, E.; Bannayan, H. 1993.; Al-Jayyousi, O. 2001. (+ 15 Mm^3 of drainage water from Amman Zarqa basin).
Water from lake Tiberius to the KAC	45*	Treaty of Peace, 1994 storage for Jordan in Tiberius 25 + 20
Water from the Yarmouk river to the KAC	70	ANTEA-BRL. 1995.
	60	Hof, F. C. 1998.
	90*	Average figure on 1990-2001 according to the JVA Water Resources Department database.
Water in the KAC before the Mucheibeh wells junction	90-110	Internet: http://www.passia.org/publications/bulletins/water-eng/pages/water04.pdf
	100-105	Al-Jayyousi, O. 2001.
	130	Hof, F. C. 1998.
	100-110	Qaisi, K. 2001.
	90	Interview: with Nayef Seder from JVA.
	135*	Our evaluation.
Water from Mucheibeh wells to the KAC	20*	Al-Jayyousi, O. 2001.

		25	Grawitz, B. 2001.
	Yarmouk basin flow drained from Jordan into the Yarmouk river (drainage water)	55*	THKJ. 2004.
	North-eastern side-wadis total base and flood flow	56,5*	THKJ. 2004. (in which 35 Mm^3/year are aquifer base flow).
		40.5	JICA. 2001.
		50	JVA database.
	North side-wadis flow into small dams in the northern valley	20*	Water Resources Department, JVA.
	Non-tapped water from north side-wadis (Discharge in the Jordan river)	10*	Our evaluation.
	Water from northern side-wadis to KAC	20*	Water Resources Department, JVA.
	Evaporation from northern side-wadis dams	2*	Our evaluation.
	Evaporation from King Talal dam	2*	Our evaluation.
	Evaporation from Karamah dam	1*	Our evaluation.
	Water from side-wadis to irrigate areas along the northern side-wadis (upstream use)	25*	Our evaluation.
	Water from the Zarqa river to irrigate areas along the Zarqa river (upstream use)	35*	Our evaluation.
	Diverted water from northern side-wadis to irrigate areas in the Jordan valley	15*	Our evaluation.
	Water from southern side-wadis to irrigate areas along the southern side-wadis Hisban-Kafrein (upstream use)	20*	Water Resources Department, JVA.
	Water from southern dams to irrigated area along southern side-wadis Hisban-Kafrein	15*	Water Resources Department, JVA.
	Water pumped from the Yarmouk basin to irrigate farms in the Yarmouk basin	30*	JICA. 2001 and MWI database.
	Water pumped from the Yarmouk basin for municipal and industrial use in Irbid	30*	JICA. 2001 and MWI database.
	Water pumped from the Amman-Zarqa basin for municipal and	20*	Water Authority of Jordan (WAJ) database.

industrial use in Irbid		
Water pumped from Azraq for municipal use in Irbid	6*	Water Authority of Jordan (WAJ) database.
Water pumped from the Amman-Zarqa basin to irrigate farms in the Amman-Zarqa basin	75*	Our evaluation.
	60	Ministry of Water and Irrigation database.
Water pumped in the Amman-Zarqa basin for municipal and industrial use in Amman-Zarqa	70*	Ministry of Water and Irrigation database.
Water pumped from Azraq for municipal uses in Amman-Zarqa	10*	Water Authority of Jordan database.
Water pumped from the Dead Sea basin for municipal and industrial use in Amman-Zarqa	17*	Salameh, E.; Bannayan, H.1993.
Unaccounted water from Amman-Zarqa municipality to the Amman-Zarqa basin return flow	30*	Our evaluation.
Unaccounted water from Irbid municipality to the Yarmouk basin return flow	10*	Our evaluation.
Agricultural return flow in Amman Zarqa basin	15*	Our evaluation.
Agricultural return flow in Yarmouk basin	5*	Our evaluation.
Agricultural return flow along the Zarqa river	10*	Our evaluation.
Total agricultural flow in the Jordan valley	70*	Our evaluation.
(Indicative) Total water pumped in Azraq	55	According to MWI digital database.
Amman Zarqa basin flow into Zarqa river	15*	Water Authority of Jordan database.
Retreated wastewater flow into the King Talal reservoir	42	Al-Jayyousi, O. 2001.
	40	Qaisi, K. 2001.
	60*	Average figure using WAJ database
Water from the King Talal reservoir (KTR) to the KAC	100	Al-Jayyousi, O. 2001.
	85*	Our evaluation.
Water from the KTR to the Jordan valley	105*	Our evaluation.
Water from the KAC to Amman-Zarqa municipality	45*	Salameh, E.; Bannayan, H.1993.

		50*	Average figure using the JVA database on the 1995-2003 period.
	Water from the KAC to the north-east and northern Ghor	60	Al-Jayyousi, O. 2001.; HKJ, MWI, JVA. 2000.
		55*	Water Resources Department, JVA.
	Water from the KAC and the KTR to the middle Ghor	35-40	Al-Jayyousi, O. 2001.
		65*	Water Resources Department, JVA.
	Water from the KAC to the southern Ghor	41	Al-Jayyousi, O. 2001.
		25*	Water Resources Department, JVA.
	Water pumped from the JV basin to southern Ghor	20*	JICA. 2001.
	Water from the north and north-east Ghor to the Jordan return flow from agriculture	10*	Our evaluation.
	Water from the Middle Ghor to the Jordan return flow from agriculture	25*	Our evaluation.
	Water from the southern Ghor to the Jordan return flow from agriculture	25*	Our evaluation.
	Noncontroled water in the KAC winter flows	30*	Our evaluation.
	Water diverted from the Zarqa river to irrigate land in the Jordan valley	5*	Our evaluation.
	Irrigated area along the northern side-wadis	1,600*	Calculation according to THKJ, DoS. 2002.; ARD. 2001 and WSSP 2004.
	Irrigated area along the Zarqa river	2,400*	Calculation according to THKJ, DoS. 2002.; ARD. 2001 and WSSP 2004.
	Irrigated area along the south side-wadis	1,485*	Calculation according to THKJ, DoS. 2002.; ARD. 2001 and WSSP 2004.
	North-east and northern Ghor irrigated area	8,280	Salman, A. 2001.
		11,630	Al-Weshah, R. A. 2000 .
		12,100*	Calculation according to THKJ, DoS. 2002 and a GIS land use analysis.
	Middle Ghor irrigated area	9,110	Salman, A. 2001.
		7,770	Al-Weshah, R. A. 2000.

		7,440*	Calculation according to THKJ, DoS. 2002 and a GIS land use analysis.
	Southern Ghor irrigated area	3,950	Khori, R. 1981.
		4,200	Grawitz, B. 2001.
		3,400*	Calculation according to THKJ, DoS. 2002 and a GIS land use analysis.
	Surface of the southern plots in the Jordan valley, Hisban Kafrein	1,660	Al-Jayyousi, O. 2001.
		1,500	Khori, R. 1981.
		1,660	Grawitz, B. 2001.
		1,600*	Mean of the figures observed in different articles.
	The 14.5 km EGC extension nonirrigated land	6,000	Khori, R. 1981.
		4,180	Al-Weshah, R. A. 2000.
		5,100*	Mean of the figures observed in different articles.
	Total irrigated land in the Jordan valley	24,600	Orthofer, R. 2001.
		30,000	Grawitz, B. 2001.
		23,580	Al-Weshah, R. A. 2000.
		22,600*	THKJ, DoS. 2002.
	Irrigated area in the Yarmouk basin	5,000*	HKJ, MWI, GTZ. 2004.
	Irrigated area in the Amman-Zarqa basin	14,350*	Calculation according to THKJ, DoS, 2002 and ARD, 2001 and WSSP 2004.
	For indication: Total irrigated areas in the highlands	23,350*	HKJ, MWI, GTZ. 2004.
	Population in Amman Zarqa municipality	2,700,000*	JICA. 2001.
	Population in Irbid	1,100,000*	JICA. 2001.
	M & I water consumption in Amman-Zarqa	145*	WAJ database records.
	M & I water consumption in Irbid	55*	WAJ database records.
2025s	Volumes of water are in Mm^3/year; population in inhabitants and areas in hectares (ha)		* indicates figures chosen in our charts and round off to 5 Mm^3/year
	We only present figures which differ from the preceding table		
	Lower Yarmouk flow after the Wehdah dam	190*	Our evaluation according to the capacity of the dam (110 Mm^3).

Evaporation in the Wehdah dam	20*	Our evaluation.
Lower Jordan flow after Israeli pumping and KAC diversion	40*	Our evaluation.
Water initially diverted to the KAC	135*	45 from Peace Treaty and 90 Mm^3 from the Yarmouk.
Lower Jordan river reaching the Dead Sea	170*	Our evaluation. To which 30 Mm^3/year have to be added from the KAC and other irrigation return flow.
Water from the Red Sea to the Dead Sea	1,500*	Harza.1998.
Water for irrigation purpose at the KAC Intake	75*	Our evaluation.
Water for municipal and industrial purposes at the KAC intake	60*	Our evaluation.
Water from the valley to the Amman-Zarqa municipality	90*	Our evaluation.
Retreated wastewater from Irbid to the KAC	25*	Our evaluation.
Water from the northern side-wadis to the KAC	45*	Our evaluation.
Water from KAC to irrigate the north-east and northern Ghor	100*	Our evaluation (+ 5 Mm^3/year of uncontroled diverted water from wadis).
Water from KAC to irrigate the middle Ghor	55*	Our evaluation (+ 15 Mm^3/year of uncontroled diverted water from the Zarqa river).
Water from KAC to irrigate the southern Ghor	55*	Our evaluation.
Water from the Jordan river basin to the southern Ghor	20*	Our evaluation.
Flow from the King Talal dam to the KAC	125*	Our evaluation.
Water flow from Zarqa river to Jordan river	45*	Our evaluation.
Water pumped from the Wehdah dam to Irbid	60*	Our evaluation.
Water pumped from the Yarmouk basin to Irbid	30*	Our evaluation.
Water Pumped from the Yarmouk basin to irrigate farms in the Yarmouk basin	15*	Our evaluation.
Water pumped from the AZB basin to Irbid for domestic purposes	20*	Our evaluation.
Water pumped from AZB basin to Amman-Zarqa for domestic purposes	70*	Our evaluation.
Water pumped from AZB for agricultural purposes in the highlands	35*	Our evaluation.

Water from Amman-Zarqa municipality to the Amman-Zarqa basin (return flow)	120*	Our evaluation.
Water from Irbid municipality to the Yarmouk basin (return flow)	5*	Our evaluation.
Retreated wastewater flow into the King Talal dam	120*	Our evaluation.
Retreated wastewater used in agriculture in the highlands	30*	Our evaluation.
Agricultural return flow in the Amman-Zarqa basin	10*	Our evaluation.
Water flow from DISI	50*	Our evaluation.
Water flow from Maïn	35*	Water Resources Department, JVA.
Water flow from Hisban	10*	Water Resources Department, JVA.
Water flow from the Mujib dam	35*	Water Resources Department, JVA.
Desalinated water from the Red Sea	100*	Our evaluation.
Wastewater flow into Samra Treatment Plant	155*	Our evaluation.
Evaporation from northern side-wadis dams	5*	Our evaluation.
Evaporation from King Talal dam	5*	Our evaluation.
Irrigated surface in AZB basin	9,300*	Our evaluation.
Irrigated surface in the Yarmouk basin	1,500*	Our evaluation.
Population in Amman Zarqa municipality	5,000,000*	Calculation based on demographic growth.
Population in Irbid	2,500,000*	Calculation based on demographic growth.
M & I water consumption in Amman-Zarqa	390*	Our evaluation.
M & I water consumption in Irbid	120*	Our evaluation.

Appendix 2

Categories of River Basin Water Accounting (Molden et al. 2001b)

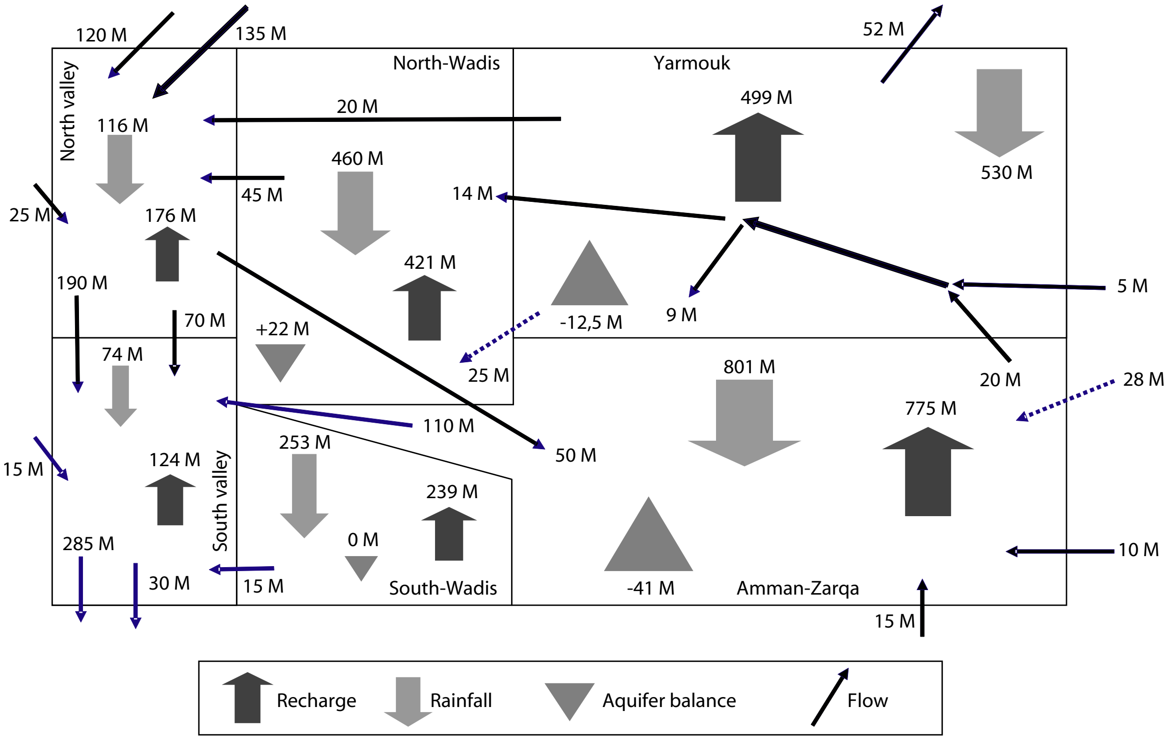
- *Gross inflow* is the total amount of water entering into the water balance domain from precipitation, and surface and subsurface sources.
- *Net inflow* is the gross inflow plus any changes in storage.
- *Water depletion* is a use or removal of water from a water basin that renders it unavailable for further use. Water depletion is a key concept for water accounting, as interest is focused mostly on the productivity and the derived benefits per unit of water depleted. It is extremely important to distinguish water depletion from water diverted to a service or use as not all water diverted to a use is depleted. Water is depleted by four generic processes:
- *Evaporation*: Water is vaporized from surfaces or transpired by plants.
- *Flows to sinks*: Water flows into a sea, saline groundwater, or other location where it is not readily or economically recovered for reuse.
- *Pollution*: Water quality gets degraded to an extent that it is unfit for certain uses.
- *Incorporation into a product*: Through an industrial or agricultural process, such as bottling water or incorporation of water into plant tissues.
- *Process consumption* is that amount of water diverted and depleted to produce a human intended product.
- *Non-process depletion* occurs when water is depleted, but not by the process for which it was intended. Non-process depletion can be either beneficial, or non-beneficial.
- *Committed water* is that part of outflow from the water balance domain that is committed to other uses, such as downstream environmental requirements or downstream water rights.
- *Uncommitted outflow* is water that is not depleted, nor committed and is, therefore, available for a use within the domain, but flows out of the basin due to lack of storage or sufficient operational measures. Uncommitted outflow can be classified as utilizable or non-utilizable.
- *Outflow* is utilizable if by improved management of existing facilities it could be consumptively used. Non-utilizable uncommitted outflow exists when the facilities are not sufficient to capture the otherwise utilizable outflow.
- *Available water* is the net inflow minus both the amount of water set aside for committed uses and the non-utilizable uncommitted outflow. It represents the amount of water available for use at the basin, service, or use levels. Available water includes process and non-process depletion plus utilizable outflows.
- A *closed basin* is one where all available water is depleted.
- An *open basin* is one where there is still some uncommitted utilizable outflow.
- In a *fully committed basin*, there are no uncommitted outflows. All inflowing water is committed to various uses.

Appendix 3

Map of the Surface Subbasins Considered

Appendix 4

Inflow and Outflow from Subbasins Considered in the 2000s



Appendix 5

Pictures (all pictures are drawn from Venot 2004c)

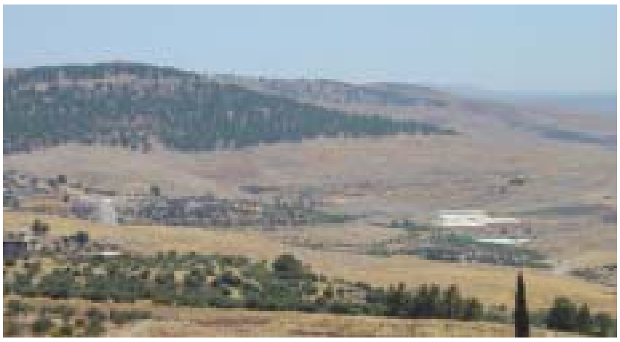
Picture 1. Jordan Valley Landscape

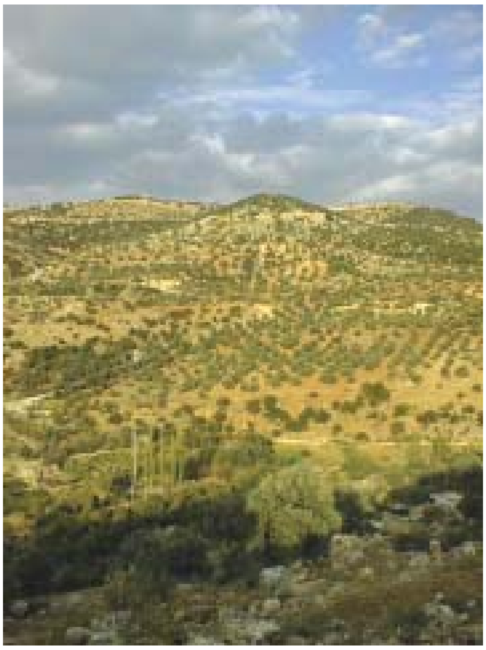
Al Zhor during an exceptional winter flow.

Al Katar.

Al Ghor.

Picture 2. General Landscape of the Jordanian Uplands





Picture 3. Rain-fed Agriculture in the Jordanian Uplands

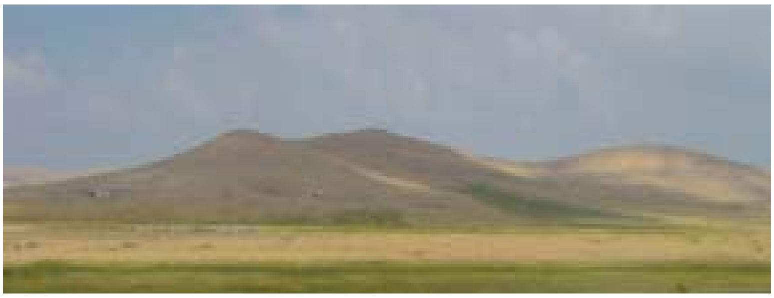
Picture 4. Irrigated Agriculture in the Jordanian Uplands

On the Plateaux.

Along the Zarqa river.

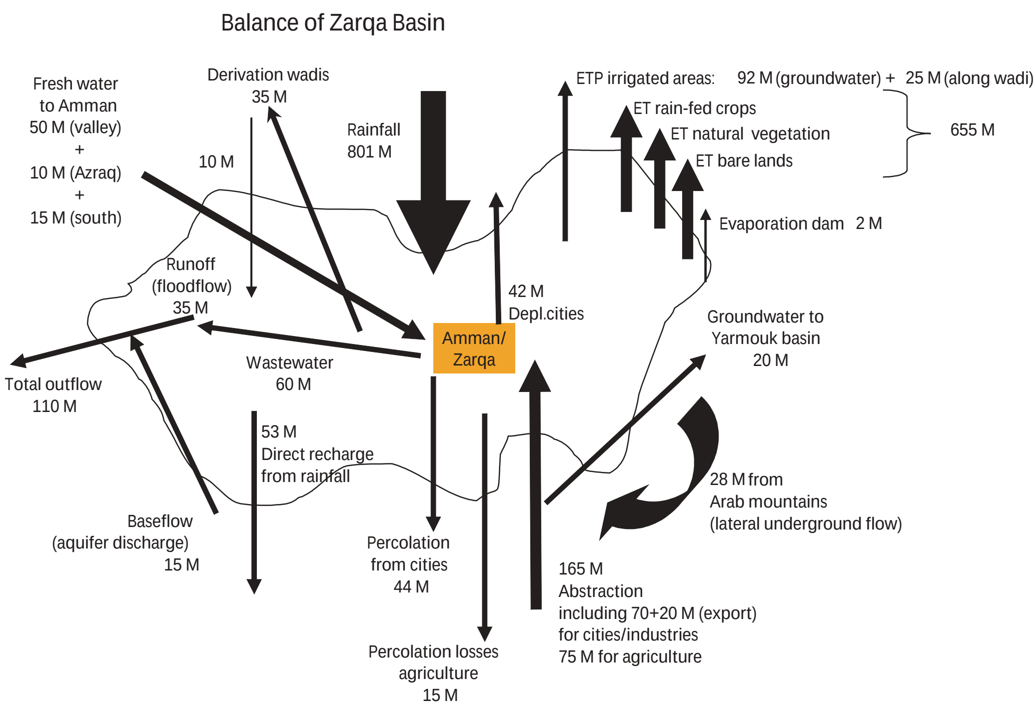
In peri-urban areas.

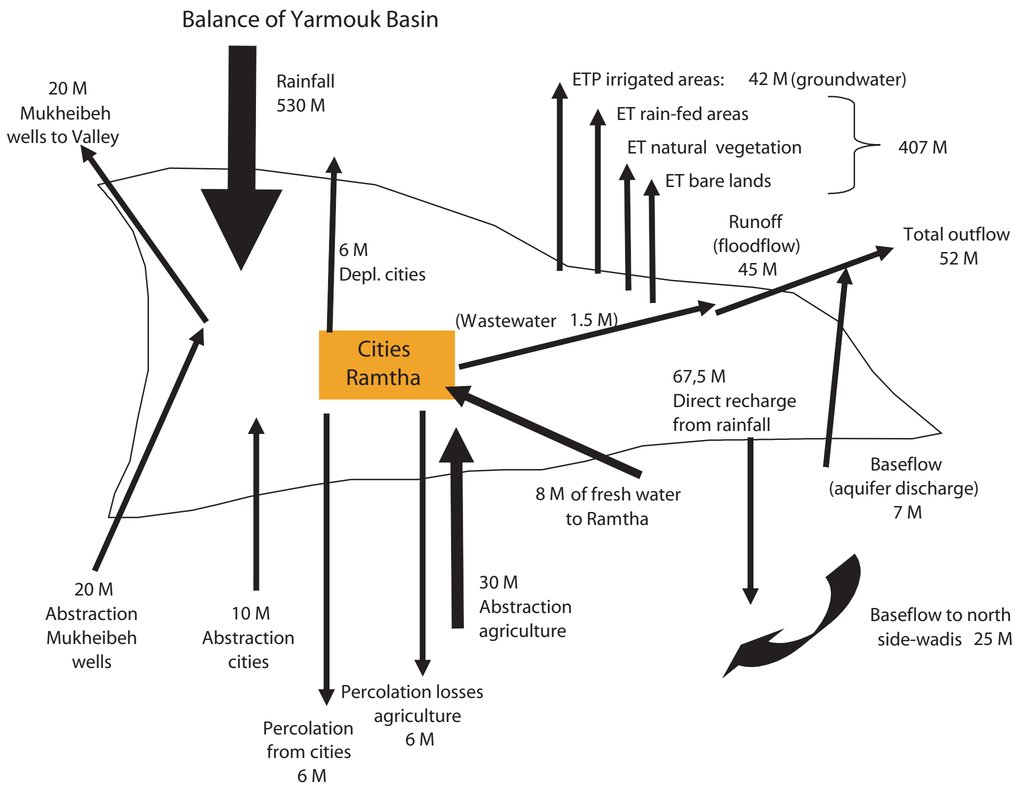
Picture 5. General Landscape of the Eastern Desert



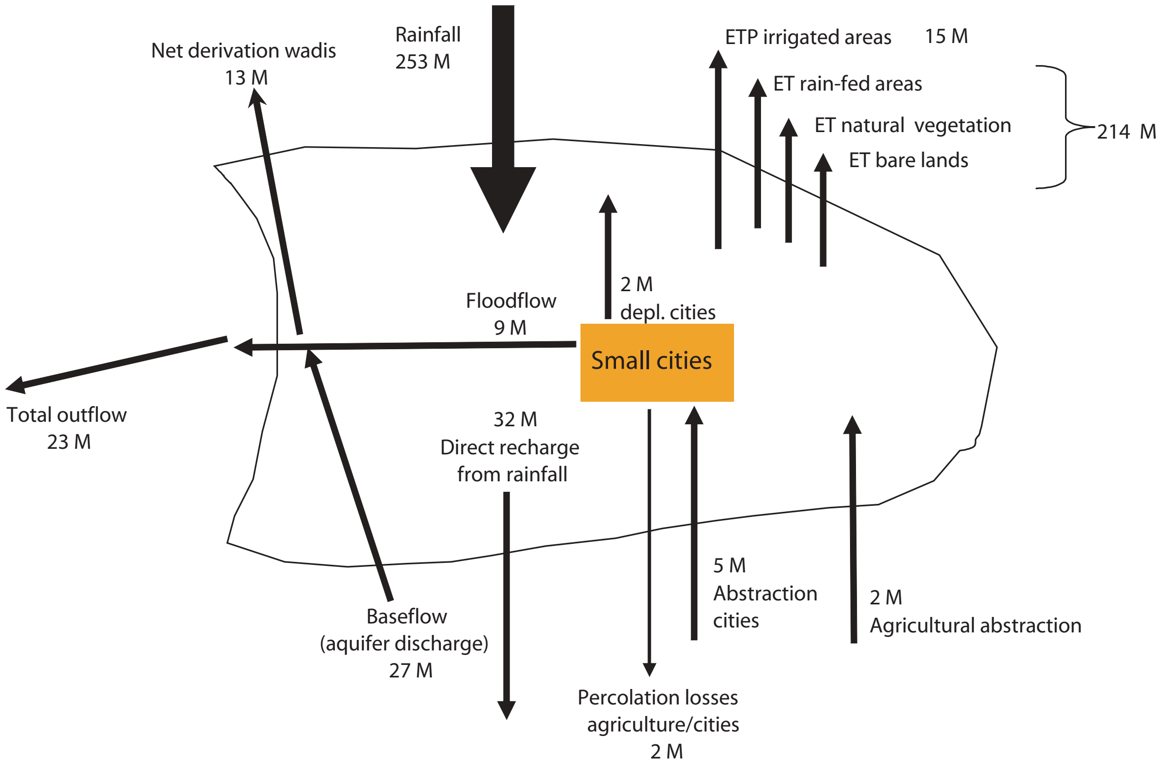
Appendix 6

Water Balances by Subbasin in the 2000s

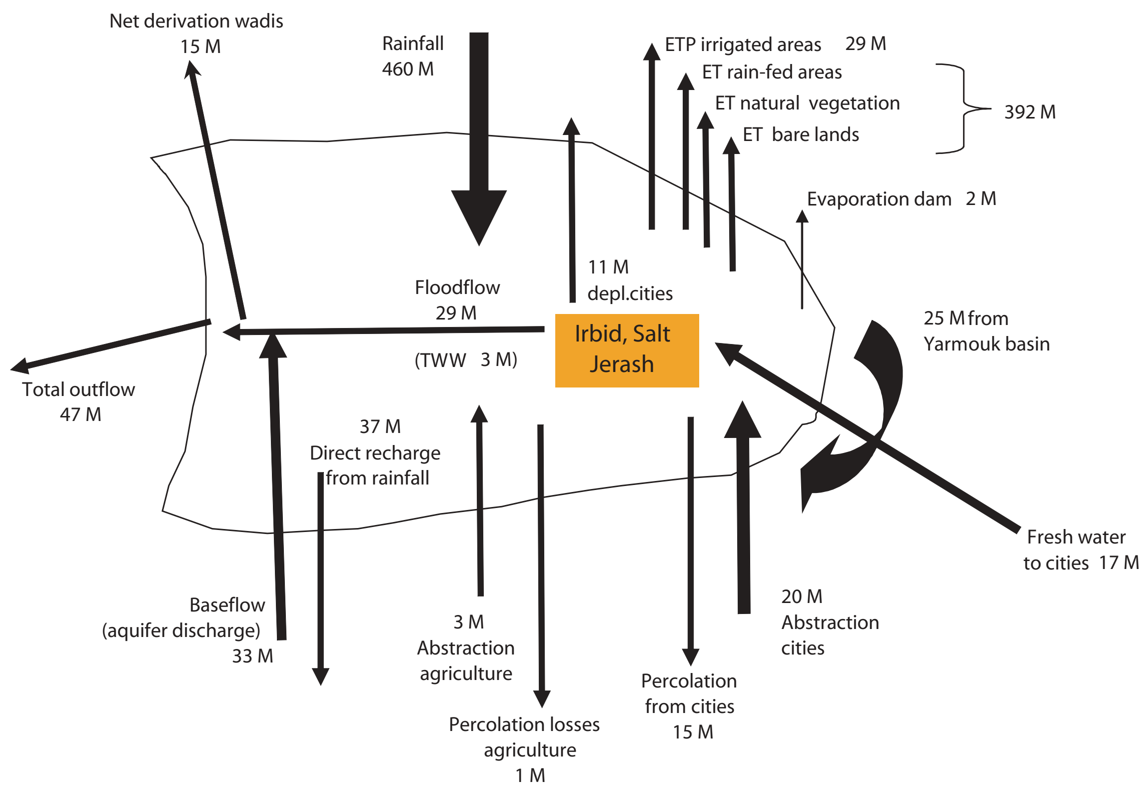




Balance of South Side-Wadis Basin



Balance of North Side-Wadis Basin



Appendix 7

Indicators of Water Mobilization and Water Use Efficiency in the Lower Jordan River Basin and Their Evolution During the Period 1950-2025

	1950	1975	2000	2025
Renewable blue water	1,588	833	705	861
Total uncontrolled Jordan River flow	1,095	290	160	55
Controlled renewable blue water	493	543	545	806
Controlled surface water	0	15	120	315
Stream water (uncontrolled diversions)	95	189	190	125
Unsued stream water	1,335	489	252	163
Groundwater abstraction	6	110	275	252
Groundwater imports	0	2	30	50
Surface imports + Red-Dead project	0	0	45	225
Withdrawals of basin resources	101	314	585	692
Total withdrawals (with imported water)	101	316	660	967
Total withdrawals (% of renewable blue water)	6	38	94	112
Total withdrawals (% of controlled renewable blue water)	20	58	121	120
Outflow to the Dead sea from inner basin	190	215	155	145
Total outflow of the basin to the Dead Sea	1,285	505	315	200
Volume of withdrawals depleted	54	202	474	705
Groundwater return flow	1	40	89	164
Depleted water (% of renewable blue water)	3	24	67	82
Depleted water (% of controlled renewable blue water)	11	37	87	87

Note: Unit of measure is Million m^3

Appendix 8

Computing and Noncomputing Return Flows and Impacts on Overabstraction Evaluation in 2000s and in the Mid-2020s in the Lower Jordan River Basin

	Jordan Valley Basin	Side-Wadis Basin	Yarmouk Basin	Amman-Zarqa Basin	Lower Jordan River Basin
Annual recharge+(rainfall direct Recharge + lateral groundwater flow - base flow)	17.5	34	35.5	66	153
2000s					
Current abstraction (Mm^3/yr.)	25	30	60	165	275
Current abstraction (% of annual recharge)	125	88	169	250	180
Current abstraction minus return flow (% of annual recharge)	100	35	135	161	119
Mid-2020s					
Expected abstraction (Mm^3/yr.)	25	32	40	140	237
Expected abstraction (% of annual recharge)	125	94	113	250	155
Expected abstraction minus return flow (% of annual recharge)	100	29	87	11	45

Note: Unit of measure is Million m^3

Bibliography

Abujaber, R. 1988. *Pioneers over Jordan: The frontier of settlement in Transjordan, 1850-1914* London: I.B. Tauris and Co.

Abu-Shams, I.; Rabadi, A. 2003. The strategy of restructuring and rehabilitating the Greater Amman water network. *Water Resources Development* 19 (2): 173–183.

Abu-Sharar, T. M.; Battikhi, A. M. 2002. Water resources management under competitive sectoral demand: A case study from Jordan. *Water International* 27 (3): 364–378.

Al-Hadidi, K. 2002. La valeur économique de l'eau: Cas de la Jordanie valeur économique de l'eau agricole. Forum sur la gestion de la demande en eau, Beyrouth, June 2002.

Al-Hadidi, K. 2002. Water valuation. The case of Jordan: Valuation of water for domestic use. Beirut, Lebanon: Water Demand Management Forum, June 2002.

Alias, L.; Mathieu, L. 1998. La culture de la banane en Jordanie: Dysfonctionnement de la production et enjeux politiques. *Fruits* 53 : 15. Paris: Elsevier.

Alias, L. 1997. La culture de la banane en Jordanie: Modes de production et enjeux. Rapport de fin d'étude d'ingénieur PURPAN ESAP.

Al-Jayyousi, O. 2001, February. Jordan valley improvement project phase A-report 2: Water resources. Jordan Valley Authority (JVA): The Hashemite Kingdom of Jordan, MWI.

Al-Jayyousi, O. 2003, June. Scenarios for public-private partnerships in water management: A case study from Jordan. *International Journal of Water Resources Development* 19 (2): 185–201.

Allan, T. 1996. *Water, peace and the Middle-East. Negotiating resources in the Jordan basin.* London: Tauris.

Allan, T. 2002. *The Middle East water question. Hydropolitics and the global economy.* London: Tauris.

Al-Rimawi, A. S. 1997. *Women agricultural development in Jordan*. Amman: GTZ (Deutsche Gesellschaft fur Technische Zusammenarbeit).

Al-Salihi, A.H.; Himmo, S. K. 2003. Control and management study of Jordan's water resources. International Water Resources Association. *Water International* 28 (1): 1–10.

Al-Weshah, R. A. 2000. Optimal use of irrigation water in the Jordan valley: A case study. *Water Resources Management* 14: 327–338.

Anbar, A. H. 1984. *Changing land patterns in the East Jordan valley*. Amman: University of Jordan.

ANTEA. 1995. Schéma directeur indicatif de gestion des ressources en eau du bassin du Jourdain. BRL Ingénierie, Paris, 217p.

ARD (Associate in Rural Development, Inc.); USAID (United States Agency for International Aid). 2001. *Groundwater management action plan, Amman-Zarqa basin highlands.* Amman: USAID. 63p.

ARD; USAID. 2001. *Hydrogeological impacts of over pumping and assessment of groundwater management options in the Amman-Zarqa highlands.* Amman:USAID.

ARD; USAID. 2001. *Study of groundwater use and users in the northern Amman-Zarqa basin highlands.* Amman: USAID.

Arrighi de Casanova, A.; Courcier, R. 2002. Quelles perspectives pour l'agriculture jordanienne? In *Du Maghreb au Proche-Orient : Les défis de l'agriculture. Sous la direction de Pierre Blanc,* ed. L. Harmattan, 215–237.

ASAL-JORDAN Agricultural Sector Adjustment Loan. 1994. Draft: Working Paper-Issues in water pricing.

Ayeb, H. 1993. *Le bassin du Jourdain dans le conflit Israélo-Arabe*. CERMOC, Beyrouth, 102p.

Ayeb, H. 2000. *Proche Orient: La Guerre de l'Eau n'aura pas lieu*, ed. L. Harmattan.

Baker, Michael, Inc.; Harza Engineering Company. 1955. The Hashemite Kingdom of Jordan-Yarmouk-Jordan valley project- Master Plan Report. Rochester, USA. 8 volumes, 4 appendices.

Bataineh, F.; Najjar, M.; Malkawi, S. 2002. *Réutilisation des eaux usées.* Forum de la Gestion de la demande en eau. Ministère de l'Eau et de l'Irrigation- Royaume Hashémite de Jordanie. Traduction provisoire.

Battikhi, A. M.; Abu-Hammad, A. H. 1994. Comparison between the efficiencies of surface and pressurized irrigation systems in Jordan. *Irrigation and Drainage Systems* 8: 109–121.

Beaumont, P. 1997. Dividing the waters of the river Jordan: An analysis of the 1994 Israel-Jordan Peace Treaty. *Water Resources Development* 13 (3).

Beaumont, P. 2002. Water policies for the Middle East in the 21st century: The new economic realities. *Water Resources Development* 18 (2): 315–334.

BGR (German Federal Institute for Geosciences and Natural Resources) /WAJ (Water Authority of Jordan). 1994. *Groundwater resources of northern Jordan. Advisory services to the Water Authority of Jordan in the field of hydrogeology.* Amman: WAJ.

Bocco, R.; Jaubert, R.; Metral, F. 1993. *Steppes d'Arabie. Etats, pasteurs agriculteurs et commerçants: Le devenir des zones sèches*. Paris: Presses Universitaires de France.

Central Bank of Jordan, Department of Research and Statistics. Special issue, May 1996. *Yearly statistics series 1964–1995.*

Chebaane, M.; El-Naser, H.; Fitch, J.; Hijazi, A.; Jabbarin, A. 2004. Participatory groundwater management in Jordan: Development and analysis of options. Groundwater: from development to management. *Hydrogeology Journal* 12 (1). Springer.

Courcier, R. 2003. *Questions « socio-politiques » pouvant être liées aux changements éventuels de gestion de l'eau et de l'agriculture en Jordanie*. Working Paper. Amman: French Regional Mission for Water and Agriculture.

Daher, R. 2001. *Jordan valley improvement project phase A-report 6*. The Hashemite Kingdom of Jordan, MWI, JVA, February 2001.

Dalin, Y. 1982. *Assessment of the expected floods to the Dead Sea. Proceeding: The hydrology and the energy crisis.* Ministry of Energy and Infrastructure. pp 5-24.

Darmane, K. 2004, June. *Gestion de la rareté: Le service d'eau potable d'Amman entre la gestion publique et privée.* IWMI-IFPO-MREA Working Paper. Amman: French Regional Mission for Water and Agriculture.

De Bel-Air, Françoise. 2003. Population, politique et politiques de population en Jordanie 1948–1998. Thèse de doctorat. Paris: Ecole des Hautes études en Sciences Sociales.

Decker, C. 2004. Managing water losses in Amman's renovated network: A case study. Paper presented at the Water Demand Management Forum. Dead Sea, Jordan. May 31-June 3, 2004.

Department of Statistics, Directorate of Agriculture and Environmental Statistics. 2002, May. *Analysis of the structure of agriculture in Jordan.* Amman, Jordan: Department of Statistics.

Doppler, W.; Salman, A.Z.; Al Karableih, K.E.; Wolff Heiz, P. 2001. The impact of water price strategies on the allocation of irrigation water: The case of the Jordan valley. *Agricultural Water management* 55(2002):171-182.

Elmusa, S. 1994. *A harvest of technology, the super green revolution in the Jordan valley*. Georgetown: Center for contemporary Arab studies, Georgetown University.

Elmusa, S. 1998. Toward a unified management regime in the Jordan basin: The Johnson Plan revisited. *Yale F&ES Bulletin*.

El-Naser, H. 1998. *The partition of water resources in the Jordan river basin: History and current development.* Paper presented at the Conference on Water in the Mediterranean Countries: Management Problems of a Scarce Resource, Naples, 4–5 Dec. 1997.

El-Naser, H. 1991. Groundwater Resources of the Deep Aquifer Systems in NW - Jordan. Hydrogeological and Hydrochemical quasi Three-dimensional Modeling – Hydrogeologi und Umwelt, Heft 3, Wuerzburg.

Euro-Med Partnership-Jordan. 2002. *Country strategy paper 2002-2006 and national indicative programme 2002-2004.* Jordan.

EXACT (Executive Action Team) . 1998. *Temporal trends for water-resources data in areas of Israeli, Jordanian, and Palestinian interest.* Middle East Water Data Banks Project.

Fardous, A.; Mazahreh, N. 1996. *The reuse of treated wastewater in Jordan.* Working Paper. Amman, Jordan: NCARTT–National Center for Agricultural Research and Technology Transfer.

Ferragina, E. 2000. *La gestion intégrée des ressources hydriques du bassin du Jourdain*. Economies et Sociétés, H.S No. 37.

Ferragina, E. 2002. Social adaptive capacity to water crisis: The case of Jordan. In *Jordan in transition,* ed. George Joffé, 346–367. London: Hurst and Company.

Fitch, J. B. 2001. *Curtailment of groundwater use for irrigated agriculture in the Amman-Zarqa basin. Uplands: An economic analysis. For ARD-USAID 38p + Appendixes.* Amman, Jordan: USAID.

FORWARD (Fostering Resolution of Water Resources Disputes Program). 1999. *Assessment of the impact of water quality. Variations on crop production in the Jordan valley: Restructuring irrigation water tariffs in Jordan.* Amman: USAID.

Goffen, M.; Gal, Y. 1992. The Kinneret Book. Israel: Ministry of Defense and The Kinneret Authority.

Grattan, S. R. 2001. *Impact of increasing supplies of recycled water on crops, soils and irrigation management in the Jordan valley.* Technical Report, ARD USAID.

Grawitz, B. 1998. *Water management information system for the Jordan valley.* Aix-en Provence: Société du Canal de Provence.

GTZ (Deutsche Gesselshaft für Technishe Zusammenarbeit). 1993. *Study for the recovery of operation and maintenance costs of irrigation water in Jordan.* Amman, Jordan: GITEC Consult GMBH, CEC.

GTZ (Deutsche Gesselshaft für Technishe Zusammenarbeit). 1998. *Middle East regional study on water supply and demand development. GTZ Evaluation Report.* Amman, Jordan: GTZ.

GTZ; Regner J. 2001. *Water resources management for irrigated agriculture: Annual progress report, June 2000-May 2001*. Amman, Jordan: GTZ.

GTZ; Regner J. 2002. *Water resources management for irrigated agriculture: Annual progress report, June 2001-May 2002.* Amman, Jordan: GTZ.

GTZ (Deutsche Gesselshaft für Technishe Zusammenarbeit) —JVA (Jordan Valley Authority). 2001 March. *Reclaimed water project-irrigation water quality information system.* Amman, Jordan: GTZ.

GTZ-JVA. 2003. *Brackish water project. Guidelines for brackish water irrigation in the Jordan valley.* Amman, Jordan: GTZ.

Haddadin, M. J. 2001. Diplomacy on the Jordan: International conflict and negotiated resolution. Collection: Natural Resource Management & Policy S., V. 21. Boston, Mass, and London: Kluwer Academic.

Haddadin, M. J. 2002. Water issues in the Middle East: Challenges and opportunities. *Water Policy* 4: 205–222 (2002).

Haddadin, M. J. Date unknown. The socio-economic role of the King Talal dam in the Kingdom of Jordan. Part of the World Commission on Dams Knowledge Base. Online at http://www.dams.org/kbase/submissions/showsub.php?rec=SOC090

Hagan, R. E. 1999. *Water supplies and use.* Hashemite Kingdom of Jordan. Amman, Jordan: Ministry of water and Irrigation.

Hagan, R. E.; Taha, S.E. 1997. *Water quality improvement and conservation project: Irrigated agriculture in Jordan.* Background Paper. Water Quality Improvement and Conservation Project. DAI, JVA.

Hanbali, M. T. 2001. *Jordan valley improvement project phase A-report 4: Agronomy.* The Hashemite Kingdom of Jordan, Ministry of Water and Irrigation, Jordan Valley Authority.

Harza, JRV Group. 1998. *Jordan Rift valley integrated development study. Red Sea-Dead Sea canal project.* Pre-feasibility Report. Volume 1-Main Report.

HKJ (Hashemite Kingdom of Jordan), Ministry of Agriculture. 2001. *Agricultural sector development program 2001-2010.* Amman. 43p. Amman, Jordan: Ministry of Agriculture.

HKJ, Jordan Valley Commission. 1972. *Rehabilitation and development plan of Jordan Valley East Bank 1973-1975.* Amman, Jordan: Jordan Valley Commission.

HKJ, MWI, GTZ. 2004. Water Sector Planning Support Project (WSPSP). Amman, Jordan: Ministry of Water and Irrigation.

HKJ, MWI, Gesellschaft für Technische Zusammenarbeit (GTZ). 1993. *Study for the recovery of operation and maintenance costs of irrigation water in Jordan* HKJ, MWI. 1995. *Water supply and demand projections 1995-2020.*

HKJ, MWI. 1997a. *Water utility policy.* Amman, 14p. Amman, Jordan: Ministry of Water and Irrigation.

HKJ, MWI. 1997b. *Jordan's water strategy.* Amman, 7p. Amman, Jordan: Ministry of Water and Irrigation.

HKJ, MWI. 1998a. *Study on strategic aspects of irrigation water management in the Jordan Valley.* JVA, GTZ. Amman, Jordan: Ministry of Water and Irrigation.

HKJ, MWI. 1998b. *Groundwater management policy.* Amman, 7p. Amman, Jordan: Ministry of Water and Irrigation.

HKJ, MWI. 1998c. *Wastewater management policy.* Amman, 10p. Amman, Jordan: Ministry of Water and Irrigation.

HKJ, MWI. 1998d. *Irrigation water policy.* Amman, 8p. Amman, Jordan: Ministry of Water and Irrigation.

HKJ, MWI. 2000. *Strategic issues facing the Jordan Valley Authority.* Amman, Jordan: Ministry of Water and Irrigation.

HKJ, MWI. 2002. *Water sector planning and associated Investment Program 2002-2006.* Amman, 107p. Amman, Jordan: Ministry of Water and Irrigation.

HKJ, MWI. 2002. *Water sector planning and associated Investment Program 2002-2011.* Amman. Amman, Jordan: Ministry of Water and Irrigation.

HKJ, MWI. 2003. *Water economics update.* ECO-consult document. Amman. Amman, Jordan: Ministry of Water and Irrigation.

HKJ, MWI, JVA. 1980. *An interim evaluation of the Jordan Valley development effort: 1973-1980.* Amman: Ministry of Water and Irrigation.

HKJ, MWI, JVA. 2002. *2003-2008 Strategic Plan.* Amman: Ministry of Water and Irrigation.

HKJ, MWI, JVA. 1987. *The Jordan Valley Development. The plans, the achievements, future activities.* Amman, Jordan: Ministry of Water and Irrigation.

HKJ, MWI, JVA 1988. *The Jordan Valley dynamic transformation 1973-1986.* TECH LOUIS BERGER-JVA, Amman. 217p. Amman, Jordan: Ministry of Water and Irrigation.

HKJ, MWI, JVA.2000. *Jordan Rift Valley Improvement Project*-Project Identification. Amman. 217p. Amman, Jordan: Ministry of Water and Irrigation.

HKJ, MWI, WAJ. 2004. *Feasibility study for the reuse of treated wastewater in irrigated agriculture in the Jordan valley.* Project financed by the KFW, in cooperation with GITEC Consult GmbH, AHT International GmbH and Consulting Engineering Centre.

Hof, F. C. 1998. Dividing the Yarmouk's waters: Jordan's treaties with Syria and Israel. *Water Policy* 1: 81–94. 1998.

Hussein, I. A. J. 2002. Water planning in Jordan: Future scenarios. *Water International* 17 (4): 468–475.

Ionides, M. J. 1939. *Report on water resources of Transjordan and their development.* London: G.S Blake.

ISPAN (Irrigation Support Project for Asia and the Near East) documentation. 1994, November. *Irrigation management and water quality in the Central Jordan valley.* Amman, Jordan: USAID.

Jabarin, A. 2001. *Curtailment of groundwater use for irrigated agriculture in the Amman-Zarqa basin uplands: A socio-economic analysis.* MWI and USAID-WRPS, 2001.

Jaber, J.; Mohsen, M. 2001. Evaluation of non-conventional water resources supply in Jordan. *Desalination* 136: 83–92. 2001.

JICA (Japan International Cooperation Agency) study team. 2001a. *Understanding of present conditions of water resources management in Jordan.* JICA 2nd Seminar April, 2001.

JICA. 2004. *The study on water resources management in the Hashemite Kingdom of Jordan.* Draft Report Vol. I & II + Annexes. Prepared for the Ministry of Water and Irrigation, Amman-Jordan. Tokyo, Japan: Yachiyo Engineering Co. Ltd.

Joffé, G. ed. 2002. *Jordan in transition, 1990–2000*. London: Hurst and Company.

Jridi, A. 2002. *The development of the Jordanian Jordan river basin: The main historical steps*. Rapport de stage ENGREF. 34p.

Keller, J.; Keller, A.; Davids, G. 1998. River basin development phases and implications of closure. *Journal of Applied Irrigation Science* 332: 145–164.

Khouri, R. G. 1981.*The Jordan valley: Life and society below sea level*. London and New York: Longman.

Klein, M. 1998. Water balance of the Upper Jordan river basin. *Water International* 23 (4): 244–248.

Kolars, J. 1992. Water Resources of the Middle East. *Canadian Journal of Development Studies*. Special Issue. pp.107-108.

Kolars, J. 1995. Observations regarding water sharing and management: An intensive analysis of the Jordan river basin with reference to long-distance transfers. *Water Resources Development* 11:4.

Lancaster, W. 1999. *People, land, and water in the Arab Middle East*. Amsterdam: Harwood Academic Publishers.

Lavergne, M. 1996. *La Jordanie.* Paris: Karthala.

Loyer, D.; Pires, Jean-Claude. 2004. Jordanie-Gestion des ressources en eau. Compte rendu de la mission d'identification de TEN du 13 au 18 mars 2004.

Macoun, A.; El-Naser, H. Date unknown. *Groundwater resources management in Jordan: Policy and regulatory issues.* Personal communication.

McCornick, P.G.; Grattan, S. R.; Abu-Eisheh, I. 2003. Water quality challenges to irrigated agriculture productivity in the Jordan Valley. In *Water for a sustainable world – Limited supplies and expanding demand. Proceeding from the Second International Conference on Irrigation and Drainage, United State Commission on Irrigation and Drainage Conference, Phoenix, AZ, USA,* ed. A.J. Clemmens and S.S. Anderson.

McCornick, P. G.; Taha, S. S. E.; El Nasser, H. 2002. *Planning for reclaimed water in the Amman-Zarqa basin and Jordan valley.* American Society of Civil Engineering - Environmental and Water Resources Institute, Conference and Symposium on Droughts and Floods, Roanoke, Virginia, USA.

McCornick, P.; Haddadin, M.; Sabella. 2001. *Water reuse options in the Jordan valley.* Water Reuse Component, Water Policy Support Activity, USAID, Amman, Jordan: USAID.

MEDAGRI (Mediterranean Agriculture). *Yearbook of agricultural and food economies in the Mediterranean and Arab countries.* CIHEAM-IAMM. 1995, 1998, 2003.

Mimi, Z. A.; Sawalhi, B. I. 2003. A decision tool for allocating the waters of the Jordan river basin between all riparian parties. *Water Resources Management* 17: 447–461.

Ministry of Agriculture, Hashemite Kingdom of Jordan. 2002. *National strategy for agricultural development*. Amman, Jordan: Ministry of Agriculture.

Molden, D.; Amarasinghe, U.; Hussain, I. 2001a. *Water for rural development.* Background paper on water for rural development prepared for the World Bank. IWMI Working Paper No. 32. Colombo, Sri Lanka: International Water Management Institute.

Molden, D. 1997. *Accounting for water use and productivity.* SWIM Paper 1. Colombo, Sri Lanka: International Irrigation Management Institute.

Molden, D.; Sakthivadivel, R.; Samad, M. 2001b. Accounting for changes in water use and the need for institutional adaptation. In *Intersectoral management of river basins: Proceedings of an international workshop on "Integrated Water Management in Water-Stressed River Basins in Developing Countries: Strategies for Poverty Alleviation and Agricultural Growth," Loskop Dam, South Africa, 16-21 October 2000.* ed. C. L. Abernethy, 73–87. Colombo, Sri Lanka: International Water Management Institute; Deutsche Stiftung für Internationale Entwicklung.

Molle, F. 2003. *Development trajectories of river basin: A conceptual frame*work. Research Report No. 72, Comprehensive Assessment of Water Management in Agriculture. Colombo, Sri Lanka: International Water Management Institute.

Molle, F.; Mollinga, P. 2003. Water poverty indicators: Conceptual problems and policy issues. *Water Policy* 5(5).

Molle, F.; Turral, H. 2004. Demand management in a basin perspective: Is the potential for water saving overestimated? Paper prepared for the International Water demand Management Conference, June 2004, Dead Sea, Jordan.

Nachbaur, J. W. 2004. The Jordan river basin in Jordan: Impacts of support for irrigation and rural development. MREA Working Paper. Amman: French Regional Mission for Water and Agriculture. 50p.

Ohlsson, L. 1998. Water and social resources scarcity, an Issue Paper Commissioned by FAO-AGLW. Roma: Food and Agriculture Organization.

Orthofer, R. 2001. *Land use and water use in the Jordan valley*. *Workshop: water, land, agriculture, and policies in the Mediterranean workshop.* Brussels: Joint Research Center, Institute for Prospective Technology Studies, 19-20 Apr 2001.

Orthofer, R. 2001. *Options for a more sustainable water management in the Lower Jordan valley. Workshop: "*Rewriting the Water History in Palestine," Oxford Environment Week, Environmental Change Institute, Oxford University, October 24, 2001.

Orthofer, R.; Daoud, R.; Fattal, B.; Ghanaye, M.; Isaac, J.; Kupfersberger, H.; Safar, A.; Salameh, E.; Shuval, H.; Wollman, S. 2001. *Developing sustainable water management in the Jordan valley*. European Commission, DG Research, Final Project Report, Project ERBIC18CT970161. August 2001.

Orthofer, R.; Loibl, W. 2002. Nitrate water pollution risk in the Lower Jordan valley. In *Water resources quality. Preserving the quality of our water resources, Chapter 13,* ed. H. Rubin; P. Nachtnebel; J. Fuerst; U. Shamir. . Berlin: Heidelberg. New York: Springer 230-243.

Orthofer, R.; Lipchin, C.; Isaac, J.; Daoud, R.; Trottier, J. 2004. The "Dead Sea" Project: *Is a more sustainable water management in the Dead Sea Basin possible?* MEDAQUA II. The INCO-MED Water Conference, 14-15 Jun 2004, Amman, Jordan. Online at: http://217.160.142.135/MedressaCDB/Conferences/Amman2004/ProceedingsFrameset.asp.

PASSIA (The Palestinian Academic Society for the Study of International Affairs). 2001. *Jordan River Basin (Water Balance and Uses).* Jerusalem: PASSIA.

Peace Treaty between the Hashemite Kingdom of Jordan and the State of Israel. October 26, 1994.

Perry, C. J. 1996. *The IIMI water balance framework: A model for project level analysis*. Research Report 5. Colombo, Sri Lanka: International Irrigation Management Institute.

Petitguyot, T. 2003 October. *Water consumptions and available resources: How to improve JVA allocation system in TO 41 north scheme?* ENGREF, MREA Working Paper. Amman: French Regional Mission for Water and Agriculture.

QAISI, K. 2001. Jordan Valley Improvement Project Phase A-Report 8. Environmental Aspects. The Hashemite Kingdom of Jordan, Ministry of Water and Irrigation, Jordan Valley Authority, 2001.

Qasem, R. 1995. Land tenure in the Jordan Rift valley. In *Future adjustment of the agricultural production systems in the Jordan Rift valley*. Amman: GTZ & OIAD.

Ramsar Bureau. 1998. *Update on the Azraq oasis, Jordan.* Ramsar Convention Bureau.

Richards, A. 1993. Bananas and Bedouins: Political economy issues in agricultural sector reform in Jordan. Democratic Institutions Support DIS Project, USAID. Memorandum Paper.

Ruf, T.; Mathieu, P. 2001. Water rights and the institutional dynamics of irrigated systems: between state, market and community action. Introduction for the *Special Issue of The International Journal of Water* 1-3-4, 2001, pp. 243-249.

Salameh, E.; El-Naser, H. 2000. Changes in the Dead Sea level and their impacts on the surrounding groundwater bodies. *Acta Hydrochimica et Hydrobiologica* 28: 24–33.

Salameh, E.; Bannayan, H. 1993. *Water resources of Jordan: Present status and future potentials.* Royal Society for the Conservation of Nature/Friedrich Ebert Stiftung. 183p.

Salameh, E. 1996. *Water quality degradation in Jordan: Impact on environment, economy and future generation resources base.* Royal Society for the Conservation of Nature/Friedrich Ebert Stiftung. 179p.

Salameh, E.; Daoud, R. 2000. *Analysis and review of the prospects of implementing a differential irrigation water pricing/tariff system in the Jordan Rift valley*. Technical Report. International Development Research Center.

Salman, A. 2001. *Jordan Rift valley improvement project phase a — Report 5: Agricultural economics*. MWI, JVA.

Salman, A.; Al-Karablieh, E. 2004. Measuring the willingness of farmers to pay for groundwater in the highlands areas of Jordan. *Agricultural Water Management* 68 (1): 61–76.

Salman, A.; Khamis, R.; Mohammad, S.; Hussein, Al-Qudah. Date unknown. The economics of groundwater use in agriculture under different water prices and supply regimes in the upland area of Jordan. In *Water valuation and cost recovery mechanisms in the developing countries of the Mediterranean region*, ed. A. Hamdy; C. Lacirignola; N. Lamaddalena. Bari: CIHEAM-IAMB, 2002. pp. 177-190.

Scott, C. A.; El-Naser, H.; Hagan, R. E.; Hijazi, A. 2003. Facing water scarcity in Jordan: Reuse, demand reduction, energy and transboundary approaches to assure future water supplies. *Water International* 28 (2): 209-216.

Shatanawy, M.; Salman, A. Date unknown. *Impact of full cost recovery of irrigation water on the farming system economics in the Jordan valley*. World Bank document.

Soffer, A. 1994a. The relevance of Johnston plan to the reality of 1993 and beyond. In *Water and Peace in the Middle East,* ed. J. Isaac; H. Shuval. Amsterdam: Elsevier.

Soffer, A. 1994b. Rivers of Fire. Am Oved-State of Israel, Water Commission. Development, Use, and the Condition of Groundwater Resources in Israel until autumn 1993. Jerusalem, Israel: Ministry of Agriculture, Hydrological Service.

Speetjens, P. 2004. *Oasis town of Azraq is symbolic of Jordan's unquenchable thirst*. The Daily Star, April 7, 2004.

Spencer, J. N. 1958. *Development principles for the East Ghor Canal Scheme*. Washington: US Department of the Interior, Bureau of Reclamation.

Strzepek, K.; Molden, D.; Galbraith, H. Date unknown. *Comprehensive global assessment of costs, benefits and future directions of irrigated agriculture: A proposed methodology to carry out a definitive and authoritative analysis of performance, impacts and costs of irrigated agriculture.* Dialogue on Water Food and Environment, Working Paper 3. Colombo, Sri Lanka: International Water Management Institute.

Suleiman, R. 2002. Privatization of Jordan's capital water utility: Assessment and evaluation of water supply and wastewater services of Amman Governorate. TRITA-LWR Master Thesis. Stockholm.

Suleiman, R. 2004. *The historical evolution of the water resources development in the Jordan river basin in Jordan*. MREA-IWMI Working Paper. Amman: French Regional Mission for Water and Agriculture.

Taha, S.; Richard, A.; Klaus, J.; Edward, Q. 2001. *Evapotranspiration and irrigation water requirements for Jordan's National Water Master Plan: GIS-based ET Calculations.* Abstract for presentation in USCID, July 10-13, 2002, San Luis Obispo, California.

Taha, S.; Bataineh, F. 2002. *Water valuation, the case of Jordan: Valuation of water for domestic use.* Beirut, Lebanon: Water Demand Management Forum, June 2002.

Taminian. Economic and Social Commission for Asia-Pacific 1990. *Part time farming, agricultural development in the Zarqa river basin*. Irbid, Jordan: Institute of Archaeology and Anthropology, Yarmouk University.

Tessier du Cros, M.; Vallin, B. 2001. Analyse diagnostique de l'agriculture du nord de la vallée du Jourdain, rive jordanienne. Rapport de fin d'étude INA P-G. Paris: Institut National Agronomique de Paris-Grignon.

The Hashemite Kingdom of Jordan, DoS (Department of Statistics). (1978-2003). *Statistical Yearbook-Different Volumes.* 1978, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003. Amman, Jordan: Department of Statistics.

The Hashemite Kingdom of Jordan, Dept. of Statistics, Annual Agricultural Statistics, 1995, 2000, 2001, 2002. Amman, Jordan: Dept. of Statistics.

THJK (The Hashemite Kingdom of Jordan). 1977. German Agency for Technical Cooperation. *National water master plan.* Amman, Jordan: Ministry of Water and Irrigation & German Agency for Technical Cooperation.

THJK (The Hashemite Kingdom of Jordan). 2004. German Agency for Technical Cooperation. *National water master plan.* Jordan.

The Hashemite Kingdom of Jordan. Ministry of Water and Irrigation. 2002. *Underground water control by-law. By-law No. 85 of 2002.* Amman, Jordan: Ministry of Water and Irrigation.

UNESCO (United Nations Educational, Scientific and Cultural Organization). 1972. *Convention on wetlands of international importance especially as waterfowl habitat.* Iran: Ramsar, UNESCO. Iran, 1971, as amended in 1982 and 1987.

Van Aken, M. 2003. *Facing home: Palestinian belonging in a valley of doubt*. Amman, Jordan: Shaker publishing.

Van Aken, M. 2004. *Social and cultural aspects of current and future governance for the management of water resources in the Jordan river valley*. MREA Working Research Paper. French Regional Mission for Water and Agriculture.

Venot, Jean-Philippe. 2004c. Changes in water management and irrigated agriculture in the Lower Jordan river basin in Jordan - A technical review of irrigated farming systems: Present situation and impacts of the water management changes in prospect. Main report-Technical Approach. Working Paper INA P-G, MREA, IWMI. Masters' thesis.

Venot, Jean-Philippe. 2004a. *Reclamation's history of the Jordan river basin in Jordan, a focus on agriculture: Past trends, actual farming systems and future prospective.* Vol. 1 to 4 and appendixes. MREA/INA P-G. Internship report-updated version.

Venot, Jean-Philippe. 2004b. *Water management and agriculture in Jordan: Impacts of water-scarcity-context policies on the Jordanian agriculture. Complementarity of the farming-system and the river-basin-scale approaches-context, global issues and methodology of the study*. Bibliographical Paper. Working Paper INA P-G, MREA, IWMI. Amman: French Regional Mission for Water and Agriculture.

Wolf, A. 1993. Water for peace in the Jordan river watershed. *Natural Resources Journal* 33: 797–839.

Wolf, A.; Hamner, J. 2000. Trends in transboundary water disputes and dispute resolution. In *Green Cross International, Water for Peace in the Middle East and Southern Africa,* Geneva.

World Bank. 1999. December. *Jordan agricultural development project*. Final report. Study by Agridev-Agricultural Development Company.

World Bank. Rural Development Water and Environment Department Middle East and North Africa Region. 1997. The Hashemite Kingdom of Jordan. *Water Sector Review*. Vol. 1: Main report and annexes A-B, Vol 2: Annexes C-N.

Research Reports

1. *Integrated Land and Water Management for Food and Environmental Security.* F.W.T. Penning de Vries, H. Acquay, D. Molden, S.J. Scherr, C. Valentin and O. Cofie. 2003.

2. *Taking into Account Environmental Water Requirements in Global-scale Water Resources Assessments.* Vladimir Smakhtin, Carmen Revenga and Petra Döll. 2004.

3. *Water Management in the Yellow River Basin: Background, Current Critical Issues and Future Research Needs.* Mark Giordano, Zhongping Zhu, Ximing Cai, Shangqi Hong, Xuecheng Zhang and Yunpeng Xue. 2004.

4. *Does International Cereal Trade Save Water? The Impact of Virtual Water Trade on Global Water Use.* Charlotte de Fraiture, David Molden, Mark Rosegrant, Ximing Cai and Upali Amarasinghe. 2004.

5. *Evolution of Irrigation in South and Southeast Asia.* Randolph Barker and François Molle. 2004.

6. *Macro Policies and Investment Priorities for Irrigated Agriculture in Vietnam.* Randolph Barker, Claudia Ringler, Nguyen Minh Tien and Mark Rosegrant. 2004.

7. *Impacts of Irrigation on Inland Fisheries: Appraisals in Laos and Sri Lanka.* Sophie Nguyen-Khoa, Laurence Smith and Kai Lorenzen. 2005.

8. *Meta-Analysis to Assess Impact of Watershed Program and People's Participation.* P.K. Joshi, A.K. Jha, S.P. Wani, Laxmi Joshi and R.L. Shiyani. 2005.

9. *Historical Transformations of the Lower Jordan River Basin (in Jordan): Changes in Water Use and Projections (1950–2025).* Rémy Courcier, Jean-Philippe Venot and François Molle. 2005.

COMPREHENSIVE
Assessment
of water management
in agriculture

Postal Address: IWMI, P O Box 2075, Colombo, Sri Lanka **Location:** 127 Sunil Mawatha, Pelawatte, Battaramulla, Sri Lanka
Telephone: +94-11 2787404, 2784080 **Fax:** +94-11 2786854
Email: comp.assessment@cgiar.org **Website:** www.iwmi.org/assessment

ISSN 1391-9407
ISBN 92-9090-609