Desalination: The Red Sea-Dead Sea Conveyor Project

Emily M. Thor
University of Edinburgh, Law School
Candidate for Master of Laws in International Law, 2014

Mailing Address:
Brew House Flat 9 Room C
41 Holyrood Road

Email: emilythor@gmail.com

Telephone: +447826669501

INTRODUCTION

Many regions of the world, in particular arid regions, have scarce freshwater resources and are in need of additional water supplies ("Thirsty?" 2014). Only 2.5% of Earth's water is fresh and less than one percent, of this 2.5%, is easily accessible, with most of it being "frozen in polar icecaps." The remaining 97.5% of water is saline ("Health in Water" n.d.). As such, a lot of attention is being given to how the problem of freshwater scarcity can be solved. One such possible solution is desalination, which is the process of turning saline water into fresh water ("Thirsty?" 2014).

Essentially, desalination removes "dissolved salts and other inorganic species" from water. "Desalination occurs naturally in the hydrologic cycle as water evaporates from oceans and lakes to form clouds and precipitation, leaving dissolved solids behind" (NRCNA 2004, 11). The evaporated water then re-condenses when it comes in contact with cooler air and becomes precipitation. "This process can be imitated artificially, and more rapidly than in nature, using alternative sources of heating and cooling ("Thirsty?" 2014). In fact, desalination techniques have been used for centuries to produce drinking water (NRCNA 2004, 11). For example, "[i]n ancient times, many civilizations used this process on their ships to convert sea water into drinking water." Today, desalination plants are used, not only to convert saline water into freshwater, but also to treat water "that is fouled by natural and unnatural contaminants ("Thirsty?" 2014).

This paper will provide an overview of desalination and the various modern desalination technologies. Additionally, this paper will discuss concentrate management, which concerns the disposal of the byproduct created by the desalination process. To conclude, this paper will analyze the Red-Dead Sea Conveyor project. This analysis will show that, while the project will provide some benefits to the region, it would be premature to go forward with the project until certain project alternatives are fully analyzed.

AN OVERVIEW OF DESALINATION

As mentioned above, desalination is the process of turning saline water, into fresh water. Saline water is water which "contains significant amounts (referred to as 'concentrations') of dissolved salts." The concentration of salts in water is measured in parts per million or ppm. For instance, "[i]f water has a concentration of 10,000 ppm of dissolved salts, then one percent (10,000 divided by 1,000,000) of the weight of the water comes from dissolved salts." Freshwater contains less than 1,000 ppm, whereas highly saline water contains between 10,000 ppm to 35,000 ppm, the latter being about the salt concentration of the ocean ("Thirsty?" 2014).

Over the past fifty years, desalination technology has substantially evolved. The desalination process, of either brackish water or seawater, consists of five key elements. The first element is intakes. Intakes are "structures used to extract source water and convey it to the process system" (CDTNRC 2008, 59). The source water supply needs to be reliable and the quantity and quality of source water, as well as the environmental impacts, will vary depending on the intake sight (60). As such, the site should be chosen carefully. The second element is pretreatment. This stage of the process removes suspended solids and prepares "the source water for further processing" (59). "Pretreatment is generally required for all desalination processes" and helps to ensure the desalination plants' performance (65, 66). The extent of the pretreatment will, in part, be determined by the quality of the source water. It will also depend upon the intake and desalination methods being used (66).

The third element is the actual desalination, or the removal of the dissolved solids, of the water. This element will be discussed in more detail in the next section. The fourth element in desalination is post-treatment (ibid., 59). This is when chemicals are added to the water in order "to prevent corrosion of downstream infrastructure piping" caused by the water's low alkalinity and hardness (59, 97). This is of concern because the corrosion could not only reduce the life of the desalination infrastructure, but also introduce metals into the desalinated water (97). Meaning, that the water that has just been desalinated would be contaminated and possibly be unsafe to drink. The final element, which will also be discussed in more detail below, is concentrate management. Concentrate management concerns the handling and disposal of the byproducts created by desalination. "Depending on the source water and the desalination technology used, specific elements may vary in their importance in the overall system" (59).

While desalination can help with freshwater scarcity it is not without its drawbacks. There are four general categories of environmental issues that go hand in hand with desalination. The first concerns the "impacts from the acquisition of source water." There are different environmental considerations depending on the type of source water (ibid., 108). For instance, "[f]or inland aquifer systems, the renewability of the resource and land subsidence over time are significant issues" (109). The second environmental issue is the impact from concentrate management (108). Desalination creates waste products such as "salt concentrates, cleaning and conditioning regents, and particulate matter" and these byproducts have to either be reused or disposed of(119). The implications of this will be more fully discussed below. The third category of environmental issues concerns the water produced by desalination (108). "[A]lthough desalination technologies remove various constituents to a large extent, not all constituents are fully removed and some species are removed to a lesser extent than others" (138). The fourth, concerns greenhouse gas emissions created by the desalination processes, which is a very energy-intensive process (108, 141).

In addition to environmental considerations, there are also economic considerations that have to be taken into account. Although the costs of desalination have decreased, they remain high (ibid., 147). While desalination may provide some relief for freshwater scarcity, it is not a cure all and its costs as well as its benefits have to be carefully examined on a case by case basis.

DESALINATION TECHNOLOGY

There are multiple technologies used to desalinate water. The main technologies can be grouped into two categories, membrane desalination and thermal evaporation.

Membrane Desalination

Membrane desalination technologies use semi-permeable membranes "to selectively allow or prohibit the passage of ions, enabling the desalination of water." These technologies can be used for seawater or brackish water desalination, but because "energy consumption is proportional to the salt content in the source water," these technologies are "more commonly used to desalinate brackish water." They also "have the potential to contribute to water supplies through their use in treating degraded waters in reuse or recycling applications since membrane technology can remove microorganisms and many organic contaminants from" source water (NRCNA 2004, 25). About 35% to 60% of seawater, which goes through membrane desalination, is recovered as freshwater and 50% to 90% of brackish water is recovered (CDTNRC 2008, 73).

Membrane technologies fall into two categories, those that operate via pressure and those that operate via electrical potential (NRCNA 2004, 25). Pressure-driven membrane technologies include reverse osmosis, nanofiltration, ultrafiltration, and microfiltration (25-26). Reverse osmosis “represents the fastest growing segment of the desalination market.” Reverse osmosis membranes are used to remove salt in brackish water and seawater. These membranes “have also been shown to remove substantial quantities of some molecular organic contaminants from water.” Nanofiltration membranes remove organics, sulfates, and some viruses. They are also “used for water softening.” Ultrafiltration membranes remove color, bacteria, some viruses, and “higher weight dissolved organic compounds” (25). Microfiltration membranes reduce turbidity, remove suspended solids, and remove bacteria. In contrast, electrodialysis uses electric potential to separate “the ionic constituents in water.” Electrodialysis reversal works the same way; however, it “periodically reverses the polarity of the system to reduce scaling and membrane clogging” (26).

Thermal Evaporation

Compared to membrane technologies, thermal distillation processes generally have higher capital costs and require more energy, and therefore have higher operating costs. However, thermal technologies tend to produce lower salinity product water than membrane technologies produce (ibid., 25). These technologies are primarily used in the Middle East because they “can produce high purity . . . water from seawater and because of the lower fuel costs of the region” (32). Thermal technologies in use today include multi-stage flash distillation, multi-effect distillation, and vapor compression (33).

Multi-stage flash distillation “uses a series of chambers, each with successively lower temperature and pressure, to rapidly vaporize (or ‘flash’) water from bulk liquid brine.” The vapor is then condensed into liquid form. This technology uses large amounts of energy, but is reliable and “capable of very large production capacities per unit.” Multi-effect distilliation “is a thin-film evaporation approach, where the vapor produced by one chamber (or ‘effect’) subsequently condenses in the next chamber, which exists at a lower temperature and pressure, providing additional heat for vaporization.” Similarly, vapor compression technology mechanically compresses vapor from an evaporator into liquid form and its heat is “used for subsequent evaporation of” source water (ibid.).

Other Technologies

There are other technologies which can be used to desalinate water; however, none have achieved as much success as the technologies discussed above. These other technologies include ion-exchange methods, “freezing, and membrane distillation.” Ion-exchange methods remove undesirable ions from water using resins. “The greater the concentration of dissolved solids, the more often the expensive resins have to be replaced, making the entire process economically unattractive” (Cooley et al. 2006, 17). Freezing technology produces desalinated water by separating pure ice crystals from saline water. This is possible because “[w]hen ice crystals form, dissolved salts are naturally excluded.” This technology has some advantages over distillation, such as requiring less energy, however, it is difficult to handle and process “the ice and water mixtures.” Membrane distillation is a hybrid of thermal evaporation and membrane desalination. “The process relies primarily upon thermal evaporation and the use of membranes to pass vapor, which is then condensed to produce fresh water.” Membrane distillation is simple and only needs small temperature differentials in order to operate, however is also requires more space, energy, and money than other desalination technologies (18). Another desalination technique is solar distillation, which uses solar radiation to generate distilled water (Dev and Nath Tiwari 2011, 161).

CONCENTRATE MANAGEMENT

Desalination processes produce freshwater, but they also produce a byproduct known as concentrate or brine. Brine is typically used to refer to the concentrate produced from seawater desalination because of its higher salinity content, "whereas the more general term 'concentrate' can be used for any concentrated stream generated from either brackish or seawater" (Fitchner 2011, 3-5). This concentrate contains the dissolved salts and other constituents removed during desalination to produce the freshwater (ibid.; NRCNA 2004, 45). The desalination technology used and the salinity level of the source water will affect how much of the source water is discharged as concentrate (Fitchner 2011, 3-5), which, in turn, "typically constitutes 90% to 95% of the total desalination plant discharge volume" (WRA 2011, 1).

Concentrate Disposal

As already mentioned above, the concentrate produced during desalination has to either be reused or disposed of (CDTNRC 2008, 119). It "must be handled in a manner that minimizes environmental impacts" (NRCNA 2004, 45). There are various methods for concentrate disposal, including: surface water discharge, sewer discharge, deep well injection, evaporation ponds, and zero liquid discharge (Firtchner 2011, 4-20 to 4-26).

The most common disposal method, when there is access to a body of water to receive the concentrate, is surface water discharge. The two methods for surface water discharge disposal are direct discharge at a coastline and discharge through an outfall pipe. Direct discharge at a coastline releases the concentrate in shallow waters near shore. As a result, "the mixing and dilution of the concentrate may take" time (ibid., 4-20). Furthermore, this method "can have significant impacts on the marine environment" (Cooley et al. 2006, 62). Discharge through an outfall pipe can "enhance the mixing and dispersion of the concentrate plume from desalination plants." Additionally, many outfall pipes have "multiport diffusers to dilute the seawater concentrate rapidly to avoid and reduce the sinking tendency of the concentrate" (Fitchner 2011, 4-21). The environmental impacts of surface water discharge depends upon the characteristics of the body of water the concentrate is discharged into and the composition of the concentrate (4-20).

Sewer disposal is what it sounds like. An existing sewer system is used to dispose of the concentrate (ibid., 4-22). This method allows the concentrate to mix with "other low-salinity waste waters" before being discharged and thereby dilutes the concentrate (4-22 to 4-23). In contrast, deep well injection "involves the disposal of concentrate into unusable groundwater aquifers" (4-23). This method is not without its downfalls either. One of the downsides being a thorough geological investigation has to be done of a potential injection site, which is expensive (4-24).

The evaporation pond method takes a different approach than the methods above. It reduces the volume of the concentrate through evaporation. In dry climates, this method "can offer a viable solution for concentrate disposal." The costs of evaporation ponds depend, among other things, upon the cost of land, piping and pumping costs, and the cost of monitoring of the ponds. Additionally, there is a risk of groundwater contamination due to seepage from the ponds (ibid., 4-25).

Similar to evaporation ponds, the Zero Liquid Discharge disposal and Near-Zero Liquid Discharge disposal approaches reduce the concentrate to a slurry or solid for landfill disposal. This reduction is done by thermal methods, such as thermal evaporators, crystallizers, and spray dryers. "These methods are well-established and developed, however, their capital and operating costs are characterized with relatively high to very high costs," possibly even exceeding the cost of the desalination plant. As such, these methods are not used very often (ibid.).

Environmental Impacts of Concentrate

As already touched on above, the disposal of concentrate poses "a significant environmental challenge." The composition of the concentrate will depend upon the source water. For instance, in addition to a high salt content, concentrate from seawater may also contain constituents - such as lead, manganese, iodine, and other chemicals - which are commonly found in seawater (Coolet et al. 2006, 60). The concentrate may also contain chemicals used during the desalination process (61). It is also important to note that concentrate "behavior varies according to local conditions . . . and discharge characteristics," such as bottom topography, wave action, and quantity and temperature of the concentrate (63). All of these things will affect the ecosystem. Concentrate, for one, can raise the salinity level of the water at the discharge site (AWWA 2011, 58). Aside from raising the salinity level, concentrate discharge may also "lead to increased stratification reducing vertical mixing," and thereby reduce the oxygen level in the water (59). This would mean that organisms in the water would have less oxygen.

As such, it is crucial to use an appropriate concentrate disposal method and to minimize the environmental impacts of the concentrate. Each of the discussed disposal methods have their own particular advantages and disadvantages, which will have different implications for every desalination project. The best concentrate disposal method should be selected "on a site-specific basis based on economic and environmental considerations" (NRCNA 2004, 45).

CASE STUDY: THE RED SEA-DEAD SEA CONVEYOR PROJECT[1]

In the Middle East, desalination is extremely important for water supply. Water demand for the region will create a need for more seawater desalination plants in the area, which begs the question of how much environmental impact the current desalination plants are having in the area and if limitations should be placed on future plants (Fitchner 2011, 3-12).

For the last several years, the World Bank has been investigating a proposed Red Sea-Dead Sea Conveyor Project for the benefit of Jordan, Israel, and the Palestinian Authority. The three goals of the conveyor project are: "to provide a critical potable water resource for the region; to save the Dead Sea from environmental degradation; and to provide a symbol of peace and cooperation in the Middle East" (Allan et al. 2012, x). In pursuance of these goals, the project would convey around 2 billion cubic meters of water, annually, from the Gulf of Aqaba on the Red Sea, to the Dead Sea through a 180 kilometer pipeline (Glausiusz 2013). Some of this water would be desalinated, and some, at least initially, would flow into the Dead Sea, along with the concentrate created during desalination (ERM 2012, 6-7).

[1] See Appendix 1 for the recommended conveyor schematic.

The Red Sea

The proposed conveyor project could have significant impacts on the two seas (Fitchner 2011, 3-13; TAHAL Group 2011). The Red Sea, called Bahr al-Ahmar in Arabic, is surrounded by nine countries ("Red Sea Facts" n.d.). It is one of the most saline bodies of water in the world and is environmentally fragile (Fitchner 2011, 3-13). "The Red Sea is connected to the Indian Ocean in the south through the narrow strait of Bab al Mandab and the Gulf of Aden." In the north, the Red Sea is connected to the Mediterranean Sea by the Suez Canal ("Red Sea Facts" n.d.). Further extraction of seawater from the Red Sea could make the discharge site hypersaline. This is of special concern because the Red Sea is semi-enclosed and is therefore "more susceptible to significant increases in salinity" as it experiences limited flushing. In turn, an increase in salinity could significantly affect organisms in the Red Sea, despite their tolerance to the already relatively saline environment (Fitchner 2011, 3-13).

The Dead Sea

The Dead Sea "is the world's lowest inland area" (Glausiusz 2013) and, like the Red Sea, has a high salinity content. It "is a hypersaline terminal desert lake located in the Dead Sea rift valley" (TAHAL Group 2011, 27). As a result of its salinity, only one kind of algae and several kinds of bacteria can survive in the lake ("Lowest Elevation" n.d.). The water level of the lake decreases about a meter a year, leading to sinkholes, mudflat exposure, and sediment shrinkage (TAHAL Group 2011, 28-29). Part of this decrease is due to the fact that evaporation exceeds inflows to the lake because of domestic and agricultural water diversions affecting the Jordan River, which is an important water source for the Dead Sea (30). Evaporation has also increased because of the chemical industries of Israel and Jordan. There has been some increased inflow from groundwater discharge, however it is minimal and at most only partially offsets the increase in evaporation (31).

The Red Sea –Dead Sea Conveyor Project

As mentioned above, "[t]he Dead Sea is the world's lowest inland area." The proposed pipeline would be built to take advantage of the low elevation "so that the downward flow of the water goes through a hydroelectric plant that would in turn power a desalination plant" (Glausiusz 2013). This desalination plant will provide, via reverse osmosis (ERM 2012, 7), up to 850 million cubic meters of the potable water to be shared between the three project beneficiaries – Jordan, Israel, and the Palestinian Authority (Allan et al. 2012, x). The concentrate produced through desalination will be discharged into the Dead Sea (Rolef 2013). Then, the desalinated water will be pumped (200 meters) uphill towards Amman, Jordan. The altitude difference between the Dead Sea and Amman is 1,000 meters (Glausiusz 2013).

In order to fully understand the various impacts this project would have it is important to know about the economic, social, and environmental implications of the project. The area around the project is mostly semi-arid and sparsely populated. However, "[t]he region has historically been of strategic economic importance, providing land trade routes." The Dead Sea contributes to the economic importance of the region through tourism and mineral extraction (ERM 2012, 10) and the Red Sea supports "a vital fishing industry" ("Red Sea Facts" n.d.).

As already mentioned, the project would be for the benefit of Jordan, Israel, and the Palestinian Authority (ERM 2012, 6). While there are claims that the three governments have thus far been working well together on this project, this does not mean that political considerations won't affect the future of the project. "The governance structure laid out by the

World Bank requires recognition of all parties' riparian rights to the Dead Sea, but the West Bank that borders the Dead Sea is still under Israel's control." Meaning, that Israel would have to recognize "Palestinian sovereignty of the Dead Sea in the West Bank," which is unlikely (O'Brien 2013).

Additionally, the preferred schematic for the pipeline would place it solely in Jordanian territory. As such, "Israel investment could be a hard sell if the conduit is vulnerable to the tap being turned off in the event of war." This concern could pose a significant challenge to the project because, despite being at peace with Israel, it is what led Jordan to reject a previous conduit proposal (ibid.).

Furthermore, financing the project poses some challenges. The cost of the project is estimated to be around $10 billion (Glaysiusz 2013). About $3 billion would come from Israel, and another $2.5 billion from Jordan. In addition to these funds, "[c]ritics say the project would require international donations totaling $4.5 billion, while the world still grapples with the aftermath of a global economic crisis" (O'Brien 2013). Even so, the international community is not going to just throw money at the project without a treaty in place, which comes back to the issue of Israel recognizing Palestinian sovereignty (Glausiusz 2013).

In relation to the cost of the project, is the cost of the water that will be produced by the project. There is some speculation as to whether the project would be as beneficial as the World Banks claim it will be. The World Bank feasibility study estimated "a potential benefit of $10 billion over 50 years, based on the increased availability of water as a result of the project, but it calculated that number on the cost of tankered water," which is "the most expensive option to obtain water in Jordan." In fact, the cost of water from the project would be up to $2.70 per cubic meter for Amman residents. For Israel and the Palestinian Authority, the cost of the water "would be up to $1.85 per cubic meter." In comparison, in 2013, Israel's desalination plants along the Mediterranean were producing drinking water at around a cost of $0.61 per cubic meter (O'Brien 2013).

Additionally, the World Bank feasibility study estimates a $1.4 billion benefit, over 50 years, from the project's hydropower production. However, the project's two power stations would not produce enough power to pump the desalinated water to Amman, meaning that more power stations would need to be built and the project's carbon footprint would therefore be increased (ibid.).

As it is, the project's environmental impacts on the Dead Sea have already sparked opposition in Israel, who fears the project "will cause irreversible environmental damage, and inter alia turn the Dead Sea White, as a result of the creation of large quantities of gypsum in the Sea, or red, as a result of the development of algae." It is argued that instead of conveying water between the two seas, the diversions from the Jordan River should be reduced in order to stop the deterioration of the Dead Sea (Rolef 2013).

In order to investigate the "physical, chemical and biological aspects of the effects of mixing Red Sea and Dead Sea waters in the Dead Sea" the World Bank set up a Red Sea-Dead Sea Water Conveyance Study Program (TAHAL Group 2011, 1, 9). The team leader for this program, Alex McPhail, recently declared "that the environmental and social assessment, led by Environmental Resources Management, an international consultancy, indicates that 'all potential environmental and social impacts can be mitigated to acceptable levels," save one. That being the impact from the inflows of Red Sea water into the Dead Sea (Glausiusz 2013).

The Dead Sea Study team examined this inflow issue in detail. The study team analyzed both what would happen if no action was taken and what would happen if water from the Red

Sea, along with concentrate discharge, was added to the Dead Sea (TAHAL Group 2011). The no action scenario assumes that there will be "no changes in inflows, climate and activity of the chemical industries." If no changes are made, the Dead Sea level will continue to decline, although the rate at which it does will decline over time because of surface area and evaporation rate decreases (317). As this happens, "the salinity, density and temperature of the Dead Sea will continue to rise" and the sea's condition "will become increasingly difficult." The Dead Sea will become "ever more hostile to life, even to the extent that the brines eventually will become sterile" (318). In contrast, adding seawater and concentrate to the Dead Sea could potentially raise the water level, depending on the volume of water added (320-23). A rise in water level would result in the stratification of the water column, thereby increasing the evaporation rate and water activity (320).

First, the study team looked at what would happen if 400 million cubic meters of Red Sea water is added, annually, to the Dead Sea. This is not enough to raise or stabilize the Dead Sea's water level; however, it may still impact the sea. The sea's response to the introduction of 400 million cubic meters of Red Sea water depends upon how the concentrate (in a volume of 270 million cubic meters) mixes in the water column. For example, if the concentrate mixes evenly, the introduction of the concentrate "is not enough to counter the effect of the dilution due to the introduction of" the seawater. This would lead to long term stratification. If the brine mixes entirely in the water column, however, the added concentrate will buffer the added Red Sea water and the salinity level of the entire Dead Sea water column will rise. Either way, though, an introduction of 400 million cubic meters of seawater and 270 million cubic meters of concentrate will not allow for biological blooming (ibid., 322).

A second scenario the study team looked at was what adding 1000 to 1500 million cubic meters of Red Sea water would do to the Red Sea. If the inflows from the Red Sea are between 1000 to 1500 million cubic meters, the water level of the Dead Sea would rise, eventually to the target water level. This water level rise would turn the Dead Sea from monomictic to meromictic (ibid.), meaning that the sea would be "chemically stratified with an incomplete circulation" (Hakala 2004, 37). The inflows would also mean that biological blooming could occur in the surface water because the salinity level of the water would be reduced (TAHAL Group 2011, 322-23).

All of this means that smaller inflows will have less effect on the chemical composition of the Dead Sea, but would not stabilize the water level (ibid., 325). This also means that the study team does not actually know the effect of adding Red Sea water to the Dead Sea. In order to actually determine this, a pilot study or 3D modeling is necessary. It has been estimated that in order for a pilot stage to make economic sense 75% of the full scale project would need to be constructed (O'Brien 2013).

In December 2013, the three project beneficiaries signed a Memorandum of Understanding providing for a water sharing agreement to help alleviate some of the water shortage issues in the region (World Bank 2013b; Ackerman 2013). It is important to note that this agreement 'is "a new initiative arising from the Study program . . . .However, it is not the same as the proposed Red Sea-Dead Sea Water Conveyance.'" (Ackerman 2013). Under this agreement, a desalination plant will be built in Aqaba to produce water, there will be "increased releases of water by Israel from Lake Tiberius for use in Jordan, and 20 to 30 million cubic meters of water will be sold by Israel to the Palestinian Authority. "In addition, a pipeline from the desalination plant at Aqaba would convey brine to the Dead Sea to study effects of mixing the brine with Dead Sea water. However, "[t]his phase is limited in scale" (World Bank 2013b).

For instance, only “100 million cubic meters of water a year” would be conveyed through this pipeline, which is half the amount of the Red Sea –Dead Sea Conveyor Project. (Ackerman 2013; Glausiusz 2013). Even so, the World Bank is treating this agreement “as a pilot test for the conduit plan” (Ackerman 2013). However, as brine will be added to the Dead Sea, this ‘pilot test’ may pose the same risks that the full scale conveyor project does (Kiliç 2013; TAHAL Group 317, 318, 320-23). Also, some of the other challenges of the conveyor project would still be an issue, such as the danger of the pipeline breaking (*Red Sea-Dead Sea Water Conveyor Project* 2014; Kiliç 2013). This is of concern because the area has “frequent earthquake activity” and damage to the pipeline could result in groundwater contamination, thus creating even more challenges for this water scarce region (*Red Sea-Dead Sea Water Conveyor Project* 2014). As such, neither plan may be the best option.

As already mentioned, there has been some support for pursuing alternatives to the conveyor project (Rolef 2013). One of the alternatives is to take no action, in which case, the Dead Sea will continue to decline and there will still be a shortage of potable water which will need to be addressed. Another is to restore the Lower Jordan River. Although, according to a draft report on the Study of Alternatives done by the Red Sea-Dead Sea Water Conveyance Study Program, this is not really an option because, while desirable, the amount of water needed to restore the Lower Jordan River is “beyond the ability of the region” (Allan et al. 2012, 106). Another alternative that has been considered is water transfers. This alternative, however, brings with it concerns on reliability, cost, and quantity (107-109).

Aside from the above alternatives, other desalination options have been looked into. One of these would be to expand the desalination facilities and “desalination capacity on the Mediterranean cost in northern Israel.” The concentrate produced would be discharged into the Mediterranean Sea and “desalinated water would be distributed to the Beneficiary Parties and the Jordan River.” According to the study, this alternative would provide potable water for the region and combat the degradation of the Dead Sea. Additionally, aside from the impacts from expanding the desalination facilities there would be low “environmental impacts from the water conveyance.” However, the Study of Alternatives estimates that the annual operating cost would be significantly higher than that of the proposed Red Sea-Dead Sea conveyor project ($1,210 million compared with between $58 million and $344 million annually) and would require around $7 billion in investments (ibid., 109). Also, that fact that the desalination plants would be in Israel would pose a problem, as Jordan has previously turned down a conduit project from the Mediterranean Sea for fear that Israel would turn off the tap (O’Brien 2013). It should be noted, however, that the Study of Alternatives does not make it clear whether the estimated operating cost of $1,210 million would be in addition to the operating costs of the current desalination facilities of the Mediterranean coast, or whether it includes what is already being spent. (Allan et al. 2012, 109).

Using a combination of alternatives has also been considered (ibid., 112-14). The Study of Alternatives determined that most of the alternative combinations were only short-term solutions (113-14). The one combination that would be more long term and “could potentially have a strategic impact on the Lower Jordan River and a positive incremental impact on the Dead Sea” is: desalination at the Gulf of Aqaba and the Mediterranean Sea; water transfers from Turkey; and water conservation and recycling (112-14). This combination would address the degradation of the Dead Sea, provide potable water, and would promote cooperation (112), the three goals of the Red Sea-Dead Sea Conveyor Project (ERM 2012, 4). Additionally, “[i]t would avoid the risks of mixing Red Sea or Mediterranean Sea water with Dead Sea water” (Allan et al.

2012, 112). The Study of Alternatives basically dismisses this combination because it "would require unprecedented cooperative planning and sustained engagement at the operational level among the Beneficiary Parties." Furthermore, to determine the viability of this alternative combination, more investigation would need to be done "of the potential technical, economic, environmental and social aspects of this proposition" (113).

CONCLUSION

As demonstrated above, there are many advantages and disadvantages of the Red Sea-Dead Sea conveyor project. The advantages include the production of potable water for the project beneficiaries, the stabilization of the Dead Sea (which in turn could help keep the tourist industry of the region alive and well) (ERM 2012, 15), and the promotion of cooperation in the Middle East (O'Brien 2013; World Bank 2013a). The disadvantages include the cost of the project water (O'Brien 2013), the possible impacts to the fish industry in the Red Sea ("Red Sea Facts" n.d.; Fitchner 2011, 3-13), and the ecological impacts on the Dead Sea from the inflow of Red Sea water (TAHAL Group 2011, 322-23).

The head of the Red Sea-Dead Sea Water Conveyance Study Program has stated that the environmental and social impacts of the proposed conveyor project can all be mitigated to an acceptable level. That is, except for the impacts from the inflow of Red Sea water into the Dead Sea. More than 400 million cubic meters of water will lead to biological growth, but more than that is needed to stabilize the Dead Sea (Glausiusz 2013). Even though 400 million cubic meters of Red Sea water would not lead to biological growth, the addition of the concentrate to the Dead Sea would still have unknown effects to the Dead Sea (TAHAL Group 2011, 322). It should also be noted that the Dead Sea is not the only one at risk, as the composition of the Red Sea could also be significantly affected. Large extractions of water from the Red Sea would cause a rise in the sea's salinity levels. (Fitchner 2011, 3-13).

On the other hand, the Dead Sea supports a tourist industry that is of importance to the regions' economy, but if nothing is done to stabilize the Dead Sea the tourist industry will continue to be impacted due to the sinkholes and other damage caused by the Dead Sea's decreasing water levels (ERM 2012, 10). Also, even though Israel is concerned with the biological growth caused by the inflows of Red Sea water into the Dead Sea (Rolef 2013), there is nothing to indicate that their suggestion of decreasing diversions from the Jordan River, thereby increasing inflows into the Dead Sea, will not have similar effects as inflows from the Red Sea. It is possible that it could have the same effect because the inflows from the Jordan River would also dilute the Dead Sea. This brings everything back to the fact that no one actually knows what impact the conveyor project would have on the Dead Sea (TAHAL Group 2011, 322). The fact that the possible damage to the Dead Sea is so unknown is a strong indication that the proposed conveyor project should not go forward. This is especially true since the benefits of the project may not actually be as beneficial as they appear to be on the surface. An example of this is that the project would produce potable water for the region, but the cost of the project water could prove to be prohibitively expensive (O'Brien 2013).

As for the alternatives that have been examined, one stands out as being able to meet all three goals of the proposed conveyor project. That being the combined alternative of desalination at the Red Sea and the Mediterranean Sea, water conservation and recycling, and water transfers from Turkey. This alternative, however, has not been pursued because it would require 'unprecedented' cooperation between Jordan, Israel, and the Palestinian Authority (Allan et al. 2012, 112-14). This argument is weak, however, given that the proposed Red Sea-Dead

Sea Conveyor Project would also require unprecedented cooperation because it would require the beneficiaries to enter into some kind of agreement or treaty (Glausiusz 2013), which is also going to be difficult. At the same time, the water sharing agreement that was entered into in December 2013, shows that such an agreement between the three beneficiary parties is achievable (World Bank 2013b).

As for the environmental impacts, the alternative combination would avoid the one environmental impact that is unknown and cannot be mitigated to an acceptable level – that being the impacts of mixing Red Sea water with the Dead Sea (Allan et al. 2012, 112; O'Brien 2013). Unfortunately, as of now, there has not been enough investigation into this alternative to fully compare it economically and environmentally with the proposed conveyor project (Allan et al. 2012, 113). It is possible that this alternative combination would have different environmental impacts, which could cause greater harm than mixing Red Sea water with Dead Sea water. On the other hand, the environmental impacts from this combination might all be able to be mitigated to acceptable levels, unlike those of the Red Sea-Dead Sea Conveyor Project. Therefore, the alternative combination should be investigated further so that a sufficient comparison can be made between it and the proposed conveyor project. Without a full investigation of the alternatives, it makes it nearly impossible to determine if the Red Sea – Dead Sea Conveyor project is a good idea.

This does not mean that Red Sea-Dead Sea Conveyor Project is a bad idea. It would provide much needed water to the Beneficiary Parties, promote cooperation in the Middle East, and combat the current degradation of the Dead Sea (O'Brien 2013; World Bank 2013). On the other hand, it could have significant impacts on the ecology of the Red Sea, from water extraction (Fitchner 2011, 3-13), and the Dead Sea, from mixing its water with concentrate and Red Sea water (TAHAL Group 322-33). Whether or not it is the best long term-solution, however, requires more investigation into the alternative combination discussed above. Until then, it is premature to conclude that the Red-Sea Dead Sea Conveyor project should go forward because the alternative option may prove to be the better project. This is especially true since the benefits of the Red Sea-Dead Sea Conveyor Project don't clearly outweigh the disadvantages. In the end, no matter which proves to be the better option, it is clear that something needs to be done to address the regions' water needs (*Red Sea-Dead Sea Water Conveyor Project* 2014).

References

Ackerman, Gwen. 2013. "Israel, Palestinians in Water-Sharing Pilot Plan." *Bloomberg*, December 9. http://www.bloomberg.com/news/2013-12-09/israel-jordan-palestinians-in-water-sharing-pilot-plan.html.

Allan, John Anthony, Abdallah I. Husein Malkawi, and Yacov Tsur, 2012, *Red Sea-Dead Sea Water Conveyance Study Program Study of Alternatives: Preliminary Draft Report*, accessed May 3, 2014, http://siteresources.worldbank.org/INTREDSEADEADSEA/Resources/Study_of_Alternatives_Report_EN.pdf.

AWWA (American Water Works Association), 2011, *Desalination of Seawater*, American Water Works Association, United States of America.

CDTNRC (Committee on Advancing Desalination Technology National Research Council), 2008, *Desalination: A National Perspective*, The National Academies Press, Washington, D.C.

Cooley, Heather, Peter H. Gleick, and Gary Wolff, 2006, *Desalination, with a Grain of Salt: A California Perspective*, accessed May 3, 2014, http://www.pacinst.org/wp-content/uploads/sites/21/2013/02/desalination_report3.pdf.

ERM (Environmental Resources Management), 2012, *Red Sea-Dead Sea Water Conveyance Study Environmental and Social Assessment: Preliminary Draft Environmental and Social Assessment (ESA) – Executive Summary*, accessed May 3, 2014, http://siteresources.worldbank.org/INTREDSEADEADSEA/Resources/Environmental_and_Social_Assessment_Summary_EN.pdf.

Fitchner, 2011, *MENA Regional water Outlook: Part II Desalination Using Renewable Energy Task 3- concentrate Management*, accessed May 3, 2014, http://wrri.nmsu.edu/conf/conf11/debele-concentrate_management_final.pdf.

Glausiusz, Josie. 2013. "Environmental Concerns Reach Fever Pitch Over Plan to Link Red Sea to Dead Sea." *Nature*, February 27. http://www.nature.com/news/environmental-concerns-reach-fever-pitch-over-plan-to-link-red-sea-to-dead-sea-1.12515.

Hakala, Anu, 2004. Meromixis as part of lake evolution – Observations and a Revised Classification of True Meromictic Lakes in Finland. *Boreal Environment Research*, 9:37.

"Health in Water Resources Development," WHO, accessed May 3, 2014, http://www.who.int/docstore/water_sanitation_health/vector/water_resources.htm

Kiliç, Seyfi. 2013. "An Assessment of Water Cooperation Between Israel-Jordan-Palestine." *Todays Zaman*, December 15. http://www.todayszaman.com/news-333891-an-assessment-of-water-cooperation-between-israel-jordan-palestine.html.

"Lowest Elevation: Dead Sea," Extreme Science, accessed March 24, 2013, http://www.extremescience.com/dead-sea.htm.

NRCNA (National Research Council of the National Academies), 2004, *Review of the Desalination and Water Purification Technology Roadmap*, The National Academies Press, Washington, D.C..

O'Brien, Vanessa. 2013. "$10 Billion Red Sea-Dead Sea Middle East Water Project Roiling, Again, Israel, Palestinians, and Jordan." *International Business Times*, March 8. http://www.ibtimes.com/10-billion-red-sea-dead-sea-middle-east-water-project-roiling-again-israel-palestinians-jordan.

Rahul Dev and Gopal Nath Tiwari, "Solar Distillation," in *Drinking Water Treatment: focusing on Appropriate Technology and Sustainability*, ed. Ravi Jain and Chittaranjan Ray, 159-210. Springer Dordrecht Heidelberg, 2011.

_____. 2013 "Red Sea-Dead Sea Water Conveyor Project." *Middle East Business Magazine and News*, March 5. http://middleeast-business.com/red-sea-dead-sea-water-conveyor-project-project-outline-assessments-and-potential-benefits-to-the-palestinian-territory-by-palestine-economic-policy-research-institute-mas/.

"Red Sea Facts," Aziab, accessed April 24, 2013, http://www.aziab.com/red%20sea%20facts.htm.

Rolef, Susan. 2013. "The Red-Dead Canal, or Back to Nature?." *The Jerusalem Post,* March 3. http://www.jpost.com/Opinion/Columnists/The-Red-Dead-canal-or-back-to-nature.

TAHAL Group, 2011, *Red Sea-Dead Sea Conveyance Study Program: Dead Sea Study*, accessed May 3, 2014, http://siteresources.worldbank.org/INTREDSEADEADSEA/Resources/Tahal_Initial_Final_Report_August_2011.pdf.

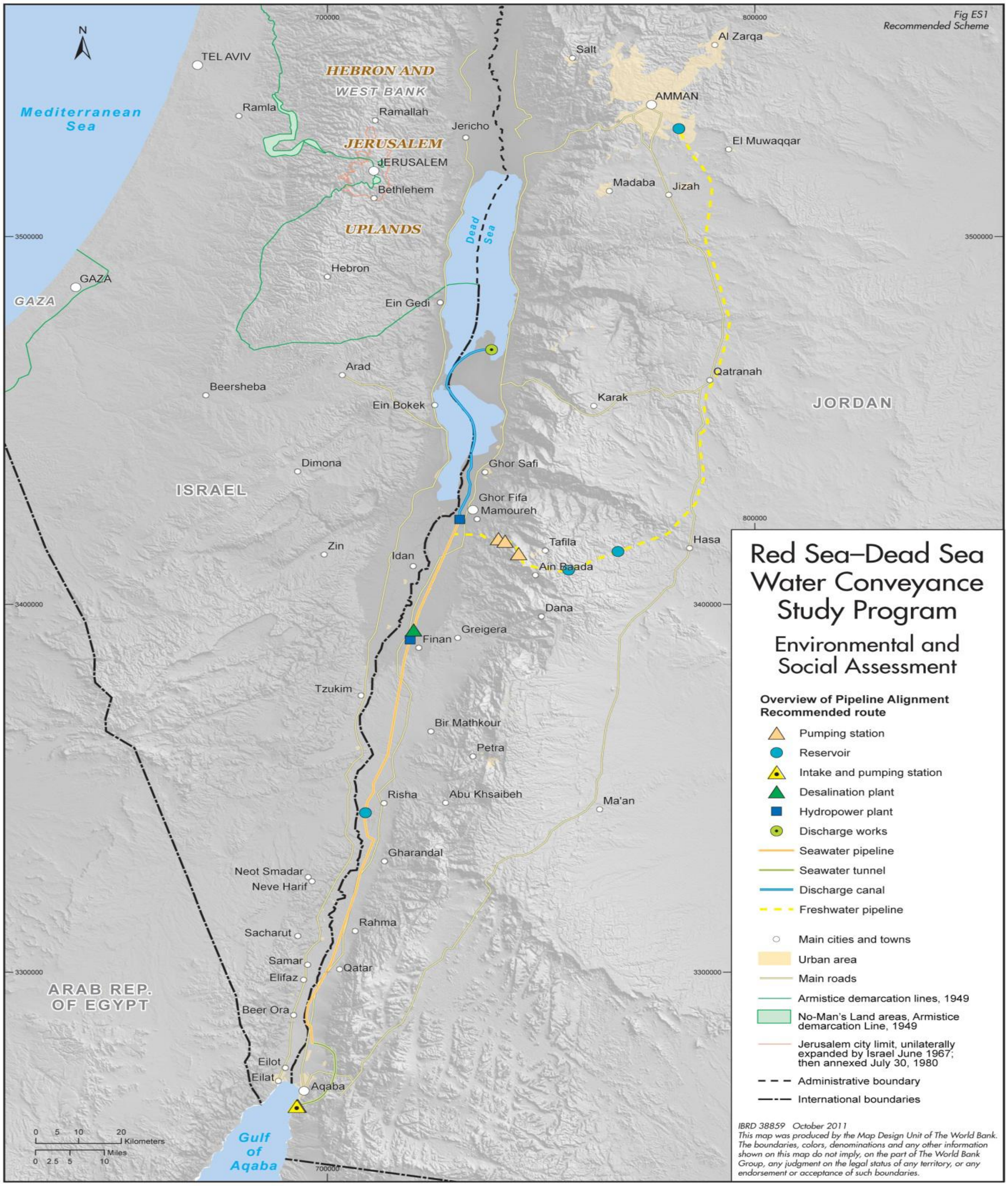
"Thirsty? How 'bout a Cool, Refreshing Cup of Seawater" USGS, last modified March 17, 2014, accessed May 3, 2014, http://ga.water.usgs.gov/edu/drinkseawater.html.

World Bank, 2013a, *Red Sea – Dead Sea Water Conveyance Study Program Overview*, last modified January 2013, accessed March 24, 2013, http://siteresources.worldbank.org/EXTREDSEADEADSEA/Resources/Overview_RDS_Jan_2013.pdf?&&resourceurlname=Overview_RDS_Jan_2013.pdf.

World Bank. 2013b. "Senior Israeli, Jordanian and Palestinian Representatives Sign Milestone Water Sharing Agreement," press release, December 9, 2013, http://www.worldbank.org/en/news/press-release/2013/12/09/senior-israel-jordanian-palestinian-representatives-water-sharing-agreement.

(WRA) Water Reuse Association, 2011, *Seawater Concentrate Management*, accessed May 3, 2014, http://www.watereuse.org/sites/default/files/u8/Seawater_Concentrate_WP.pdf.

APPENDIX 1: CONVEYOR SCHEMATIC



(ERM 2012, Figure ES.1).