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Environmental impacts on the Dead Sea, sustainability cost estimates

Abstract

The Dead Sea is a land-locked salt lake that's below sea level. Over the last decade it has undergone a continuous drop in its water level of around one meter per year, shrinking by nearly 30 m since the beginning of the 20th century. The diversion of the Jordan River, the Dead Sea's main freshwater feeder, and the use of artificial evaporation ponds by mineral extraction industries are the two main culprits of this dramatic decline. A number of different proposals have been made to resolve the inflow/outflow imbalance, but debate itself threatens the technical, economical and environmental viability of biblical salt water lake. One of these proposals includes a plan to re-diverting water from the Jordan River into the Dead Sea and to reduce the intensity of neighboring mineral extraction industries.

We present an economic model to assess the costs of preserving the Dead Sea and stabilizing its water level and an estimate of the opportunity cost of environmental flows based on the economic value of irrigated agriculture and mineral extraction industries. Our results indicate that the total costs required to maintain the Dead Sea at its current level and offset a water shortfall of 690 hm^3/year would amount to some €93 million per year.

Keywords: opportunity cost, sustainability, Dead Sea, Jordan River.
JEL Classification: D24, Q51, Q56.

Introduction

The sustainability of natural resources can, of course, be defined in numerous ways. One such definition is that of the benchmark Brundland Report (WCED, 1987): "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This embodies the two key concepts of *needs* and *environmental impacts*. Relating this definition to a particular ecosystem or socio-cultural heritage is relative, and the exercise depends on a process of social reconstruction to reconcile the intention to preserve natural resources for future generations with potentially significant socioeconomic obstacles and long-term challenges.

In the case of the Jordan River basin, the Dead Sea appears as an essential part of any strategy of sustainability, notwithstanding the need to study the river's other ecosystems, including its lakes, riversides, forests and flood plains, in order to balance ecosystems in the region and sustain its unique natural heritage and emblematic historical and cultural values.

Looking at the ecological status of the Jordan River Basin's ecosystems, we find a serious process of degradation due to overuse of water along the whole of the river valley. The ecosystem that most plainly reflects this degradation is the Dead Sea Basin, where the water level has declined from 392 m below sea level in 1930 to 422 m below in June 2009 (Yechieli et al., 2006; Talafeha, 2009; Khlaifat, 2010). This means the Dead Sea's water volume has shrunk from 155 km^3 in 1930 to some 132 km^3 in 2005 (Gavrieli et al., 2002; Lensky et al., 2005), reducing its water surface area by one third (33%) from nearly 950 km^2 to approximately 630 km^2 (World Bank, 2009; Gavrieli et al., 2002). Over the last decade, the water level in the Dead Sea has dropped by an average of one meter per year, representing an annual water deficit of nearly 650 hm^3 (Gavrieli and Bein, 2006).

Clearly, the Dead Sea represents an ecological crisis, even a catastrophic non-sustainable scenario, which requires immediate attention if we are truly serious about managing and/or sustaining the Jordan River Basin. It is an established fact that the annual flow of the Jordan River into the Dead Sea has plunged from 1300 hm^3/year[1] to a current estimate of just 20-30 hm^3/year (EcoPeace/FoEME, 2010) cutting the river's historical flows by some 98%. This has undoubtedly contributed to lowering the water level in the Dead Sea, resulting in grave ecological damage to the lower part of the Jordan River basin. Moreover, the construction of artificial evaporation ponds by the Israeli and Jordanian mineral extraction industries at the southern end of the Dead Sea have compounded this drastic decline and magnified the impact of the shortfall in water availability. Approximately, 200-250 hm^3/year of this deficit, accounting for an annual 35 cm drop in water level, may be attributed to mineral extraction activities (Gavrieli and Bein, 2006). The industries of the two countries together pump out 450-500 hm^3/year from the Dead Sea into their evaporation ponds. Less than 200 hm^3/year of the concentrated brines left over after the mineral extraction process are returned to the Dead Sea, leaving a net water loss of about 250-300 hm^3/year (Gavrieli and Oren, 2004; Gavrieli and Bein, 2006).

[1] One cubic hectometer (hm^3) = one million cubic meters.

1. Objectives

The phenomena associated with environmental degradation have traditionally been regarded as an unavoidable. The prevailing consensus is that market rules entail an inexorable future of environmental degradation, unlike the satisfaction of a population's basic needs. Nevertheless, such views are not based on any sound economic analysis that might justify such a belief. This impression is, then, attributed to powerful *economic reasons* that are not to be studied, estimated or contrasted compare with the possible alternatives.

Recently, *Friends of the Earth Middle East* (FoEME, 2004) reported for the first time on its investigation of the non-market (i.e. the *non-use*) economic value of conservation and development in the Dead Sea basin. FoEME made an impressive effort to assess the benefits gained from conservation of the Dead Sea, measured as a consumer surplus, by applying internationally recognized techniques, the contingent valuation method and the travel cost method for non-use and use values, respectively (FoEME, 2004; Becker and Katz, 2006).

Though our study is rather more limited, we nevertheless cite the efforts made up to now to estimate the economic costs and benefits provided by different uses of the Dead Sea's water and the surrounding land. These references will provide us with estimated data in monetary units that allow an approximation to the importance of maintaining and conserving the environmental health of the Dead Sea.

In this study, we discuss the possibility of stabilizing the water level of the Dead Sea in different scenarios, estimating the opportunity costs of the environmental flows required to offset the water deficit and ensure the sustainability of good environmental conditions. Reasoning this connection, we estimate the opportunity cost of irrigated agriculture in the Jordan Valley and the net profit obtained by mineral extraction industries per cubic meter of evaporated water. Government agencies may use the information presented to explain how the Dead Sea might be saved, but in any advanced water management model, such as those applied in the US and the EU, conservation is currently regulated by law.

2. Background

The Dead Sea is a closed lake located in the northern part of the Syrian-African Rift. It is the lowest place on Earth and its current water level is -422 m (i.e. 422 m below mean sea level). The riparian countries of the Dead Sea are Israel, Jordan and Palestine, which are represented by the West Bank and Gaza Strip. As a terminal lake, its level is determined by the water balance between evaporation and inflows from rain and runoffs, mainly from the Jordan River basin (Figure 1). Estimates based on historical data indicate that before 1948, the inflows into the Dead Sea from the Jordan Basin, as well as the Dead Sea basin itself, totaled some 1600 hm^3/year, of which 1200 hm^3/year came from the Jordan River and other streams and springs. The evaporation rate for the same period has been estimated at some 1600 hm^3/year. Hence, the Dead Sea's historic water level of -391 m before 1948 was largely stable with an equilibrium between inflows and evaporation (Qudah and Harahsheh, 1994; Kobori and Glantz, 1998).

Today, the Dead Sea is threatened mainly by the unsustainable water management policies that originated in the early 60s, allowing the diversion of water from the Jordan River Basin, the lake's principal feeder. Meanwhile, rapid demographic growth in the Jordan Basin has unquestionably raised basic water needs, extracted mainly from the river itself. Nevertheless, the main factor contributing to the loss of the Dead Sea and the associated ecological and cultural damage in the basin is water diversion for agriculture. The largest diversion plans responsible for this situation are the drainage of the Huleh wetlands to the north of Lake Tiberias and the construction of the National Water Carrier by Israel in 1964, which involved diverting water from the Upper Jordan; the East Ghor Canal built by Jordan in 1966, using the Lower Yarmouk waters; and Syrian extractions from the Upper Yarmouk, the main tributary of the Jordan River Basin. Recent studies estimate that the average flow in the Upper Jordan River system is about 1300 hm^3/year, where some 47% is abstracted by Israel, 22% by Jordan, 16% by Syria and 2% by Lebanon (JRV, 1996a; Al Weshah, 2000).

Moreover, the Israeli and Jordanian mineral industries account for around 30%-40% of the decline in the level of the Dead Sea via the artificial evaporation ponds located at the southern end of the Basin (Gavrieli et al., 2005). In 1976, when the lake's level dropped to an elevation of -400 m, the southern basin dried up (Steinhorn et al., 1979), and since 1978 the southern basin has become completely separated where artificial evaporation ponds have been built by Jordan and Israel. Meanwhile, the length of the Dead Sea has shrunk from over 75 to 55 km (Anati and Shasha, 1989).

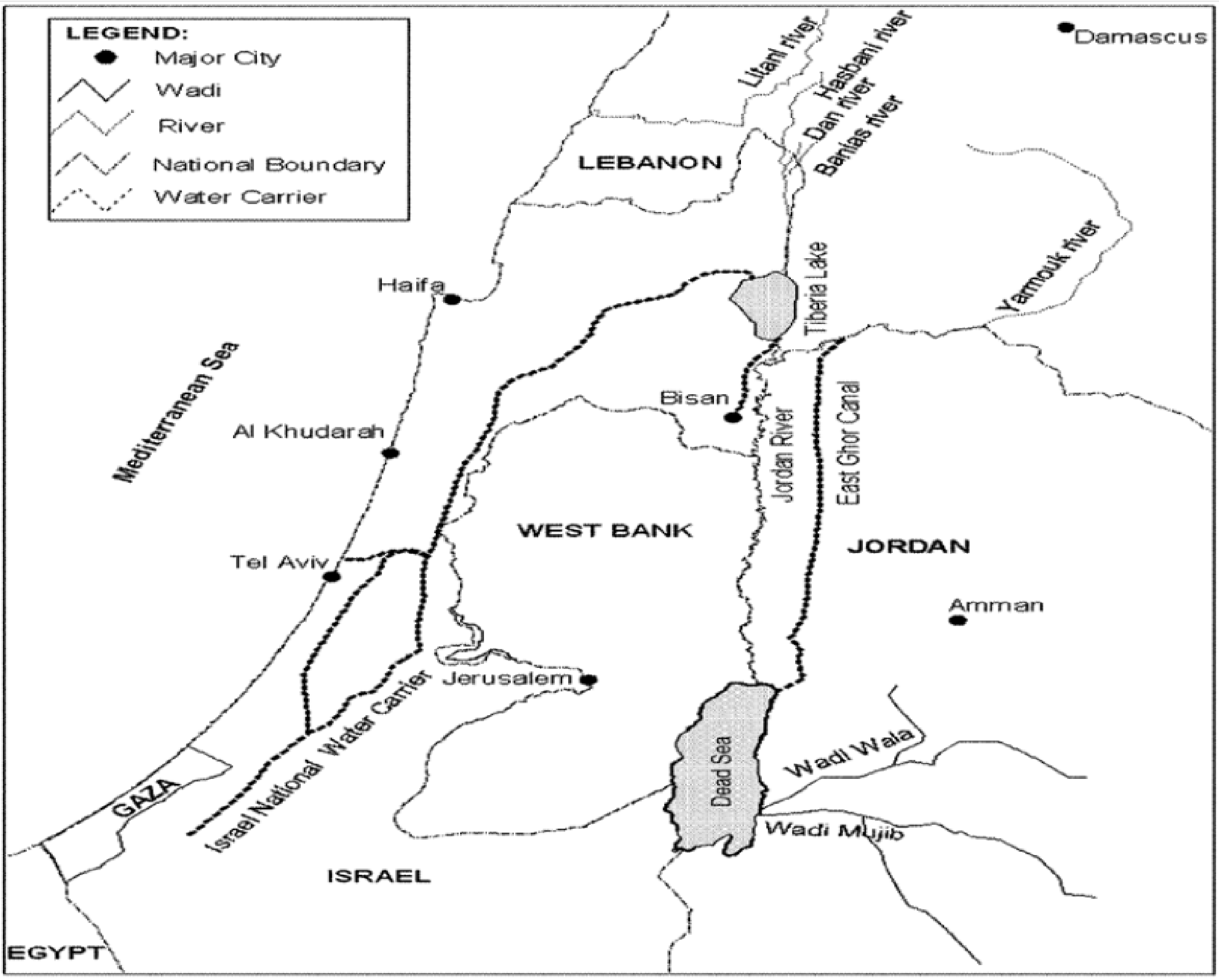

Fig. 1. Jordan River basin and location of the Dead Sea

In the early 1990s, before the 1994 Peace Treaty between Jordan and Israel, the net estimated water flow to the Dead Sea from the Jordan River system was 175 hm^3/year. However, Jordan is entitled to additional water use from the Jordan and Yarmouk Rivers, and the flow into the Dead Sea decreased to 60 hm^3/year after the Peace Treaty was signed (JRV, 1996a). These Figures reveal the impact of the Treaty allocations on the upstream inflow into the Dead Sea, which fell from some 13% of the total flow in the Jordan River system before to about 5% after the allocations (Al-Weshah, 2000). Furthermore, the construction of the Wehda Dam on the Yarmouk River by Jordan and Syria in 2007 cut the Yarmouk's flow into the Dead Sea almost to nothing. Despite the existence of cooperation on some parts of the Jordan River between Israel and Jordan, and between Jordan and Syria on the Yarmouk, the political conflicts and tensions in the Basin have prevented the emergence of a sustainable management approach that might address the whole basin as "a unit of management". Taking the basin as a unit of water management is a necessity today if sustainable perspectives are to be established on an ecosystem-based approach. This principle has now become the basis of modern water management and planning in both the EU and US. Indeed, one of the EU Water Framework Directive's main innovations is the integrated river basin management approach (EC, 2000).

3. Dead Sea water balance

Numerous studies addressed the Dead Sea balance by estimating the inflows and outflows. However, the existing estimations for the water balance in the literature vary widely because of the limitations affecting the precise calculation of certain parameters, in particular the amount and rate of evaporation, salt accumulation and fresh subsurface inflow. The first difficulty lies in determining the amount and rate of evaporation, because these factors depend on other variables, mainly the salinity and water surface area. Generally, the rate of evaporation decreases with increasing salinity (Yechieli, et al., 2006). The second difficulty is to determine salt accumulation and therefore the true net water deficit. The decline in the Dead Sea water level does not represent the true change in the volume of the lake because the accumulation of the salts raises its floor. The water deficit is, therefore, larger than it appears from simple level changes (Lensky et al., 2006).

The third is the interface between fresh surrounding groundwater and saline water, since any lowering of the Dead Sea's water level causes a drop in the groundwater level (Kafri, 1982; Yechieli, 1993; Yechieli et al., 1995).

Let us now present the highlights from some of these studies. Natural water inflows into the Dead Sea in the first half of the 20^{th} century have been estimated in the range of 1600-2000 hm^3/year (Neumann, 1958; Salameh, 1996; Klein, 1998; Salameh and El-Naser, 1999). This estimation includes water sources from the Jordan River Basin, eastern and western side *wadis* of the Dead Sea and springs, subsurface discharge, winter flooding and direct precipitation of about 70-90 mm/year.

Salameh and El-Naser (2000) estimated that the riparian countries of the Dead Sea currently release some 370 hm^3/year of fresh groundwater into the Dead Sea through the interface readjustment mechanisms as a result of the decline in the level of the lake.

Moreover, total water inflow to the Dead Sea today is substantially lower than in the past, with estimates ranging from 475 hm^3/year and to more than 1000 hm^3/year (Salameh and El-Naser, 1999). This difference, of more than 500 hm^3/year, is due to different estimations of the unobserved subsurface inflow.

Salameh's and El-Naser's (1999) upper inflow estimates based on a higher rate of loss (2 m/year) from evaporation ponds. Nevertheless, Stanhill (1994) suggests a much lower evaporation rate of 1.05 m/year for the 1980s and 1990s using an energy balance model.

Gavrieli and Bein (2005) argue that the flow to the Dead Sea has gradually decreased from some 1800 hm^3/year to only about 400-600 hm^3/year since the 1930s. As a result, the rate of decline in the level of the lake has increased gradually to about 0.9-1.0 m/year in recent years (Gavrieli, 2006).

A water-balance model proposed by Yechieli et al. (1998) and the thermodynamic calculations of Krumgalz et al. (2000) suggest that, under the present conditions (1997), the level of the Dead Sea will reach a steady state, where total inflow will compensate evaporation, after some 400 years at an elevation of -510 in the case of the former study and -550 m in that of the latter. In this case, its surface area would shrink to 515 km^2. Meanwhile, Yechieli et al., (1995) and Yechieli et al., (1998) estimated the groundwater discharge at some 300 to 560 hm^3/year into the Dead Sea.

A modified simulation model proposed by Asmar and Ergenzinger (2002) predicted that the Dead Sea will not dry up, but its level will continue to drop without reaching equilibrium in 500 years. Furthermore, the cessation of industrial pumping would result in a rise in the level of the Dead Sea, restoring it to its normal level after approximately 1500 years, though under changed conditions.

Given the Dead Sea's status in 2005, with a surface area of about 625 km^2 and a level of about -418 m, Lensky et al. (2005) estimate an average inflow of 265-325 hm^3/year with an evaporation rate of 1.1-1.2 m/year and salt precipitation of about 0.1 m/year by calculating the energy and mass balances for the Dead Sea utilizing data from 1996 to 2001. However, they also argue that the lake's water deficit is about 690 hm^3/year, some 250 hm^3/year of which is accounted for by mineral extraction industries in the southern basin of the Dead Sea.

3.1. Proposed solutions to save the Dead Sea. The proposed solutions to restore the water level in the Dead Sea have frequently been based on supply-side management and the search for new water resources. However, they have generally avoided any suggestive of legislation to set extractions at a level that might guarantee the conservation of the Dead Sea. Such measures would have to be accompanied by demand management strategies that could meet demand at sustainable levels. Any strategy of this kind would need to be similar to the policies implemented by the US in similar cases, such as the protection of Mono Lake through the enforcement of the *Public Trust Doctrine*, or to the efforts of the EU in its new Water Directive Framework.

However, the objective is to establish appropriate development and territorial plans that respect the sustainability of water ecosystems by assuming water demand management capable of adjusting prices so as to guarantee economic rationality in the different productive uses of water, taking into account sustainable restrictions on the aquifers and fluvial and lakes ecosystems of the Basin, such as Lake Tiberias and the Dead Sea.

There are currently four alternatives under debate for the Dead Sea crisis:

1. The current Red Sea-Dead Sea Water Conveyance Project, also referred to as the "Peace Conduit", which was proposed in 2005. The idea of water transfer from the Mediterranean Sea to the Dead Sea, as well as from the Red Sea to the Dead Sea goes back to the early 19^{th} century. Since then, many plans have been drawn up to bring seawater from either sea to the Dead Sea to recover its natural water level, generate electricity and produce freshwater by seawater desalination. Such in-

ter-sea transfers have always raised concerns about economic feasibility and ecological impacts, mainly because mixing seawater could lead to negative changes in the salt composition of the Dead Sea. The Red Sea-Dead Sea project has again been taken up by the three beneficiaries, Israel, Jordan and Palestine and its economic, technical and environmental feasibility as a means of saving the Dead Sea is currently under consideration. The World Bank, which has coordinated the *Red Sea-Dead Sea Water Conveyance Study Program*, continues to support the socio-economic and environmental impact assessment studies for the proposed Red Sea-Dead Sea Canal (RDC), but its spokesman, Alexander McPhail, has nevertheless announced that other alternatives will also be examined (Jordan Times, Monday, July 28, 2008).

2. Another option is to maintain the status quo, taking no action because all alternatives might prove unfeasible. In this case, the Dead Sea level is expected to decline further to around -550 m (i.e., about 130 m below the present level), when a steady state will be reached. This would reduce its area to some 515 km^2, 54% of its surface area in 1930 (Yechieli et al., 1998; and Krumgalz et al., 2000).
3. The third option is to change the water management paradigm in the basin to divert the required environmental flows back from the Jordan River Basin to the Dead Sea, and at the same time to cut back or halt industrial mineral extraction. This option does not need any major investments, but would rather entail small annual compensation payments, as we shall explain below, until new substitute activities can be set up to offset of the necessary reductions in agriculture and the minerals industries.
4. Experts will also investigate a Mediterranean-Dead Sea Canal option and the extension of a water pipeline from Turkey.

3.2. Agriculture in the region. As we have already mentioned, the primary cause of the declining level of the Dead Sea is the extraction of water from the Jordan River Basin, the main source of freshwater, for use by the riparian countries, particularly Jordan, Israel and Palestine. The latter currently has no access to the surface water of the Jordan River and its main source is underground waters (mountain aquifers in the West and the Gaza Aquifer in Gaza Strip). In the West Bank, the Palestinians' total use was 144.43 hm^3 in 2008, 91.5 hm^3 of which came from wells and springs and about 53 hm^3 was purchased from Mekorot, the Israeli Water Utility. Of this total, 48 hm^3 was allocated to agriculture (PCBS, 2009). However, Palestinian water extraction is actually minimal and has almost no effect on the Dead Sea. Furthermore, transferring water to the Palestinians is a necessary condition for the future development of a Palestinian State and a lasting peace settlement in this volatile region.

Agriculture is the primary consumer of water in the Basin. It accounts for about 57% of total use in Israel, 65% in Jordan and 64% in Palestine. On average, Israel allocated some 1140 hm^3 to agriculture in 2005-2007 (CBS, 2009a). Agricultural water withdrawals in Jordan accounted for 604-611 hm^3 in 2005 (Aquastat, 2009; Hadadin et al., 2010). In Palestine, agricultural use was about 123 hm^3 in 2008, of which 48 hm^3 were used in the West Bank and 75 hm^3 in the Gaza Strip. This water has a significantly lower return per cubic meter than urban-industrial uses. Thus, any solution for stabilizing the Dead Sea water level by diverting water back to the course of the Jordan River must begin by taking account of agricultural uses in the region, concentrating particularly on the crops that generate the lowest returns.

Israeli agriculture currently accounts for 1.4% of GDP (CBS, 2009b) and 1.7% of total employment. Meanwhile, the sector's share of the country's GDP has decreased from 11% in 1950 (Plait, 2000) to 1.6% in recent years (2003-2008). Employment also has dropped from 16.5% of total jobs in 1960 to 1.7% in the period of 2006-2008 (CBS, 2009c). Evidently, farming was a priority for successive Israeli governments in the early years of the nation's emergence and consolidation, but the decline in agricultural GDP and employment to less than 2% today clearly shows that the sector has been sacrificed to concentrate on the development of new industries and economic activities. Even so, this is a modest contribution because farming still plays an important role for Israel as a nation.

Moreover, most crops are grown for off-season export to the European market, but local farms also serve to supply the domestic market with perishable foodstuffs, especially fruit, vegetables and dairy products.

In Jordan, agriculture contributed an average of 4.2% of the GDP in the period of 1994-1998, declining to an estimated 3.2% in 2009 (DOS, 2009). In terms of employment, the sector accounted for an average 5.8% of jobs in the period of 1994-2000, which has since fallen to 2.7% in 2007 and an average of 3% in the period of 2005-2007.

Palestinian agriculture contributed an average of around one third of national GDP in the period of 1968-1992. However, this contribution decreased to about 11% in the period of 1994-2002 and had dropped to approximately 4.8% of GDP in 2009. Employment in agriculture represented an average of 13% of total jobs between 1995-2008, and in 2004-2007 it was 15.6%.

5. Opportunity cost of the environmental flows needed to guarantee the sustainability of the Dead Sea

Three key factors underline the decline in the Dead Sea's water level: irrigated agriculture in the Jordan River Basin, mineral extraction industries around the Dead Sea and natural evaporation from the lake itself. Clearly, we cannot act to halt the last factor, but we can do on first two. Hence, this study concentrates on estimating the opportunity costs of water used in agriculture and water abstracted from the Dead Sea by mineral extraction industries.

The first factor we need to determine is the water level we wish to achieve and stabilize in the lake, which is the level that matches a particular water surface, salt composition, water inflow and evaporation rate. Given the wide range of data and the different estimations referred to above, we will adopt the estimations of Lensky et al. (2005) for the present situation and the historical situation at the beginning of the 20^{th} century (1942-1946). Specifically, we will base our estimations on the assumption that the current surface area of the Dead Sea is 625 km^2, an average evaporation rate of 1.1-1.2 m/year and an estimated inflow of 265-325 hm^3/year. In order to maintain the present Dead Sea level, an estimated inflow of 1050 hm^3/year will be needed. Accordingly, the water deficit of the lake is nearly 690 hm^3/year.

With regard to the historical situation, we assume that the surface elevation at that time was about –392 m and the lake's area, including the southern basin, was about 950 km^2. The estimated inflow would be in the range of 1550-1750 hm^3/year. Accordingly, the evaporation rate was 1.6-1.85 m/year. Assuming the current estimated inflow of 265-325 hm^3/year, the water deficit to be compensated is 1285-1425 hm^3/year.

Given these conditions, we propose three scenarios with two possible targets for water levels to stabilize the Dead Sea.

Scenario 1: Maintain the present Dead Sea level. An estimated deficit of 690 hm^3/year will be required to stabilize the current level.

Scenario 2: Maintain the present level, splitting the contribution effects between upstream diversion of water from the Jordan River Basin and the mineral extraction industries, which are responsible for roughly 35% of the loss of the Dead Sea.

Scenario 3: Restore the historical level at the beginning of the 20th century, when the surface area was 950 km^2. This would require compensating for an estimated deficit of 1400 hm^3/year.

The second factor is to estimate the opportunity cost curves for water used by agriculture in the Jordan Basin and by the mineral extraction industries along the Dead Sea shores. These calculations seek to make an economic assessment of possible transfers of fresh water from the Jordan and the Yarmouk River systems for diversion back to the Dead Sea and the reduction of artificial ponds along the lake's southern shores. Such transfers would affect the lowest areas on the opportunity cost curves, which relate to the least profitable irrigation uses.

We, therefore, use the returns from agriculture and mineral extraction industries as the basis for the utility function, which allows us to estimate the opportunity cost of the flows needed for the sustainability of the Dead Sea.

To this end, we have analyzed the agricultural uses of the Jordan River Valley in the different riparian countries, except for the Lebanon given the difficulty of accessing significant data on its water use. In any event, the omission of irrigated land in Lebanon is of little significance, in view of the country's limited involvement in the River Valley. Difficulties also exist in the case of Syria, which has a significant involvement in the Yarmouk basin, because of a paucity of segregated data on Syrian agriculture in the Jordan River Basin, as opposed to general Figures which include the Euphrates basin. This makes it difficult to analyze the irrigated land fed by the waters of the Yarmouk. However, Syria also receives water from other sources, mainly the Euphrates and Orontes basins, which together account for most of the country's irrigation, accounting for about 63% and 17% respectively of the total irrigated area, while the Yarmouk basin represents only about 3% (36,000 ha) (World Bank, 2001). We encountered a similar lack of detailed crop-based data for water use, costs and benefits. Consequently, we have opted in the end to assume the crop structure and productivity of Jordanian irrigation for the 36,000 hectares of irrigated land in the Syrian Yarmouk Basin.

The 2001-2002 agricultural data for Israel, Palestine and Jordan have basically been taken from the websites of their respective statistical bureaus. Based on an analysis of the revenues and costs generated by irrigated agriculture, we have estimated the standard gross margin generated by each crop per cubic meter of water used as revenues less direct costs (seeds, fertilizers, pesticides, water, machinery, energy, etc.). The total volume of water used in irrigation by these farmers is some 1528 hm^3/year (Atwi and Chóliz, 2009). Assuming that Syrian irrigated agricultural in the Upper Yarmouk has the same structure and productivity as Jordanian irrigated land, the total amount of irrigation water in the Jordan Basin is about 1715 hm^3/year. Our approximation is acceptable if we take into account Syrian extractions of about 200-250 hm^3/year from the Yarmouk in recent years.

Based on this analysis of agricultural data in the different countries, we estimated the standard gross margin obtained on each crop per cubic meter of water used. By adding the price paid per cubic meter in each country to this standard gross margin, we then obtained what we have identified as the irrigation water opportunity cost in each country.

The empirical results are given in Figure 2, which reflects a clear downward and roughly hyperbolic trend. For ease of mathematical operation, we have therefore opted to adjust the data using a hyperbolic curve (also shown in Figure 2). As may be seen, the curve provides a good fit with the observed data. The empirical results of this analysis provide the curve (Figure 2) with the economic value of water used in irrigation based on the benchmark of the standard gross margin generated by these water flows.

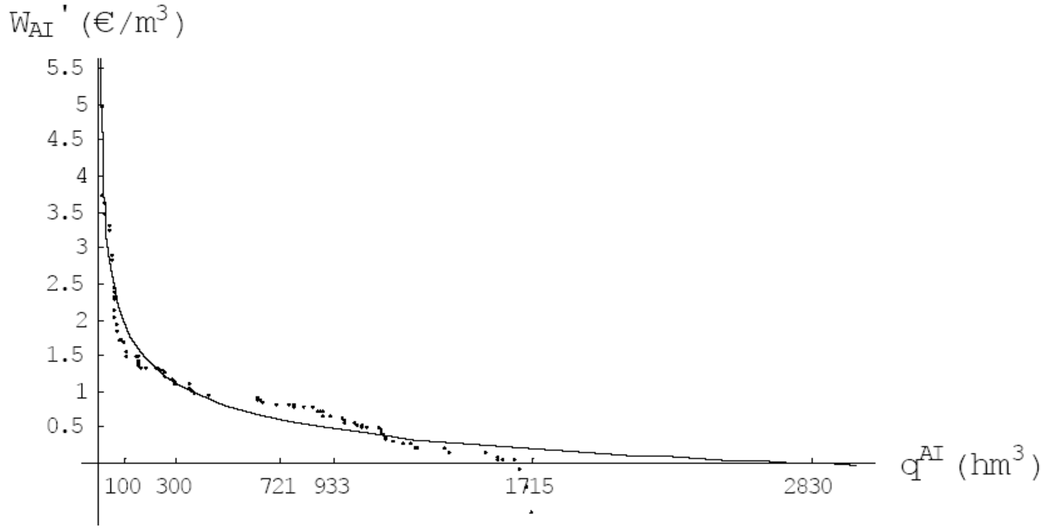

Fig. 2. Standard gross margin of irrigated agriculture and adjusted function for Jordan basin

By adjusting this empirical curve, we have obtained the following marginal value for agricultural uses:

$$W'_{AI} = -1.53474 + 10.7007\, q^{AI(-0.244325)},$$

where W'_{AI} is marginal value of irrigated water in the Jordan River basin including both Israel and Arabs. q^{AI} is water used in agriculture in the Jordan River basin.

In order to obtain the results in terms of transferable flows, which we shall call x, we changed the variable from q to x, where $x = q^{AI}_{act} - q^{AI}$, the current estimated amount of water used in agriculture in the Jordan Valley being $q^{AI}_{act} = 1715.68$ hm^3/year. Hence, in terms of transferred flows:

$$W'_{AI} = -1.53474 + 10.7007(1715.68 - x)^{(-0.244325)}.$$

A similar procedure was applied to estimate the-marginal value of water use by the mineral industry. However, we take the Producer Surplus estimated by Friends of the Earth Middle East (FoEME, 2004) as the benchmark. Also, as we lack the marginal value function for this producer surplus, it was possible only to obtain the average value of €143 million per year (FoEME, 2004).

Therefore, given estimated evaporation of 250 hm^3/year, an approximation to the average opportunity cost of the environmental flow V^{AI}_{Ind} associated with the water evaporated by mineral extraction activities gave:

$$V^{AI}_{Ind} = (143.10^6\ €/year) / (250.10^6\ m^3/year) = 0.57\ €/m^3.$$

Finally, we added the average net profit € 0.57 per cubic meter of evaporated water obtained from the Dead Sea by mineral extraction industries over the marginal irrigation value curve. By aggregating this net profit to the curve, which reflects agricultural profits for the Jordan River basin, we can construct the total curve shown in Figure 3.

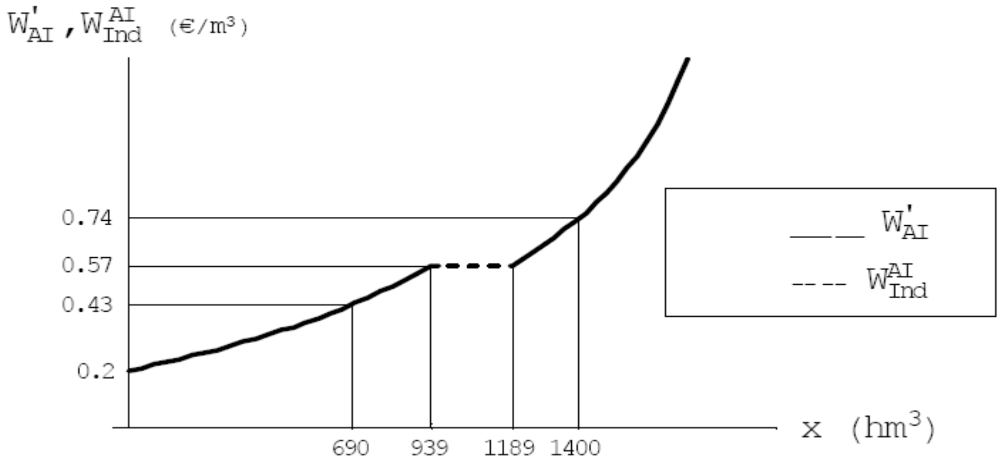

Fig. 3. Opportunity cost curve for irrigated agriculture in the Jordan Basin and mineral extraction industries in the Dead Sea

As we may observe, the deficit of 690 hm^3 (Scenario 1) required to stabilize the current water level of the Dead Sea is saved entirely by sacrificing irrigation in the Jordan River basin, while the contribution of the mineral extraction industries to water saving is null.

More realistically, however, the cessation of less efficient mineral extraction, with economic returns less than €0.43 per cubic meter (below 75% of the average) might also be considered, as well as the introduction of advanced water saving technology in the mineral extraction process.

In contrast, a deficit of 1400 hm^3/year (Scenario 2) would require sacrificing almost all mineral extraction industries, so that only the most efficient with economic returns above € 0.74 per cubic meter (some 30% above the average) might keep their activities.

Let us now calculate W_E, the environmental opportunity cost of stabilizing the Dead Sea's water level for each of the three scenarios are explained above.

4.1. Scenario 1. Integrating this curve, the Section corresponding to the flow required to offset the current deficit of 690 hm^3/year, the opportunity cost of environmental flows is:

$$W_E = \int_0^{690} 1.53474\,(10.7007 - x)^{(-0.244325)} dx =$$

= €209.42 *million/year*

which gives an average of €0.30/m^3.

This sacrifice first affects the lowest areas of this curve, representing the least profitable irrigation uses.

4.2. Scenario 2. However, other reasons of social, environmental and territorial planning may exist that would make it more appropriate to share the responsibility for conserving the Dead Sea between both agriculture and the mineral industries. One criterion that could be applied here is to allocate water extraction responsibilities proportionally to both sectors. Let it be clear, however, that this is not a proposal but merely an example. Thus, assuming that upstream diversion accounts for roughly 75% and mineral extraction industries for about 25% of the current deficit of 690 hm^3/year. Water use foregone in the Jordan River basin must come from agriculture but if each sector assumes its responsibility in the terms stated above to stabilize the Dead Sea water level, however, then agriculture will sacrifice some 518 hm^3/year and the mineral extraction industries around 172 hm^3/year. Accordingly, the opportunity cost of the hypothetical flows sacrificed is:

$$W_E = [(172 \cdot 10^6\ m^3/year) * (0.57\ €/m^3)] + \left[\int_0^{518} 1.53474\,(10.7007 - x)^{(-0.244325)} dx\right] €/year = [€98.04\ million/year] + [€141.58\ million/year] = €239.62\ million\ per\ year.$$

In this case, the average opportunity cost required to offset the estimated deficit in this scenario is 0.35 €/m^3.

4.3. Scenario 3. The objective of this scenario is to estimate the opportunity cost of the inflows required to restore the historical water level of the Dead Sea. In this case, the estimated deficit is about 1,400 hm^3/year, assuming its historical surface area was 950 km^2. This amount is almost double the current volume of water required to maintain the present level of the lake.

Following the steps described in the previous scenarios, the opportunity costs of these flows are:

$$W_E = \left[\int_0^{939} 1.53474\,(10.7007 - x)^{(-0.244325)}\,dx \right] + [250 * 0.57] + \left[\int_{1189}^{1400} 1.53474\,(10.7007 - x)^{(-0.244325)}\,dx \right] =$$

= 333.14 + 143 + 193.58 = € 669.72 *million/year.*

Therefore, the average opportunity cost of the environmental flows is 0.48 €/m^3, higher than in the either of the other two scenarios.

As can be seen in Figure 3, first we sacrifice an agricultural Section of 939 hm^3/year, then 250 hm^3/year from the mineral extraction industries, and then another more productive agricultural Section of 211 hm^3/year. Consequently, the saving made at the expense of agriculture would be 1150 hm^3/year. This amount represents more than two thirds of the total water use in agriculture.

The total annual surplus generated by agriculture is €1304.58 million per year, so this scenario means that the reduction in agriculture required to preserve the Dead Sea in this scenario would be approximately of 40.37%. The scenario would, therefore, entail a far-reaching transformation of local farming.

Meanwhile, the complete elimination of the mineral extraction industries implies the total loss of the €143 million surplus they generate each year. Only a handful of very efficient industries generating high economic returns might remain.

In the three scenarios discussed above, we have estimated the sacrifices that it would be necessary to make in agriculture and the mineral extraction industries to divert water back to the Dead Sea. These estimates are based, on the one hand, on the economic returns obtained from agricultural water use in the Jordan River basin and, on the other, on the producer surplus from mineral extraction industries as estimated by FoEME as an indication of the economic returns from artificially evaporated water in these industries.

Without ruling out any other option, we believe Scenario 1 would offer a number of reasonable objectives on which to focus. Stabilizing the water level of the Dead Sea would produce a whole series of tangible and intangible economic benefits, and these must subtracted from the opportunity costs estimated to obtain the true *cost of sustainability* for the environmental objectives marked out. The first type of value refers to benefits that can be easy evaluated in monetary units. In this sense, the Dead Sea produces many tangible benefits (direct and indirect) such as minerals, agriculture, tourism, aquifer recharge and habitat, etc. The second type of value relates to the existence value, which reflects benefits from simply knowing that the Dead Sea exists and is protected, while the bequest value refers to benefits from ensuring that the Dead Sea will be preserved for future generations even if we do not directly benefit ourselves. Obviously, economic benefits of this type are difficult to define clearly.

The economic study by *Friends of the Earth Middle East* mentioned above made an impressive effort to calculate these profits by applying internationally recognized techniques. Specifically, an assessment of the *values of non-use and use* produced a global estimated profit of €116 million per year that could disappear or would be substantially decreased if we do not halt the degradation of the Dead Sea. In addition to these profits, certain other costs would be avoided by the prevention of impacts from subsidence, landslides and the appearance of sinkholes, phenomena that are already gradually affecting housing blocks, hotels and transport infrastructure as a consequence of the systematic drop in the level of the Dead Sea. Given the lack of data regarding these costs, however, we have not sought to compute the benefits derived from avoiding these phenomena. Moreover, the annual value would be relatively small in comparison with the non-use values.

Globally, therefore, the goal of sustainability to be achieved by stabilizing the current level of the Dead Sea (Scenario 1) would entail approximate total net costs of about €93 million per year, which implies an opportunity cost of €0.135 per m^3 for the environmental water flows it would be necessary to conserve.

In the case of Scenario 3, the cost would be €410 million, were this scenario politically viable, which it is not.

It might be asked whether it is worth to accepting this cost to guarantee the objective of sustainability. Specifically, would it be worth a cost of 0.135 €/m^3 to save the Dead Sea from the present process of ecological degradation. On this score, we would note that seawater desalination costs of about 0.45 €/m^3 are already assumed in the basin for multiple uses, and this is actually higher than the opportunity cost estimated for Scenario 3, which represents the restoration of historical conditions.

We may also observe that the cumulative costs if the compensation required by Scenario 1 were kept up for 25 years would still be less than 50% of the estimated €5 billion cost of the RDC. Meanwhile, former Israeli Water Commissioner, Professor Dan Zaslavski, has estimated that regenerating the flow of the Jordan River to bring water to the Dead Sea would cost no more than $800 million, substantially less than the $5 billion it is estimated would be required to complete the RDC project. In addition to this comparatively low cost, the regeneration of the Jordan River would in itself deliver hundreds of millions of dollars worth of benefits each year, given its immense historical, cultural and natural values, and its significant unexploited value for tourism.

Conclusion and discussion

This paper presents our results for the opportunity cost of environmental flows in Scenarios 1, 2 and 3, which are €209.42 million per year, €257.73 million per year and €669.72 million per year, respectively, representing an average cost of €0.30, €0.37 and €0.48 per m^3, respectively. Considering such a minute cost to stabilize the water level of the Dead Sea, which would produce a whole series of tangible and intangible economic benefits, the estimated true *cost of sustainability* for the environmental objectives addressed in the three scenarios, would be the sum €93 million per year, €142 million per year and €554 million per year, respectively. All three Scenarios appear cheap in comparison to the investment of €5 billion required for the RDC project.

Just to stabilize the Dead Sea at its current level (Scenario 1) would cost 0.135 €/m^3/year. Stabilizing the Dead Sea and regenerating the flow of the Lower Jordan River would in itself produce many benefits, which extend to tourism, environmental impacts and the overall sustainability of the region. In addition, action would save costs incurred as a result of undesirable phenomena like subsidence, landslides and the appearance of sinkholes affecting housing development, hotels and transport infrastructure as a consequence of the systematic drop in the level of the Dead Sea. Data on these costs is lacking, and we were therefore unable to compute the benefits derived from avoiding these phenomena.

The Dead Sea is not only a source of economic value for the region. It is also the source of numerous socioeconomic values including religion, cultural heritage, health characteristics, and the scenery enjoyed by local people and international tourists.

History has shown that the economic benefits of many large scale projects such as water transfers (Owens Valley aqueduct and Mono Lake in the USA; Spanish National Hydrological Plan, in Spain) and large-scale dam construction are questionable, and are at the very least outweighed by the costs resulting from environmental and socioeconomic impacts. Moreover, the growing social concern and awareness of environmental and aesthetic values have forced the developed countries thoughtfully to reconsider their regional and national water management policies, shifting from the traditional productive strategy to an ecosystem focus. In this regard, the proposed Red-Dead Sea Canal is a controversial project from the economic and environmental standpoint, though it has been dubbed a "Peace Conduit". The author does not believe that the future Peace Process in the region should be a matter for the project. If politicians from Israel, Jordan and Palestine have agreed to and supported this sort of inter-seas water transfer project, this does mean that it would be economically and/or environmentally sound. Former Israeli water commissioner, Professor Dan Zaslavski, has estimated that regenerating the flow of the Jordan River would cost no more than $800 million, significantly less than the estimated $5 billion required to complete the RDC project.

Moreover, there is intense concern about the feasibility of the RDC project in the scientific world, especially when other options are technically, economically and environmentally more feasible. Leaving aside the economic factor, many scientific studies, in particular by the *Geological Survey of Israel*, have shown that mixing the two seawaters would result in significant negative environmental impacts.

According to Ittai et al. (2005), such impacts would affect limnology, geochemistry and biology. Specifically, the massive inflow of sea water and/or reject brine would result in the dilution of surface water, in all likelihood leading to microbial blooms, the formation of a stratified body of water body, mineral precipitation (in particular gypsum) and changes in the rate of evaporation and in the composition of the Dead Sea brine.

Undoubtedly, such impacts would change the main feature of the Dead Sea as a unique body of water. Based on current findings, moreover, a complete understanding of the major anticipated and unexpected effects that would result from mixing water from two different seas remains out of our reach.

Red-Dead and Med-Dead inter-sea water transfer canals were proposed more than 100 years ago. Today, however, environmental sciences and newly developed technologies allow us to adapt projects that are profitable economically to make them more environmentally friendly. A new water management paradigm now exist that leans toward the conservation and sustainability of ecosystems, an approach which is badly needed in the Middle East.

Aside from the data limitations affecting the estimation of actual opportunity costs, the estimated costs in this article should be understood as guide to decision makers suggesting that other alternatives are possible. We suggest an approach that is based on the sacrifice of all or part of current agricultural and mineral production activities. Many options could be adapted and combined in this regard, such as eliminating the least profitable products, changing agricultural patterns to focus on less thirsty crops, adopting more realistic pricing policies (agriculture in the region is highly subsidized), halting exports of agricultural products, expanding desalination plants to allow for agricultural use (the desalination cost in the region is around of 0.45 €/m^3), expanding water reutilization, and increasing irrigation efficiency, especially in Jordan and Syria. Taking into account the Virtual Water alternative, even this policy requires political trust among the countries of the region.

Nevertheless, transferring water from agriculture to the Dead Sea is a debatable issue, in particular in view of the disparities in development between Israel and the other riparian users. Israel has a well developed economy whereas economic backwardness in Palestine and Jordan and the social problems of unemployment mean it is often harder to find alternatives to agriculture. Thus, it will be necessary to increase economic value by introducing new technologies and industries, and improving educational and living standards. In a developed and complex economy such as Israel, in contrast, there are many alternatives both for capital and employment, which are also replaceable. For example, Israel has the economic and technological capacity to substitute its extractions from the Jordan River with desalinated water. In any case, diverting water back to the Jordan River basin would need to be accompanied by the other strategies referred to in this paper.

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