CHAPTER 1

CLOSING THE (WIDENING) GAP BETWEEN NATURAL WATER RESOURCES AND WATER NEEDS IN THE JORDAN RIVER BASIN: A LONG-TERM PERSPECTIVE

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The supply of renewable natural water available in a sustainable fashion in the Jordan River Basin (JRB), comprising Israel, Jordan, and the Palestinian Authority (PA), will soon drop below 100 cubic meters (m^3) per person per year. Drawing on recent technological progress and policy innovations, a comprehensive policy to address the region's water problems in the long run is offered. The policy has a dual goal: to satisfy the needs of a growing population (domestic, irrigation, and industry) and to preserve important environmental amenities, including restoration of the lower Jordan River (LJR) and stabilization of the Dead Sea. The gap between natural water supplies and the basic needs of the growing population will be closed by conservation and desalination; at the same time, all domestic water will be recycled and will be available for reuse in irrigation and environmental restoration. Over time, the supply of recycled water that *should* be allocated for environmental restoration (accounting for the compensation of irrigators) will suffice to partially restore the LJR and contribute to the stabilization of the Dead Sea. The analysis is relevant in a wide range of real-world situations, where satisfying the basic needs of a growing population and preserving environmental amenities become critical.

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1.1. Introduction

The average supply of natural water available in a sustainable fashion (without systematically drawing down water stocks) in the JRB, comprising Israel, Jordan, and the PA, will soon drop below 100 m³ per person per year. As a result, extensive diversions from natural sources have led to the deterioration, if not complete demolition, of natural stream flows and ecosystems. Two prominent environmental “victims,” shared by the three parties, are the LJR and the Dead Sea: the LJR’s flow has been reduced to a trickle of mostly brackish water and partially treated sewage and its historically rich ecosystem no longer exists (Gafny *et al.*, 2010); the Dead Sea level has been declining at a rate exceeding 1 m per year with far reaching detrimental consequences to its surrounding environment (Becker and Katz, 2009; Tahal and Geological Survey of Israel, 2011; Rawashdeh *et al.*, 2013). In this chapter, we propose a comprehensive policy to address the water problems of the JRB in the long run. The policy has a dual goal: first and foremost, to satisfy the essentials of the growing population in subsistence (drinking, hygiene) as well as agricultural (irrigation) and industrial production; and second, to maintain an acceptable level of environmental amenities, including partial restoration of the LJR and stabilization of the Dead Sea level. The proposed policy draws on recent technological progress and policy innovations. The analysis is relevant in a wide range of real-world situations, where the limited water resources make the dual goal of satisfying the needs of a growing population and preserving environmental amenities — a critical problem.

Water scarcity is a fuzzy and complex concept because of the “liquid” nature of the resource, which often exhibits large temporal and spatial variability, variation in quality, and dependence on idiosyncratic climate conditions (e.g., evapotranspiration). At the root level, water scarcity has to do with the availability of water needed to satisfy human livelihoods, including drinking, washing, and

food production as well as environmental preservation. The ability to satisfy these needs depends both on the available quantity of renewable, natural water as well as on how this water is managed. A region can experience abundance of water some of the time (e.g., in the winter or monsoon periods) and a severe shortage in other times (e.g., in the summer or dry periods) and water shortage depends also on demand management and on the ability to transfer water across time and across space (from water-abundant periods/locations to water-scarce periods/locations), requiring, *inter alia*, storage and conveyance facilities. It is thus understandable that multiple indices of water scarcity exist with no consensus regarding which one to use in any given circumstance (discussions of the different water scarcity indicators can be found in Rijsberman [2006], Gleick [2002], and references they cite).

These qualifications notwithstanding, a rough and widely used index of water scarcity is the supply of renewable (i.e., available in a sustainable fashion) natural water suitable for human use, measured in units of cubic meters per person per year. Widely accepted measures of water scarcity defined by this index are due to Falkenmark *et al.* (1989). Based on estimates of water requirements for households, agricultural, industrial, and environmental needs, Falkenmark *et al.* (1989) proposed the following thresholds: regions whose renewable water supplies fall below 1700, 1000, or 500 m³ per person per year are said to experience *water stress*, *water scarcity*, or *absolute scarcity*, respectively. The threshold of 100 m³ per person per year is often mentioned as the water supply needed to satisfy basic human needs (Gleick, 1996) and we call this threshold *subsistence scarcity*. Water scarcity measures based on annual supplies of natural renewable water available per person are popular because their calculation requires data that are often available. Notice that these indices change over time due to population growth.

We begin in the next section with a description of the water scarcity situation in the JRB and its projected time evolution. We shall see that the region as a whole will soon suffer from subsistence scarcity, and parts of it have already entered this phase. In Section 1.3, we discuss recent technological progress in desalination

and policy innovations that have been used to deal with water scarcity in Israel and show in Section 1.4 how these policies underline the basic principles of a comprehensive solution to the water shortage problem in the region. Section 1.5 discusses how the environmental goals of partially restoring the LJR (the stretch of the river between Lake Tiberias-Kinneret and the Dead Sea) and stabilizing the Dead Sea level can be incorporated within this comprehensive water policy. Section 1.6 concludes.

1.2. Water Scarcity in the JRB

We consider the part of the JRB that comprises Israel, Jordan, and the PA (see Fig. 1.1).¹ The situation of the three parties is not symmetric: while Israel and Jordan are free to set their water policies, the PA is limited as it does not yet possess the same state status. While this political obstacle has consequences regarding feasible water policies in the short run, one hopes that it will be resolved and once this happens, these (short term) restrictions will no longer be effective. As this work takes a long-term perspective (as the title suggests), current political restrictions and mutual mistrusts among the parties are ignored and the emphasis is on what *could* be done under collaborative political conditions.

1.2.1. *Water Resources*

We discuss first the water resources of Israel and the PA jointly, followed by the water resources of Jordan.

1.2.1.1. *Water resources in Israel and the PA*

Table 1.1 presents average recharge into the main water sources west of the Jordan River for the periods 1976–1992 and 1993–2009. It also gives the quantities of brackish water recharge, where brackish water refers to water with chloride concentration above

¹The JRB contains also parts of southern Lebanon and southwest Syria. Due to lack of data on these regions, they will not be included in this study.

Figure 1.1: The JRB. The upper Jordan River extends between its headwater (at the confluence of the Dan, Baniyas, and Hatzbani) and Lake Tiberias-Kinneret. The LJR is the southern stretch of the river between Lake Kinneret and the Dead Sea.
Source: United Nations Environment Programme (http://www.grid.unep.ch/products/4_Maps/jordanb.gif).

Table 1.1: Average annual recharge (MCM/y) of main water sources west of the Jordan River and the share of brackish water (with chloride concentration above 400 mg/L).

Basin	1976–1992		1993–2009	
	Average Recharge	Brackish	Average Recharge	Brackish
Kinneret	623	18	540	14
Coastal	252	124	232	116
Western Mountain	369	0	333	0
Eastern Mountain	211	0	174	0
NortheastMountain	151	0	134	0
Lower Galilee	30	6	26	6
Western Galilee	139	30	132	30
Carmel	42	15	40	15
Negev andArava	32	28	32	28
Gaza	44	31	40	23
Total	1893	252	1683	232

Source: Weinberger *et al.* (2012).

400 mg/L. To obtain quantities of fresh water recharge (with chloride concentration below 400 mg/L) one needs to subtract the brackish from the average, for example, the total average recharge of fresh water during 1993–2009 was $1683 - 232 = 1451$ million cubic meters per year (MCM/y).² Figure 1.2 provides a map view of Table 1.1. These are the quantities of natural water available to Israel and the PA on a sustainable fashion. Brackish water is unsuitable for drinking and when used for irrigation often requires mixing with good quality water to reduce salinity.

Figure 1.3 shows the actual realizations of natural recharge for the period 1976–2009. It illuminates two features of renewable water resources in the JRB: high (temporal) fluctuations and a declining trend. Part of the declining trend (of 8.92 MCM/y) could be the result of climate change processes.

²The breakdown into subperiods in Table 1.1 shows temporal changes of water recharge, which could be the result of climate trends.

Figure 1.2: Average renewable (natural) supplies (with chloride concentration <400 mg/L), based on the 1993–2009 data of Table 1.1 (numbers in parenthesis give brackish water — with chloride concentration >400 mg/L).

Source: Weinberger *et al.* (2012).

1.2.1.2. Water resources in Jordan

Table 1.2 presents Jordan's renewable water resources. The total average supply of renewable natural water in Jordan is 745 MCM/y on average.³

³The total of 745 MCM/y in Table 1.2 also includes brackish water (with chloride concentration above 400 mg/L). As the share of brackish water is not clearly indicated, it will not be subtracted from the total supplies, as was done for Israel and the PA earlier. It is thus likely that the total supply of 745 MCM/y overestimates the natural supplies of fresh water in Jordan.

Figure 1.3: Actual observations of total natural water recharge of all major water sources (including brackish water) west of the Jordan River during the period 1976–2009.

Source: Weinberger *et al.* (2012).

Table 1.2: Jordan’s renewable water resources.

Source	MCM/y
Groundwater (safe yield)	275
Surface water (by 2022)	365
Artificial recharge (in 2007)	55
1994’s peace treaty (from Lake Kinneret)	50
Total	745

Source: Hashemite Kingdom of Jordan’s Ministry of Water and Irrigation (2010, Executive Summary, p. 7).

1.2.1.3. *Water resources in the JRB*

The average supply of renewable natural water in the JRB (available to Jordan, Israel, and the PA in a sustainable fashion, i.e., without drawing down stocks) is therefore 2428 (1683 + 745) MCM/y, of which (at least) 232 MCM/y is of brackish quality (with chloride

concentration exceeding 400 mg/L, unsuitable for drinking and for irrigation of many crops without mixing). The annual supply of renewable, fresh natural water (with chloride concentration below 400 mg/L) available in the JRB is therefore 2196 (=1683 – 232 + 745) MCM/y on average.

1.2.2. Population and Per Capita Water Supplies

Figure 1.4 presents actual (up to 2011) and projected populations of Israel, Jordan, and the PA from 1950 to 2050.

Dividing the annual natural water supplies of 2196 MCM/y by the population gives the per capita annual water supplies, presented in Table 1.3.⁴

As Table 1.3 reveals, the region as a whole is already far below the absolute scarcity mark of 500 m³ per person per year and within two decades will cross the subsistence scarcity mark of 100 m³ per

Figure 1.4: Actual (until 2011) and projected population (million).

Source: United Nations (2011).

⁴The average per capita water supplies presented in Table 1.3 mask a considerable spatial variability among the three parties, with Jordan suffering the most acute water shortage.

Table 1.3: Population and per capita supplies of natural water in the JRB. The latter is obtained by dividing natural water supply (2196 MCM/y) by the population.

Year	Population (million)	m ³ /person/year
2013	18.8	117
2030	25.0	88
2050	31.6	69

person per year. At such an acute scarcity, the problem of allocating natural, potable water becomes also a human right issue, implying that any water allocation policy in the region should give priority to the supply of domestic (potable) water. Increasing the allocation of domestic water can be achieved by reallocating water from irrigation or by introducing new water supplies or a combination of these. In the next section, we describe recent experience of Israel's water policy, which can serve as a guide for water policy in the regions as a whole.

1.3. Dealing with Water Scarcity: Israel's Experience

Water scarcity in Israel has been addressed by demand management aimed at improved conservation and efficiency of water use, and by supply management through augmenting water supplies in the form of desalinated and recycled water. We discuss demand and supply measures in turn.

1.3.1. Demand Management

Policy measures aimed at affecting water demand must rely in one way or another on a combination of water pricing and water quotas and these tools have always been the foundations of Israel's water policy (see Tsur [2009] for a discussion of water pricing in general, and Kislev [2011] for a detailed account of water pricing in Israel). The efficacy of strict volumetric pricing of domestic water is demonstrated in Fig. 1.5, which presents domestic water consumption during the period 1996–2011. As the figure shows, domestic water consumption increased more or less in proportion with the population growth until 2007, reaching a peak of 767 MCM

Figure 1.5: Domestic water consumption (MCM/y) in Israel during 1996–2011.

Source: Israel Water Authority (2011). Water consumption by sectors: 1996–2011 (in Hebrew). Available at: <http://www.water.gov.il/Hebrew/ProfessionalInfoAndData/Allocation-Consumption-and-production/20112/1996-2011.pdf>.

in that year. Thereafter, it decreased to 665 MCM in 2011 — a decline of more than 10% or 100 MCM/y (the equivalent of a large-scale desalination plant). As population continues along its secular growth trend, water consumption per person has decreased even more drastically. What happened in 2007 that led to such a shift in domestic water consumption?

A number of measures are responsible for this shift. First, Israel's Water Authority was formed in 2007 as an independent, statutory regulatory body with authority to set extraction permits and water prices in all sectors.⁵ Second, municipal water management shifted from the municipalities (city, regional, and local councils) to Water Corporations. Third, 2007 was the third winter in a sequence of five of

⁵Prior to 2007, water policies were spread over a number of agencies and committees: the Water Commission (the agency that preceded the Water Authority) was responsible for protecting the natural water resources, thus providing extraction permits; a Knesset (Parliament) committee was responsible for setting prices in various sectors; and a number of governmental committees for allocating quotas (see Kislev, 2011).

below average precipitation (see Fig. 1.2). These three events have led to a number of interventions. First, domestic water prices increased sharply to reflect the cost of water supply (including scarcity cost).⁶ Second, the transfer of the management of municipal water to Water Corporations has reduced water loss (due to leakage or theft) and improved collection of water fees from users. Third, the prolonged period of below-average rainfall has increased the public awareness for the need to reform the water sector and was conducive to the implementation of drastic measures to conserve water and improve management.

These three processes combined have acted to reverse the domestic water consumption trend, as seen in Fig. 1.5. This episode illuminates the importance of demand management tools: an effective implementation of a number of demand measures (strict volumetric pricing, effective management practices, reduced leakage, and unaccounted water) resulted in water-saving equivalent to the quantity produced by a large-scale desalination plant.

Similar processes took place in Israel's agriculture, albeit more gradually. Figure 1.6 shows trajectories of two price indices during the period 1952–2011 (adjusted for consumer price index): the price index of natural, fresh (nonbrackish) water in agriculture; and a price index of agricultural output (crop prices). The crop price declined moderately until the late 1990s and has been stable since then. The water price index, on the other hand, has increased fivefold during this period, with a sharp increase following the early 1990s. This price trend has led to a decline in the demand for irrigation water from fresh, natural sources and accelerated the transition of Israel's agriculture to recycled water (see Fig. 1.7).⁷

⁶A description of municipal water tariffs during 1975–2008 can be found in Kislev (2011, pp. 62–72). Current rates can be found in the Water Authority's tariffs book (in Hebrew) at <http://www.water.gov.il/Hebrew/Rates/DocLib1/prices-books-1.1.14.pdf>.

⁷The actual water prices are based on historical (1986–1987) quotas, where actual quotas are adjusted each year according to precipitation, with a base rate that applies up to a certain percentage of the quota and add on fees for deviations (details can be found in the above-cited water tariffs book).

Figure 1.6: Trajectories of the price indices of natural (nonbrackish) water in agriculture and of crop prices during 1952–2011 (1952 = 100, adjusted for consumer price index).

Source: Kislev and Tzaban (2013).

1.3.2. Supply Management

In addition to the above-mentioned demand management measures, the supply of water has been increased by the development of recycling and desalination. We discuss each in turn.

1.3.2.1. Recycling

Figure 1.7 shows the water allocation in Israel's agriculture sector during the period 1996–2011. As the figure reveals, the allocation of natural water to agriculture has reduced from 892.3 MCM in 1996 to 413.7 MCM in 2011 — a decline of 54%. At the same time, the supply of recycled water increased from 270 MCM in 1996 to 414.8 MCM in 2011. Israel's growers now use more recycled water than natural water and this trend (of replacing natural water by recycled and brackish water) is ongoing.

The direct effect of reallocating natural water from agriculture to households is to increase the supply of (potable quality) domestic water. However, each cubic meter reallocated to households provides 0.6–0.65 m³ of recycled water that in turn is allocated

Figure 1.7: Water allocation in Israel's agriculture during 1996–2011 (brackish refers to water with chloride concentration above 400 mg/L).

Source: Israel Water Authority (2011). Water consumption by sectors: 1996–2011 (in Hebrew). <http://www.water.gov.il/Hebrew/ProfessionalInfoAndData/Allocation-Consumption-and-production/20112/1996-2011.pdf>.

to irrigation.⁸ Thus, the overall effect of reallocating 1 m^3 from agriculture to households is to increase domestic supply by 1 m^3 and reduce agricultural supply by only $0.3\text{--}0.4 \text{ m}^3$. Almost all domestic and industrial water supplies in Israel are now recycled and made available to irrigation (pending conveyance facilities). Moreover, all recycling facilities are expected (required by law) to be upgraded to tertiary level by 2015, reducing the limitation on the use of recycled water for most crops.

1.3.2.2. Desalination

The cost of desalination has declined substantially during the last decade mainly due to learning by doing associated with the

⁸The conversion rates in Israel's water economy master plan range from 0.592 in 2010 to 0.64 in 2030 (Israel Water Authority, 2012, p. 14).

increased scale of installed desalination capacity. Figure 1.8 presents the desalination costs (\$/m³ at the plant's gate) of the major desalination plants in descending order. Also shown, for each plant, are the year operation began (all plants are in operation except for Ashdod, which is expected to begin operation soon) and the plant's production capacity (MCM/y). At the completion of Ashdod plant, Israel's desalination capacity will exceed 600 MCM/y, which is about 90% of the total household consumption in 2011. The desalination capacity will reduce reliance on natural water sources and allow a more sustainable management of the natural water sources, by reducing average extractions in order to increase stock levels, thereby eliminating risks such as seawater intrusion into the coastal aquifer or potentially detrimental algal bloom in Lake Kinneret. In addition, more water will be allocated for environmental purposes such as river restoration.⁹

To sum up, the recent Israeli experience emphasizes the potential of demand management measures in dealing with water scarcity. The pricing and management practices that were implemented in 2007 reduced domestic water use by more than 10% or 100 MCM/y. Regarding supply management, recycling is an immediate and relatively cheap way to increase water supply. It is cheap because of the rapid technological progress in recycling and because the alternative environmental cost of not recycling is high. A cubic meter allocated to household or industrial use can generate 0.6–0.65 m³ of recycled water suitable for irrigation and environmental restoration. Technological progress due to research and development (R&D) and learning by doing associated with increased desalination activities have led to a substantial decrease in the cost of desalination. These trends, together with the fact that the bulk of Israel's population is concentrated along the coast, imply that desalination is an economically viable source of water supply for households.

⁹See the planned fivefold increase in freshwater allocated to nature and landscape in Israel's long-term master plan of the water sector (Israel Water Authority, 2012, p. 14).

Figure 1.8: Cost of desalination (\$/m³ at the plant's gate calculated under the exchange rate: \$1 = 3.6 NIS). The numbers in parentheses give the capacity in MCM/y ($x + z$ means that the original capacity of x MCM/y has been or will soon be expanded by z MCM/y to give a total capacity of $x + z$ MCM/y).

Source: Israel Water Authority (2012).¹⁰

1.4. Managing Water Scarcity in the JRB

Is the Israeli experience relevant to Jordan and the PA? Regarding recycling, the answer is clearly in the affirmative, as recycling can be applied in Jordan and the PA in much the same way as in Israel.¹¹ This means that most of the fresh (potable) natural water should be allocated to domestic use, collected, treated, and reused in agriculture and environmental (rivers, ecosystems) restoration. The household demand over and above the natural water supplies (which increases over time due to population growth) can come from desalination plants. Regarding desalination, the case of Jordan differs

¹⁰The desalination prices are based on the original prices at the time the contracts were signed. Over time, these prices have been adjusted for inflation and changed with the capacity expansions. The prices listed in the figure, thus, should be taken as estimates.

¹¹Indeed, water reuse captures an important role in Jordan's plans for future water policy reforms (Jordan's Ministry of Water and Irrigation, 2010, Chap. 6). Regarding the PA, construction of sewage treatment plants has been delayed mainly due to political obstacles (associated with reluctance to share plants with Israeli settlements). One hopes that these obstacles will be resolved soon.

from that of Israel and the PA. I, therefore, discuss Jordan and the PA separately.

1.4.1. *Jordan*

The bulk of Jordan's population resides in the Amman area at about 1000 m above sea level and more than 300 km away from Jordan's only sea access (the Gulf of Aqaba). Desalination in Aqaba and conveyance to Amman is an expensive operation: the cost in Amman of 1 m³ desalinated in Aqaba (before distribution to households and sewage treatment) is estimated above \$2/m³ — about four times the cost of supplying desalinated water to Israel's densely populated areas (see Fig. 1.8). Moreover, discharging large quantities of brine (1 m³ of desalinated water generates about 1.22 m³ of brine) in the Gulf of Aqaba could have detrimental effects on the sensitive coral reef ecology and is objected to by the other Gulf of Aqaba's riparian states (Egypt, Saudi Arabia, and Israel). For these two reasons, desalination in Aqaba (with brine discharge in the Red Sea) and conveyance to Amman is nonviable as a comprehensive solution to Jordan's water scarcity problems in the long run.

These demographical and topographical features of Jordan imply that reallocating fresh (natural) water from irrigation to urban use requires considerable pumping. However, the cost associated with such reallocation is still lower than the cost of desalinating in Aqaba and conveyance to Amman due to the shorter distances (see World Bank, 2012). At the same time, these features are conducive to using recycled water in irrigation. This is so because conveyance of the recycled water from treatment plants near higher urban centers to lower agricultural areas (e.g., in the Jordan Valley) can be based more on gravitation and less on energy, and hence entails a lower cost.¹²

¹²The alternative cost of fresh (natural) water allocated for irrigation in Jordan is the cost urban dwellers are willing to pay for fresh water, which is very high (due to the acute shortage of potable water) and cannot be afforded by Jordanian farmers (although this is the price they *should* pay for irrigating with fresh water). On the other hand, the price of recycled water in irrigation is very low, since it consists only of the cost of conveying this water from treatment plants located

1.4.1.1. *Water management: pricing, conservation, and reduction of water loss*

Water losses from Jordan's municipal supply networks were estimated at 43%, which amounts to 137 MCM/y of total municipal allocation of 320 MCM/y (Yorke, 2013, p. 100). A reduction of water loss, through improved management and pricing practices, to internationally conventional levels would increase the supply of potable water by more than 100 MCM/y. Water tariffs for irrigation do not cover the operational costs of conveyance, let alone the fix cost of the infrastructure (Yorke, 2013, p. 46). In the Jordan Valley, for example, farmers pay an average tariff of JD 0.012/m³ (\$0.017/m³), while domestic and industrial tariffs are much higher, ranging between JD 0.250/m³, or \$0.35/m³, and JD 1.800/m³, or \$2.55/m³ (Yorke, 2013).

The existing water allocation (Jordan's Water Strategy, 2008–2022) could be changed by reallocating at least 300 MCM/y of good quality natural water from irrigation to domestic use, while fully compensating farmers with recycled water. This reallocation will increase the supply of potable water (by 300 MCM/y) and will add about 200 MCM/y of recycled water (60%–65% of the 300 MCM/y) to total water supplies that were not available before the reallocation. Overall, improved management and allocation practices could increase the supply of potable water by more than 400 MCM/y.

1.4.1.2. *Water swap*

On Monday, 9 December 2013, a memorandum of understanding was signed between Israel, Jordan, and the PA, at the World Bank's Washington headquarters, with the following basic principles: Jordan will desalinate about 80–100 MCM/y near Aqaba and discharge

near urban centers (which are mostly in higher plains) to the agricultural areas located mostly in lower plains (notice that the cost of conveying the fresh natural water to the urban centers as well as the cost of recycling should be paid by urban dwellers). Thus, reallocating fresh water to urban, recycling and reusing in irrigation are the correct way to keep the cost of irrigation water low.

the brine in the Dead Sea (to be conveyed via a pipeline).¹³ Israel will buy about 50 MCM/y from the Aqaba plant to be used in Eilat (for drinking) and the Arava valley (for irrigation) and will sell Jordan 50 MCM/y from Lake Kinneret (to be conveyed to Amman via existing conveyance facilities). The agreement also involves additional water allocation to the PA, but its main feature is a water swap between Jordan and Israel, where Israel obtains water from Aqaba's desalination and provides the same quantity from Lake Kinneret in the north. The cost of Lake Kinneret water in Amman is about \$1–\$1.2 per m³,¹⁴ which is about half the cost of the Aqaba-Amman default alternative. The potential scale of such a water swap is, however, limited by the annual flow of water into Lake Kinneret (see Weinberger *et al.* [2012], for a description of Lake Kinneret's water balance). At most it could support an additional 50 MCM/y, bringing the total amount of Lake Kinneret water allocated to Jordan to 150 MCM/y (including the 50 MCM/y supplied to Jordan following the 1994 peace treaty).

1.4.1.3. Red Sea–Dead Sea conveyance projects

A recurrent idea that has recently been studied in detail entails conveyance of water from the Red Sea (or the Mediterranean) to the Dead Sea, desalination near the Dead Sea, discharge of the brine reject in the Dead Sea, using the elevation difference (of about 350–400 m) to generate electricity, and conveyance of the desalinated water mostly to Amman (see Vardi [1990], for a survey of studies prior to 1990). The recent incarnation of this idea is the Red Sea–Dead Sea (RSDS) Conveyance Project, investigated by a suit of feasibility studies conducted under the World Bank's auspices (see Markel *et al.*, 2013, for an overview; the detailed studies can be found

¹³ As was already mentioned, discharging brine in the Gulf of Aqaba could have detrimental effects on the sensitive coral reef ecosystem and discharging the brine in the Dead Sea overcomes this obstacle. In addition, it will provide information on possible effects of mixing seawater or brine in the Dead Sea, relevant for the implementation of the RSDS project (see discussed in the following).

¹⁴ This cost consists of \$0.3–\$0.4 per m³ purchasing price plus \$0.7–\$0.8 per m³ treatment and conveyance (see World Bank, 2012).

in www.worldbank.org/rds). The RSDS project is planned to be constructed in phases over three to four decades. Upon completion, a full-scale RSDS project will convey 2000 MCM/y from the Red Sea to the Dead Sea, desalinate 850 MCM/y (near the Dead Sea), to be conveyed mostly to Amman (but also to the PA and Israel), discharge the 1150 MCM/y brine in the Dead Sea and generate electricity. A number of environmental (e.g., effects on the Dead Sea due to mixing with large quantities of brine and/or sea water, potential hazards associated with earthquake threats) and economic (ability to finance a large and expensive project) issues render the realization of a full-scale project questionable.

The Study of Alternatives (World Bank, 2012) considered a small-scale RSDS project, under which only 200 MCM/y will be desalinated and conveyed mostly to Amman. This requires conveyance of 440 MCM/y from the Red Sea to the Dead Sea and will generate 240 MCM/y of brine, to be discharged in the Dead Sea. No reliable estimates of the cost of potable water in Amman associated with this small-scale RSDS project exist, but it is expected to be lower than the cost in Amman of water desalinated in Aqaba (see World Bank, 2012).

1.4.1.4. *Water from the Mediterranean*

The Study of Alternatives (World Bank, 2012) examined also the cost in Amman of water derived from the Mediterranean Sea. One of the options considered (the northern alignment) entails desalination along the Mediterranean coast (between Haifa and Atlit) and conveyance to Amman via Naharayim-Bakura (at the confluence of the Jordan and Yarmouk Rivers). The cost in Amman (desalination and conveyance) was calculated to be in the range of \$1/m³–\$1.2/m³ (World Bank, 2012), which is substantially lower than the \$2/m³ cost in Amman of water desalinated in Aqaba. The cost advantage is due to the shorter conveyance distance. The scale of this operation can reach 200 MCM/y.¹⁵

¹⁵As noted by a reviewer, the Jordanians have been explicit about not wanting to be dependent on Israel (or the PA) for all of their water supply, but may

1.4.1.5. *Actions combined*

The above four actions combined will augment Jordan's supply of potable water by about 900 MCM/y (about 400 MCM/y from improved management and allocation practices, 100 MCM/y from Lake Kinneret by water swaps, 200 MCM/y from the Mediterranean via Naharayim-Bakura, and 200 MCM/y from a mini RSDS project). These additional supplies will satisfy Jordan's potable water needs in the long run.

1.4.2. *Palestinian Authority*

The many issues on which the Palestinians and Israelis disagree include ownership of the mountain aquifer (see Fig. 1.2). I have nothing to contribute to this particular dispute. I note, however, that water rights over natural sources are of lesser importance once water scarcity reaches a point where existing natural supplies can at most satisfy basic human needs and water allocation policies are driven by human right considerations. The Israelis and Palestinians will reach this point very soon, as Table 1.4 reveals. The implications are that, independent of ownership rights, the mountain aquifer's water should be allocated to satisfy basic human needs in the most economical way.

The renewable supply of drinking quality water available from the water basins west of the Jordan River is currently 1451 MCM/y on average (see Table 1.1). The population of Israel and the PA

Table 1.4: Annual per capita supplies of natural (potable) water available for Israel and the PA.

Year	Population (million)	m ³ /person/year
2011	11.5	127
2030	16.6	88
2050	21.8	67

Source: Data from Weinberger *et al.* (2012) and United Nations (2011), as per Table 1.1 and Fig. 1.4.

not object to a fraction of the total water supply (say 100–200 MCM/y) at a substantial lower cost than that of water desalinated in Aqaba.

combined is expected to reach 16.6 million in 2030 and 21.8 million in 2050 (see Fig. 1.4). The corresponding expected annual supplies per person from natural sources are similar to those given in Table 1.3 (will reach 88 or 67 m³/person/year in 2030 or 2050, respectively).

As far as recycling and desalination are concerned, the PA's situation is similar to that of Israel, in that it has an easy access to the Mediterranean (Gaza strip) and a large share of its population resides near the sea. The actions needed to deal with the water scarcity can therefore be similar to those taken by Israel.

1.5. Water for the Environment

The water policy discussed so far focused on direct human needs (domestic, irrigation, and industry). Satisfying these needs entails extractions and diversions from natural sources, which inevitably come at the expense of environmental needs (see Beyth [2006] for a historical account of diversions by Israel and Jordan). In this respect, two environmental assets, shared by Israel, Jordan, and the PA, stand out: the LJR and the Dead Sea (see map in Fig. 1.1). Diversions from Lake Kinneret and the upper Jordan River, mostly by Israel, have virtually eliminated the water flow from the lake to the LJR. Diversions from the Yarmouk basin (mostly by Syria) have diminished its flow into the LJR. Further diversions downstream (by Jordan, Israel, and the PA) have deprived the LJR of an additional 200–300 MCM/y. The historic flow of 1300 MCM/y on average has been diminished to a trickle of mostly brackish water and sewage (Gafny *et al.*, 2010). The most pronounced environmental consequences have been the destruction of the LJR's ecosystem and declining Dead Sea levels.¹⁶ I discuss here how partial restorations of the LJR and stabilization of the Dead Sea level can be incorporated within the water policy discussed earlier. The approach taken here is

¹⁶ Additional diversions (e.g., from the Mujib at the Dead Sea's eastern escarpment) as well as the Dead Sea potash industries (of Israel and Jordan) also contribute to the decline of the Dead Sea level.

similar to the alternative called “Combined Alternative 1” in World Bank (2012).

1.5.1. *Partial Restoration of the LJR*

Gafny *et al.* (2010) conclude that the LJR requires an annual flow of 400–600 MCM/y in order to restore its ecosystem. We explain how such a flow can be implemented over a period of three to four decades. Water for LJR restoration can come from three possible sources: Lake Kinneret, desalination plants, and recycled water; the cost of each is determined by its alternative cost. The alternative cost of potable water (from Lake Kinneret or from desalination plants) is the cost of providing Amman with the same quantity of potable water (either from Lake Kinneret or by desalination along the Mediterranean and conveyance via Naharayim-Bakura). As was discussed previously, this cost exceeds \$1/m³. The alternative cost of recycled water is the cost farmers are willing to pay for this water.¹⁷ This cost can be estimated by the cost of recycled water to Israeli growers, which currently is in the range of \$0.2–\$0.4/m³ (see Kislev, 2011).

The associated benefit is the willingness to pay (WTP) for restoring the LJR. Because the LJR, in addition to the environmental services it provides to the local population, has historical, religious, and cultural values, the WTP for its restoration has local and international components. Estimates of regional (Israel, Jordan, and the PA) WTPs for LJR restoration were recently calculated by Becker *et al.* (2014) for different annual flows (220 and 400 MCM/y) and water quality levels. Their WTP values for restoration involving annual flow of 400 MCM of water of different quality range between \$0.23/m³ and \$0.87/m³.¹⁸ These values fall below the alternative costs of potable water but are compatible with costs of recycled water. We conclude, given the WTP estimates of Becker *et al.*

¹⁷The technical cost of recycling is borne by the domestic sector (i.e., households), since, for environmental reasons, the water must be treated disregarding how it is used afterward.

¹⁸These estimates are obtained by dividing the total WTP corresponding to scenarios S3 and S4 by the restoration flow of 400 MCM/y (see Becker *et al.*, 2014, Tables 2–3).

(2014), that the use of potable water (either from Lake Kinneret or from desalination plants) for LJR restoration cannot be justified on economic grounds.¹⁹ In the remainder of this subsection we consider LJR restoration by recycled water.

According to Israel's master plan of the national water sector (Israel Water Authority, 2012, p. 14), the allocation of water to agriculture in 2050 is planned to reach 1450 MCM/y, of which 900 MCM/y will come from recycling plants,²⁰ 100 MCM/y will be brackish (saline) water, and 450 MCM/y will come from fresh natural sources. An allocation of 80 MCM/y is planned for environmental purposes. The value in agricultural production of the 1000 MCM/y of recycled and brackish water allocated to irrigation depends on how and where it is used (crops in different locations). The value of *some* of this allocation will fall below the value that would be generated had this water been reallocated to LJR restoration (which, as noted earlier, generates benefit in the range of \$0.23/m³–\$0.87/m³). The quantity of reallocated water that will satisfy this criterion (i.e., will generate higher benefit in LJR restoration than in irrigation) is expected to exceed 20% of the total recycled and brackish water allocation, that is, around 200 MCM/y by 2050. Thus, in three to four decades, about 200 MCM/y of recycled water planned for agriculture use in Israel would generate a higher value in LJR restoration, and hence *should* be reallocated for that purpose.²¹

By the same calculation applied to Jordan and the PA (recalling from Fig. 1.4 that their population will be similar to that of Israel), it is expected that by 2050, each will be able to supply

¹⁹This conclusion could be changed if international WTP were high enough. Unfortunately, such estimates are not available and will not be considered here.

²⁰Recent legislation requires all recycling plants in Israel to be upgraded to tertiary level by 2015.

²¹The demand for irrigation water is expected to increase over time as food prices rise with the increased demand from a growing population. However, the WTP for environmental amenities will also increase with economic growth and wealthier population, and there is no reason to assume that the former process will outpace the latter. While the evaluation based on current irrigation water demand and WIP for environmental amenities should be updated as new data come along it is unlikely to change in any substantial way.

at least 100 MCM/y for LJR restoration. We conclude that by 2050, the allocation of recycled water for LJR restoration from the three parties combined *should* (according to a cost–benefit criterion) exceed 400 MCM/y, which is the flow necessary for LJR restoration (Gafny *et al.*, 2010). This process, however, will be gradual and will evolve over time. It is a direct outcome of the water policy discussed earlier, namely, of providing enough potable water to satisfy the needs of the growing population, while recycling all domestic and industrial water use.

Using recycled water for LJR restoration requires conveyance (of the recycled water) from where it is produced (treatment plants) to the upper end of the LJR (near Naharayim-Bakura) and the associated cost will increase the cost of the restoration water. Mekonen (2013) calculated the cost of conveying 100 MCM/y of recycled water from the Jerusalem-Ramallah area to Naharayim-Bakura, while using the elevation difference (of about 1000 m) to generate electricity. Mekonen (2013, Table 6) calculated the conveyance cost at \$0.19/m³ (equivalent to 0.68 NIS/m³)²² and the hydroelectricity profit at \$0.12/m³. The compensation to farmers was estimated at \$0.26/m³. The net cost of using this water for LJR restoration (conveyance minus hydroelectricity profit plus compensation to irrigators) is therefore \$0.33/m³, which falls at the lower part of the benefit range (WTP) from LJR restoration, estimated by Becker *et al.* (2014) between \$0.23/m³ and \$0.87/m³.

1.5.1.1. *Stabilizing the Dead Sea*

The second most notable effect of the extensive upstream diversions discussed earlier is the declining Dead Sea levels (Klein, 1982; Salameh and El-Naser, 1999, 2000; Tahal and Geological Survey of Israel, 2011). The Dead Sea level, which has recently been declining at an annual rate above 1 m, is measured now at about 428 meters below sea level (mbsl) — about 35 m below its historical level of 390–400 mbsl (Fig. 1.9). Most proposals for reclaiming the Dead Sea,

²² At the time of writing, the exchange rate is \$1 = 3.63 NIS.

Figure 1.9: Dead Sea levels: 1810–2006.

Source: Rawashdeh *et al.* (2013).

by either stopping its decline or restoring its level to the pre-diversions state, involve conveyance of large quantities of sea water to the Dead Sea either from the Mediterranean or from the Red Sea (see Vardi [1990] and Beyth [2007] for overviews of past proposals, and the studies in www.worldbank.org/rds of the recent “Red Sea–Dead Sea Conveyance Study Program,” compiled under the World Bank auspices). The approach taken here is based on the actions needed for solving the water shortage problem considered above and avoids a major sea-to-sea water conveyance project.

Stabilizing the Dead Sea at its current level requires increasing the water inflow by 700–800 MCM/y (Tahal and Geological Survey of Israel, 2011). Over time, due to the LJR restoration discussed earlier, the flow of the LJR into the Dead Sea will increase by 400 MCM/y or more. In addition, 360 MCM/y of brine will be discharged into the Dead Sea at its southern end: 240 MCM/y from the desalination near the Dead Sea associated with the small-scale RSDS project discussed earlier and 120 MCM/y of brine from the desalination in Aqaba (associated with the water swap action). The total flow into the Dead Sea will thus increase by about 760 MCM/y — about the flow needed to stabilize the Dead Sea at the current level.

The cost of discharging seawater or brine from the Red Sea into the Dead Sea is estimated between $\$0.1/\text{m}^3$ and $\$0.27/\text{m}^3$, depending on assumptions made regarding the interest rate and cost of electricity (see World Bank, 2012, p. 156). The risks associated with mixing the Dead Sea with sea water or brine (stratification, gypsum precipitation, and biological bloom) are low for a discharge flow below 400 MCM/y (Tahal and Geological Survey of Israel, 2011, p. 6). The 360 MCM/y of brine discharge, therefore, is unlikely to inflict detrimental effects on the Dead Sea and can be considered safe.

Regarding the cost of the recycled water, it was discussed previously that the residual cost after paying for the LJR restoration is negligible. However, the inflow of recycled water is filled with nutrients and, without further treatment, could give rise to severe biological bloom. Avoiding this risk will therefore require further treatment before the water enters the Dead Sea. No estimates are available regarding the cost of such further treatment.

The total cost of Dead Sea stabilization should be compared to the benefit associated with stabilizing the Dead Sea at about its current level. This benefit includes the cost avoided as a result of stopping the decline of the Dead Sea level. Becker and Katz (2009) estimated this cost to be in the range of 73–227 million dollars a year. Like in the case of LJR restoration, the unique characteristics of the Dead Sea imply that the benefit of its preservation extends beyond the region and includes the international community as a whole. The total benefit of preventing the decline of the Dead Sea is therefore likely to be much larger.

1.6. Concluding Comments

The JRB, comprising Israel, Jordan, and the PA, suffers from acute water scarcity: the average supplies of natural water available in a sustainable fashion (without drawing down stocks) in this region will soon drop below 100 m^3 per person per year. This is far below the supplies needed for human activities and the ensuing diversions have deprived many environmental sites of the minimal water supplies required to sustain living ecosystems. The three parties share

some of the water sources, and thus must coordinate their water policies.

A water policy consists of demand management and supply management measures. The purpose of a demand management policy is to increase the efficiency of water use, that is, to do more with the same quantity of water. It includes measures such as water pricing and water quotas as well as institutional arrangements such as the delegation of municipal water to special corporations designed for that purpose, which (in the case of Israel) improved collection of water fees and reduced water leakage and theft. The purpose of supply management policies is to increase the available supply of water mainly from recycling and desalination plants. Drawing on recent Israeli experience, we offer a comprehensive, long-run policy to address the region's water shortage problems based on demand and supply management measures.

Special attention is given to environmental water and in particular to the restoration of two environmental assets shared by the three parties: the LJR and the Dead Sea. We show how a partial restoration of the LJR and a stabilization of the Dead Sea level can be achieved within the water policy that addresses human needs. A key element of this policy is that each cubic meter allocated to households and industrial use should be collected, treated, and be available for reuse in irrigation and environmental restoration. Over time, the supply of this water grows (with the population) to the extent that it can support comprehensive environmental policies. This approach is gradual and depends on the rate of population growth. In the case under study, it was found that within three to four decades the supply of (high quality) recycled water will suffice to partially restore the LJR and stabilize the Dead Sea level while fully compensating farmers for reallocating the recycled water from irrigation to environmental restoration.

Far from being anecdotal, the case of the JRB involves elements common in many water basins, where population growth and rising living standards have increased water scarcity and intensified the tradeoffs associated with the multidimensional role of water. These elements include transboundary management of water resources

shared by multiple parties, the need to balance environmental and human water consumptions, and the combination of demand and supply management policies in an erratically fluctuating environment. The main lessons drawn from this study are therefore relevant in many real-world situations.

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