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Closing the (widening) gap between natural water resources and water needs in the Jordan River Basin: A long term perspective

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Closing the (widening) gap between natural water resources and water needs in the Jordan River Basin: A long term perspective

Yacov Tsur*

January 15, 2014

Abstract

The supply of renewable natural water available on a sustainable fashion in the Jordan River Basin, comprising Israel, Jordan and the Palestinian Authority, will soon drop below 100 cubic-meters (m^3) per person per year. Drawing on recent technological progress and policy innovations, I offer a comprehensive policy to address the region's water problems in the long run. The policy has a dual goal: to satisfy the direct needs of a growing population (domestic, irrigation and industrial); and to restore and preserve important environmental amenities, including restoration of the Lower Jordan River and stabilization of the Dead Sea. The analysis is relevant in a wide range of real world situations, where the dual goal of satisfying basic needs of a growing population and preserving environmental amenities becomes a critical issue.

Key Words: Water scarcity, environmental amenities, recycling, desalination, Lower Jordan River, Dead Sea.

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Introduction

The average supply of natural water available on a sustainable fashion (without systematically drawing down water stocks) in the Jordan River Basin (JRB), comprising Israel, Jordan and the Palestinian Authority, will soon drop below 100 cubic-meters (m^3) 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 Lower Jordan River (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 reach ecosystem no longer exists (Gafny et al. 2010); the Dead Sea level has been declining at a rate exceeding one meter per year with far reaching detrimental consequences to its surrounding environment (Tahal and Geological Survey of Israel, 2011, Rawashdeh et al. 2013, Becker and Katz 2009). In this work 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; 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 makes 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, 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 on a sustainable fashion) natural water suitable for human use, measured in units of m^3 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 m^3 per person per year are said to experience *water stress*, *water scarcity* or *absolute scarcity*, respectively. The threshold of 100 m^3 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 3 we discuss recent technological progress in desalination and policy innovations that have been used to deal with water scarcity in Israel and note that these policies underline the basic principles of a comprehensive solution to the water shortage problem in the region. Section 4 discusses how the environmental goals of partially restoring the lower Jordan River (the stretch of the river between Lake Tiberias-Kineret and the Dead Sea) and stabilizing the Dead Sea level can be incorporated within this comprehensive water policy. Section 5 concludes.

Water scarcity in the Jordan River Basin

We consider the part of the Jordan River Basin (JRB) that comprises Israel, Jordan and the Palestinian Authority (see Figure 1).[1] We begin with a description of the renewable natural

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

water supplies and population dynamics, and the ensuing water scarcity measures, based on cubic meter (m^3) per person per year.

Figure 1: The Jordan River Basin (JRB). The Upper Jordan River extends between its headwater (at the confluence of the Dan, Banias and Hatzbani) and Lake Tiberias-Kineret. The Lower Jordan River (LJR) is the southern stretch of the river between Lake Kineret and the Dead Sea. Source: United Nation Environment Programme, http://www.grid.unep.ch/products/4_Maps/jordanb.gif

Water resources

We consider the water resources of Israel and the Palestinian Authority (many of which are shared) and of Jordan in turn.

Israel and the Palestinian Authority

Table 1 presents average recharge into the main water sources west of the Jordan River for the periods 1976-1992, 1992-2009 and 1976-2009. It also gives the quantities of brackish water recharge, where brackish water refers to water with chloride concentration above 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, e.g., the total average recharge of fresh water during 1976-2009 was 1789 – 242 = 1547 million cubic meter per year (MCM/y).[2] Figure 2 provides a map view of the two rightmost columns of Table 1. These are the quantities of natural water available to Israel and the Palestinian Authority on a sustainable fashion. The average recharge for the period 1976-2009 was 1789 MCM/y, of which 242 MCM/y of brackish quality (above 400 mg/l Cl). Brackish water is unsuitable for drinking and when used for irrigation it often requires mixing with good quality water to reduce salinity.

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

Basin	1976 - 1992		1993 - 2009		1976 - 2009	
	Average Recharge	Brackish	Average Recharge	Brackish	Average Recharge	Brackish
Kinneret	623	18	540	14	581	16
Coastal	252	124	232	116	243	120
Western Mountain	369	0	333	0	352	0
Eastern Mountain	211	0	174	0	192	0
Northeast Mountain	151	0	134	0	142	0
Lower Galilee	30	6	26	6	28	6
Western Galilee	139	30	132	30	136	30
Carmel	42	15	40	15	41	15
Negev & Arava	32	28	32	28	32	28
Gaza	44	31	40	23	42	27
Total	1893	252	1683	232	1789	242

[2] The breakdown into sub-periods in Table 1 shows temporal changes of water recharge, which could be the result of climate trends.

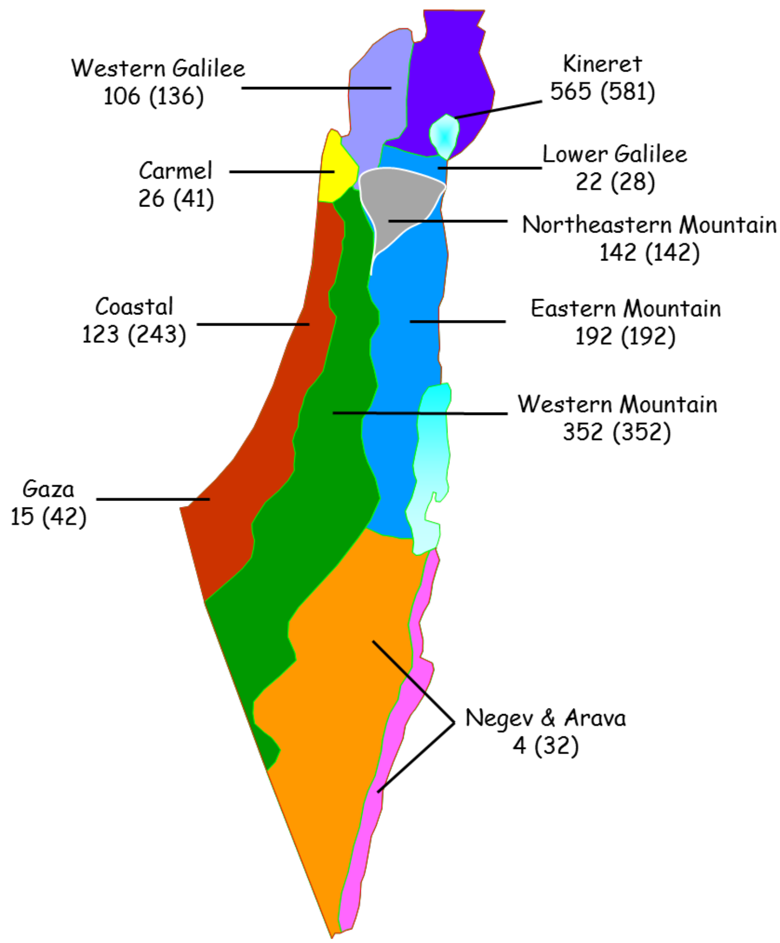

Figure 2: Average renewable supplies of fresh water (with chloride concentration below 400 mg/l), based on the 993-2009 data of Table 1 (numbers in parenthesis give brackish water -- with chloride concentration above 400 mg/l). Source: Weinberger et al. 2012.

Figure 3 shows the actual realizations of natural recharge for the period 1976 – 2009, based on which the averages of Table 1 were calculated. It illuminates two features of renewable water resources in the Jordan Basin: high (temporal) fluctuations and a declining trend. The declining trend of 8.92 MCM per annum could be the result of a climate trend. Although this decline will eventually taper off, in the meantime a loss of 8.92 MCM/y entails a loss of 100 MCM/y every 11 years -- the quantity produced by a large scale desalination plant.

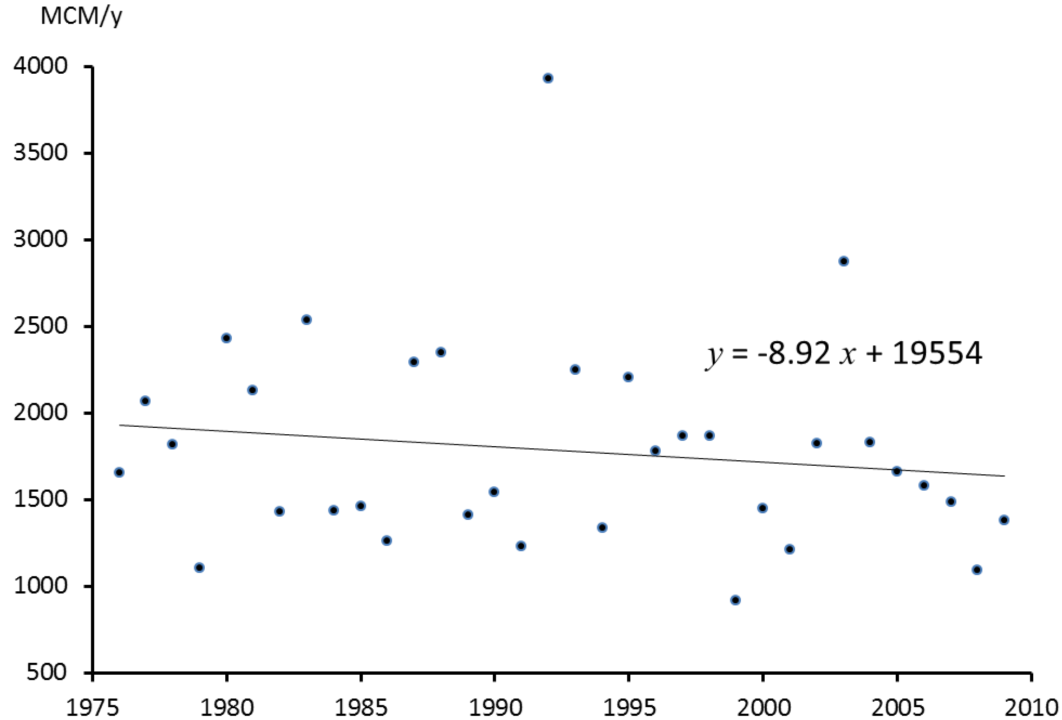

Figure 3: Actual observations of total natural water recharge of all major water sources (including brackish water) west of the Jordan River during the period 1976 – 2009. Source: Weinberger et al. (2012).

Jordan

Table 2 presents Jordan's renewable water resources. The total annual supply of renewable natural water in Jordan is 745 MCM on average.3

Table 2: Jordan's renewable water resources. Source: Ministry of Water and Irrigation, 2010 (executive summary, p. 7).

Source	MCM/y
Groundwater (safe yield)	275
Surface Water (by 2022)	365
Artificial recharge (in 2007)	55
1994's Peace Treaty (from Lake Kineret)	50
Total	**745**

[3] The total of 745 MCM/y in Table 2 includes also 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 Palestinian Authority above. The total supply of 745 MCM/y, thus, likely overestimates the natural supplies of fresh water.

Water resources in the JRB

The average supply of renewable natural water in the JRB (available to Jordan, Israel and the Palestinian Authority on a sustainable fashion, i.e., without drawing down stocks) is therefore 2534 (1789+745) MCM/y, of which (at least) 242 MCM/y is of brackish quality (with chloride concentration exceeds 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.

Population

Figure 4 presents actual (up to 2011) and projected populations of Israel, Jordan and the Palestinian Authority 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 3.

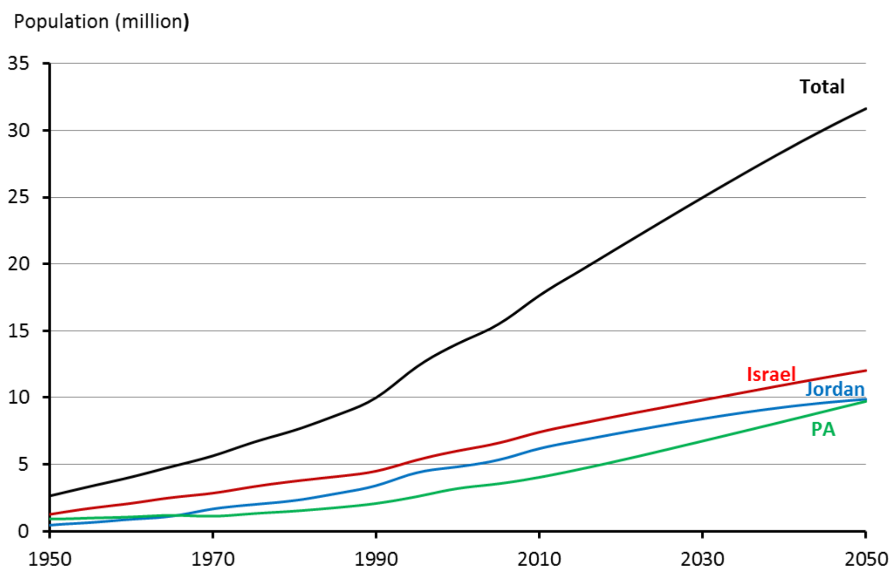

Figure 4: Actual (until 2011) and projected population (million). Source: United Nations (2011).

Table 3: Population in the JRB and annual per-capita supplies of natural (potable) water. The supply of renewable water (non-brackish) available to Israel and the Palestinian Authority is 1683-232 = 1451 MCM/y (where averages over the period 1993-2009 are used) and for Jordan is 745 MCM/y. The total supply is 2196 MCM/y on average. Dividing by the population gives the per capita annual supplies reported on the right-most column.

year	Population (million)	m3/person/year
2013	18.8	117
2030	25.0	88
2050	31.6	69

As Table 3 reveals, the region as a whole is already far below the absolute scarcity mark of 500 m^3 per person per year and within two decades will cross the subsistence scarcity mark of 100 m^3 per 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 describer recent experience of Israel's water policy, which can serve a as guide for water policy in the regions as a whole.

Dealing with water scarcity: Israel's experience

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

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 Figure 5, which presents domestic water consumption during the period 1996 – 2011. As the figure shows, domestic water consumption has increased more or less proportional to the population growth until 2007, reaching a peak of 767 MCM at this year. Thereafter, it decreases to 665 MCM in 2011 – a decline of more than 10 percent or the equivalence of a large scale desalination plant (100 MCM/y). 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?

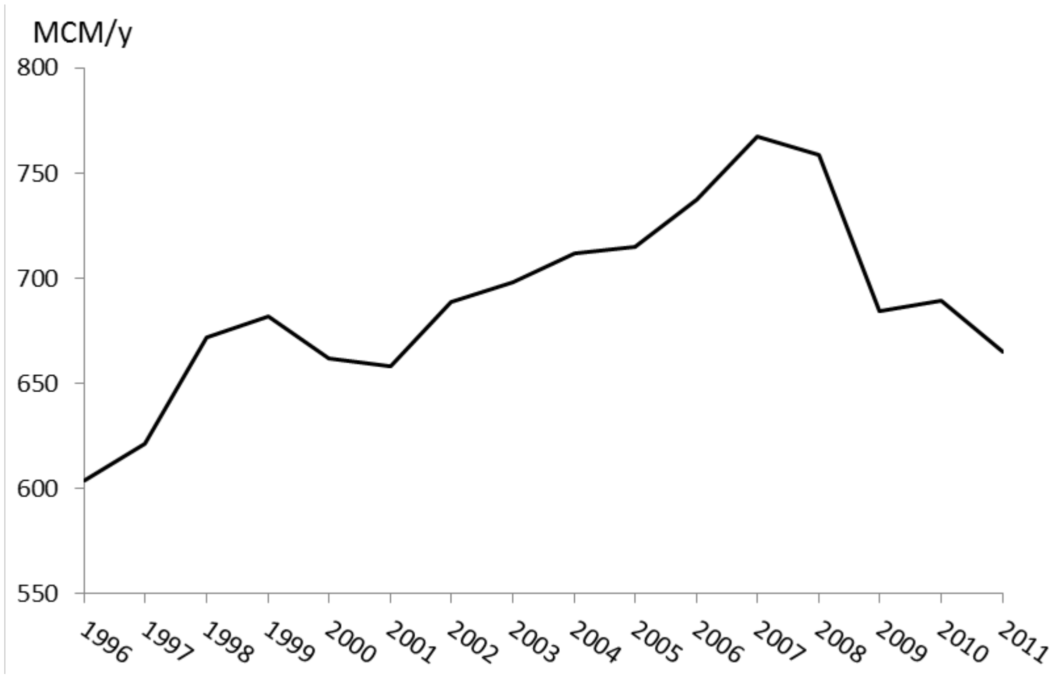

Figure 5: Domestic water consumption (MCM/y) in Israel during 1996 – 2011. Source: Israel's Water Authority. 2011. Water consumption by sectors: 1996 – 2011 (in Hebrew). http://www.water.gov.il/Hebrew/ProfessionalInfoAndData/Allocation-Consumption-and-production/20112/1996-2011.pdf.

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.[4] Secondly, municipal water management shifted from the municipalities (city, regional and local councils) to Water Corporations. Thirdly, 2007 was the third winter in a sequence of 5 of below average precipitation (see Figure 2). These three events have led to a number of interventions. First, domestic water prices increased sharply to reflect

[4] Prior 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 permit; a Knesset (Parliament) committee was responsible for setting prices in various sectors; and a number of governmental committees for allocating quotas (See Kislev, 2011).

the cost of water supply (including scarcity cost).[5] Secondly, 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. Thirdly, the prolonged period of below-average rainfall has increased the public awareness for the need to reform the water sector and was conducive for 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 Figure 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 process took place in Israel's agriculture, albeit more gradually. The following figure shows trajectories of two price indices during the period 1952 - 2011 (adjusted for the consumer price index): the price index of natural, fresh (non-brackish) water in agriculture; and a price index of agricultural output (crops' prices). The crops' price has declined moderately until late 1990s and has been stable since then. The water price index, on the other hand, has increased more than fourfold 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 Figure 7 below). The 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.[6]

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[5] A 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.

[6] As of January 1, 2014, the prices (before 18% VAT) of fresh, natural water for agriculture (supplied by the national water company Mekorot, owned by the government, which supplies about two third of the water in Israel) are set as follows (see the 2014 water tariffs' book in http://www.water.gov.il/Hebrew/Rates/DocLib1/prices-books-1.1.14.pdf) : the price of water up to the quota is 2.15 shekel per m^3 (or \$0.61/m^3 at the current exchange rate of 3.5 shekel per \$1); for up to 30% deviation above the quota the price is 2.688 shekel per m^3 (or \$0.77/m^3); and for deviations above 130% of the quota the price is 6.746 shekel per m^3 (or \$1.93/m^3).

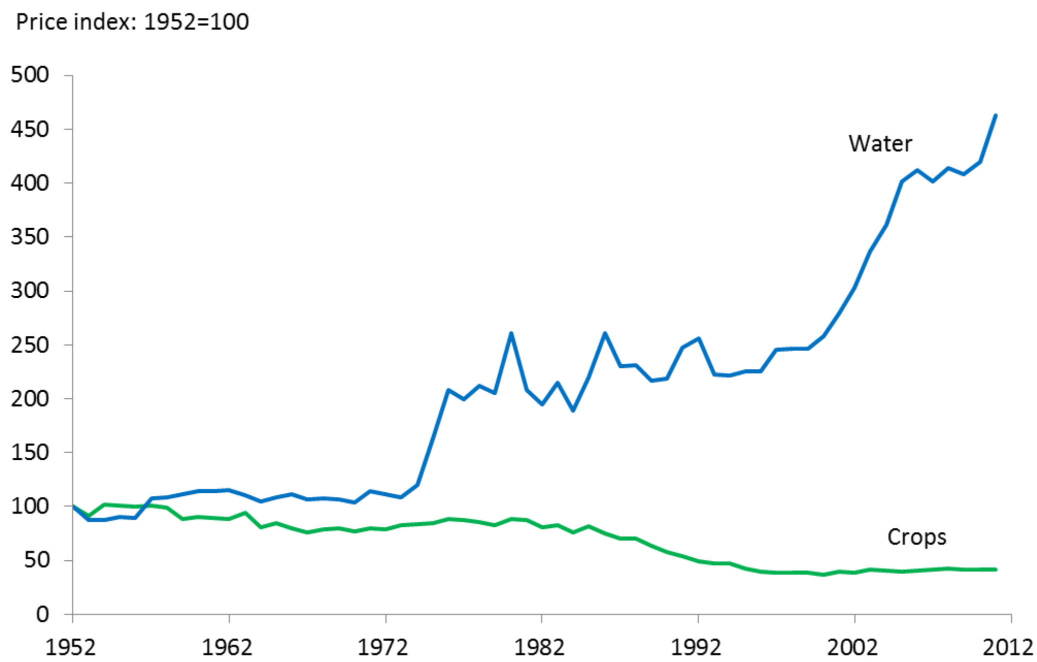

Figure 6: Trajectories of the price indices of natural (non-brackish) water in agriculture and of crops' prices during 1952 – 2011 (1952=100, adjusted for consumer price index). Source: Kislev and Tzaban (2013), based on publications of Israel's Central Bureau of Statistics.

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.

Recycling

Figure 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 than natural water and this trend (of replacing natural water by recycled and brackish water) will continue.

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 –0.7 m^3 of recycled water that in turn is allocated to irrigation. Thus, the overall effect to reallocating one cubic meter from agriculture to households is to increase domestic supply by one cubic meter and reduce agricultural supply by only 0.3-0.4 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.

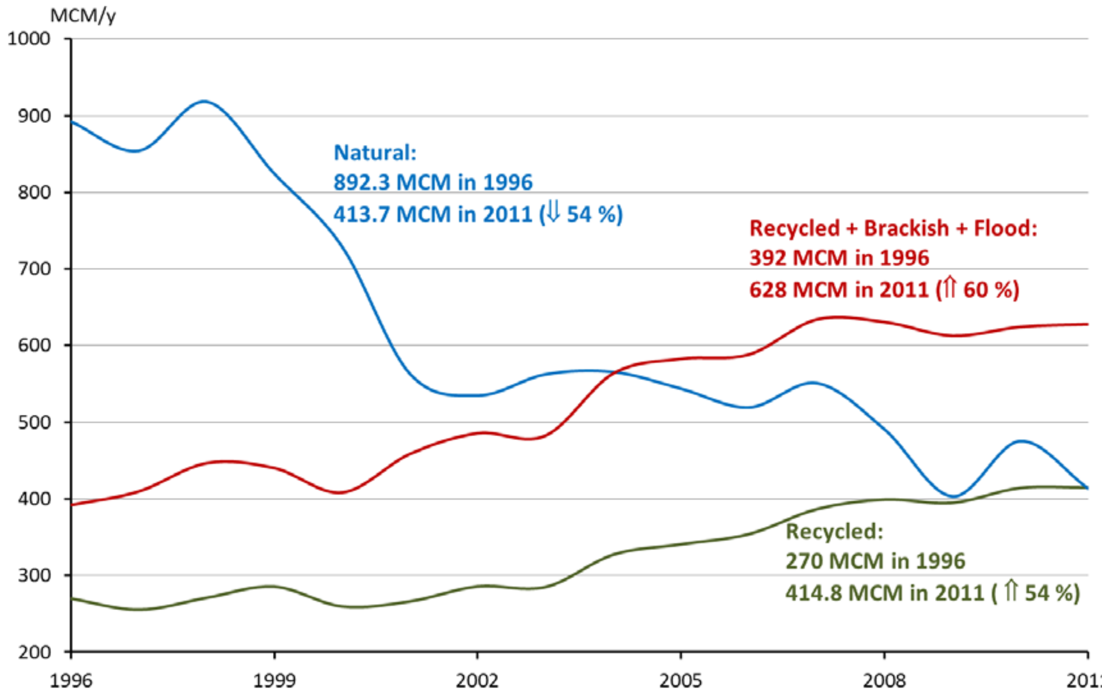

Figure 7: Water allocation in Israel's agriculture during 1996 – 2011 (brackish refers to water with chloride concentration above 400 ml/l). Source: Israel's Water Authority. 2011. Water consumption by sectors: 1996 – 2011 (in Hebrew). http://www.water.gov.il/Hebrew/ProfessionalInfoAndData/Allocation-Consumption-and-production/20112/1996-2011.pdf.

Desalination

The cost of desalination has declined substantially during the last decade due mainly to learning by doing associated with the increased scale of installed desalination capacity. Figure 8 presents the desalination costs ($\$/m^3$ 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 operating during 2014) and the plant's production capacity (MCM/y). At the completion of Ashdod plant (during 2014), Israel's desalination capacity will exceed 600 MCM/y, which is more than 90 percent of household consumption during 2011. This will reduce reliance on natural sources and allow a more sustainable management of the natural water sources.

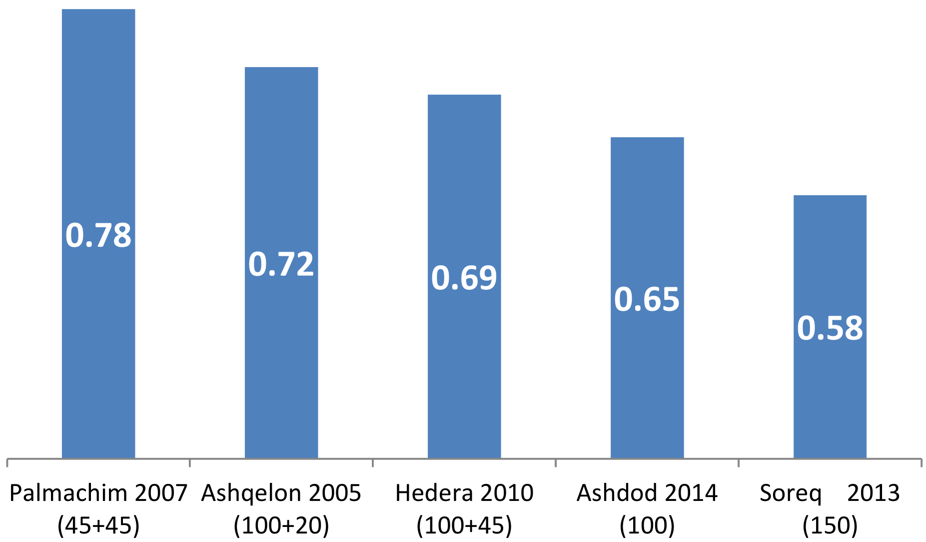

Figure 8: Cost of the desalination plants ($/m^3 at the plant's gate calculated under the exchange rate: $1 = 3.7 NIS). The numbers in parentheses give the capacity in MCM/y (x+z means that the original capacity of x MCM/y has been or will soon be expanded by z MCM/y to give a total capacity of x+z MCM/y). Source: Israel's Water Authority.[7]

Summary

The recent Israeli experience shows that the potential of demand management policy measures in dealing with water scarcity should not be understated. The stricter pricing and management practices that were implemented in 2007 reduced domestic water use by more than 10 % -- a quantity equivalent to a large scale desalination plant (at a fraction of the cost of desalination). 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 - 0.7 cubic meter of recycled water suitable for irrigation and environmental (e.g., river restoration) purposes.

The other source for increasing the supply of potable water is desalination. Technological progress due to R&D and learning by doing associated with increased

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[7] The 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 expansions. The prices listed in the figure, thus, should be taken as estimates.

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 desalinated water becomes an economically viable source of water supply for households and industries.

Managing water scarcity in the Jordan River Basin

Is the Israeli experience relevant to Jordan and the Palestinian Authority? Regarding recycling, the answer is clearly in the affirmative, as recycling can be applied in Jordan and the Palestinian Authority in much the same way as in Israel. This means that most of the fresh (potable) natural water should be allocated to domestic use, collected, treated and reuse 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 from that of Israel and the Palestinian Authority. I therefore discuss Jordan and the Palestinian Authority separately.

Jordan

The bulk of Jordan's population resides (in the Amman area) at about 1000 meter above sea level and over 300 kilometer 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 one cubic meter desalinated in Aqaba (before distribution to households and sewage treatment) is estimated above $\$2/m^3$ – this is about 4 times the cost of supplying desalinated water to Israel's densely populated areas (see Figure 8). Moreover, discharging large quantities of brine (1 m^3 of desalinated water generates about 1.22 m^3 of brine) in the Gulf of Aqaba could have detrimental effects on the sensitive coral reef ecology and is objected 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. We discuss a number of actions that, taken together, could provide a comprehensive solution.

Water management: pricing, conservation and reduction of water loss

Water losses from Jordan's municipal supply networks were estimated at 43%, which in amounted to 137 MCM of total municipal allocation of 320 MCM (York, 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 / m^3 ($0.017/$m^3$), while domestic and industrial tariffs are much higher, ranging between JD 0.250/m^3, or $0.35/m3, and JD 1.800/$m^3$, or $2.55/$m^3$ (Yorke, op cit.)

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 to 70 percent 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.

Water swap

On Monday, December 9, 2013, a memorandum of understanding was signed between Israel, Jordan and the Palestinian Authority, at the World Bank's Washington headquarter, with the following basic principles: Jordan will desalinate about 80 - 100 MCM/y near Aqaba and discharge the brine in the Dead Sea (to be conveyed via a pipeline). 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 Kineret (to be conveyed to Amman via existing conveyance facilities). The agreement also involves additional water allocation to the Palestinian Authority, 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 Kineret in the north. The cost of Lake Kineret water in Amman is about $1 - $1.2 per m^3,[8] 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 Kineret (see Weinberger et al. 2012, for a description of Lake Kineret's water balance). At most it could support an

[8] This cost consists of $0.3 – $0.4 per m^3 purchasing price plus $0.7 – $0.8 per m^3 treatment and conveyance (see World Bank, 2012).

additional 50 MCM/y, bringing the total amount of Lake Kineret water allocated to Jordan to 150 MCM/y (including the 50 MCM/y supplied to Jordan following the 1994 Peace treaty).

A small-scale Red Sea – Dead Sea conveyance project

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, desalinate near the Dead Sea, discharge the brine reject in the Dead Sea, using the elevation difference (of about 350-400 meter) to generate electricity, and convey the desalinated water mostly to Amman (see Vardi, 1990, for a survey of ideas and 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 in www.worldbank.org/rds). The RSDS project is planned to be constructed in phases over 3 to 4 decades. Upon completion, a full-scale RSDS project will convey 2 billion m^3 per year (BCM/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 Palestinian Authority 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 to this project (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 expected to be substantial lower than the cost in Amman of water desalinated in Aqaba, (see World Bank, 2012).

Water from the Mediterranean

The Study of Alternatives (World Bank, 2012), conducted as part of the suit of studies associated with the RSDS Water Conveyance program under the World Bank's auspices, analyzed 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 Naharaym-Bakura (at the confluence of the Jordan and

Yarmouk rivers). The cost in Amman (desalination and conveyance) was calculated at the range of \$1/m^3 to \$1.2/m^3 (World Bank, 2012), which is substantially lower than the \$2/m^3 cost in Amman of water desalinated in Aqaba. The cost advantage is due to the shorter conveyance distance. The scale of this operation can easily reach 200 MCM/y.

Actions combined

The above four actions combined will augment Jordan's supply of potable water by about 900 MCM/y (above 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.

Palestinian Authority

The many issues on which the Palestinians and Israelis disagree include ownership of the mountain aquifer (see Figure 2). We have nothing to contribute to this particular dispute. We 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 4 reveals. The renewable supply of drinking quality (non-brackish) water available from the water basins west of the Jordan River is currently 1451 MCM/y on average.[9] The population of Israel and the Palestinian Authority combined is expected to reach 16.6 million in 2030 and 21.8 million in 2050 (see Figure 4). The corresponding expected annual supplies per person from natural sources are given in Table 4.

Table 4: Annual per capita supplies of natural (potable) water for Israel and the Palestinian Authority. The population data are taken from the source of Figure 4 and renewable supply data are from Table 1: the annual supply of renewable water of good quality (non-brackish) is 1683-232=1451 MCM/y on average (where the average is taken over the period 1996 – 2009).

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

[9] This number is obtained by subtracting average brackish recharge (232 MCM/y) from average total recharge (1683 MCM/y), where the averages are taken over the period 1993 – 2009 (see Table 1).

As far as recycling and desalination are concerned, the Palestinian Authority'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.

Water for the environment

The water policy discussed so far focused on direct human needs (domestic, irrigation, industry). Satisfying these needs entails extractions and diversions from natural sources which inevitably come on the expense of environmental needs (see Beyth, 2006, for an historical account of diversions by Israel and Jordan). In this respect, two environmental assets, shared by Israel, Jordan and the Palestinian Authority, stand out: the Lower Jordan River (LJR) and the Dead Sea (see map in Figure 1). Diversions from Lake Kineret 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 Palestinian Authority) have deprived the LJR of additional 200 – 300 MCM/y. The historic annual flow of 1.3 billion m^3 (BCM) 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.[10] I discuss how partial restorations of the lower Jordan River and stabilization of the Dead Sea level can be incorporated within the water policy discussed above. The approach taken here is similar to the alternative called "Combined Alternative 1" in World Bank (2012).

Partial restoration of the Lower Jordan River

Gafny et al. (2010) conclude that the Lower Jordan River (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 3 -4 decades. Water for LJR restoration can come from three possible sources: Lake Kineret, desalination plants and recycled water; the cost of each is determined by its alternative cost. The alternative cost of potable water (from Lake Kineret or from desalination plants) is the cost of providing Amman with the same quantity of potable water (either from

[10] 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.

Lake Kineret or by desalination along the Mediterranean and conveyance via Naharayim-Bakura). As was discussed above, this cost exceeds $\$1/m^3$. The alternative cost of recycled water is the cost farmers are willing to pay for this water.[11] This cost can be estimated by the cost of recycled water to Israeli growers, which currently is in the range of $\$0.2/m^3$ – $\$0.4/m^3$ (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 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 Palestinian Authority) WTPs for LJR restoration were recently calculated by Becker et al. (2014) for different annual flows (220 MCM/y 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 $\$0.23/m^3$ and $\$0.87/m^3$.[12] 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. (2014), that the use of potable water (either from Lake Kineret or from desalination plants) for LJR restoration cannot be justified on economic ground.[13] In the remainder of this subsection we consider LJR restoration by recycled water.

According to Israel's master plan of the national water sector (Water Authority, 2012, p. 14), the allocation of water to agriculture in 2050 is planned to reach 1.45 BCM/y, of which 900 MCM/y will come from recycling plants[14] , 100 MCM/y of brackish (saline) water and 450 MCM/y from fresh natural sources. An allocation of 80 MCM/y is planned for environmental purposes. The value in agricultural production of the 1 BCM/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 above, generates benefit in the range of $\$0.23/m^3$ and $\$0.87/m^3$). The precise quantity of the reallocated water that will satisfy this

[11] The 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.
[12] These estimates are obtained by dividing the total WTP corresponding to scenarios S3 and S4 by the restoration flow of 400 MCM/y (see Becker el al., 2014, Tables 2-3).
[13] This conclusion could be changed if international WTP were high enough. Unfortunately, such estimates are not available and will not be considered here.
[14] Recent legislation requires all recycling plants in Israel to be upgraded to tertiary level by 2015.

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, i.e., 200 MCM/y in 2050. Thus, in 3 to 4 decades, at least 200 MCM/y of recycled water planned for agriculture in Israel would generate a higher value in LJR restoration, hence *should* be reallocated for that purpose.[15][16]

By the same calculation applied to Jordan and the Palestinian Authority (recalling from Figure 4 that their population will be similar to that of Israel), it is expected that by 2050, each will be able to supply 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 above, 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 16) calculated the conveyance cost at \$0.19/m^3 (0.68 NIS/m^3, which translates to \$0.19/m^3 at the current exchange rate of \$1 = 3.5 NIS) and the hydroelectricity profit at \$0.12/m^3. The compensation to farmers was estimated at \$0.26/m^3. The net cost of using this water for LJR restoration (conveyance minus hydroelectricity profit plus compensation to irrigators) is therefore \$0.33/m^3, which falls at the lower part of the benefit range (WTP) from LJR restoration, estimated by Becker et al. (2014) between \$0.23/m^3 and \$0.87/m^3.

[15] The demand for irrigation water is expected to increase over time as food prices rise with the increased demand from a growing population. However, the willingness to pay 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. The evaluation based on current irrigation water demand and willingness to pay for environmental amenities, while should be updated as new data come along, is unlikely to change in any substantial way.

[16] This requires a mechanism by which farmers are compensated for the recycled water reallocated away from agriculture to LJR restoration—a problem common to situations involving public good finance (see, e.g., Roberts, 1987, and Varian, 1994).

Stabilizing the Dead Sea

The second most notable effect of the extensive upstream diversions discussed above 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 one meter, is measured now at about 428 meter below sea level (mbsl) – about 35 meter below its historical level of 390 - 400 mbsl (Figure 9). Most proposals for reclaiming the Dead Sea, 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.

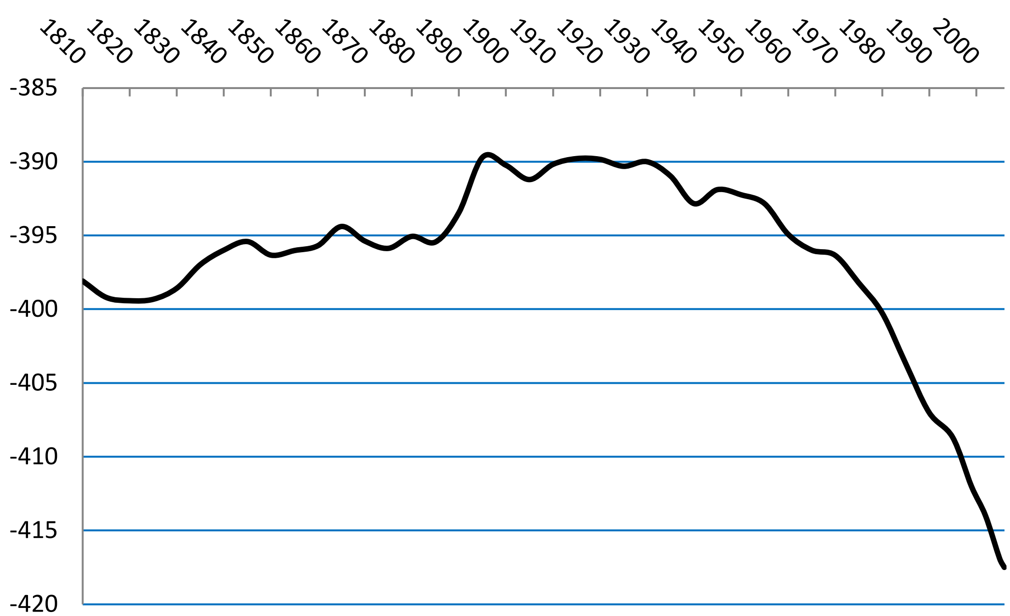

Figure 9: Dead Sea levels: 1810 - 2006. Source: Rawashdeh et al. (2013).

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 above, the flow of the LJR into the Dead Sea will increase by 400 MCM/y or more. In addition, 340 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 Red Sea – Dead Sea project discussed above and 100 MCM/y of brine reject from the desalination in Aqaba (associated with the water swap action). The total flow into the Dead Sea (from the LJR and brine) will increase by 740 MCM/y – about the flow needed to stabilize the Dead Sea at the current level.

The risks associated with mixing the Dead Sea with sea water or brine (stratification, gypsum precipitation, biological bloom) are low for a discharge below 400 MCM/y (Tahal and Geological Survey of Israel, 2011., p. 6). The 340 MCM/y of brine discharge, therefore, is unlikely to inflict detrimental effects on the Dead Sea and can be considered safe.

However, the 400 MCM/y inflow of recycled water (via the LJR) is filled with nutrients and, without further treatment, will likely give rise to severe biological bloom. Avoiding this risk requires further treatment of the (recycled) water before it enters the Dead Sea. The cost of this additional treatment 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 in the range of 73–227 million dollar 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.

Concluding comments

The Jordan River Basin, comprising Israel, Jordan and the Palestinian Authority, suffers from acute water scarcity: the average supplies of natural water available on a sustainable fashion (without drawing down stocks) in this region will soon drop below 100 m^3 per person per year (Table 3). This is far below the supplies needed for human activities (households, irrigation and industry) and the ensuing diversions have deprived the environment of the minimal water supplies required to sustain living ecosystems. The three parties share some of the water sources, 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, i.e., 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 Lower Jordan River (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 compensate farmers for reallocating the recycled water from irrigation to environmental restoration.

Far from being anecdotal, the case of the Jordan River Basin resembles an increasing number of regions around the globe, where population growth and rising living standards have led to water shortage. The lessons drawn from this study are therefore relevant in a wide range of situations.

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