Chapter 14
Reclaiming the Dead Sea: Alternatives for Action

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Abstract The sustainable supply of natural water available in the water basin feeding the Dead Sea (comprising of Israel, Jordan and the Palestinian Authority) will soon drop below 100 cubic metres (m^3) per person per year. This has resulted from upstream diversions that over time have deprived the Dead Sea of more than 90 % of its historical inflow and led to a progressive decline of its water level with detrimental effects on the surrounding environment and infrastructure. We examine four alternatives to stabilise or restore the Dead Sea and evaluate the costs associated with each alternative. We also offer a mechanism to pay for the reclamation alternatives based on a surcharge levied on all upstream diversions (including water consumed by the potash industries). The surcharge rates associated with the four alternatives range between zero and USD 0.10 per m^3.

Keywords Dead Sea reclamation • Water scarcity • Environmental amenities • Recycling • Desalination • Study of alternatives • World Bank • Jordan River • Yarmuk River • RSDS conveyance project

14.1 Introduction

Upstream diversions have diminished water flow into the Dead Sea by over $1{,}500 \times 10^6$ m^3/year during the last 50 years. The most significant diversions have been from the upper Jordan River (mostly by Israel) and the Yarmuk River (mostly by Syria), while the remaining diversions are mostly from side wadis in the Dead Sea eastern escarpment (Salameh and El-Naser 2000; TAHAL and GSI 2011). The Dead Sea water balance is further exacerbated by the additional

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water loss of about 262×10^6 m^3/year due to the potash industries of Israel and Jordan (Zbranek 2013). The Dead Sea water level is currently at about 428 m below sea level (mbSL), some 30 m lower than its 1960 level, and continues to decline by more than a metre annually on average (Rawashdeh et al. 2013). The progressive decline in the water level and the ensuing retreat of the shore line have given rise to sinkholes, mud flats and landslides with serious damage to infrastructure and irreversible damage to habitat of unique species. The estimated direct costs range between USD 73 million per year and USD 227 million per year (Becker and Katz 2009).[1]

Stabilising the Dead Sea at its current level requires an additional water inflow of 700–800 × 10^6 m^3/year, while fully restoring the Dead Sea to its historical level (of 395–400 mbSL) would mean increasing the inflow by more than 1,100 × 10^6 m^3/year (Malkawi et al. 2010; TAHAL and GSI 2011). Reclaiming the Dead Sea, thus, necessitates substantial additional inflows, which raise three interrelated questions: from where (i.e. what are the possible sources of the additional inflow), at what cost and how to pay for the reclamation? The first and second questions have been analysed in a number of studies, and the main findings of these studies will serve as a benchmark and a point of departure for this effort.[2] The third question, regarding who should pay for the Dead Sea reclamation, has not been properly addressed and will receive special attention in this chapter.

To put the Dead Sea reclamation problem in context, we begin in the next section with a brief summary of the current water situation in the Jordan River Basin comprised of Israel, Jordan and the Palestinian Authority – the three riparian parties to the Dead Sea. Section 14.3 discusses the Dead Sea reclamation alternatives involving seawater conveyance from the Red Sea or from the Mediterranean, drawing mainly on the study of alternatives to the Red Sea–Dead Sea Water Conveyance Project (Allan et al. 2014), giving special attention to the costs of the different alternatives. Section 14.4 elaborates on an alternative, first offered in the abovementioned study of alternatives, which takes a long-term perspective (3–4 decades) by combining measures that will be implemented incrementally over time. Section 14.5 discusses the issue of how to cover the costs of Dead Sea reclamation and Sect. 14.6 concludes.

[1] These estimates are based on the local population's willingness to pay to prevent further decline of the Dead Sea level. However, 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 declining of the Dead Sea is therefore likely to be larger than the above range.

[2] See Vardi (1990) and Beyth (2006, 2007) for overviews of past proposals and the recent ensemble of studies coordinated by the World Bank available at http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/MENAEXT/EXTREDSEADEADSEA/0,,contentMDK:21827416~pagePK:64168427~piPK:64168435~theSitePK:5174617,00.html.

14.2 Water Scarcity in the Jordan River Basin

We consider the part of the Jordan River Basin that includes the three Dead Sea riparian parties, namely, Israel, Jordan and the Palestinian Authority (see Fig. 14.1).[3] A useful (albeit rough) index of regional water scarcity is the quantity of renewable (natural) water available per person in a sustainable fashion, obtained by dividing the average annual supply of renewable natural water by the existing population and measured in units of cubic metre (m^3) per year and person (m^3/year per person). Regions whose renewable water supplies fall below 1,000 m^3/year per person or 500 m^3/year per person are said to experience water scarcity or absolute scarcity, respectively (Falkenmark et al. 1989). The 100 m^3/year per person threshold is often mentioned as the supply required to satisfy basic human needs (Gleick 1996). While the supply of natural renewable water is on average constant (with possible trends over the long run, due, e.g. to climate change), the population is expanding quite rapidly in this region, implying that the m^3/year per person index will decline over time and therefore aggravating water scarcity.

Table 14.1 presents the average supply of renewable water in the Jordan River Basin. It shows that the renewable (natural) water supplies (available on a sustainable fashion, i.e. without drawing down stocks) in the region comprised of Jordan, Israel and the Palestinian Authority are on average $2{,}428 \times 10^6$ m^3/year, and this quantity includes 232×10^6 m^3/year of brackish water (i.e. water with chloride concentration above 400 mg/l, which is unsuitable for drinking and irrigation of many crops without mixing).[4] The total supply of good quality natural water is therefore $2{,}196 \times 10^6$ m^3/year (=2,428 − 232) on average.

Figure 14.2 presents actual (as of 2011) and projected populations for Israel, Jordan and the Palestinian Authority from 1950 to 2050. The m^3/year per person scarcity index is obtained by dividing the average annual water supply ($2{,}196 \times 10^6$ m^3/year or $2{,}428 \times 10^6$ m^3/year) by the population. The results are shown in Table 14.2.

As the table reveals, the region as a whole is already far below the absolute scarcity mark of 500 m^3/year per person and will soon enter subsistence scarcity below 100 m^3/year per person. Such an acute scarcity implies that increasing the supply of potable water for domestic uses receives the highest priority. This observation virtually implies that natural (potable) water cannot on its own achieve the goal of Dead Sea reclamation (which, as noted above, requires 700×10^6 m^3/year to 800×10^6 m^3/year just for stabilising the current level) and other sources must be found for that purpose. These other sources are seawater or recycled water. Indeed, most proposals for reclaiming the Dead Sea, either by stopping its decline or restoring its level to its

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[3] The Jordan River basin 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.

[4] A detailed account of natural, renewable water supplies (including inter-temporal fluctuations) can be found in Tsur (2014).

Fig. 14.1 The Jordan River Basin. The Upper Jordan River extends between its headwater (at the confluence of the Dan, Banias and Hatzbani) and the Lake Tiberias. The Lower Jordan River is the southern stretch of the river between Lake Tiberias and the Dead Sea (Source: UNEP/DEWA/GRID-Geneva(http://en.wikipedia.org/wiki/Jordan_River#mediaviewer/File:JordanRiver_en.svg))

Table 14.1 Renewable water resources in the Jordan River Basin

	10^6 m^3/year	Source
Israel and Palestinian Authority	1,451 (1,683)[a]	Weinberger et al. (2012)
Jordan	745	Ministry of Water and Irrigation (2009; executive summary, p. 7).
Total	2,196 (2,428)	

[a]Average over the period 1993–2009 without the 232×10^6 m^3/year of brackish water (*in parenthesis*: total supply with brackish water)

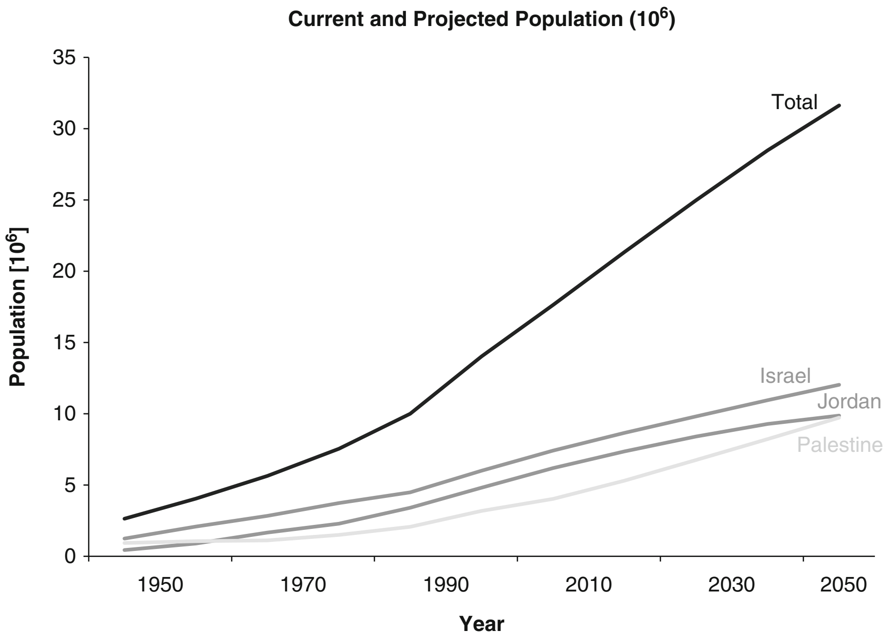


Fig. 14.2 Current (until 2011) and projected population (million) (Source: United Nations (2011))

Table 14.2 Population and annual per person supplies of natural (potable) water

Year	Population (million)	m^3/year per person based on $2{,}428 \times 10^6$ m^3/year	m^3/year per person. based on $2{,}196 \times 10^6$ m^3/year
2013	18.8	129	117
2030	25	97	88
2050	31.6	77	69

pre-diversion state, involve conveyance of large quantities of seawater from the Mediterranean or from the Red Sea (see Vardi 1990; Beyth 2007 for overviews on past proposals and www.worldbank.org/rds for the ensemble of studies associated with recent "Red Sea–Dead Sea Conveyance Study Program"). These sea-to-sea conveyance alternatives involve large-scale infrastructure projects and require large upfront investment, raising doubts about their feasibility. In the next section, we briefly summarise one Red Sea–Dead Sea Project and two Mediterranean Sea–Dead Sea Projects considered in the abovementioned World Bank studies.

14.3 Water Conveyance from the Red Sea and the Mediterranean Sea

Our cost calculations are based on the most recent data available from Coyne et Bellier's (2014) feasibility study. This feasibility study considers a comprehensive project with the dual goal of reclaiming the Dead Sea and increasing the supply of potable water in the region: upon completion, the project will convey $2,000 \times 10^6$ m^3/year from the Red Sea to the Dead Sea, desalinate 850×10^6 m^3/year that will be delivered mostly to Amman and discharge $1,150 \times 10^6$ m^3/year of brine in the Dead Sea. As we focus on the Dead Sea reclamation, the cost of seawater–brine discharge in the Dead Sea reported here pertains to the cost of a project, the sole purpose of which is to stabilise the Dead Sea water level. This involves the conveyance of up to $1,150 \times 10^6$ m^3/year seawater from the Red Sea or the Mediterranean to the Dead Sea exploiting the elevation difference to generate hydropower.[5] We discuss water conveyance from the Red Sea and from the Mediterranean Sea in turn.

14.3.1 Red Sea–Dead Sea Water Conveyance

The feasibility study of the Red Sea–Dead Sea alternative (Coyne et Bellier 2014) considered two basic alignments that vary according to the method of water conveyance: surface (buried) pipelines or tunnelling. The advantage of the pipeline approach is that it can be implemented in phases over time (by adding pipelines as needed); the disadvantage is that it requires lifting the water to an altitude of 220 m before letting it flow downward to the Dead Sea (at 390–400 mbSL), and this (pumping) operation adds on to the running costs. The tunnel option, on the other hand, does away with the need to lift the conveyed water, but requires complete investment of the entire infrastructure upfront. Due to environmental risks (associated with possible stratification, gypsum crystallisation and algae bloom), it is strongly recommended that the quantities of seawater (or brine) discharge in the

[5] A detailed explanation of how the cost of Dead Sea reclamation is calculated, based on Coyne et Bellier's (2014) data, can be found in Allan et al (2014).

Dead Sea will be increased gradually over a period of time (TAHAL and GSI 2011). We therefore focus on the surface pipeline option.[6]

Figures 14.3 and 14.4 present the costs of seawater (or brine) discharged in the Dead Sea from the Red Sea–Pipeline Project under two electricity tariff regimes: under regime A, electricity is bought from and sold to the Jordanian grid at the Jordanian tariffs (which prevailed in 2012); under electricity tariff B, electricity is obtained from the Jordanian grid at the Jordanian tariff and the electricity generated is sold to the Israeli grid at the (higher) Israeli tariffs. The costs are in 2012 prices.

The costs in Figs. 14.3 and 14.4 are calculated as follows: First, the fixed investment (infrastructure construction) cost is calculated using Coyne et Bellier's (2014) data. This cost is then annualised based on the interest rate and the depreciation rate. To this cost, one adds the annual variable cost (O&M, energy), reported in Coyne et Bellier's (2014), to obtain the gross annual cost. The net cost is obtained by subtracting the annual profit of the hydropower plant. The costs in Fig. 14.4 are obtained by dividing the annual costs of Fig. 14.3 by $1,150 \times 10^6$ m^3/year which is the quan-

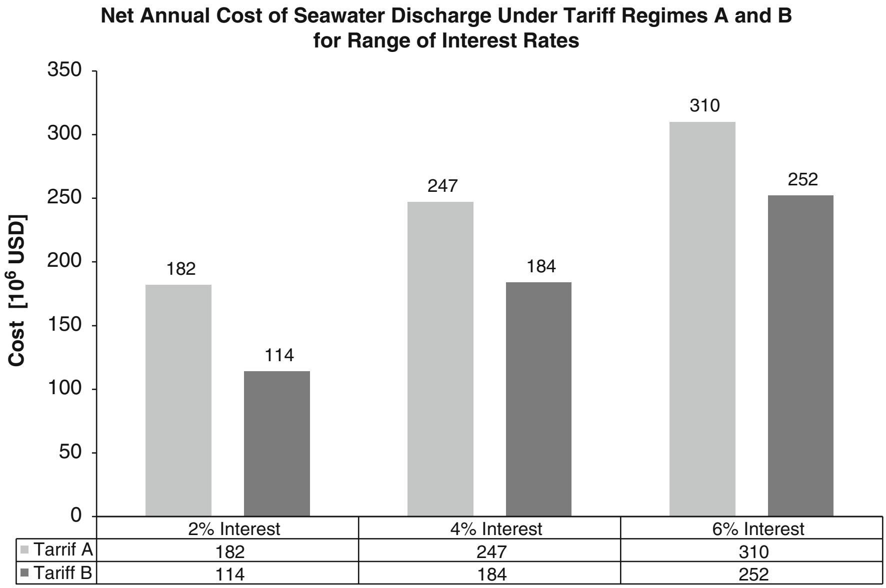
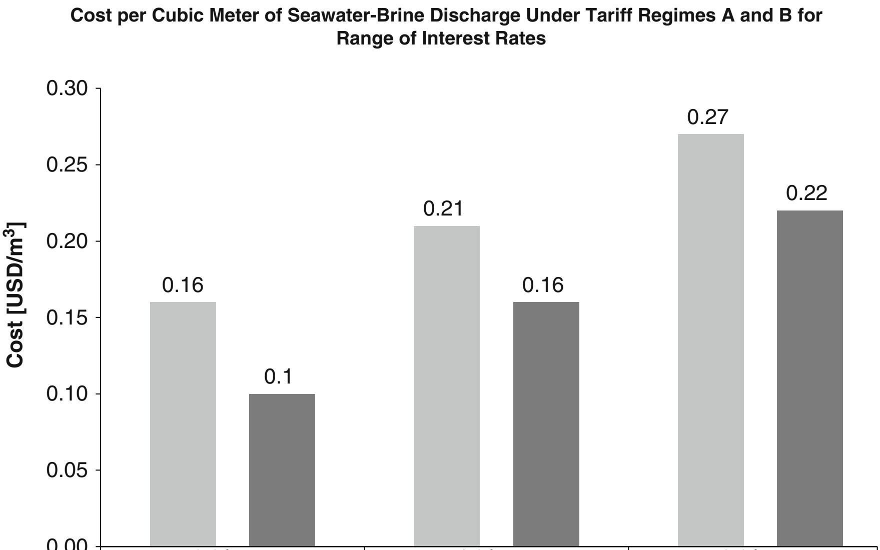


Fig. 14.3 Net annual cost (*million USD*) of seawater discharge in the Dead Sea of the Red Sea Pipeline Project under electricity tariff regimes A and B for a range of interest rates

[6] While the tunnel should be constructed in full, it is always possible to increase the flow of water gradually. If the added cost of the upfront investment in building the tunnel, compared to the cost associated with the gradual pipeline project, exceeds the saving of the energy cost required by the former, then the pipeline option is more cost effective. It turns out that the costs of the two alignments are similar, with a slight advantage to the tunnel option at low interest rates (capital cost) and to the pipelines option at higher interest rates (see details as well as a map of the area in Allan et al. (2014)).



	2% Interest	4% Interest	6% Interest
Tarrif A	0.16	0.21	0.27
Tariff B	0.1	0.16	0.22

Fig. 14.4 Cost per cubic metre (*USD/m³*) of seawater–brine discharge in the Dead Sea of the Red Sea Pipeline Project under electricity tariff regimes A and B for a range of interest rates (the annual costs of Fig. 14.3 divided by the annual discharge of $1{,}150 \times 10^6$ m^3/year)

tity of seawater–brine to be discharged in the Dead Sea after project completion. Expressing the cost in USD/m^3 of discharged seawater will facilitate comparisons with other alternatives. Because the hydropower profits under electricity tariff regime B (hydroelectricity is sold to the Israeli grid) are higher than under electricity regime A (hydroelectricity is sold to the Jordanian grid), the net costs are lower under regime B than under regime A. At a 2 % capital cost (interest rate), for example, the annual cost of a Pipeline Project that discharges $1{,}150 \times 10^6$ m^3/year of Red Sea water (or brine) in the Dead Sea is USD 182 million (USD 0.16/m^3) or USD 114 million (USD 0.1/m^3) under tariff regime A or B, respectively. All costs and (hydropower) profits are calculated using Coyne et Bellier's (2014) data (see details in Allan et al. 2014, Appendix 2).

For the Dead Sea reclamation to pass a cost-benefit test, the benefit generated by the project must exceed its cost. As common when measuring economic values of environmental amenities, such as in the present case, the benefit of reclaiming the Dead Sea is measured by the willingness to pay to stabilise (or restore) its water level. One study estimates this value between USD 73 million a year and USD 227 million a year (Becker and Katz 2009). Consider, for the sake of illustration, the midpoint of USD 150 million per year. Then, observing Fig. 14.3, the project passes the cost-benefit criterion at 2 % capital cost (interest rate) and electricity tariff regime B. As mentioned above, the study of Becker and Katz (2009) estimates the local population's willingness to pay. The unique historical, cultural and environmental characteristics of the Dead Sea imply that the benefit of its preservation extends beyond the local region and the overall willingness to pay to reclaim the Dead Sea is credibly wider ranging than the above.

The above discussion illuminates the crucial role of the discount rate: with an annual benefit of USD 150 million, the project passes the cost-benefit criterion at 2 % (and tariff regime B) but not at 4 % or above. This raises the question regarding the more appropriate discount rate to use. One approach is to use the discount rate used to evaluate public projects. This discount rate varies across countries as well as across types and durations of the public projects and ranges between 1 and 10 % (see Gollier 2013, p. 8–9, for an overview). A different approach, which accounts for the unique characteristic of the project under consideration, is to use an ecological discount rate, estimated by Gollier (2010) at about 1.5 %.

To sum up, preliminary estimates of the benefit to the local population associated with stabilising (or restoring) the Dead Sea range between USD 73 million a year to USD 227 million a year. Taking the midpoint of USD 150 million a year as a point estimate, a Red Sea–Dead Sea (phased) Pipeline Project passes the cost-benefit criterion (i.e. is justified on economic ground) at an interest rate (capital costs) of about 2 % and electricity tariffs regime B (where the electricity consumed is purchased from the Jordanian grid and the electricity generated is sold to the Israeli grid). The unique characteristics of the Dead Sea imply that the benefit of its reclamation extends beyond the local population and is therefore likely to be larger than Becker and Katz's (2009) estimates. Because the project's benefit extends into the distant future and is environmental (ecological) in nature, a low discount rate, around 1.5 %, is justified.

14.3.2 Mediterranean Sea–Dead Sea Water Conveyance

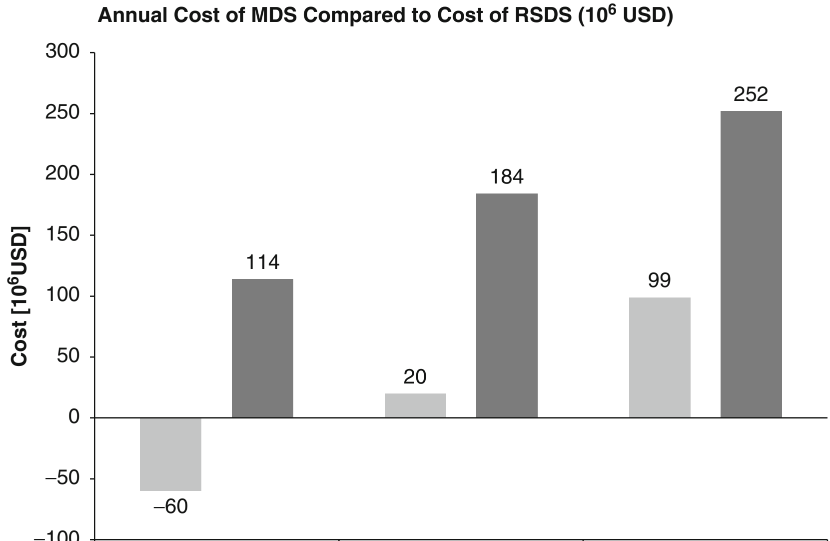
The main advantage of using the Mediterranean rather than the Red Sea as a source of water conveyance is the shorter distance (see Fig. 14.5). For this reason, most past proposals of water conveyance to the Dead Sea considered the Mediterranean as the preferred source (see Vardi 1990). Following the study of alternatives to the Red Sea–Dead Sea Project (Allan et al. 2014), we consider two Mediterranean Sea–Dead Sea routes: a southern route from Ashkelon to Qumran and a northern route from Atlit (south of Haifa) to Naharayim–Bakura (where the Yarmuk joins the Jordan River) and to the Dead Sea along the lower Jordan River route. We discuss each in turn.

Fig. 14.5 Conveyance routes from the Red Sea and the Mediterranean to the Dead Sea (Adopted from Wikipedia)

14.3.3 Southern Route (Ashkelon → Qumran)

As in the previous case, water can be conveyed via surface pipelines or a tunnel. The topography of the area implies that the former option requires lifting the water more than 800 m before letting it flow downward to the Dead Sea. The cost of pumping the water to such an altitude renders the pipeline option too expensive, and we concentrate only on the tunnel option.[7]

[7] As in the previous case, the disadvantage of the tunnel option is that it has to be constructed in full upfront and cannot be phased out over time. However, the shorter distance implies that the added



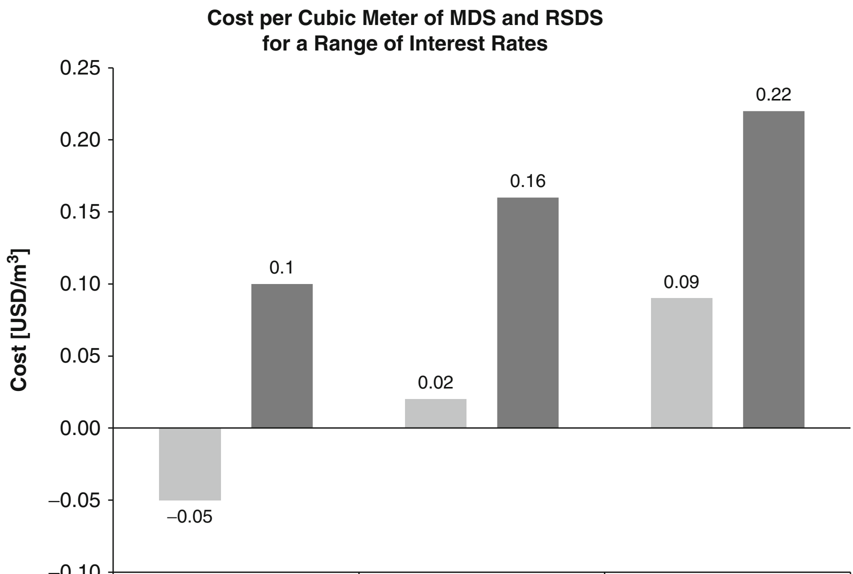
	2% Interest	4% Interest	6% Interest
MDS (Tunnel)	–60	20	99
RSDS (Tariff B)	114	184	252

Fig. 14.6 Annual cost (*million USD*) of the Southern Mediterranean Sea–Dead Sea (MDS) Conveyance Project (from Ashkelon to Qumran) and the comparable costs of the Red Sea–Dead Sea (RSDS) Pipeline Project (tariff regime B)

Figure 14.6 presents the net annual cost (million USD) of the Ashkelon–Qumran (tunnel) Conveyance Project with a comparison to the comparable costs of the Red Sea–Dead Sea (Pipeline) Project under electricity tariff regime B (of Fig. 14.6). Figure 14.7 presents the same costs in USD/m^3 units (obtained by dividing the annual costs by 1,150 m^3/year – the annual quantity of brine discharge). The tables reveal the cost advantage of the Mediterranean over the Red Sea as a source of seawater conveyance. It also shows that conveying seawater from Ashkelon to the Dead Sea (around Qumran), using the elevation difference to generate hydroelectricity, is a profitable operation at 2 % interest rate.

To sum up, because of the shorter distance, the Ashkelon–Qumran Water Conveyance Project (via tunnel) is more cost effective than the Red Sea–Dead Sea Pipeline Project. At a 2 % interest rate, the Ashkelon–Qumran (tunnel) Project is profitable – the hydropower profits more than compensate for the tunnel costs (construction and operation).

cost associated with this disadvantage is much smaller than that of the Red Sea–Dead Sea Project. The course of a tunnel from Ashkelon to the northern Dead Sea intersects the mountain aquifer, and the exact route would need to be determined in order not to potentially harm this sensitive and important water source.



	2% Interest	4% Interest	6% Interest
MDS (Tunnel)	–0.05	0.02	0.09
RSDS (Tariff B)	0.1	0.16	0.22

Fig. 14.7 The costs of Fig. 14.6 expressed in USD/m^3 units (Obtained by dividing the annual costs of Fig. 14.6 by $1{,}150 \times 10^6$ m^3/year – the annual quantity of brine discharge)

14.3.4 Northern Route (Atlit → Naharayim-Bakura → Dead Sea)

The distance from Atlit to Naharayim–Bakura is 65–70 km (Fig. 14.5). The possibility of conveying seawater along this route is ruled out because the course extends over fertile valleys and sensitive aquifers, and the risk for damage from leakage is high. Therefore, this alternative involves desalination along the Mediterranean coast near Atlit and conveyance of the desalinated water (via pipeline) to Naharayim–Bakura, where the Yarmuk flows into the Jordan River. The location of the eastern outlet (Naharayim–Bakura) opens up opportunities to combine this option with partial restoration of the lower Jordan River; from Naharayim–Bakura, the water flows along the lower Jordan River to the Dead Sea, performing a dual goal: partially restoring the lower Jordan River and stabilising (or halting the decline of) the Dead Sea level.

Allowing for a pumped storage reservoir near Kaukab-el-Houa (Belvoir), at 300 m elevation (more than 500 m above Naharayim–Bakura), and exploiting the Israeli peak-load electricity tariffs to pump water during low demand (nights) and generate hydropower during high demand, it was found that the profit of the hydropower plant is sufficient to cover the entire cost of conveying the desalinated water from Atlit to Naharayim–Bakura.[8] The total cost of the desalinated water in Naharayim–Bakura is therefore the desalination cost, which will soon approach USD 0.5/m^3 (see Tsur 2014).

From Naharayim–Bakura, the water flows to the Dead Sea along the lower Jordan River route. The total cost of water discharge in the Dead Sea of the Atlit–Naharayim Project is therefore solely the cost of desalination of about USD 0.5/m^3, which is higher than the comparable costs under the Red Sea–Dead Sea (pipeline) or Mediterranean–Dead Sea (tunnel) Projects (see Figs. 14.3 and 14.5). However, the water flow from Naharayim–Bakura to the Dead Sea contributes to the (partial) restoration of the lower Jordan River, which has an economic value of its own (see Gafny et al. 2010 for a description of the current situation of the lower Jordan River and restoration options). Estimates of regional (Israel, Jordan and the Palestinian Authority) willingness to pay (WTP) for partial restoration of the lower Jordan River were recently calculated by Becker et al. (2014). Considering different flows (220×10^6 m^3/year and 400×10^6 m^3/year) and two levels of water quality (high-quality natural and recycled), these authors estimate the WTP between USD 0.23/m^3 and USD 0.87/m^3, with the good quality (natural) water receiving the higher values (see Becker et al. 2014, Tables 2–3).[9] Based on these findings, it is not implausible that the benefit due to (partial) restoration of the lower Jordan River is high enough to cover most (if not all) of the cost of the Atilit–Naharayim–Bakura Project, leaving very little (if any) cost to the Dead Sea reclamation.

To sum up, high damage due to risk of leakage rules out the possibility of conveying seawater from the Mediterranean (near Atlit) to Naharayim–Bakura and requires desalination along the Mediterranean coast. The cost of desalination is approaching USD 0.5/m^3. The cost of conveying the desalinated water from Atlit to Naharayim–Bakura can be fully covered by the profits of a pumped energy plant near Kaukab-el-Houa (Belvoir). From Naharayim–Bakura, the (desalinated) water flows to the Dead Sea along the lower Jordan River, contributing to the partial restoration of the lower Jordan River along the way. Preliminary estimates of the benefit (in terms of WTP of the local population) associated with partial restoration of the lower Jordan River range between USD 0.23/m^3 and USD 0.87/m^3, with the good quality water receiving the higher values. The cost left for the Dead Sea reclamation is the cost of desalination (USD 0.5/m^3) minus the benefit of lower Jordan

[8] The cost of conveyance from Atilt to Naharayim–Bakura was calculated based on Coyne et Bellier's (2014) data with the appropriate modifications needed to fit to the different situation. These data, together with the peak-load pricing schedule of the Israeli grid, were used to calculate the profit of the pumped energy plant near Koukab-el-Houa (see Appendix of Allan et al 2014 for details).

[9] These estimates are obtained by dividing the total WTP corresponding to scenarios S3 and S4 by the restoration flow of 400×10^6 m^3/year (see Becker et al 2014, Tables 2–3). It should be noted that these estimates are based on WTP of the local population and do not include WTP for Dead Sea reclamation (only lower Jordan River restoration was considered). Adding WTP of the international community and WTP for Dead Sea restoration (on which no data are yet available) will increase the WTP for allocating recycled water for environmental restoration of the lower Jordan River and the Dead Sea.

River restoration. Given estimates of the latter, the cost of Dead Sea reclamation associated with the northern Mediterranean route is negligible. However, performing desalination at a scale needed to stabilise the Dead Sea (above 700×10^6 m^3/year) may not be feasible, implying that this project may not suffice on its own and should come in combination with other options.

14.4 Dead Sea Reclamation Based on Recycled Water

This alternative is based on the evolution of the following processes:

(i) The population of the region will continue to grow more or less along the projections of Fig. 14.2.
(ii) The supply of potable water (from natural sources, desalination or importation) will accordingly grow to provide at least the quantity deemed necessary for basic human needs – about 100 m^3/year per person (Gleick 1996).
(iii) Environmental standards require appropriate treatment of domestic sewage, disregarding its outlet and whether or not it will be reused. Accordingly, each cubic metre (m^3) allocated to households and industrial use will be collected, treated and become available for reuse (mainly in irrigation and environmental restoration). Under current recycling technology, each m^3 allocated for domestic use provides between 0.6 m^3 and 0.65 m^3 of treated (recycled) water (Cohen et al. 2008).
(iv) Water will be priced according to its cost of supply (see Tsur 2009). Pricing water in this way will affect farmers' choices of crops (e.g. away from water-thirsty crops) and will induce them to switch irrigation water away from expensive natural (potable) sources into marginal (recycled, saline) water.

The population projections of *(i)* are reasonable because they are based on 60 years of actual data and account for the anticipated decline in the population growth rate due to economic development. Processes *(ii)*–(i*v)* have been progressively implemented in Israel: Firstly, five large-scale desalination plants, with accumulated capacity of 600×10^6 m^3/year (more than 85 % of domestic water consumption in Israel), have been built in the last decade, and plans to increase desalination capacity in the future match the population growth projections (see Israel Water Authority 2012; Tsur 2014). Secondly, virtually all domestic water is collected, treated and made available for reuse in irrigation and environmental restoration (Israel Water Authority 2012). Thirdly, a series of water pricing reforms in the domestic and irrigation sectors have increased the efficiency of water use by reducing leakage, changing the mix of irrigated crops and inducing farmers to switch from natural (potable) water to recycled water (Tsur 2014; Kislev 2011). These measures have led, inter alia, to a 10 % reduction in domestic water consumption (about 100×10^6 m^3/year – equivalent to a large-scale desalination plant) and induced farmers to switch natural water quotas (which become more expensive) for recycled water (see Tsur 2014). Israel currently produces more than 450×10^6 m^3/year of recycled water and plans to increase this quantity to 930×10^6 m^3/year by 2050 (Israel Water Authority 2012).

Jordan and the Palestinian Authority have already begun to apply similar measures and will (sooner or later) catch up with Israel's policy. The only exception is Jordan's ability to implement *(ii)* via desalination, as Jordan's main population centre (Amman) is some 1,000 m above sea level and 300 km away from its only sea access (the Gulf of Aqaba); thus, desalinating in Aqaba and conveying to Amman can be prohibitively expensive. However, there exist other, more economical ways to increase the supply of drinking water in Jordan in tandem with its population growth (see Tsur 2014).

Observing the population projections (Fig. 14.2), we see that by 2050 the region's population will exceed 30 million. Under Assumptions *(ii)–(iv)*, this population size will be capable of producing more than $2,000 \times 10^6$ m^3/year of recycled water. The bulk of the recycled water will be allocated for irrigation (as farmers switch from the more expensive natural water to the cheaper recycled water), but some of the recycled will be allocated for environmental restoration, including lower Jordan River restoration and Dead Sea reclamation. This requires conveyance of recycled water from the treatment plants to the upper end of the lower Jordan River (near Naharayim–Bakura) as well as compensating farmers for reallocating the water away from irrigation.

Mekonen (2013) calculated the cost of conveying 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 USD 0.19/m^3 and the hydroelectricity profit at USD 0.12/m^3. The required compensation to farmers (under which farmers are indifferent between receiving the recycled water or the compensation) was estimated at USD 0.26/m^3. The net cost of using the recycled water for (partial) restoration of the lower Jordan River and the Dead Sea (conveyance minus hydroelectricity profit plus compensation to irrigators) is therefore USD 0.33/m^3. As was noted above, the associated benefit (based on WTP to restore the lower Jordan River) was estimated by Becker et al. (2014) between USD 0.23/m^3 and USD 0.87/m^3. The cost of using recycled water for lower Jordan River and Dead Sea restoration (USD 0.33/m^3 as estimated by Mekonen (2013) falls at the lower half of the benefit range. Based on these preliminary calculations, we conclude that in 3 to 4 decades, allocating 400×10^6 m^3/year of recycled water for partial restoration of the lower Jordan River and the Dead Sea is likely to pass a cost-benefit test.

Stopping the Dead Sea decline requires increasing its inflow by $700–800 \times 10^6$ m^3/year (TAHAL and GSI 2011), implying that an additional inflow of $300–400 \times 10^6$ m^3/year (in addition to the 400×10^6 m^3/year of recycled water) is needed. This additional inflow can come from a mini Red Sea–Dead Sea Project that will desalinate 300×10^6 m^3/year at Aqaba (100×10^6 m^3/year) and near the Dead Sea (200×10^6 m^3/year) and will convey the 367×10^6 m^3/year brine discharge (1 m^3 of seawater generates 0.45 m^3 of desalinated water and 0.55 m^3 of brine) to the Dead Sea.[10] The combination

[10] This mini Red Sea–Dead Sea Project was suggested by the study of alternatives team under CA1 (see Allan et al 2014) as a contribution to a comprehensive solution for Jordan's severe water

of the recycled water and the brine from the mini Red Sea–Dead Sea Project will be sufficient to stabilise the Dead Seat at its current level.

An advantage of this alternative is that it does not require investment in a large-scale conveyance project, such as those considered in the Red Sea–Dead Sea and Southern Mediterranean–Dead Sea Projects.[11] Moreover, the 367×10^6 m^3/year of brine discharge in the Dead Sea is below the 400×10^6 m^3/year flow considered safe (i.e. unlikely to give rise to gypsum crystallisation, stratification or algae bloom) by the Dead Sea study (TAHAL and GSI 2011). Disadvantages are the potential risks associated with letting 400×10^6 m^3/year of recycled water flow into the Dead Sea (e.g. effect on algae bloom), and these risks will need to be investigated and are likely to have ramifications regarding associated recycling technologies and costs.

To sum up, population growth will require increasing the supply of potable water to satisfy the needs of the growing population. As the natural water sources are already fully exploited, this will require better management of existing water sources (e.g. by pricing water to reflect true costs of supply) and increasing the supply of potable water from an alternative source such as desalination. Environmental standards require appropriate treatment of all sewage, implying, given the current recycling technology, that 60 to 65 % of the total domestic water consumption will be available for reuse, mostly in irrigation and environmental restoration. Given the population projections of Fig. 14.2, by 2050 the supply of recycled water will exceed $2,000 \times 10^6$ m^3/year. About 400×10^6 m^3/year of this supply can be allocated for the joint purpose of partial restoration of the lower Jordan River and the Dead Sea. The additional $300–400 \times 10^6$ m^3/year required to stabilise the Dead Sea at its current level may come from a mini Red Sea–Dead Sea Project that will desalinate 300×10^6 m^3/year at Aqaba (100×10^6 m^3/year) and near the Dead Sea (200×10^6 m^3/year) and will discharge 367×10^6 m^3/year of brine in the Dead Sea. The mini Red Sea–Dead Sea Project will serve the dual purpose of alleviating the shortage of potable water in the region (mainly in Jordan) and contributing to the stabilisation of the Dead Sea.

The cost of recycled water is estimated at USD 0.45/m^3 (the cost of conveyance to Naharayim–Bakura of USD 0.19/m^3 plus USD 0.26/m^3 compensation to irrigators). The benefit due to partial restoration of the lower Jordan River was estimated between USD 0.23/m^3 and USD 0.87/m^3, where restoration by recycled water is receiving the lower values. The net cost left for the Dead Sea reclamation is therefore below USD 0.22/m^3 (= USD 0.45/m^3 minus USD 0.23/m^3). The costs of the brine discharge from the mini Red Sea–Dead Sea Project are comparable to the costs of the full-scale project reported in Figs. 14.3 and 14.4.

scarcity problem (see discussion in Tsur (2014). The brine discharge in the Dead Sea is a by-product that contributes to stabilising the Dead Sea.

[11] The infrastructure investment required by the Red Sea–Dead Sea Project was estimated above USD 10 billion (Coyne et Bellier 2014).

14.5 How to Cover the Cost of Dead Sea Reclamation?

Using any of the alternatives discussed earlier to halt the decline of the Dead Sea level or to restore its historical state inflicts costs (except for the Southern Mediterranean Project under 2 % capital cost). This raises the questions stated in the title of this section. The problem arises because environmental amenities, such as the Dead Sea reclamation, have public good characteristics, and as such market mechanisms fail to allocate them properly. This feature often (though not always) implies that the value of an amenity cannot be inferred from market prices; hence, the need to use alternative approaches to obtain WTP measures, such as the contingent valuation method used by Becker et al. (2014), complicates the regulation needed to correct the failure. In the present context, the market failure arises because the benefits of reclaiming the Dead Sea (stabilising or restoring) stem from many reasons and affect different groups, some more directly (e.g. the hotels that will suffer less from deteriorating roads) and some indirectly (e.g. present and future pilgrims who aspire to see the Dead Sea ecosystem as it was during times of prophecy).

The issue of who should pay for environmental restoration (those who perpetrated the damage, or who stand to benefit from the restoration, or who suffer from the damage) and how to extract the correct sum from the different groups (polluters, beneficiaries, victims) is central to any environmental policy (see discussion in Goulder and Parry 2008, and the references therein). We propose here a simple mechanism to cover the costs of a Dead Sea reclamation project, based on a widely used environmental policy principle known as the polluter pays principle. The basic idea is to levy a surcharge on any cubic metres of water that would have reached the Dead Sea had it not been extracted or diverted upstream. This applies to diversions from the Jordan River (including Lake Tiberias), from the Yarmuk River (by Jordan) and from side wadies (tributaries) that flow into the Jordan River or directly into the Dead Sea (e.g. Zarqa, Mujib). It also applies to the 262×10^6 m^3/year diversions (evaporation) of the Israeli and Jordanian potash industries (Zbranek 2013).

The exact surcharge rate will vary across the alternatives based on the cost of each alternative. We calculate the range of surcharge rates corresponding to the costs of the alternatives discussed above. As noted in the introduction, the total upstream diversion based on historical flows is about $1{,}500 \times 10^6$ m^3/year (TAHAL and GSI 2011). Allowing for a decline in average precipitation due to climate change (Weinberger et al. 2012), we assume that total diversion today is about $1{,}300 \times 10^6$ m^3/year, of which 460×10^6 m^3/year is diverted from the Yarmuk River, mostly by Syria (which is excluded from the mechanism for a number of reasons, including the fact that it is not a Dead Sea riparian). The remaining diversions to be taxed are therefore about $1{,}100 \times 10^6$ m^3/year, accounting for about 850×10^6 m^3/year of upstream diversions plus the 262×10^6 m^3/year consumed by the potash industries. This quantity is similar to the $1{,}150 \times 10^6$ m^3/year to be discharged into the Dead Sea by the (full-scale) Red Sea and Southern Mediterranean Sea Projects. The surcharge per cubic metre needed to cover the costs of these projects is therefore equal to the costs per cubic metre presented in Fig. 14.7. Assuming a 2 % interest rate, which is justified by the low ecological discount rate to be used in environmental projects of this sort (see Gollier 2010), the required surcharge (which will raise the annual proceeds needed to cover the annual costs) is zero for the Southern Mediterranean Project and USD 0.1/m^3 for the Red Sea (pipeline, tariff regime B) Project.

Regarding the Northern Mediterranean Project, the cost of desalination and conveyance to Naharayim–Bakura is about USD 0.5/m^3 (recall that the conveyance cost is covered by the profit of the pumped energy operation). From there, the water flows to the Dead Sea, partially restoring the lower Jordan River along the way. The Dead Sea reclamation cost is therefore the USD 0.5/m^3 minus the benefit associated with the lower Jordan River restoration. The latter benefit, as discussed above, lies in the upper half of the USD 0.23/m^3–USD 0.87/m^3 span estimated by Becker et al. (2014) (the higher values refer to restoration with good quality water and the lower values to restoration with recycled water). Assuming also that the flow of water under this alternative will be the flow needed to stabilise the Dead Sea at its current level (700–800 × 10^6 m^3/year), we conclude that the surcharge needed to cover the Dead Sea reclamation costs should range between zero and USD 0.1/m^3.

Regarding the alternative of combining recycled water and a mini Red Sea–Dead Sea Project, it was found that the benefit associated with using the recycled water for the lower Jordan River restoration will outweigh the costs of the recycled water, leaving only the costs of the mini Red Sea–Dead Sea Project. The USD/m^3 cost of the mini project will be similar to that of its large (full)-scale counterpart, which was found to be about USD 0.1/m^3 (see Fig. 14.4). However, the mini Red Sea–Dead Sea Project will discharge only 360 × 10^6 m^3/year of brine into the Dead Sea, which is less than a third of its large (full)-scale counterpart considered above. Accordingly, the annual costs will be about a third of the annual costs of the large (full)-scale project, and the surcharge will accordingly be about a third of that under the large-scale project, i.e. about USD 0.03/m^3 (recall that the surcharge is levied on the same quantity of diverted water as under the large-scale project).

To sum up, following the logic of the polluter pays principle, we offer a mechanism to finance a Dead Sea reclamation project by levying a surcharge on all diversions that otherwise would have reached the Dead Sea. These diversions are estimate at about 1,100 × 10^6 m^3/year (850 × 10^6 m^3/year of upstream diversions plus 262 × 10^6 m^3/year consumed by the potash industries). The surcharge rate is calculated such that the annual proceeds cover the cost of the reclamation project. Because the costs vary across alternatives, so will the surcharge rates. Under a 2 % capital cost (consistent with ecological discount rate), the surcharge needed to cover the cost of the Red Sea and Southern Mediterranean Projects is USD 0.1/m^3 and zero, respectively. The surcharge needed to cover the costs of the Northern Mediterranean Project is between zero (if the subtracted lower Jordan River restoration benefit is low) and USD 0.1/m^3 (if the subtracted lower Jordan River restoration is high). The surcharge needed to cover the costs of the alternative combining recycled water and a mini Red Sea–Dead Sea Project is about USD 0.03/m^3. The feasibility of imposing these surcharge rates determines the feasibility of reclaiming the Dead Sea.

14.6 Concluding Comments

The average supplies of natural water available on a sustainable fashion in the water basin feeding the Dead Sea (comprising Israel, Jordan and the Palestinian Authority) will soon drop below 100 m^3/year per person – the quantity deemed necessary for basic human consumption. Upstream diversions have deprived the Dead Sea of more than 90 % of its historical inflow, leading to progressive decline of its water level, which currently exceeds one metre per year on average. Stabilising the Dead Sea at its current level requires increasing the inflow by 700 to 800×10^6 m^3/year, while restoring historical levels requires above $1{,}100 \times 10^6$ m^3/year. We addressed four alternatives to stabilise or restore the Dead Sea: a large-scale Red Sea–Dead Sea Project, examined by Coyne et Bellier's (2014) feasibility study; two Mediterranean Sea–Dead Sea Projects (examined in the study of alternatives to the Red Sea–Dead Sea project); and an alternative based on recycled water and a mini Red Sea–Dead Sea Project (also examined in the abovementioned study of alternatives). We evaluate the costs associated with each alternative and offered a mechanism to pay for their implementation, based on a surcharge levied on all upstream diversions (including water consumed by the potash industries).

The Southern Mediterranean Project was found to be the most economical, in that it is a profitable project (the hydroelectricity profits more than compensate for the infrastructure and operating costs), thus requires no surcharge on upstream diversions. The full-scale Red Sea–Dead Sea Project was found to be the most expensive one, and financing it would require a surcharge of about USD 0.1/m^3 on all upstream diversions (including the water consumption by the potash industries). Both projects are capable of restoring the Dead Sea level to its historical state. However, they should be implemented gradually, and discharge flows above 400×10^6 m^3/year are currently considered risky in terms of possible damages due to stratification, gypsum crystallisation or algae blooms (TAHAL and GSI 2011).

The Northern Mediterranean Project involves desalination at the coastline, conveyance to Naharayim–Bakura, while exploiting the elevation difference to generate hydroelectricity and letting the water flow to the Dead Sea along the lower Jordan River route. The profit from the pumped energy plant covers the conveyance cost from Atlit to Naharayim–Bakura. A by-product of this alternative is a partial restoration of the lower Jordan River, and the ensuing benefit is sufficient to cover all or most of the desalination cost. The costs of the stabilisation of the Dead Sea level are therefore negligible. However, desalinating 700–800×10^6 m^3/year (the minimal flow needed to stabilise the Dead Sea at its current level) along the northern Mediterranean coast may not be feasible, implying that this alternative should be combined with other alternatives.

The fourth alternative considered was built on the evolution of the following three ongoing processes: population growth, increased supply of potable water by desalination and reuse of domestic water after appropriate treatment. Over time (3–4 decades), these processes will give rise to a regional supply of recycled water above $2{,}000 \times 10^6$ m^3/year, which will be available for reuse in irrigation and environmental restoration. We predict that 300–400 × 10^6 m^3/year of the recycled water could be allocated for the purpose of partially restoring the lower Jordan River and the Dead Sea. Estimates of the benefit associated with the partial restoration of the lower Jordan River suggest that the associated benefit is sufficient to cover the costs of the recycled water (conveyance cost plus compensation to irrigators). The residual costs of the recycled water to the Dead Sea reclamation are therefore negligible. Stabilising the Dead Sea, however, requires additional flow of 300 × 10^6 m^3/year to 400 × 10^6 m^3/year. This additional flow can come from a mini Red Sea–Dead Sea Project that will desalinate 300 × 10^6 m^3/year at Aqaba (100 × 10^6 m^3/year) and near the Dead Sea (200 × 10^6 m^3/year), while conveying and discharging the brine (367 × 10^6 m^3/year) into the Dead Sea (the purpose of the desalination is to alleviate Jordan's severe water shortage problem). Since the cost of the mini Red Sea–Dead Sea Project is about a third of its large (full)-scale counterpart, the surcharge on all diversions (which remain unchanged) needed to finance this project will be USD 0.03/m^3 – about a third of the surcharge of the large-scale project.

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