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Salt storms, sinkholes and major economic losses: Can the deteriorating Dead Sea be saved from the looming eco crisis?

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ABSTRACT

The Dead Sea continues to shrink with an annual drop of over one meter in its sea level paving a road to a new reality; the environmental consequences of this phenomenon are clear, most notably, the significant numbers of sinkholes that have appeared on the Dead Sea shores. While the sinkholes problem is deteriorating in the Dead Sea, there are several other case studies of similar salt lakes from all around the world, ranging from Aral Lake (between Kazakhstan and Uzbekistan), Lake Urmia in Iran and Lake Mono in the United States. These examples can provide invaluable information for the research to save the Dead Sea. These cases have highlighted the devastating environmental impacts of drying seas, causing salt storms and drop in ground water levels, thus endangering human lives.

The case of saving the Dead Sea has not yet been lost. The potential options to mitigate this catastrophe have been studied in the past decades, but so far no solution has been implemented. At the end of the day, it seems that out of several alternatives, a seawater conveyance to the Dead Sea – such as the Mediterranean Dead Sea project – is one of the major feasible options.

1. Introduction

Regional civil wars and conflicts have created political insecurity in the Middle East. Many of its current conflicts have emerged from the concern of environmental security, which consist of the following: Energy security, water security, food security, land degradation and desertification. All these concerns are closely knit to the environmental challenges in the region.

The Dead Sea is a transboundary watershed. It is a hypersaline lake spanning part of the border between Israel, the Palestinian Authority and Jordan. Due to freshwater diversions by Israel, Syria and Jordan over the last century, the level of the Dead Sea has dropped 38 meters (Figure 1 and Figure 2), from a steady state of around –390m below sea-level until the 1930s to –428m in the spring of 2014. The Dead Sea water level continues to decline at a rate of about one meter per year (Yechieli, et al., 2006 and Closson, et al., 2009).

The Dead Sea is fed mainly by the Jordan River flowing from the Sea of Galilee and from the Yarmuk River, its source being the springs of Jordan and Syria. Much of the water that formerly flowed down the lower Jordan River from the Sea of Galilee no longer does so. Most of the water is diverted by Israel, Jordan and Syria. For instance, the Degania Dam was built in the late 1920s and in 1954 the height of the dam was raised in order to increase the capacity of the Sea of Galilee.

Since 1964 it negated the flow to the Jordan River. The dam was constructed at the point where the Sea of Galilee drains into the Lower Jordan River, improving the effectiveness of the Sea of Galilee as a fresh water reservoir but severing the upstream part of the basin from the lower part thus preventing any flow of water into the lower Jordan River and the Dead Sea. Similarly Jordan and Syria have built several dams along the rivers and riverbeds draining in to the Dead Sea from the east. Since the 1930s, the flow of water into the Dead Sea has declined (Figure 1) from 1.8 billion cubic meters annually to only 100–200 million cubic meters annually (Yechieli, et al., 2006 and Yechieli, et al., 1998).

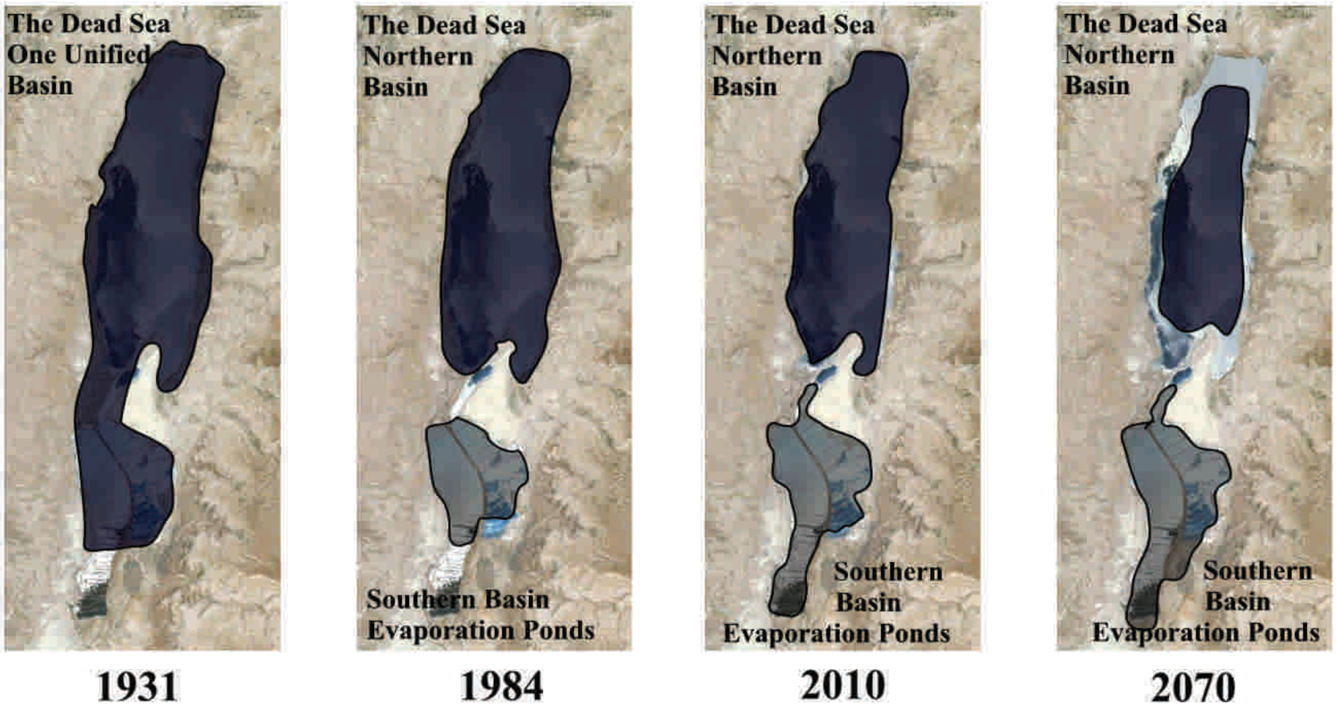
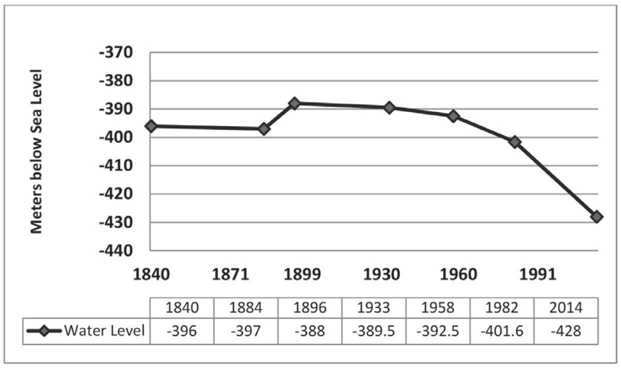


Figure 1: The shrinkage of the Dead Sea



	1840	1884	1896	1933	1958	1982	2014
Water Level	-396	-397	-388	-389.5	-392.5	-401.6	-428

Figure 2: Dead Sea water level trends

The Dead Sea sits at the lowest elevation on earth making it a unique water basin and has great significance to the riparian states. The declining Dead Sea water level has already reached a point where the damage to the ecology and environment is irreversible without human intervention; the natural inflow is not enough to "turn back the clock". As a result, the drop in the Dead Sea water level is threatening both tourism and industry at the Dead Sea. In order to solve this issue, several projects have been surveyed with the aim of importing seawater to the Dead Sea, and thus, restoring it back to its historical levels.

Due to the elevation difference between ocean water and that of the Dead Sea, such a seawater conveyance could provide various benefits for the region: Saving the Dead Sea, freshwater generation, energy security and regional development. The main factor causing the Dead Sea water level to decline is the reduced inflow of the lower Jordan River and the evaporation of water from the industrial processes of the Dead Sea mineral industries where the evaporation ponds consist of almost half of the water surface area.

The rapid population growth in the region increases water demand, which in turn has led to increased water diversion from streams flowing to the Dead Sea. The water that currently flows into the Dead Sea (Figure 3) consists mainly of irrigation return flows, treated and untreated sewage, and saline groundwater that discharges to the lower Jordan River and Dead Sea (Oren, et al., 2010). On both coasts in Israel and Jordan, the Dead

Sea provides a variety of tourism services as well as many industrial facilities, with potash (potassium salts used mainly in fertilizers), bromine and magnesium production being the largest industry in the area. Additionally, much of the land near the southern basin of the Dead Sea is used for agriculture. These industries are at risk due to problems associated with the declining water level of the Dead Sea, most notably sinkholes. Sinkholes are collapsed areas of earth caused when underground salt is dissolved by freshwater intrusion, caused by the ongoing drop in sea level. Despite the sinkholes problem, the lower the Dead Sea water level is, the better it is for the industry earnings as it means higher mineral content in the water.

Figure 3: Jordan River and Dead Sea basin

Various solutions have been proposed over the years to resolve the issue of declining Dead Sea water level. It has been argued that Israel should divert more water to the Dead Sea from its freshwater reserve of the Sea of Galilee. This, however, would not be a realistic option for increasing water levels as the required amount of water to raise the water level would have to be gigantic. It is true that in the coming years Israel's dependency on the Sea of Galilee will decrease as more coastal desalination plants will become operational. However, this does not necessary mean that Israel should divert the excess water to the Dead Sea, but rather convey part of the water to Jordan.

This paper presents a perspective to understand the deteriorating state of the Dead Sea, while acknowledging that there are not many options that would be both economically viable and politically feasible for restoring the Dead Sea water level to its historic levels. Firstly, the paper builds a case for the negative impacts of the sinkholes and salt storms and argues that the solution to the problem needs to derive from economic feasibility. Secondly, the paper presents potential options that have been suggested in the past decades. Finally, the paper concludes that out of several alternatives, a seawater conveyance to the Dead Sea – such as the Mediterranean Sea Dead Sea project – is the only viable option to save the Dead Sea despite the potential implications of changing the water quality of the Dead Sea.

2. The current situation – the problem of drying seas: Sinkholes and salt storms

The Dead Sea level drops each year around one meter causing irreversible damage to the ecosystem and infrastructure of the surrounding region. The next sub-chapters introduce the problem of sinkholes, discuss their economic impacts and present some examples of known cases of drying seas from around the world.

2.1 Emerging sinkholes

Sinkholes are collapsed areas of earth which are found in many parts of the world. They vary in size ranging from one meter to 600 meters in diameter. Sinkholes often receive attention because they can form quickly and, especially in urban areas, are potentially extremely destructive. They are able to swallow buildings, farmland, and have even been reported to cause bodily harm and fatalities to humans who have been "swallowed" by the earth. Sinkholes occur naturally in areas abundant in limestone, salts, and gypsum, and can occur up to one thousand times more frequently due to human impact in areas with salt and gypsum, such as in the Dead Sea region (Ezersky and Frumkin, 2013). Sinkholes occur when a subsurface cavity forms and the surface collapses into this cavity (Closson, 2005). These underground cavities can form due to natural or artificial causes. Both Israel and Jordan are now facing major environmental and planning problems due to these sinkholes around the shores of the Dead Sea. The sinkholes at the Dead Sea are unique because of how rapidly they form due to a human-induced cause.

The current issue of sinkholes in the region is largely due to the dropping water levels of the Dead Sea, allowing unsaturated groundwater to erode a 10,000 year old salt layer which is buried 20–70 meters below the surface (Taqieddin, et al., 2000 and Closson, 2005). The groundwater flows through underground faults and fractures, eventually reaching the edge of the salt layer and eroding the salt, creating the cavity that eventually causes the sinkhole to form (Closson, 2005). Therefore, sinkholes will appear most often at the intersection of faults and along the edge of the salt layer. Additionally, the lower water level can also create cavities in spaces that had previously been filled with water, but are drained and can eventually collapse to become a sinkhole. Sinkholes around the Dead Sea can reach a depth of about 28 meters and a diameter of 40 meters (Raz, 2000, unpublished data). They tend to form in clusters, eventually enlarging and merging with other sinkholes.

Since the 1980s, thousands of sinkholes have formed along the shores of the Dead Sea, with about 75% of them forming since 1997. Additionally, around 150–200 new sinkholes form every year (Yechieli et al., 2006). As Figure 4 shows, on the Israeli coast, the sinkholes began mostly at the southern end of the sea and have been spreading northward, while on the Jordanian coast the sinkholes are mostly located in clusters at the southern part of the coast (Ezersky and Frumkin, 2013). There are many more sinkholes forming on the Israeli coast than on the Jordanian coast (Yechieli, et al., 2006).

According to Raz (2000) "the phenomenon of subsidence and collapse of the land's surface and the appearance of sinkholes on the western side of the Dead Sea from Ein Gedi southward have been known since the late 1970s. In the 1990s the phenomena spread to the north of Ein Gedi as well as continuing southwards." Further, the high rate of sinkhole development spread to the northern Dead Sea along the coast, "the frequency of subsidence and collapse events have increased and have caused injury and damage to property as well as delayed plans for development" (ibid.).

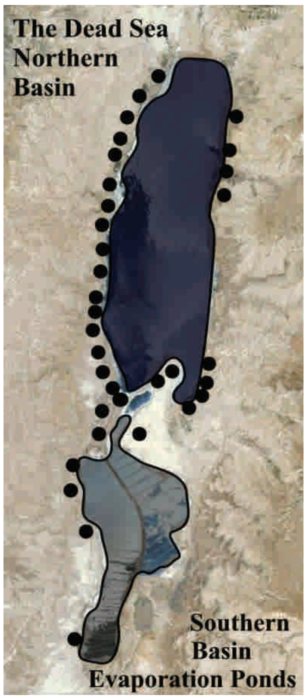


Figure 4: The sinkhole formation at the Dead Sea

2.2 Economic problems associated with sinkholes in the Dead Sea region

Sinkholes are constantly damaging the existing infrastructure, while stifling the potential for growth in the Dead Sea region. On both coasts there are farms, industrial sites including the Jordanian Arab Potash Company and the Israeli Dead Sea Works, and tourist destinations including resorts and parks. The sinkholes have already caused considerable damage to these facilities.

In addition to the physical damages caused by sinkholes, the threat that additional sinkholes will form in the near future has caused several existing facilities to close or stop production. Places which have closed down include a campground, date groves, and a naval base (Associated Press, 2009). Furthermore, the economic growth in the region is limited because the threat of sinkholes is enough to keep people from investing in new development or businesses in the area. These factors combine to make sinkholes a very costly problem.

The sinkholes have cost Kibbutz Ein Gedi more than 25 million dollars in earnings since 1995. This is because they have had to close down a resort village, abandon a date palm orchard, and cancel future development plans in these areas (Heilman, 2008). In addition, the Israel Roads Company has had to invest millions of dollars over the past years to improve highway no. 90 that runs parallel to the Dead Sea. The latest works are taking place near Ein Gedi in 2015.

Meanwhile, the Arab Potash Company is expected to suffer about 70–90 million dollars in damages due to the decreasing water level of the Dead Sea. The Arab Potash Company was constructing salt evaporation ponds when a sinkhole damaged about 100 meters of roadway. A short time later, part of a salt evaporation pond collapsed causing millions of dollars of losses on infrastructure and product (Closson, 2005). According to the Arab Potash Company, it has insurance to cover such hazards caused by the sinkholes formation (Arab Potash Company, 2013). Situations such as these are likely to continue and even become more frequent so long as the water level of the Dead Sea continues to decline.

2.3 Studying sinkholes

There are several tests and methods used to detect the formation or risk of sinkholes. Seismic refraction was used to determine the location of the edge of the salt layer. This is very significant because sinkholes tend to form along the edge of the salt layer so this is the best indication of where sinkholes are likely to form (Ezersky, et al., 2013). It is important to know where there are sinkholes that have yet to reach the surface, but since sinkholes form very quickly, it is not expected that these tests can be done regularly enough to detect all sinkholes before they surface (Arkin and Gilat, 2000). There have been attempts to fill in sinkholes and other similar engineering solutions, but the sinkholes tend to reform, making this an unsafe and non-cost-effective method (ibid.).

Landslides on the Jordanian side have also been occurring due to the lowering water level of the Dead Sea. The landslides have not been studied or given nearly as much attention as the sinkholes, but are extremely destructive and dangerous as well. From 1999 to 2009, landslides of about 100 meters each have destroyed sections of the Jordanian Dead Sea coast. In fact, 1999 was the first landslide along the coast of the Dead Sea in recent geologic history. The landslides suggest that rapid structural changes and problems relating to ground stability will continue to cascade (Closson, et al., 2009).

2.4 Global perspective

The Dead Sea is not the only case of a drying sea. The most notable case of a sea drying due to human impact is the Aral Sea (Figure 5), which has its watershed in Afghanistan, Kazakhstan, Tajikistan, Turkmenistan, and Uzbekistan. The water level of the Aral Lake began to decline rapidly in the 1990s after 30 years of gradual decline. This was mostly due to Soviet authorities diverting waters that would have normally flowed into the Aral. The water was diverted to provide irrigation for agriculture, primarily cotton production. The evaporation of the Aral Lake resulted in salt deposition and ironically, as the Aral Lake dried, the leftover salt made the land unsuitable for agriculture. This salt can be carried by the wind causing salt storms which can ruin crops in the surrounding area. The salt storms also potentially cause a variety of health issues in animals and humans such as respiratory illness, eye problems, as well as throat and esophageal cancers. The salt storms from the Aral Lake are expected to directly affect tens of millions of people living nearby (UNEP, 2012). There are concerns that the Dead Sea too will face harmful salt storms in the future and that this could negatively affect the agricultural land in the area (Abu-Qdais, 2008).

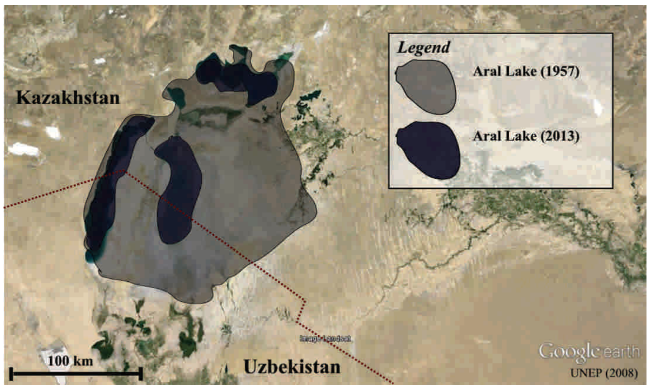


Figure 5: Aral Lake

Lake Urmia (Figure 6) in Iran is following a similar path to the Aral Lake. Lake Urmia is the largest lake in the Middle East and is the second most hypersaline lake in the world. It is an important wetland ecosystem with a unique species of brine shrimp that many migratory birds including flamingos rely on as a food source. Since 1995, the water level of the lake has been decreasing dramatically. The decreased water inflow, largely due to the diversion of rivers which discharge into Lake Urmia, is increasing the salinity of the lake, potentially putting the brine shrimp under ecological stress. This could cause major ecological problems in the area and for migratory birds. Additionally, there are concerns that salt storms will affect the region around Lake Urmia in a similar fashion to the Aral Sea (UNEP, 2012).

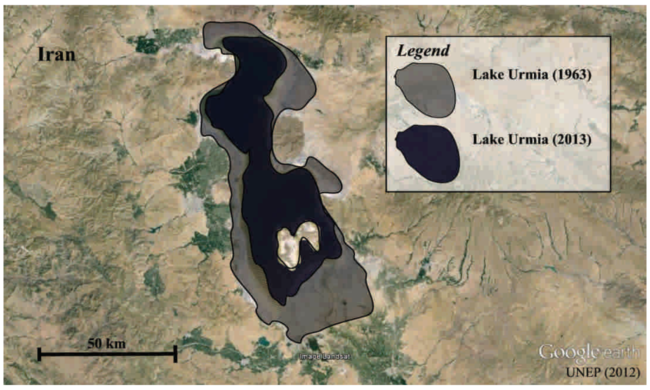


Figure 6: Lake Urmia

It is important to note that climate change plays a significant role in the drying of these lakes. As climate patterns shift, several factors change the water availability in these and other lakes. These lakes, including the Dead Sea, are in areas that are becoming warmer and dryer due to climate change. This change affects the amount of rainfall falling in the watershed of the lakes. Additionally, it increases the water demand of nearby areas, which use more water that would otherwise flow into the lakes (Abbaspour et al., 2012).

An example of how changes in policy can lead to restoring over-exploited water resources is Lake Mono in California. Lake Mono was a formerly dried lake which underwent a successful refill. It dried up because its water was diverted to provide reservoirs for Los Angeles. Unlike many other proposed lake refill projects, refilling Lake Mono was done through policy changes. It was done by implementing minimum inflow requirements based on how much precipitation fell the previous season (Ficklin et al., 2012). After a year of heavy precipitation, more water would be allowed to be diverted from the lake, while in lean years, the water was controlled more strictly. This ensured that a sustainable amount of water was always flowing into the lake basin. Applying a similar policy for the Dead Sea could provide improved watershed conditions at the cost of water supply which is already very low in the region. However, unlike for Lake Mono, this type of a policy decision for the Dead Sea would require the agreement and cooperation of Israel, Jordan and the Palestinian Authority – politically, a more complex issue than that for Lake Mono.

Yet, various solutions have been considered to alleviate the lowering water levels of Lake Urmia and the Aral Lake, along with other drying bodies of water around the world. These proposed solutions tend to be large scale projects, usually building physical structures, such as canals, to bring water from other watersheds to the drying lakes. Since these tend to be extremely costly projects, they are often proposed but not carried out. Further analysis of finding possible solutions to drying lakes are analyzed below in relation to the Dead Sea.

3. Exploring potential solutions: Building a conveyance to the Dead Sea

As of now, there is no reliable way to alleviate the issue of sinkholes without stabilizing the Dead Sea water level (Arkin and Gilat, 2000 and Taqieddin et al., 2000). If the water level stops declining, the system will balance out and prevent further sinkhole formation. There are several possible options for attempting to refill and stabilize the water level of the Dead Sea (Figure 7). These options include various ways of conveying water to the Dead Sea, either from other nearby water sources including the Mediterranean Sea or Red Sea, by increasing the inflow to the Dead Sea from the Jordan River by decreasing the water diverted from the river, or from increased rainfall by cloud enhancement (Abbaspour et al., 2012 and UNEP, 2012). However, due to the length of a possible water conveyance, the most technically feasible option would be bringing water from the Mediterranean Sea to the Dead Sea either through tunnel,

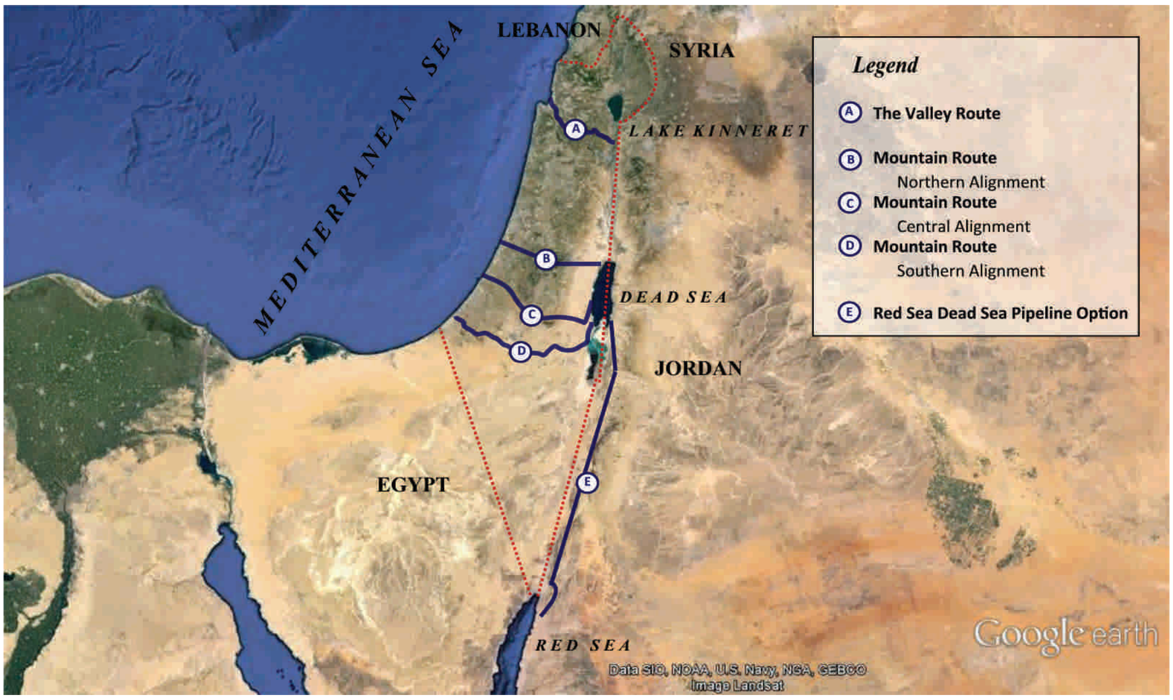


Figure 7: Conveyance routes

canal, pipeline, or a combination of all of these based on the route alignment and the natural topography. These methods have associated additional benefits and potential harmful effects which will be included when considering the best solution.

Many attempts to restore bodies of water in other locations have involved large construction projects and diversions of water from other places. To stabilize the water level of the Dead Sea it is technically possible to bring water from the Red Sea, the Mediterranean Sea, or even to import it from watersheds further away.

The engineering and financial resources required as well as political feasibility for each project heavily depend on the route chosen, and over the last 150 years several routes have been proposed for the conveyance project. The five most seriously considered proposals consist of the following: The "Valley Route", which first pumps water from Haifa Bay into a canal in the Yezreel Valley, conveys it through Bet Shean into the Jordan River, and then into the Dead Sea; three mountain routes traversing the Judean Mountains, including the "Northern Route" through Judea and Samaria (the West Bank), the "Central Route" exclusively in Israel, and the "Southern Route" through Gaza; and the Red Sea-Dead Sea route beginning at the Gulf of Aqaba in the Red Sea and conveying the water through the Arava to the Dead Sea. These plans differ considerably in terms of financial cost of construction and operation, engineering feasibility, environmental impact, and political possibility (Willner et al., 2013).

The conveyance would take advantage of the elevation difference from sea level to the Dead Sea which will utilize a 350–400 meter hydraulic head for hydroelectric power generation. Some of the proposals have included the construction of desalination plants for regional water use (Israeli et al., 2009, World Bank, 2012 and Willner et al., 2013). A few locations for water desalination in the Red-Dead and Med-Dead project have been proposed. For instance, the latest Red Sea Dead Sea project proposal includes a desalination plant located on the Aqaba Bay, while the Mediterranean Dead Sea project has proposed the construction of a desalination plant either inland near Beer Sheva or alternatively along the Dead Sea shores. The brine from the water production would be conveyed to the Dead Sea through a pipeline or tunnel along with additional sea water to refill the Dead Sea. The uniqueness of these projects is that the water would be produced in such a manner that it could be used in Israel, Jordan and the Palestinian Authority. However, both the Mediterranean Dead Sea and the Red-Dead projects are somewhat complicated projects with advantages as well as disadvantages.

One major advantage of the Mediterranean Dead Sea and the Red-Dead projects is their capacity to convey a significant amount of water to the Dead Sea and thus, gradually raise the level of the Dead Sea, which would over time flood most of the area affected by sinkholes, reversing the water level changes that caused the creation of the sinkholes in the first place (Yechieli et al., 2006). Refilling the Dead Sea would potentially solve the sinkhole problem while making it a healthier watershed and making industry and tourism in the area feasible again. However, it seems that the current plan for the Red Sea Dead Sea project aims to stabilize the Dead Sea water level rather than to increase the water level enough to flood sinkholes.

4. Challenges with the potential solutions: The environment and economics

There are potential challenges with depositing the salt water discharge into the Dead Sea. These issues would need to be addressed in an environmental feasibility assessment. The water that would be discharged into the Dead Sea would have a lower salinity than the natural Dead Sea water. This can lead to increased evaporation of the Dead Sea, because the saltier the water, the less it will evaporate (Karbassi et al., 2010). However, increased evaporation might not be a negative impact. Additionally, the less salty brine will be less dense than the existing Dead Sea water creating a layer on top of the natural Dead Sea water unless special care is taken to mix the water (Abu-Qdais, 2008). Historically, however, the Jordan River used to convey a considerable amount of sweet water to the Dead Sea resulting in layering of water.

It is also possible that mixing Dead Sea water with discharge water could create gypsum crystals, fundamentally changing the chemical properties of the Dead Sea (Reznik et al., 2011). Microbial growth, also caused by mixing of the different waters, would hardly be affected by the increased amount of gypsum in the Dead Sea water. Figure 8 summarizes the expected environmental impacts of mixing sea water with Dead Sea water (World Bank, 2012).

The gypsum could also have severe effects on the potash industry at the Dead Sea by changing the water chemistry that produces potash and other useful minerals to the potash industry. The gypsum formation will make the production process more expensive because of the need to dispose of the gypsum but it will not affect the quality of the extracted products. The effects of mixing the brine discharge with the Dead Sea water needs to be analyzed further before the plan is irreversible (Oren, et al., 2010). Finally, the discharge from the desalination process will contain antiscalant chemicals that the feed water was treated with, potentially causing ecological and health hazards (Abu-Qdais, 2008 and Karbassi et al., 2010)

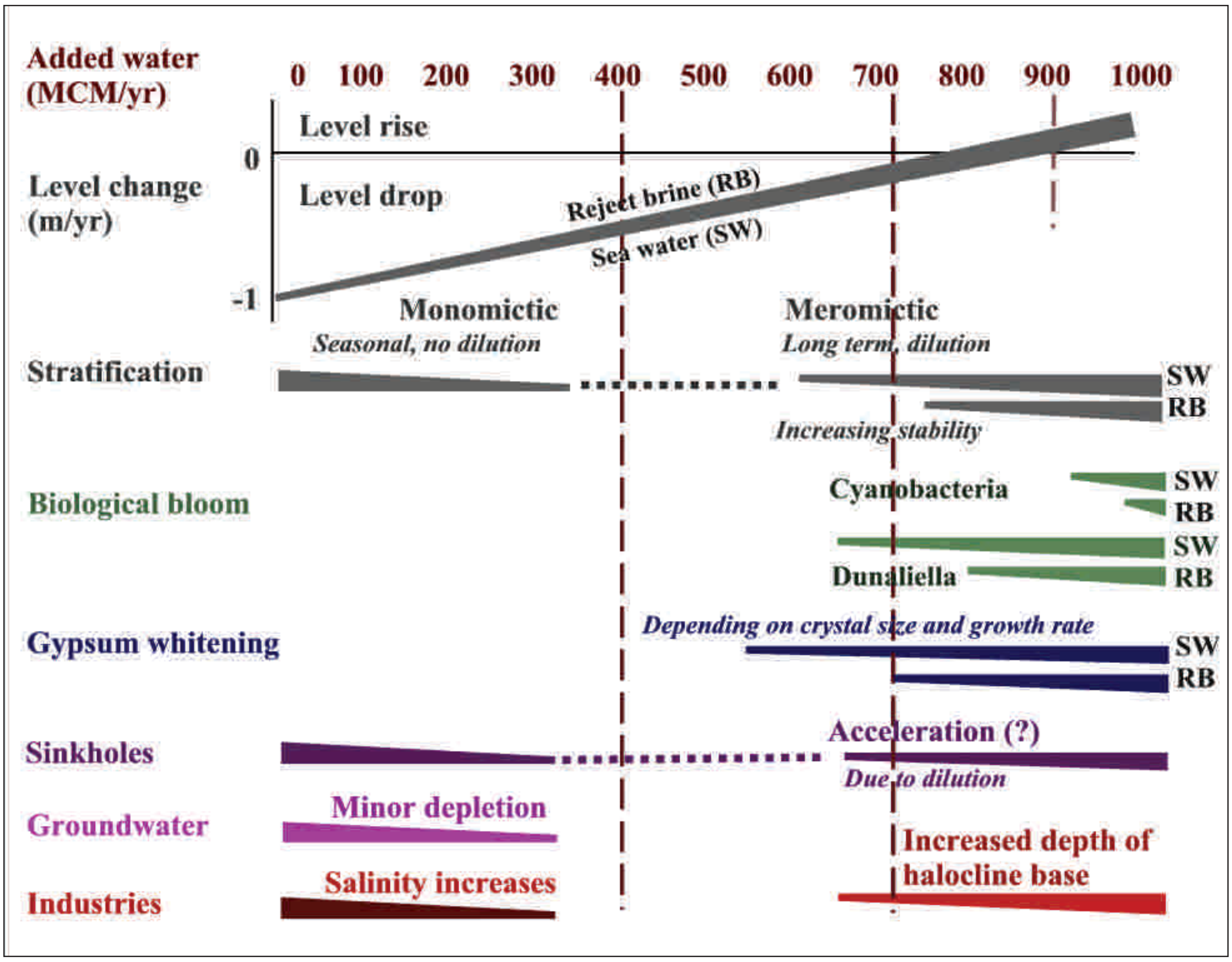


Figure 8: Expected impacts on the Dead Sea

One major problem with the Red-Sea Dead Sea pipeline is the environmental harm that would result simply from building it. Firstly, the intake pipe at the Red Sea could cause damage to the coral reefs. Even the construction at the intake location would cause sediments to cloud up the water, preventing sunlight from reaching the corals. Furthermore, constructing a large pipeline across the Arava Desert could disrupt the delicate desert ecosystem due to habitat fragmentation. Another potentially hazardous aspect of the project is that it would be built along a fault line and will be above a freshwater aquifer which the Arava Valley region depends on for its water supply.

If the conveyance is constructed along the Arava Valley between Israel and Jordan, as the Red Sea Dead Sea project proposes, there is always a risk of earthquakes along the fault line. In the case of an earthquake, there are fears that the pipeline might break, spilling salt water which might infiltrate into the groundwater. It is possible to take actions in order to prevent this, but it cannot be completely guaranteed to be safe (Willner et al., 2013). On the other hand, if the conveyance would cross through Israel, as the Mediterranean Dead Sea project suggests, the earthquake risk would be minimal as it would not cross the fault line.

Lastly, the desalination process uses a considerable amount of energy which will be provided, in a large part, from the consumption of fossil fuels, such as natural gas and coal (Abu-Qdais, 2008). This will be offset by the production of hydroelectric electricity along the conveyance. However, the total energy required for the desalination process and for pumping the fresh water to Amman in Jordan or the Negev region in Israel (at 1,000 and 300–400 meters above sea level, respectively) is greater than the potential energy gain from the a hydroelectric power station (Willner et al., 2014).

Some major questions still remain open: Will the Dead Sea still be a "Dead Sea" if conveyed seawater forms a layer of less saline water on top of the sea? Despite the changing characteristics of the Dead Sea one needs to address another puzzling question: What is the alternative scenario for the drying sea?

5. Salt storms – the case of no-conveyance

In addition to environmental and technical issues related to the Red-Dead or Med-Dead conveyance, salt storms have been studied in the case where no conveyance is built. Studies from various parts of the world have shown implications of possible salt storms in areas of dried salt lakes. If no action is implemented, one of the possible negative impacts of drying lakes is potential salt storms. However, the Dead Sea is not expected to ever dry out completely because the salt molecules hold onto water, and because at this water level the inflow balances the evaporation. The Dead Sea is expected to reach its lowest point in about 200–400 years, at which point it will be about 90–130 meters below the current level (Oren et al., 2010). Until then, one can expect to continue to see massive damage from sinkholes and landslides. Additionally, more surface area of salt and dust will be exposed, which can then cause salt storms. However, this might not be that relevant unless the evaporation ponds are abandoned, exposing the saline soil to dust storms. In any case this is an issue that needs to be further studied.

Possible ways of dealing with the potential of salt storms can be learned from Owens Lake in California. Owens Lake went dry in 1924 when its water was diverted for the Los Angeles aqueduct. In recent years, the dried lake has become the largest source of dust pollution in the United States, and is estimated to be the cause of 6% of the breathable dust in the continental United States (Tyler et al., 1997). To deal with the dust in Owens Lake, there are a couple of options being considered. Currently, groundwater is pumped up every so often in order to keep the ground damp (ibid.). This is a very inefficient use of water, as much of the water evaporates. Groenveld et al. (2007) suggest engineering a layer of salt crust over the surface of Owens Lake. The salt would retain moisture and remain wet and prevent dust storms. One other solution being employed at Owens Lake is to plant salt grass to hold the soil. Vegetation is very important for preventing erosion by absorbing the force of the wind, keeping moisture within the roots and soil and by other means. Salt grass would be used as it is extremely hearty and thrives in saline soils (Kim et al., 2000). It is especially important to keep Dead Sea salts and soils from blowing away because there is heavy metal pollution in the soils from the potash industry (Al-Khashman, 2012).

As the devastating impacts of salts storms and sinkholes have shown, the drying of major water bodies can have significant adverse impacts on the environment, agriculture and may have severe social and economic implications on the communities and industries in the region. Thus, in the case of Dead Sea, any solution is better that no solution.

6. Discussion and conclusions

The declining water level of the Dead Sea and the related sinkhole problem have accelerated since the 1970s. In order to stabilize the water level of the Dead Sea and prevent further decline in quality of the land surrounding the Dead Sea, about one billion cubic meters of water needs to be brought to the Dead Sea annually to balance out evaporation. While it is important to solve the problem quickly, any solution should be thought out and be economically, environmentally, and socially sustainable for the future, keeping in mind the potential for drought and increased population and water demand.

It has been argued that the Dead Sea water level is already on such a critical level where the negative impacts are already so severe that only a dramatic change in diverting water to the sea could change the current situation. The drastic increase in the number of sinkholes – a direct consequence of decreasing water levels – already has negative impact on tourism, industry, agriculture and other infrastructure in the Dead Sea region.

As the water level of the Dead Sea declines, tourist areas will have to move their beaches and recreation areas to stay with the coastline and industries requiring access to Dead Sea water will have to construct additional infrastructure for pumping the water to a higher level. In addition, agriculture may be negatively impacted by salt storms as documented in other dried salt lakes such as the Aral Sea.

The water situation can be improved by increasing the efficiency of water use. Higher utilization of rainwater harvesting and recycled water is a tool to obtain more sustainable solutions for water management, but it will not save the Dead Sea from drying because population growth and economic development will increase water consumption. Appropriate policy changes would be the least costly and most sustainable option for maximizing the efficiency of the existing water supply in the region. In 2008, it was estimated that leaky pipes in Jordan cause a loss of 130 million cubic meters of water each year (Douglas, 2008).

On the other hand it has been argued that Israel should divert more water to the Dead Sea from its freshwater reserve of the Sea of Galilee. This however does not seem a realistic option for increasing water levels. It is true that over the coming years Israel's dependency on the Sea of Galilee will decrease as more coastal desalination plants will become operational. However, this does not necessary mean that Israel should divert the excess water to the Dead Sea. Rather than "wasting" the water of the Sea of Galilee in such way it could sell the excess water to Jordan or the Palestinian Authority by using the existing water infrastructure that conveys over 50 MCM annually to the

Kingdom of Jordan based on the understandings of the Israel–Jordan peace agreement signed in Camp David in 1993.

It seems that the only viable solution to reversing the declining water level is to convey water to the Dead Sea from either the Mediterranean Sea or the Red Sea. A conveyance in the form of a tunnel, pipeline or canal is the only economically feasible option to increase the water level, as it would simultaneously produce hydropower utilizing the 400 meter difference between the seas and providing a means for seawater desalination.

As the current water situation in the region only worsens, bold initiatives are required. The Mediterranean Dead Sea conveyance can be one of these alternatives. As new technologies have made such projects technically feasible, realizing the negative environmental impacts of the deteriorating Dead Sea in addition to recognizing its high economic potential could pave a way for such a venture. Exploring the political feasibility is the next stage.

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