10 Formulating A Regional Policy for the Future of the Dead Sea – The 'Peace Conduit' Alternative

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Abstract

The Dead Sea is a severely disturbed ecosystem, greatly damaged by anthropogenic intervention in its water balance. Since the beginning of the 20^{th} century, the Dead Sea level have dropped by more than 20 meters, and presently (2006) it is about 419 meters below mean sea level. The rate of water level drop over the last 10 years is about 1.0 m/yr, representing an annual water deficit of about 650 million cubic meters. The sharp level drop reflects the annual interception by riparian countries of over 1000 million cubic meters of freshwater which in the past drained to the Dead Sea. In addition to the water interception upstream, the Israeli and Jordanian mineral industries contribute to this deficit by artificially maintaining extensive evaporation surfaces in the otherwise now dried southern Dead Sea basin.

Three alternatives for the future of the Dead Sea exist and need to be examined:

1. Maintaining the present situation. The Dead Sea level is expected to decline further to around -550 m, when a new equilibrium between inflow and evaporation will be reached.
2. Changing the regional water policy whereby freshwater from the Jordan and the Yarmouk river systems will be diverted back to the Dead Sea. In view of the severe regional water deficiency, such a program requires unprecedented regional cooperation and investments to compensate for the freshwater that will be diverted back to the Dead Sea.
3. Construction of the 'Peace Conduit' that will convey seawater and/or reject brine after desalination, into the Dead Sea. Such a plan has already been announced by Israel and Jordan in 2002 during the Johannesburg World Summit on sustainable development.

The renewed interest by Israel and Jordan in the construction of the 'Peace Conduit' is due to a number of related issues: (1) a growing concern that the Dead Sea must be 'saved'. (2) The possibility of utilizing the proposed conduit for desalinization of the inflowing seawater, thereby providing freshwater to the surrounding entities. (3) The development of infrastructure and tourist facilities around the lake has been adversely affected due to the receding shoreline and the danger presented by the regional collapse of the infrastructure. All parties acknowledge that the 'Peace Conduit' is an ambitious project that is bound to change the Dead Sea and its surroundings. While the project has the potential to stop and possibly restore damaging processes that currently occur in the Dead Sea and its surrounding, mixing of seawater in the Dead Sea may also lead to undesired changes in the lake.

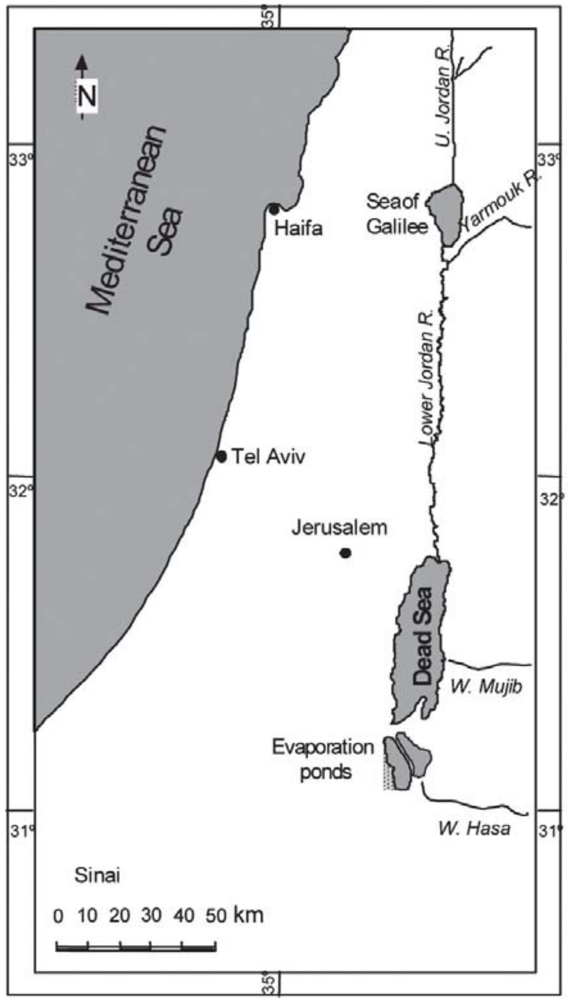
The impact of changes on the Dead Sea and its surroundings needs to be carefully evaluated before a final decision is made.

Keywords: Dead Sea water balance, water level, Peace Conduit, desalinization, gypsum precipitation, microbial blooming, sustainable development, Israel, Jordan.

10.1 Introduction

The Dead Sea is a hypersaline terminal lake located in the Dead Sea Rift valley which developed along the Dead Sea Transform (figure 10.1). Its water level is the lowest surface on earth and is currently (year 2006) 419 m below mean sea level (-419 m). At its deepest place the lake is over 300 meters deep, making it the lowest terrestrial place on Earth (-730 m). The Dead Sea brine is characterized by high salinity (TDS >340 g/l), high density (>1.236 kg/l) and a unique composition. Over the last several thousands of years the water level of the lake fluctuated around -400 m (Stein 2002; Bookman et al. 2004). This elevation coincides with the elevation of the sill that divides between the shallow southern basin of the lake and the much deeper northern basin. Higher water levels were attained during rainy periods when the lake extended into the southern basin and the surface water was diluted. Lower levels reflect dry periods, with negative water balance and large area shrinkage, including the drying out of the southern basin. The smaller surface area and higher salinity results in a drastic decrease in evaporation which serves to buffer further lake level drop.

Figure 10.1: Location Map of the Dead Sea.

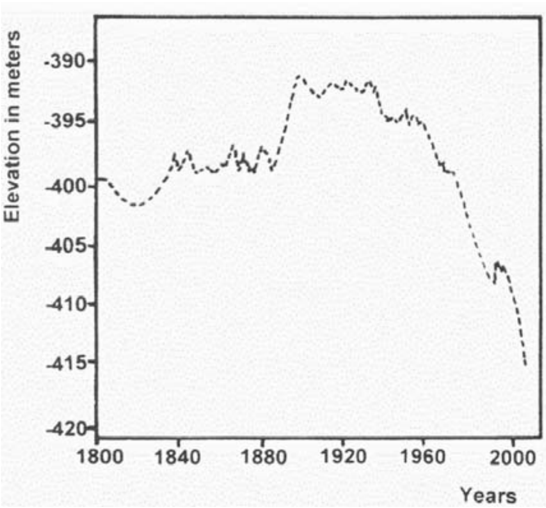


10.2 Recent and Future Changes in the Dead Sea

Since the beginning of the 20th century, the Dead Sea level has dropped by more than 20 meters (figure 10.2). The decline in the Dead Sea level is a manifestation of the negative water balance of the lake, whereby evaporation greatly exceeds inflow (Gavrieli/Oren 2004). It reflects the annual interception by riparian countries of over 1000 million cubic meters (MCM) of freshwater which in the past drained to the Dead Sea. The intercepted water is diverted from Lake Kinneret to the Israel National Water Carrier and from the Yarmuk River by Syria and Jordan. The latter constructed the King Abdullah Canal which runs along the eastern side of the Jordan Rift Valley and supplies water for irrigation. Additional water is captured upstream of the Sea of Galilee by Lebanon and from smaller tributaries either draining to the Lower Jordan River or directly to the Dead Sea.

In 1976, when the lake level reached an elevation of -400 m the southern basin dried up (Steinhorn et al., 1979; figure 10.3). A few years later, in 1979, the Dead Sea water column overturned and mixed (Steinhorn 1985), ending a period of about 300 years of stratification (Stiller/Chung 1984), whereby the upper water column of the lake was relatively diluted while the lower brine was more concentrated (Neev/Emery 1967). Since then the Dead Sea experiences mostly

Figure 10.2: Dead Sea water levels: 1800 – 2000. **Source**: After Gavrieli et al., 2005



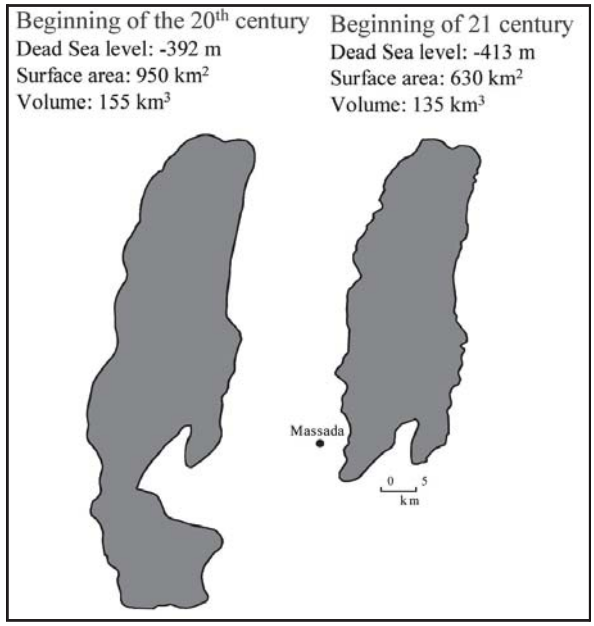
annual stratification and overturns, while its salinity rises (Anati/Stiller 1991; Gertman/Hecht 2002).

The average rate of water level drop over the last few years is about 1.0 m/yr, denoting an annual water deficit of about 650 MCM. About 200–250 MCM/yr of this deficient, accounting for about 35 cm/yr water level drop, is attributed to the activities of the Israeli and Jordanian mineral industries that are based on the Dead Sea. These industries pump together 450–500 MCM from the Dead Sea into the evaporation ponds located in the southern basin, where halite (NaCl) and carnallite ($KMgCl_3 \cdot 6H_2O$) precipitate. At the end of the process less than 200 MCM of concentrated brines (density = 1.35 kg/l; TDS = 500 g/l) are returned to the Dead Sea.

10.3 The Future of the Dead Sea

If the current situation prevails, the Dead Sea level is expected to continue to decline. Models and thermodynamic calculations proposed by Yechieli et al. (1998) and Krumgalz et al. (2000), respectively, for the future evolution of the lake suggests that under current conditions the lake level will continue to decline but will approach a steady state at an elevation of about -550 m, i.e. ~130 m below the present level (figure 10.4). The rapid water level decline will continue during the coming decades but will begin leveling off within a few hundred years. A steady state level will be approached when the evaporation will be compensated by inflowing water. Such conditions will be achieved due to the combined effect of diminishing surface area and decrease in evaporation rate due to the increasing salinity of the brine.

Figure 10.3: Comparison between the Dead Sea at the beginning of the 20th and 21st centuries. **Source**: After Gavrieli et al., 2002

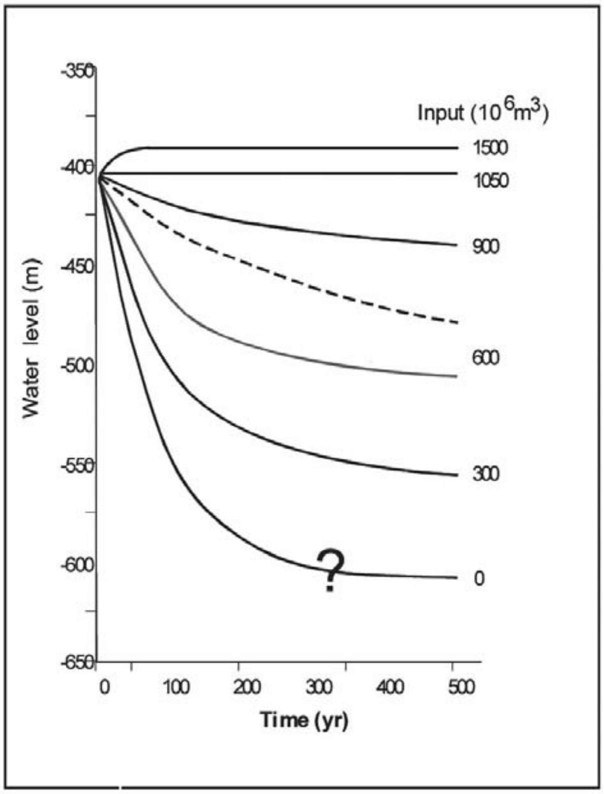


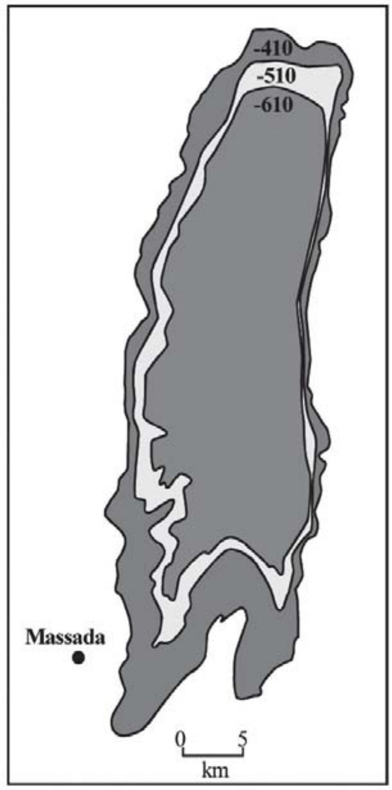
Over the last decade hundreds of sinkholes developed along the shores of the Dead Sea and large areas are subsiding. This phenomenon, which has major economic and safety implications, is linked to the drop in the level of the Dead Sea and subsurface salt dissolution (Wachs et al. 2000; Yechieli et al., 2006; Baer et al. 2002; Abelson et al. 2003). The rapid drop in the water level results in rapid geomorphological changes, which lead to damages in the surrounding infrastructure, mainly to roads and bridges (Avni et al. 2003). Thus, the Dead Sea area, which has major economic, tourist and environmental potentials, is in fact being neglected. This makes future planning difficult and needs to be reconsidered.

Three alternatives for the future of the Dead Sea exist and need to be examined:

1. Maintaining the present situation and allowing the water level to continue to decline until the above-described steady state level is attained.
2. Changing the regional water policy whereby freshwater from the Jordan and the Yarmouk river systems will be diverted back to the Dead Sea. In light of the severe regional water deficiency, such a program requires unprecedented regional cooperation and investments to compensate for the

Figure 10.4: Predicted changes in the water level of the Dead Sea for different water inputs (in 10^6 m^3/yr). All cases assume continued evaporation from the evaporation ponds of the potash industries. **Source:** after Yechieli et al. (1998)





freshwater that will be diverted back to the Dead Sea.

3. Conveying seawater from the Red Sea to the Dead Sea via the proposed 'Peace Conduit'. Such a plan has already been announced by Israel and Jordan in 2002 during the Johannesburg World Summit on sustainable development. However, the environmental impact of this project needs to be further examined, evaluated and quantified before a final decision is made.

10.4 The 'Peace Conduit'

The interest in the construction of a canal/pipeline between the Red Sea and the Dead Sea, termed lately as the 'Peace Conduit', is due to a number of related issues: (1) a growing public concern that the Dead Sea must be 'saved' in order to maintain the scenic beauty of the area and preserve its historical and environmental uniqueness for future generations. (2) The possibility of utilizing the proposed 'Conduit' for desalinization of the inflowing seawater, thereby providing freshwater to the surrounding entities. This aspect of the project is particularly attractive to Jordan, which suffers from a major water shortage as its main consumption centers are far away from any coastline. (3) The difficulty of developing the area around the Dead Sea due to the uncertainty imposed by the receding shoreline and the danger presented by the regional collapse of infrastructure described above.

The first to propose a canal between the sea and the Dead Sea was William Allen, who in 1855 suggested the use of such canals as a waterway connecting the Mediterranean with the Red Sea (Allen 1855). Some 50 years later Herzl (1902) envisioned a canal between the Mediterranean and the Dead Sea that would serve as a hydroelectric power source. This vision was also the foundation for the Mediterranean Sea – Dead Sea Company, which following the 1973 energy crisis funded diverse feasibility studies to evaluate the economic, environmental and engineering aspects of such a canal (Mediterranean Sea-Dead Sea Company 1984). More recently, following the peace treaty between Israel and Jordan, a pre-feasibility study was conducted to study a proposed Red Sea-

Dead Sea Canal (RSDSC). The principal objective of this project was to utilize the 400 meter elevation difference between the seas to desalinize seawater on the shores of the Dead Sea by reverse osmosis. The study concluded that the project is financially and environmentally feasible and can produce (with the investment of additional external energy) 800 to 850 MCM of desalinated water annually. The reject brine coming out from this plant is to be discharged to the Dead Sea (Harza JRV Group 1996).

During the Johannesburg 2002 World Summit on Sustainable Development the two countries jointly announced their mutual commitment to the project. The primary aim of the project, as stated in the announcement, is to save the Dead Sea through stabilizing its level. Desalinization of seawater is a potential by-product of this proposed 'Peace Conduit' project.

It should be emphasized that the implementation of the 'Peace Conduit' differs from intervention with an undisturbed natural ecosystem: the Dead Sea basin experiences major man-induced physical and infrastructure changes that have accelerated over the past thirty years due to the rapid water level decline. The project has the potential of stopping and even reversing the undesired environmental processes that currently occur in the basin. Yet, there is a possibility that the mixing of seawater in the Dead Sea brine may also bring about undesirable changes to the Dead Sea. Additional environmental aspects need also be considered: pumping of huge volumes of seawater from the Gulf of Eilat may harm the ecosystem at the tip of the gulf, while leakages from the Conduit pose a salinization threat to the groundwater in Wadi Arava. Below we outline the expected changes to the limnology of the Dead Sea due to seawater mixing. These changes will need to be quantified through an integrated lake-model, put into a time frame and weighed against the benefits of the project. The impact of the 'Peace Conduit' on the Gulf of Eilat and Wadi Arava are subjects of other, independent studies.

10.5 Impact of Seawater Mixing in the Dead Sea

Following is a summary of the identified changes in the limnology of the Dead Sea that will accompany the inflow of seawater into it. These are discussed in details in Gavrieli et al. (2002, 2005). It should be kept in mind that other changes that have not yet been identified might also take place.

Stratification of the water column: During the filling period of the lake to the desired level, mixing of seawater and Dead Sea brine will lead to formation of a stratified water column with a diluted surface layer, composed of a mixture of Dead Sea brine and seawater, and a lower water body with salinity similar to that of current Dead Sea. The dilution and continuous decrease in surface water density will continue throughout the filling period. The rate at which the density will decrease will be determined by the rate of inflow and depth of stratification. Once the desired lake level has been attained, inflow will be controlled so that it will only compensate for evaporation. The density of the upper water at this stage will begin to increase due to accumulation of seawater-derived salts. Its density will increase until it attains the density of the lower water column and overturn will occur. From this stage onward, the density of the entire water column will increase and the development of periodic stratification will depend primarily on the mode of operation.

Stratification of the Dead Sea water column is not a new phenomenon in the Dead Sea (Neev/Emery 1967; Anati/Stiller 1991; Gertman/Hecht 2002) and in itself will not have a negative environmental impact, provided that the composition and density of the upper water body would not alter to the degree that the Dead Sea would loose its uniqueness. Current knowledge, however, does not allow us to determine either the depth of stratification and mixing ratio, or the composition and change in density of the upper water body. These depend on numerous physical and operational parameters which will have to be modeled in the dynamic-limnological model and considered when planning the Conduit.

Precipitation of gypsum: Mixing between the calcium (Ca^{2+}) – rich Dead Sea brine and the sulfate ($SO4^{2-}$) – rich seawater will result in precipitation of gypsum ($CaSO_4 \cdot 2H_2O$) (Levy 1984; Levy/Kushnir 1981; Katz et al. 1981). Kinetic effects will determine if the gypsum will precipitate continuously or if the incoming sulfate will accumulate in the mixture and precipitate periodically once over-saturation attains a critical value. The rate at which the gypsum crystals or agglomerates settle from the upper water column will determine if, how, and to what extent the turbidity of the water column will increase. The most extreme case is that of 'whitening' of the surface water for prolonged periods of time. An increase in surface water turbidity is not a desired outcome of the project because it may be accompanied by local climatic changes due to changes in the reflectivity of the water's surface and may also impact negatively on the visual attractiveness of the Dead Sea. It is still to be determined at what point, if at all, turbidity becomes unbearable to the extent that it could hamper the project. It should be noted, however, that small-scale field studies conducted in the past do not support a scenario of prolonged whitening. Some laboratory experiments, however, do suggest that this phenomenon is nonetheless possible.

Microbial blooming: Field studies indicate that dilution of the Dead Sea brine by 10 per cent and the addition of phosphate, which is a limiting nutrient in the Dead Sea, initiate algal and bacterial blooming (Oren/Shilo, 1985; Oren et al., 2004). In desalinization plants, anti-scaling agents, usually based on phosphate, are common additives. Thus, it is essential that the anti-scaling additives in the desalinization plant envisioned for the Dead Sea will not be phosphate-based. However, this does not ensure that microbial blooming will not occur just as a result of the dilution of the upper water column. Algal and bacterial blooming has been observed in the Dead Sea in the past, following particularly rainy winters, when the upper water column was diluted (Oren 1993). Blooming lasted for several weeks during which the Dead Sea had a reddish hue. Quantitative information on the biological properties of the lake prior to 1980 is virtually absent except for a single report that describes high microbial densities in surface water in 1964. The duration of blooming events that may take place in the Dead Sea following the continuous introduction of seawater and the consequent dilution of the surface water and change in its composition has never been studied and is uncertain. Occurrence of microbial blooms will have both limnological and industrial consequences that must be examined carefully. The basic assumption is that algal and bacterial blooming is not desired in the Dead Sea just as it is not desired in any other open water system. It will impact on the ecology of the Dead Sea and its surroundings, decrease the attractiveness of the lake, which will cease to be 'dead', and will have negative impact on the potash industries. Here too it is not possible yet to define if or at what point the increased turbidity of the water due to blooming becomes unbearable to the extent that it could hamper the project.

Increased rate of evaporation: Water balance calculations constitute an integral and crucial part in the proper planning and management of the 'Peace Conduit'. Yet even the present-day water balance of the Dead Sea is not agreed upon (Lensky et al. 2005). One of the most critical factors in the calculation of the water balance is the rate of evaporation, for which estimates range between 1.05 and 2 m/yr (e.g. Stanhill 1994; Salameh/El-Naser 2000). Dilution of the surface water due to the inflow of seawater will invariably increase the rate of evaporation and will have a major impact on the required capacity of the 'Peace Conduit'. Increased turbidity of the upper water column due to possible suspended gypsum crystals and/or microbial blooming may increase evaporation rates even more than what would be expected from dilution alone. If, on the other hand, the gypsum concentrates at the surface, the evaporation rate may in fact decrease due to changes in the Dead Sea's reflectivity.

Development of anoxic conditions in the lower water column: The development of long-term stratification of the Dead Sea water column will lead to the removal of oxygen and development of anoxic conditions in the lower water column. Under these conditions the anoxic lower water column may have dissolved H_2S, elevated levels of iron (Fe^{2+}) and other trace metals at lower concentrations. Similar conditions existed in the Dead Sea prior to the 1979 overturn of the water column that ended the stratification that lasted for hundreds of years (Neev/Emery 1967). However, at that time, the anoxic brine was not brought to the surface. The potash industry (only the Israeli Dead Sea Works Ltd. existed at the time) pumped its brine from the less saline surface layer. In the context of the 'Peace Conduit' and expected dilution and compositional changes in the surface water, the potash industries would most likely prefer to pump brine from the concentrated lower water body. Exposure of large volumes of anoxic brine (hundreds of million cubic meters per year) to the atmosphere in the feeding canals and the evaporation ponds will be accompanied by release of sulfur gasses (H_2S). This, as well as the presence of iron and other trace metals in the brine, may have an environmental impact and can impair the industrial processes. It is therefore important to determine if it will be possible to overcome the above impacts through development of appropriate industrial methods.

Infrastructure collapse and sinkholes: The rise in Dead Sea level will lead to re-flooding of large areas where sinkholes have developed. Many of the areas that currently experience collapse and destruction (Baer et al., 2002; Abelson et al., 2003, 2004) will again be covered by water. Water from the upper water column, which will be unsaturated with respect to halite, will replace freshwater in the subsurface. Thus, some exposed parts of the shorelines will still be susceptible to development of sinkholes because of halite dissolution and development of cavities in the subsurface. However, over the long run, with the gradual rise in salinity in the entire Dead Sea system, these processes will slowly come to a standstill.

To conclude, the 'Peace Conduit' will have both positive and negative impacts on the future evolution of the Dead Sea. Based on current knowledge, the various aspects of Dead Sea – seawater mixing discussed above do not provide grounds for overall negation of the proposed project. Yet, the final decision regarding the implementation of the 'Peace Conduit' needs to take into consideration the expected changes in the Dead Sea following the discharge and mixing of seawater. The 'Peace Conduit' can potentially reverse processes of environmental degradation that have resulted from the diversion of freshwater from the Jordan River and other tributaries. Also, the contribution to regional cooperation and the consolidation of peace is of major significance. Yet, based on current knowledge it is not possible at this stage to quantify expected changes in the Dead Sea and therefore their environmental, industrial and economical outcome cannot be assessed. Such examination requires quantification of the processes described above and their interdependencies in the long run. A long-term complex forecast and integration of these processes is possible only through a dynamic limnological model. Such a model is currently being developed in the Geological Survey of Israel (Ministry of National Infrastructure). The environmental and economic assessments that will be based on the outcome of the model will provide decision makers with the information required to determine and shape the future of the proposed 'Peace Conduit' project.

10.6 Summary and Conclusions

The Dead Sea is a severely disturbed ecosystem, greatly damaged by anthropogenic intervention in its water balance. Since the 20^{th} century, the Dead Sea level has dropped by more than 20 meters, and at present (year 2006) it is about 419 meters below mean sea level. Three alternatives for the future of the Dead Sea exist and need to be examined:

1. Maintaining the present situation. The Dead Sea level is expected to decline further to around -550 m, when a new equilibrium between inflow and evaporation will be reached.
2. Changing the regional water policy whereby freshwater from the Jordan and the Yarmouk river systems will be diverted back to the Dead Sea. In view of the severe regional water deficiency, such a program requires unprecedented regional cooperation and investments to compensate for the freshwater that will be diverted back to the Dead Sea.
3. Construction of the 'Peace Conduit' that will divert seawater and/or reject brine after desalination, into the Dead Sea. Such a plan has already been announced by Israel and Jordan during the Johannesburg World Summit on sustainable development.

The implementation of the 'Peace Conduit' differs from intervention with an undisturbed natural ecosystem. The project has the potential of stopping undesired environmental processes that currently occur in the basin such as the decline in lake level, retreat of the shoreline, and the collapse of the surrounding infrastructure. However, the mixing of seawater in the Dead Sea brine has the potential of bringing about changes, some of which are undesirable, to the Dead Sea with significant negative environmental and economic impacts. These changes include renewed stratification of the water column, precipitation of gypsum upon mixing, change in rate of evaporation, microbial blooming in the diluted surface waters, development of anoxic conditions in the lower water column and on the long run, change in the composition of the Dead Sea brine. It is imperative that these changes be quantified in an integrative dynamic limnological model and evaluated before a decision is taken regarding the implementation of the 'Peace Conduit'.

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