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Rapidly Shrinking Dead Sea Urgently Needs Infusion of 0.9 km^3/a from Planned Red-Sea Channel: Implication for Renewable Energy and Sustainable Development[1]

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Abstract

The Dead Sea has been experiencing a severe drop in level since 1978 with an average of 0.7 m/a due to the accelerating water consumption in its catchment and stood in 2008 at -420 m. In this study, a terrain model of the surface area and water volume of the Dead Sea was developed from the SRTM data using ArcGIS. The model shows that the lake shrinks on average by 4 km^2/a in area and by 0.47 km^3/a in volume, amounting to a cumulative loss of 14 km^3 in the last 30 years. The receding level leaves almost annually shoreline terraces recorded here for the first time by DGPS field surveys. The terrace altitudes were correlated among the different profiles and dated to specific years of the lake level regression, illustrating the tight correlation between the morphology of the terrace sequence and the receding lake level. Our volume-level model and previous work on groundwater inflow suggest that the projected Dead Sea–Red Sea channel must have a carrying capacity of >0.9 km^3/a in order to slowly re-fill the lake to its former level. The channel will also exploit the net altitude of 400 m to produce hydro-energy and create a sustainable system of electricity generation and freshwater production by desalinization. Moreover, such a channel will maintain tourism and potash industry of the Dead Sea and reduce the natural hazard caused by the lake recession.

KEYWORDS: Dead Sea; Water Volume And Surface Area Loss; SRTM-Based Model; Red-Dead Sea Channel; Renewable Energy And Sustainability.

1. Introduction

The Dead Sea surface is the lowest terrestrial point on Earth at 420.86 m below sea level as of 20 January 2008 (Arab Potash Company records) and it is shrinking rapidly. It is well-known for its unique geographical, ecological and historical characteristics. The Dead Sea occupies the central part of the Jordan Rift Valley and serves as a terminal lake for a catchment area of 40,650 km², with the Jordan River as the main tributary (Figure. 1a). It used to deliver 1.21 km³/a (Salameh and El-Naser 1999) [1] to the Dead Sea, to which water of several wadis draining to the lake from the western and eastern peripheral mountains is added (Figure. 1a). The salt concentration of 34% is 10 times as salty as the ocean. Despite the lack of life in the Dead Sea, it is rich in a wide variety of minerals, making it an important source for salt industries and an attraction point for visitors wishing to benefit from the therapeutic qualities of its minerals. The distinctive cultural and historical heritage of the Dead Sea basin make it very important place not only for the riparian countries but also for the entire world. Many historical sites are located in the lake area such as Jesus's baptism site, Mount Nebo and Lot village. The excessive consumption of the water in the Dead Sea basin caused a rapid drop of the Dead Sea with severe environmental consequences. Therefore, an international effort should be done to save this unique eco-system and reserve its historical and natural treasures. This study aims at : (a) developing a terrain model of the Dead Sea water volume and surface area in order to determine the water input requirements of the shrinking Dead Sea and consequently the projected Red-Dead Sea Channel; (b)

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investigating the most recent changes in the Dead Sea level and the shore morphology by surveying the modern shoreline terraces and dating them according to the Dead Sea hydrograph; and (c) Evaluating the environmental impacts of the Dead Sea lowering and those of the projected channel as well as implication of the channel with respect to renewable energy and sustainable development.

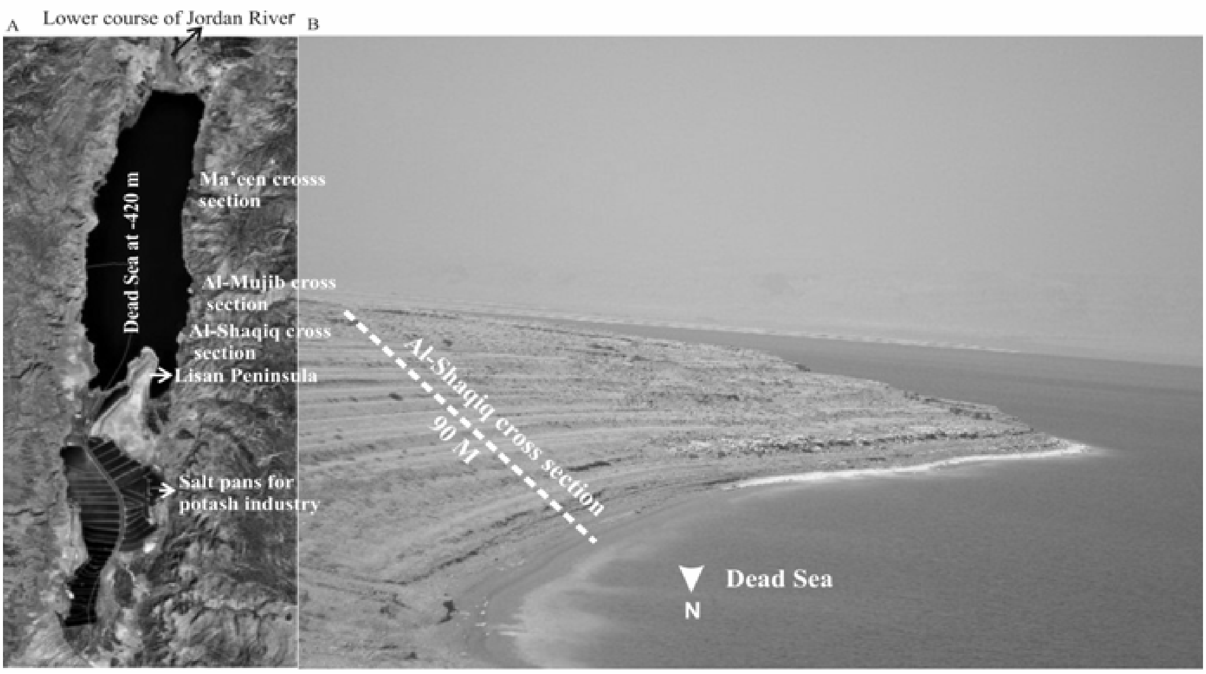

Figure 1 a. Location of the Dead Sea and the measured terrace profiles. The image was taken from w.NASA World Wind. b. Recent Dead Sea terraces north of Wadi Al-Shaqiq fan delta.

2. Material and Methods

To calculate the volume and area loss functions of the Dead Sea, a model of the rift valley volume and surface area in meter intervals was developed from SRTM data (3 arc second; CIAT 2004)[2]. ArcGIS (3D)-Analyst-“Surface Volume” tool-functionality was used to calculate the surface area and water volume of the Dead Sea below a certain altitude. The tool was applied for each meter change of the level from −389 to −415 m. Since the bathymetric contours of the Dead Sea below −415 m are not available in the SRTM data, the water volume of the current Dead Sea below −415 m (Dead Sea Data Summary. International Lake Environment Committee Foundation)[3] was added to our calculated volume in order to determine the total volume of the Dead Sea. The calculated water volume and surface area were plotted against the altitude. A polynomial function was derived that best fits the calculated graph using a least-square method.

Three profiles of the Dead Sea terraces were surveyed with the DGPS rover (Leica SR-20) at (1) Wadi Al-Shaqiq fan delta, (2) Wadi Al-Mujib fan delta, and (3) Wadi Ma’een fan delta (Figures. 1a & 3). The terrace altitudes were correlated among the different profiles and dated to specific years of the lake level regression according to the Dead Sea hydrograph as made available by the Hydrological Survey of Israel (personal communication, Eliyahu Wakshal) and previous publications.

3. Results and Discussion

3.1. Surface Area and Water Volume of The Dead Sea

The level of closed lakes—such as the Dead Sea—is a result of the hydrological balance between runoff into the lake plus direct precipitation on the lake surface minus evaporation; therefore, it serves as an indicator of climatic conditions. However, the recent Dead Sea level change (and its associated changes in surface area and volume) is mainly due to (a) transferring 500 Mio m^3/a of water from the upper Jordan River by the Israel National Water Carrier project to the Mediterranean coastal plain; (b) diverting an additional water amount of 75 Mio m^3/a from the Yarmouk River to the same carrier; (c) diverting 110 Mio m^3/a of the Yarmouk River water to the King Abdullah Channel in Jordan and an additional 135 Mio m^3/a from the same resource by Syria; (d) consuming (cumulative from 1976 to 1997) 2.4 km^3 of the surface and ground water inflow to the Dead Sea from the eastern coast and Wadi Araba by Jordan and 3.3 km^3 from the same resource in the western side by Israel; and (e) abstracting 5 km^3 from the Dead Sea water for the potash industry by both Israel and Jordan [4]. The level change is therefore mainly due to human water consumption and not a result of climate change. The terrain model shows that water volume and surface area correlate highly with the lake level (volume R^2=0.9993, area R^2=0.9899; Figures. 2a, b) reflecting the bathymetry of the flanks of the former Dead Sea and the morphology of the rift valley, according to Eqs. 1 and 2 developed based on our model.

$$WV = 0.0077x^2 + 6.8905x + 1,688.8 \quad (1)$$

$$SA = -0.0008x^5 - 1.6141x^4 - 1,301.9x^3$$
$$- 524,930x^2 - 1*10^8x - 9*10^9 \quad (2)$$

where *WV*: water volume, *SA*: surface area
x: Dead Sea level.

According to our GIS data analysis, the Dead Sea has lost 9.7 km³ (0.2 km³/a) from its volume and 365 km² (7.9 km²/a) from its area during the period between 1932 and 1978. Since 1978, the volume decreased dramatically from ~157.7 to ~147 km³ with an average of 0.47 km³/a (Figures. 2a, b). Meanwhile, the surface area shrank from 729.4 to 636.7 km² with 4 km²/a on average. The recession of the lake level caused additional groundwater inflows of about 0.5 km^3/a (Salameh and El-Naser 2000)[5]. This, plus our calculated volume loss, suggests that surface water inflow has to increase by more than 150% or by ~0.9 km^3/a, in order to stop the continuous drop of the Dead Sea. However, this is unlikely to happen due to the current intensive consumption of water resources in the Dead Sea basin that is still increasing, e.g., by population growth and recent migrations to Jordan from Iraq and Lebanon.

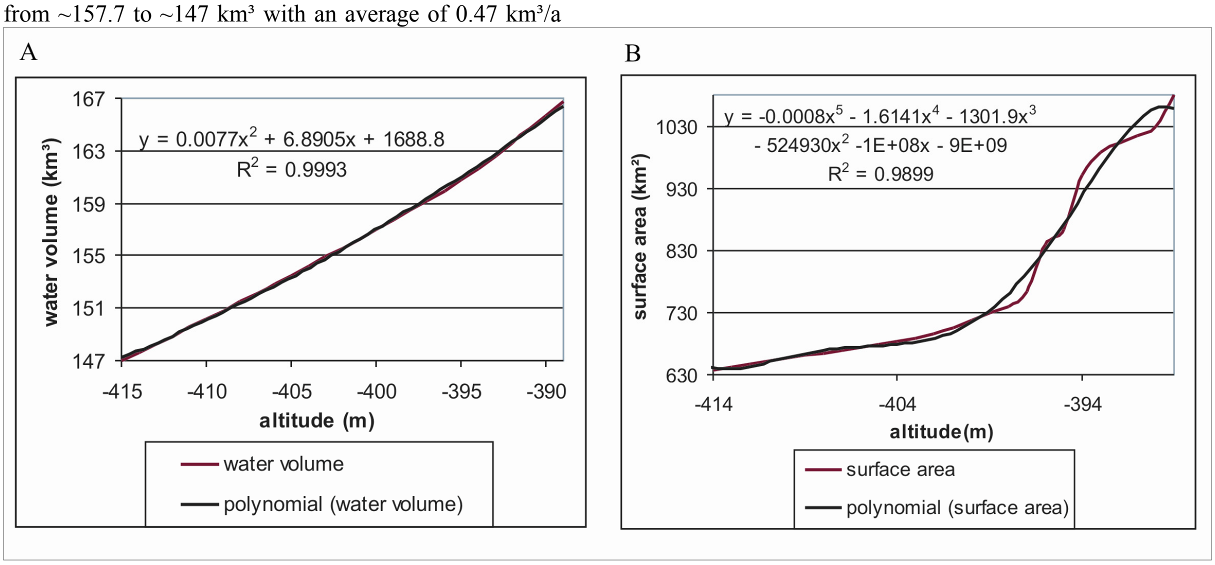

Figure 2 a. Volume–altitude model of the Dead Sea. b. Surface area–altitude model of the Dead Sea

3.2. Shoreline Terraces And Level Changes

The wadis draining to the Dead Sea experienced rapid erosion due to the lowering of the base level during the Holocene. Consequently, Gilbert-type fan deltas were formed in front of the mouths of the main wadis such as Al-Mujib, Al-Shaqiq, and Ma'een (Figure. 3a). Along some shore sections of these deltas with easily erodable lacustrine and alluvial deposits, a unique set of shore-line terraces formed that can serve as a tool to investigate this level change in details (Figures. 1b, 3a). These terraces were formed during the last 77 years as a result of a lake level drop of 30 m with an average of 0.4 m/a. Recorded levels [6] and [7] Hydrological Survey of Israel) suggest that the highest terrace at −389 m formed in 1932 (and previous years). The recorded level curve allows correlating most of the terraces to specific years (Figure. 3b). The lowest here documented terrace at −419 m formed in winter 2006–2007. Some years show a more pronounced recession than others but many of the terraces represent one winter season only. The average of lake level recession increased in rate throughout time: From 1932 to 1977, the Dead Sea level dropped relatively slowly from −389 to −399 m with an average of 0.2 m/a. In this relatively long period, only seven larger terraces can be recognized in the different profiles. This could be due to the prolonged times of stable water level that allowed the waves to abrade wide terraces.

The intensive water consumption in the Dead Sea basin in the last 30 years caused an accelerated drop from −399 m in 1978 to −419 m in 2007 with an average of 0.7 m/a. In this short period, 25 terraces formed, but with smaller dimensions. This is interpreted as a result of the fast recession and of the short period of constant water level that has not allowed the waves to form wide terraces.

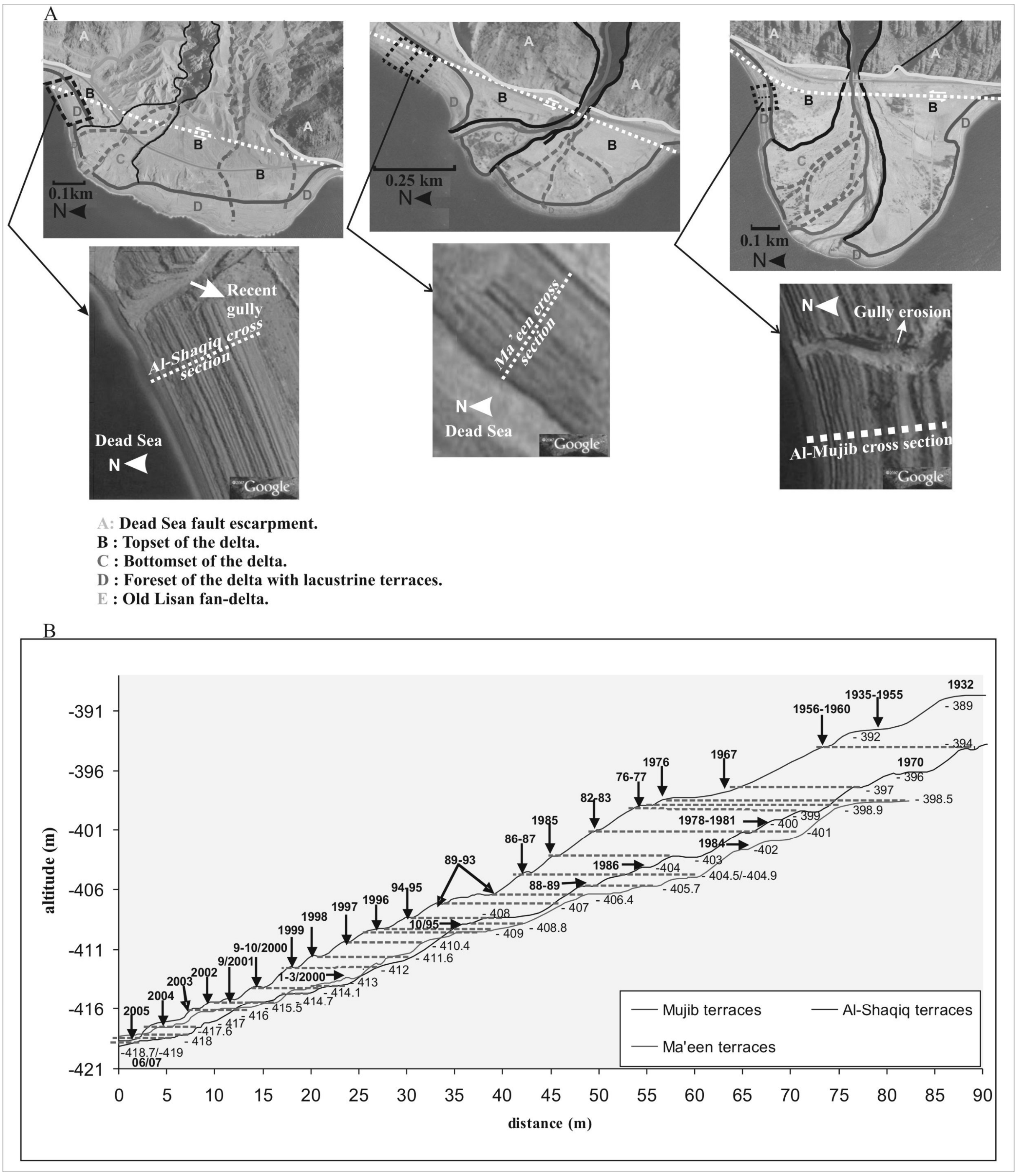

Figure 3 a. Gilbert fan deltas and sequences of lacustrine terraces north of Wadi Al-Shaqiq (upper left), north of Wadi Ma'een (upper middle), and north of Wadi Al-Mujib (upper right). Note roads crossing the deltas on the landward sections at positions near to the presumed trace of the Dead Sea eastern boundary transform fault. The lower images in this figure were taken from Google Earth. The date of these photos is 16 January 2007 http://earth.google.com. b. Three profiles of Dead Sea terraces surveyed by DGPS, correlated among each other and dated according to the recorded Dead Sea levels.

3.3. The Effects of The Dead Sea Lowering and The Implications of The Projected Channel

The rapid lowering of the Dead Sea level in the last 30 years has caused and will continue to cause severe detrimental effects both to its function as a resource and to the natural state of its shores. These effects include:

- Higher pumping costs for the factories using the former southern sections of the Dead Sea to extract potash, salt, and magnesium.
- The declining water level causes an accelerated outflow of fresh water from surrounding aquifers, thus causing a loss of this important resource.
- The receding shoreline makes it difficult (and in some places even dangerous) for tourists and hotel guests to access the water of the Dead Sea for medical baths.
- The freshwater outflow has enhanced the dissolution of buried salt deposits creating a treacherous landscape of sinkholes and mud along the entire shore of the Dead Sea (Closson et al. 2005;[8] Yechieli et al. 2004)[9] that caused severe damage to roads, salt pans, and other civil engineering structures.

- The rapid emergence of delta bodies and the thereby caused decrease in buoyancy could cause sudden (or earthquake-triggered) slips (mass waste movement and landslides, such as what happened in the north of the Dead Sea in 2000) of sections of the deltas with the prospect to trigger small tsunamis within the lake.
- The rapid down-cutting of the west-draining wadis due to the lake level lowering threatens the bases of the bridges built at the mouths of these wadis.
- The lake could soon become halite-saturated, causing incrustation along its entire perimeter (today only spray water forms intermittent salt deposits).

Given the mounting stress on the water resources in the Dead Sea basin and the environmental hazard caused by its lowering, two projects were suggested to maintain the Dead Sea and stop its lowering: the Red Sea–Dead Sea Channel (RSDSC) and the Mediterranean–Dead Sea Channel (MDSC). Two alignments were suggested for the MDSC: in the north from the Mediterranean coast through Bet She'an to the Jordan River and in the south from the Gaza strip to Masada at the Dead Sea [10]. Although the northern route of the MDSC is the shortest and the cheapest one, the RSDSC would be under the control of all riparian countries, and its benefits could therefore be distributed fairly. Such projects cannot only stop the level decrease, but can also utilize the altitude difference of 400 m to produce renewable hydro-static energy and hence freshwater by desalinization. It also introduces new salt to the lake, ensuring the long-term sustainability of the salt extraction and tourism industry in both sides of the lake. Furthermore, it reduces the severe environmental hazards caused by the lake level lowering. Based on the water volume loss calculated by our model and the ground water inflow to the Dead Sea, we suggest that the RSDSC should have a capacity of more than 0.9 km^3/a in order to slowly fill the lake back to levels as of 30 years ago and to ensure its long-term sustainability.

However, the building of this channel raises a number of questions with respect to the negative impacts on the lake itself and on the lake basin:

- One of the long-term negative impacts of the channel might be the continuous infiltration of seawater into underground aquifers. Since this would diminish energy output, the channel should be planned with an impermeable bed to begin with.
- Possible ruptures of the RSDSC bed during earthquakes along the Dead Sea Fault would not be such a risk since the channel would be segmented by pumping and turbine stations, thus sections of it could temporarily be emptied and repaired.
- The possibility of lake water stratification for a long period is not expected. This depends on the rate at which the lake level will be raised. A slow and gradual pumping rate reduces the possibility of surface water dilution. Once the target level is attained, the volume of inflowing seawater will be adjusted to maintain a constant level. Incoming seawater will evaporate and the seawater-derived salts will accumulate in the upper water column. Thus the salinity and density of the surface water will continuously increase and reach that of the lower one. Consequently, the mixing of the water layers will occur [11].
- The mixing of sulphate-rich seawater with calcium-rich Dead Sea water could lead to gypsum precipitation. Halite precipitation may also take place during the steady state period, once the salinity of the upper water has increased enough to attain saturation with respect to this mineral. However, overturn of the water column will decrease the precipitation of both minerals due to the effect of mixing of seawater with the entire water body of the Dead Sea [11].
- Blooming of algae and bacteria could occur, causing a high turbidity, and therefore a higher rate of evaporation [11]. Since the possible dilution of the Dead Sea will be limited to the filling period, the blooming is expected to be a minor problem.

4. Conclusion

The hydrological balance of the Dead Sea significantly changed since the beginning of the twentieth century mainly due to intensive consumption of water resources in the lake basin mainly by Israel and secondarily by Jordan and Syria. During the last 30 years, water consumption caused an accelerated decrease in the water level, volume, and surface area amounting to 0.7 m, 0.47 km^3, and 4 km^2 per year, respectively. Our model function can also be used to predict near-future volume and area losses. Thus, in 2020, the lake will have dropped presumably to −427.8 m and will have lost 5.6 km^3 and 48 km^2 of its current volume and area, successively. Based on the water volume loss calculated by our model and the ground water inflow to the Dead Sea, we suggest that the RSDSC should have a capacity of more than 0.9 km^3/a in order to slowly fill the lake back to levels as of 30 years ago and ensure its long-term sustainability. The channel can also benefit from the net altitude difference of 400 m to generate renewable hydro-static energy and hence freshwater by desalinization. If the diversion of Jordan water to the Mediterranean coast would be stopped (replacing the water need by desalinization of seawater), then the recession of the Dead-Sea could be considerably slowed, buying time to consider the long-term alternatives.

Acknowledgments

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