Desk Study on the Opportunities and Implications of Releasing Treated Effluent in the Lower Stretches of the Jordan River and Dead Sea

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FOREWORD

The Jordan River Dead Sea Basin extends from the Upper Jordan River, which flows into a freshwater lake known as the Sea of Galilee, through the Lower Jordan River, until it reaches its terminal lake, the hypersaline Dead Sea. Five nations are riparian to this basin: Lebanon, Syria, Israel, Jordan and Palestine. The importance of the Jordan River Dead Sea Basin to the region is based on several factors beyond fresh water, from its religious, cultural and historical value, to tourism and mineral extraction and to political and strategic significance. The Jordan Dead Sea basin is often depicted as the most disputed river basin in the world, that has precipitated hostile armed conflict in so called 'water wars'.

A combination of regional conflict, natural water scarcity, over extraction and now climate change has contributed to the severe demise of much of the basin. From a water diversion perspective, Israel has taken roughly half the historical flow of the Jordan River, while Syria and Jordan have taken roughly the other half. Lebanon in the very north and Palestine in the south of the basin have been prevented from accessing their fair share of the rivers' water. The Dead Sea ecosystem is paying the price of not only the upstream water diversion, but also from mineral extraction in the south carried out by the Dead Sea Works on the Israeli side and the Arab Potash Company on the Jordanian side of the Dead Sea. Palestinians who are riparian to the Dead Sea on the north-west side are completely denied any access including both mineral extraction and tourism.

In nature everything is interconnected. The over-extraction of fresh water has turned the once 'mighty Jordan' into little more than a sewage canal. At the Dead Sea over 6000 sinkholes have opened up, threatening the very viability of further human activity around its shores and representing in the eyes of EcoPeace 'nature's revenge'.

This report presents a creative out of the box analysis of how to rehabilitate the lower stretches of the Jordan River and help stabilize the Dead Sea water level by introducing treated effluent into the basin. The analysis is premised on the assumption that all parties will need to cooperate on their fair share of existing water resources and on producing and distributing new water sources through desalination. Based on this premise and the research undertaken, there will be quantities of wastewater produced in the region that can be utilized beyond the needs of agriculture, for nature and specifically to help stabilize the Dead Sea.

The authors of this paper, Dr. Bookman et al., have undertaken desk study research from a purely scientific perspective. They highlighted the potential impacts on the Dead Sea's physical, chemical and biological composition of treated wastewater inflow. The recommendations of the authors recognize the need for further data collection, research and analysis through experimentation, piloting and modeling.

For the rehabilitation of the Lower Jordan River, in 2015 EcoPeace Middle East completed a regional integrated development master plan for the Jordan Valley. The master plan envisions that the Jordan River from the Sea of Galilee to the Dead Sea will be rehabilitated through the utilization of the river as a multi-use and multi-purpose water body. The master plan proposes that all sides utilize the river itself as the natural water carrier, instead of diversion of its waters upstream, into national water carriers. In parallel with the investments needed to remove all pollutants, the master plan, over time, envisions two thirds of the river carrying high quality water that can be purified to meet multi purpose needs including domestic water needs. After serving domestic needs, the lower stretches of the Jordan can be fed with higher salinity water, captured and diverted from upstream sources, with water quality still adequate for agricultural purposes. Large quantities of treated wastewater would then feed the river for its final stretch south of the baptism site and flow into the Dead Sea for the purpose of contributing towards partial Dead Sea stabilization.

Following exceptionally good winter rainfalls in 2019 and 2020, the Sea of Galilee is for the first time in 30 years at full capacity. With the reversal of the Israeli national water carrier enabling desalinated water soon to flow into the Sea of Galilee, high water levels of the Sea of Galilee can be maintained. EcoPeace therefore calls on the Government of Israel, as a first step, to increase water flow from 9 mcm to 30 mcm as it had previously committed to executing in 2014, much due to EcoPeace advocacy efforts.

The significance of the current desk study on the feasibility of treated wastewater, as a water source for the last stretch of the Jordan and to then flow into the Dead Sea, is that it contributes to a holistic concept of basin wide rehabilitation. This holistic concept can be utilized to help build trust between the parties in a broader geo-political perspective, including the advancement of regional governance that includes all riparians and recognizes the needs of nature itself as a legitimate user. By looking at the contrasting data on water availability and wastewater generation between the three countries, it is evident that Palestine and Jordan would need a set of incentives and require financial support for interventions to engage proactively in the concept, so as to contribute with substantial quantities of treated effluent to be discharged to the environment. Regulatory commitments will need to be met for an enhanced water and sanitation sector, including the improvement of resource management, accountability and capacity of service providers, including the need to meet the financial requirements to upgrade necessary infrastructure.

The EcoPeace concept includes sufficiently meeting the water demands of all contributing communities, both on fresh water for domestic use and wastewater for reuse. Considering that Palestine is not a major contributor to the demise of the basin, to say the least, the set of incentives extended to Palestine need to reflect a new geo-political understanding. Hence, for the high level of cooperation over water and wastewater to take place, there is a need for a new political will to be advanced based on recognition of riparian rights to the basin's water, both from a perspective of sovereignty and access to a fair share of these resources. Unilateral actions such as the proposed annexation of the Jordan Valley by Israel would run contrary to a new political will required.

As highlighted in previous EcoPeace Middle East literature, such a breakthrough in the creation of new political will requires building trust on all levels. It often starts from the community level as well as engaging with scientific and expert opinion makers. It must reveal the self-interest and mutual gain at a broad stakeholder level for all parties concerned. EcoPeace Middle East has a well-established methodology and 25 years of experience that is recognized as world-class. While this latest study gives reason for optimism in helping complete a holistic vision for the basin, it equally leaves us all with a lot of work on our agenda in order to achieve the overall sustainability and stability that our region requires.

Gidon Bromberg, Yana Abu Taleb, Nada Majdalani, Israeli, Jordanian and Palestinian co-directors, EcoPeace Middle East

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INTRODUCTION

The Dead Sea, bordered by Jordan, Israel, and Palestine, is a natural wonder with unique geological, ecological, and historical importance that is valued world-wide by the general public, both locally and globally, as well as by scientists, scholars, and environmentalists. Its hypersaline waters are rich in minerals that have therapeutic benefits and considerable economic value. Its unique desert climate, fresh spring waters, vegetation and biota, and majestic archeological sites attract millions of tourists that support communities from all over the region.

However, the Dead Sea basin ecosystem is suffering from several major threats: unsustainable water management policies that originated in the early 1960s, water diversion from the Upper Jordan River, the principal feeder of the Dead Sea, in addition to the construction of many upstream dams, together decrease the water flow into the Dead Sea. The construction of artificial evaporation ponds by the Israeli and Jordanian mineral extraction industries at the southern end of the Dead Sea have contributed to this drastic decline in water flow and magnified the impact of the shortages in water availability. Additionally, natural factors such as increased evaporation due to temperature rise as part of the global climate change have an adverse impact on the Dead Sea ecosystem. These impacts on the Dead Sea as a terminal lake with a sensitive water balance clearly represents non-sustainable interventions and an ecological catastrophe, which requires immediate attention. Currently, the lake level drops more than one meter per year, and since the 1960s the level has fallen tens of meters from its natural level, which resulted in more than 6,000 sinkholes, exposure of the marginal shallow lake floor, and rapid incision along its retreating landscape. This environmental catastrophe destroys the natural environment and puts in danger the future existence of infrastructure and tourism.

Accordingly, the Dead Sea needs an additional 700-800 MCM/yr to stabilize its level (Allan et al., 2014). Despite the various initiatives brought to the table to save the Dead Sea environment (See Appendix), including the Red Sea-Dead Sea Canal project, these efforts have not provided a clear outline for stabilizing the sea level and sustaining its unique ecology. EcoPeace Middle East urges that a combination of measures is required to stabilize the Dead Sea. A proposed partial solution for the Dead Sea shrinkage is to increase water flow from different sources through the Lower Jordan River. This solution, proposed by EcoPeace, will help to rehabilitate the Jordan River before entering the Dead Sea and sustaining the Dead Sea water balance. Stabilization using treated wastewater from the three riparian nations is proposed as an alternative to the scarce fresh water. As such, the purpose of this report is to examine the feasibility of utilizing treated wastewater from Israel, Jordan, and Palestine to rehabilitate the Lower Jordan and partially contribute to stabilizing the Dead Sea water balance. This report investigates, through a literature review, the physical, chemical, biological and economic influences of using treated wastewater for partial Dead Sea stabilization.

The results of this report may lead to a new approach to Dead Sea stabilization and Jordan River rehabilitation as well as increase the feasibility of the EcoPeace Jordan Valley Master Plan. Furthermore, the results of this study may inform rehabilitation for other lakes around the world such as Lake Alberta in south Australia, Lake Urmia in Iran, the Aral Sea and Lake Chad that are increasingly saline, desiccating, and shrinking due to climate change and anthropogenic use of their waters.

1. The State of the Dead Sea

As shown in Figure 1A, Israel and Palestine border the Dead Sea to the west, while Jordan borders it to the east. The current lake volume is ca. 132km3 with a surface area of ca. 630km2. Unlike other hypersaline water bodies, which are shallow continental basins or coastal lagoons, the Dead Sea is 300 m deep. Located at ca. 430 meters below sea level, it is the lowest point on land and dropping at a rate of >1 m/yr (Lensky & Dente, 2015). In 2011, Gavrieli et al. presented a Dead Sea water balance (Figure 1B) demonstrating a total loss of water, and one that has not yet been reversed. This is due to both a decrease in flow from the Jordan River, the primary feed into the Dead Sea, as well as the continuous pumping of the Dead Sea waters into evaporation ponds to extract its valuable brines (Katz & Starinsky, 2009). Any rehabilitation scenario must consider how the addition of water and its chemistry will affect the ecology of the Dead Sea.

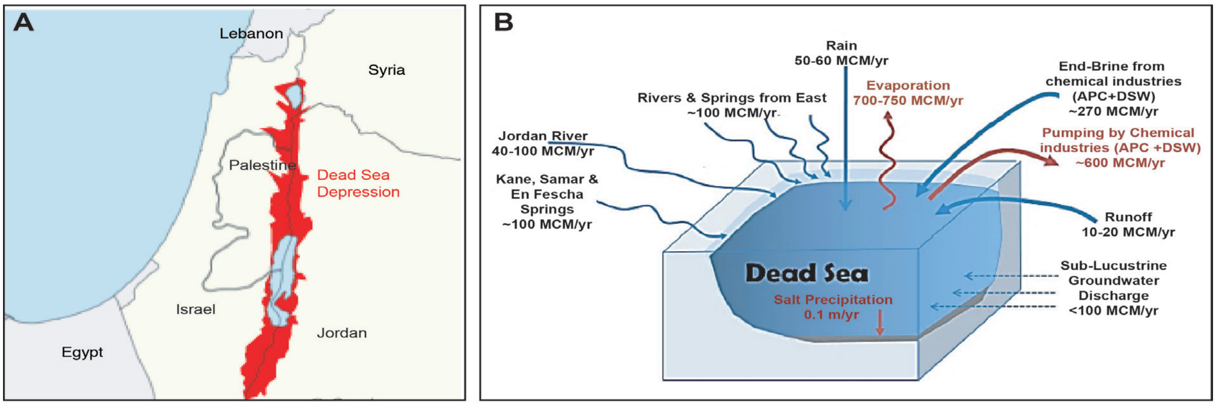

Figure 1- The Dead Sea. (A) map of the Dead Sea modified from (geologi.com) (B) Water balance of the Dead Sea (Gavrieli et al., 2011).

1.1 Flow from the Lower Jordan River

The Lower Jordan River, the primary feed into the Dead Sea has a significantly lower flow with a different water composition compared to its original state. Prior to human intervention, the Jordan River discharged an estimated 1500 MCM/yr into the Dead Sea (Malkawi & Tsur, 2016). Currently, that flow is reduced to tens of MCM/yr (Lensky & Dente, 2015), estimated to be around 5-8% of its historical rate ((EcoPeace, 2015; Hillel et al., 2015).

Originally the Sea of Galilee fed the Lower Jordan River. Today the river flow comprises water from the Sea of Galilee (TDS 0.6 g/l), Yarmouk River (TDS 2.8 g/l), treated wastewater (TDS ~1.2 g/l), diverted saline springs from the Sea of Galilee, various unregulated volumes from untreated wastewater, agricultural runoff and fish farm waste. As a result, the electrical conductivity of the river, a measure related to its salinity, is at least an order of magnitude greater than general freshwater rivers (EcoPeace, 2015; Hillel et al., 2015; Hillel et al., 2019).

1.2 Dead Sea Limnology

1.2.1 Historical Dead Sea Composition

From the 1800s to the 1960s the Dead Sea was stratified, and the shallow, southern sub-basin was flooded. A less saline upper water mass floated over a denser brine solution (Neev & Emery, 1967). The composition was determined to be as presented in Table 1.

Table 1- Original composition of the Dead Sea compared to average sea water, the Jordan River, and the Ocean. Modified from (Bentor, 1961).

Ion Name	Abr.	Dead Sea Surface	Average Dead Sea Water	Jordan River	Ocean
		mg/l	mg/l	mg/l	mg/l
sodium	Na+	33500	34940	253.40	10561
potasium	K+	6300	7560	14.85	380
rubidium	Rb+	60	60	--	0.2
calcium	Ca2+	13000	15800	80	400
magnesium	Mg2+	34500	41960	71.42	1272
chloride	Cl-	180800	208020	473.5	18980
bromide	Br-	4100	5920	4.338	64.6
sulfate	SO42-	900	540	174.49	2648.6
bicarbonate	HCO3-	248	240	237.9	139.7

1.2.2 Current Dead Sea – Limnology under a negative water balance

Presently the Dead Sea salinity is as high as ca. 340 g/l (Katz & Starinsky, 2009). Over time, as the water level fell (Figure 2), the shallow southern basin shrank and disconnected from the rest of the lake and the long-term stability of the water column weakened until a complete overturn occurred in the winter of 1978-1979 (Steinhorn et al., 1979). The overturn resulted in homogenization and oxidation of the entire water column. Now each winter, due to increased runoff, a thin upper layer with relatively low salinity forms and is separated from an anaerobic bottom layer by a salinity gradient. At least once a year, due to water shortages, the density of the upper layer equals that of the deep water, resulting in vertical mixing. As a result, the deep layers of the lake become exposed to the atmosphere and change from anaerobic to aerobic (Anati & Stiller, 1991).

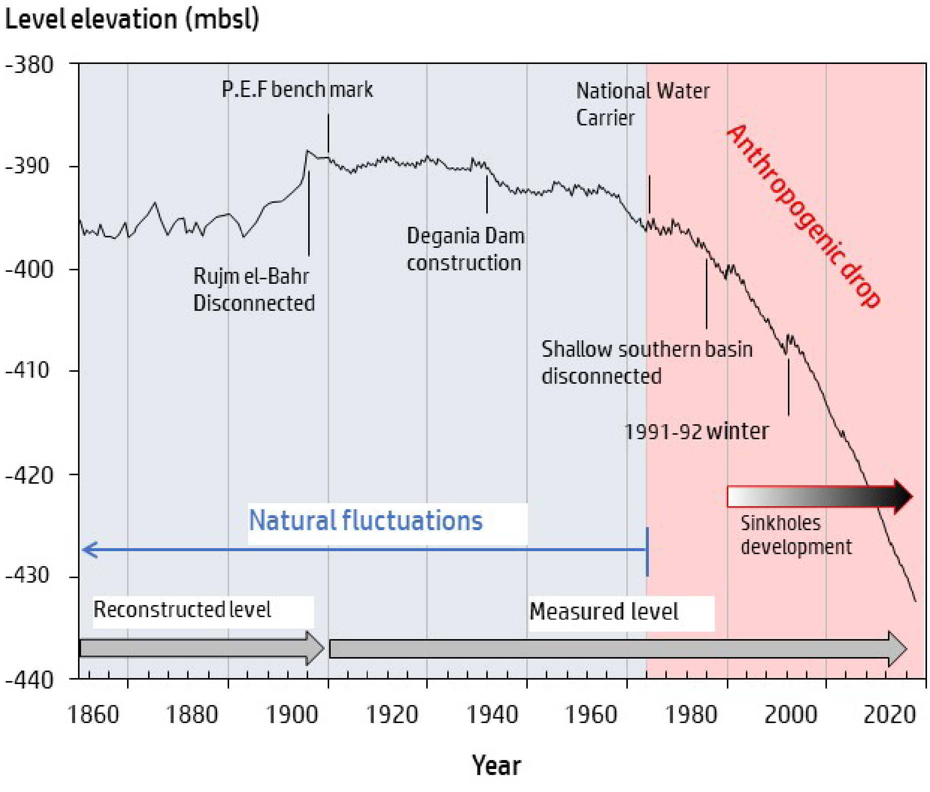

Figure 2 – Dead Sea level since 1850. Natural levels were recorded in historical documentations (Klein, 1986). Later the level was measured by a benchmark engraved on a rock used by the Palestine Exploration Fund (P.E.F.) in the beginning of the 20th century. Since the completion of the Israel National Water Carrier, water has been diverted from the Sea of Galilee, resulting in reduced flows. By 1976–1977, the Dead Sea level fell to 402 mbsl, exposing the sill at the Lynch Straits, separating the lake into its two sub-basins. The rate of level drop that intensified after the 1980s was interrupted twice after the exceptionally rainy winters of 1979–1980 and 1991–1992. Sinkholes were first described in the 1980s, however their rate of occurrence has increased dramatically since 2000. Figure modified from (Bookman, 2020).

1.2.2.1 Life in the Dead Sea

Despite its name, unique, indigenous microbial communities do exist, albeit sparsely, in the Dead Sea waters. This includes a variety of eukaryotic flagellate algae and different types of cyanobacteria (Elazari-Volcani, 1943; Kaplan & Friedmann, 1970). The unicellular green algae, *Dunaliella parva,* and a halophilic Archaea from the Halobacteriaceae family are the main communities, and typically only appear during exceptionally rainy years that cause at least a 10% dilution of the water column upper layer (Oren, 2010).

1.2.2.2 Impact of the Dead Sea level drop on surrounding areas

The rapid Dead Sea level retreat in the past decades accelerated environmental deterioration, including soft sediment erosion that resulted in rapid stream head-cut migration and widespread development of collapse sinkholes (Yechieli et al., 2006). The sinkholes started to appear in the 1980s (Figure 2), however their rate of occurrence has increased dramatically since 2000 as the Dead Sea level drop rate also increases (Abelson et al., 2017). This process threatens coastal infrastructure and daily human life with an impact on the natural environment. Although many efforts were invested in supporting the Dead Sea coastal margins and infrastructure collapse, the process is unavoidable since the Dead Sea continues to shrink.

2. Treated Wastewater for Rehabilitation

Treated wastewater is a potential source for Dead Sea stabilization. However, discharge of limitedly treated wastewater has resulted in environmental degradation (Carey & Migliaccio, 2009). As such, it is necessary to assess potential impacts based on wastewater treatment and water quality.

2.1 Fundamentals of wastewater treatment processes

There are three levels of wastewater treatment; primary, secondary and tertiary (Figure 3). Each plant has a unique process, but general processes are fairly consistent within each treatment level (Tchobanoglous et al., 2003). Primary treatment typically consists of a settling basin where larger particulate matter settles to the bottom while fats, oils, and grease (FOG) float to the surface and are skimmed off the top. Primary treatment removes large objects and small inorganic solids from incoming wastewater via flocculation, settling, screening and sedimentation basins. Secondary treatment

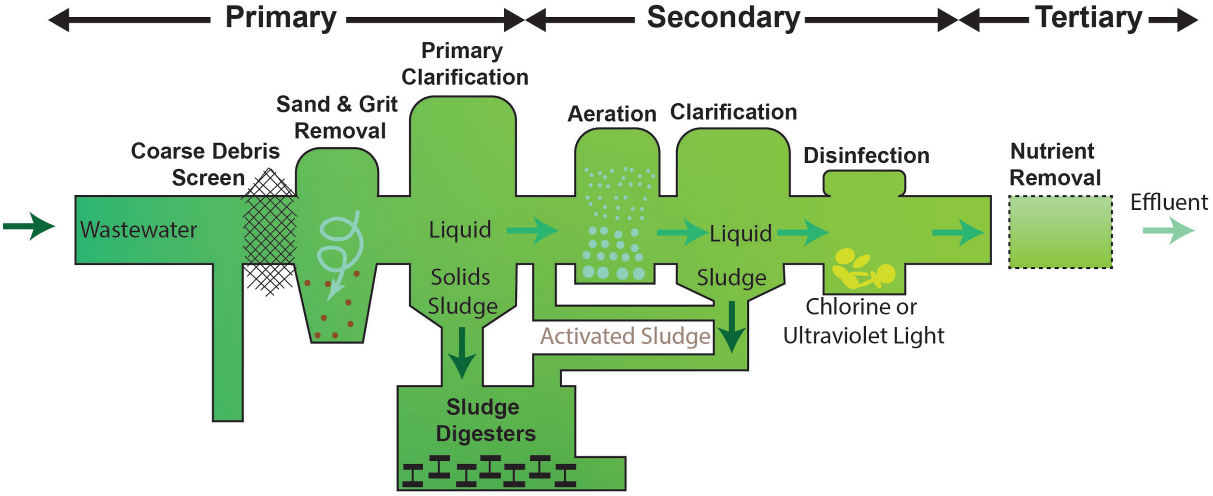

Figure 3 - Schematic of wastewater treatment. Raw wastewater first goes through a pretreatment stage where large solids are removed. Then the water goes through primary treatment to remove particulate matter and FOG. Secondary treatment removes additional organic matter and often, though not always, involves a disinfection step. Tertiary treatment removes additional dissolved and suspended material and may include additional disinfection.

handles the leftover organic matter present in wastewater after the primary treatment stage. Although there are a few different secondary treatment processes, most plants utilize some form of aerobic biological process to reduce the bacteria and organic content of the waste. So, after the primary treatment, wastewater flows to a secondary treatment tank where the water either flows over a fixed biological process such as a trickling filter or membrane bioreactor, or through a suspended growth system where the wastewater is mixed with an activated sludge. Suspended and dissolved material may remain in the effluent and advanced tertiary treatment may be required to meet regulatory requirements for protecting receiving waters. There are many different types of processes that are used for tertiary treatment. The purpose of tertiary treatment is to provide a final cleaning process to ensure that the treated wastewater is at a high enough quality to be used for almost any purpose and may even include a disinfection process. Nutrients and metals may be targeted during advanced treatment and several chemical and biological nutrient removal (BNR) processes. However, it must be noted that every wastewater treatment plant (WWTP) is designed to treat a specific amount of waste and if that amount is exceeded the plant will not perform as designed.

2.2 Review on treated wastewater in surface waters

Although the impact of treated wastewater on highly saline systems needs to be studied, worldwide, treated wastewater is starting to be utilized as a water source to successfully rehabilitate rivers and streams and has been successful when integrated with broader catchment management strategies (Bernhardt & Palmer, 2007). Plumlee et al. (2012) reviewed different rivers that have been rehabilitated with treated wastewater and their impacts (Table 2) (Plumlee, Gurr, & Reinhard). Although the wastewater was tertiary treated, it is important to note that release into the catchments are based on local environmental regulations (Plumlee et al., 2012) that may require tertiary treatment to be achieved.

Table 2- Examples of successful rehabilitation of natural water bodies using treated wastewater. Modified from (Plumlee et al., 2012).

River/Stream	Location	Wastewater Treatment	Result
San Antonio River	Texas, USA	Tertiary treatment with filtration and disinfection (chlorination & de-chlorination or UV-disinfection)	improved water quality and return of sensitive, pollutant intolerant species
Bell Creek	Washington, USA	Tertiary treatment with UV-disinfection and aeration	improved salmon habitat and maintained benthic species
San Luis Obispo Creek	California, USA	Secondary with nitrification; Tertiary with filtration and chlorination/de-chlorination	maintained creek flow and increased presence of endangered animals
Tossa de Mar Creek	Tossa de Mar, Spain	Secondary treatment with filtration and disinfection (UV & chlorination); Tertiary treatment from bank filtration	increased vegitation due to year-round creek flow
Rivers in Tokyo	Tokyo, Japan	Tertiary treatment with rapid sand filtration	enhanced landscaping and recreational activity

Treated wastewater may provide a constant source of nutrients, like nitrogen and phosphorus, even at the lowest loadings due to the quantity of wastewater used (Carey & Migliaccio, 2009; Ekka et al., 2006). Excessive nitrogen and phosphorus can lead to conditions that cause eutrophication and dead zones (Carpenter et al., 1998; Vitousek et al. 1997). Further, nitrogen as ammonia, also found in treated wastewater, is particularly toxic to aquatic life (Passell et al., 2007). A study assessing wastewater quality impact on ecosystems in Berlin, Germany found that the stream receiving secondary treated wastewater had elevated concentrations of total organic carbon (TOC), total nitrogen (T-N) and total phosphorus (T-P) in the sediments compared to the stream receiving tertiary treated wastewater (Gücker et al., 2006). The elevated nutrient levels resulted in greater primary production and respiration in the streams. Table 3 provides an example of the nutrient removal efficiency of different wastewater treatment systems.

Table 3 - Typical nutrient concentration ranges in untreated wastewater and achievable in treated effluent considering secondary and tertiary processes (Carey & Migliaccio, 2009). All units in mg/L

Nutrient	Untreated wastewater	Conventional activated sludge[a]	Activated sludge with BNR[b]	Activated sludge with BNR, microfiltration and reverse osmosis[c]
Total Nitrogen*	20-70	15-35	3-8	≤ 1
NH3-N	12-45	1-10	1-3	≤ 0.1
NO3-N	0-trace	10-30	2-8	≤ 1
Total Phosphorus**	4-12	4-10	1-2	≤ 0.5

a Secondary treatment: activated sludge including a nitrification step
b Tertiary treatment: activated sludge and biological nutrient removal (BNR) of nitrogen and phosphorus
c Tertiary treatment: activated sludge and biological nutrient removal combined with advanced treatment.
*Israeli Inbar Standards for release to a river for Total Nitrogen = 10 mg/L
**Israeli Inbar Standards for release to a river for Total Phosphorus = 1 mg/L

Trace metals and organics also found in wastewater can be nutrients at low levels and toxic at high levels (Reiley, 2007). In a survey of 16 WWTP it was found that secondary treatment only partially removes pesticides-nearly half of tested pesticides were not even reduced (Campo, Masiá, Blasco, & Picó). The level of pesticides found would cause ecosystem damage if released into surface water. An additional study showed that parasites were still present in secondary treated wastewater (Castro-Hermida et al., 2008). Pharmaceuticals, personal care products and other contaminants of emerging concern are also problematic as their impacts on the environment are still relatively unknown and the ability of different wastewater treatment processes to remove these contaminants is also relatively understudied.

Regardless of the specific treatment process used, it is clear that for rehabilitation it is important that the quality of the water used in the natural environment reaches a quality that is safe for the environment. Depending on the specific treatment processes utilized, the water may require tertiary treatment.

2.3 Wastewater Treatment in Jordan, Palestine, & Israel

Effluent discharges from WWTPs are dependent on source water and different source waters may require different degrees of treatment to meet regulations. This is important because effluent discharges from WWTPs can influence both water quality and overall hydrologic characteristics of receiving waters. Israel has a total water supply of 700 l/c/d, (Avgar, 2018) of which 263 l/c/d were supplied for domestic uses. Freshwater is sourced increasingly from desalinated water, with 750 MCM supplied from desalinated water in 2020 and hopefully to double by 2050 (Avgar, 2018). Surface water acts as the other primary source of Israel's drinking water (Avgar, 2018). The total water supply per capita in Jordan, which is substantially lower than that of Israel, has steadily decreased over the last 10 years from 134 l/c/d in 2010 to 125 l/c/d in 2017 (Alzoubi, 2018). However, over 40% of Jordan's supplied water is unaccounted for either through leaks or siphoning. Currently over 50% of Jordan's water is sourced from groundwater with many groundwater sources being over-abstracted or non-renewable. Around 25% is sourced from surface water and the rest from treated wastewater (Soud & Subah, 2017). However, Jordan's agricultural sector accounts for only 50% of the total water demand (El-Naser, 2016). In Palestine, per capita daily demand is even less, with ~80 l/c/d supplied (World Bank, 2018). Under the arrangements of the interim Oslo Accords, 69 MCM (60%) of Palestinian water comes from the Israeli water company, Mekorot, with the remaining 48 MCM coming from ground or other natural water, pumped by the Palestinian Water Authority and private well and spring owners (World Bank, 2018). Both Jordan and Palestine rely on groundwater which suffers from salt water intrusion, high nitrogen content, and increased salinity. Thus, a higher salt load in supply water and low water use results in higher salinity of the wastewater with greater organic loading (Abdulla et al., 2016). Israel, on the other hand, has a significant amount of desalinated water. In general, wastewater treated from desalinated water will have high sodium and boron levels, and low magnesium, calcium, and organic matter content (Lahav & Birnhack, 2007).

In the West Bank, Palestine currently has 6 centralized WWTP and 3 are under construction or tendering, another 16 collective small to medium scale WWTP exist, and another three under construction. Only four of the wastewater plants utilize aeration ponds or wetlands while the remaining advanced treatment process such as membrane bioreactors, rotating biological contractors, or sequencing batch reactors. Unfortunately, most of the existing plants are overloaded thus failing to achieve their designed wastewater standard capacity, essentially releasing even more than the estimated partially- or un-treated wastewater to the wadis and surrounding environment (Samhan et al., 2010). As mentioned previously, the majority of the wastewater produced in Palestine is domestic, thereby the primary concern regarding release of wastewater from overloaded plants, in addition to pathogens, is high BOD, high nitrogen from contaminated groundwater as well as increased TDS from a higher salinity starting point. Additionally, because the primary treatment processes are ponds, the high salinity may further impair the treatment processes.

In contrast to Palestine, 93% of all Israeli wastewater is treated in WWTP, 87% of that is reused in irrigation for agriculture (Avgar, 2018). In 2016, 575 MCM of treated wastewater was used for irrigation (Avgar, 2018). However, according to the 2017 WWTP regulation report, only 39% of the 90 WWTP presented in the report create treated water meeting the criteria for agricultural reuse. This agrees with the 2019 protocol report that stated only 53% of effluent comes from tertiary treatment plants while the remaining 47%

comes from secondary treatment plants (Eichen, 2019). Despite being a world leader in wastewater treatment and reuse, over 40 MCM/yr of partially or fully untreated wastewater is still released to the environment (Zalul.org). Unlike Jordan or Palestine however, Israel's wastewater is more likely to have a lower salt content due to the higher use of desalinated water.

Jordan's current wastewater situation falls somewhere between that of Israel and Palestine. Of the 458.2 MCM of drinking water supplied in Jordan in 2017, 163.68 MCM of the wastewater was treated, and this treated wastewater composed 14% (146.7 MCM) of all water used (1054 MCM) (Alzoubi, 2018). The majority of Jordan's WWTPs currently use secondary or are in the process of being upgraded or built to secondary treatment practices. These primarily include activated sludge, trickling filters or other biological treatment systems. Despite having the appropriate technology, Jordan still lacks enough capacity and thus suffers from overloading the existing systems. This often results in a lower capacity to reduce BOD and COD. Furthermore, the majority of Jordan's water quality failures stem from high pathogens, specifically E. coli (appendix, Table 7) (Alfarra et al., 2011; Alzoubi, 2018; Soud & Subah., 2017) which can be easily and cost-effectively mitigated with a disinfection process.

2.4 Regulations for release of wastewater to surface water in Israel, Palestine, & Jordan

Attention to environmental and human health in relation to the quality of each state's raw wastewater is seen in the standards developed for release of wastewater to the environment across Jordan, Palestine, and Israel (Table 4). Although Jordan has a more comprehensive list of parameters assessed, Israel's regulations are the strictest. This is a result of Israel's standard overhaul for both unregulated irrigation and for disposal to surface water when Israel set the goal to use 100% of treated wastewater for irrigation (Inbar, 2007). All states monitor parameters in major common areas of interest: 1) organics, nutrients, and pathogens (ONP), 2) salts (S), 3) fats, oils, and greases (FOG), and 4) metals (M). There is no universal standard for what should be monitored in general, but the parameters that are seen most frequently worldwide for surface water are marked by (*) in Table 4. Metals are primarily a result of wastewater from industrial processes, that are most expensive to test and the most difficult to remove, thus it is not surprising that Palestine does not have as many metal requirements as Jordan or Israel. However, one would expect Israel to have more heavy metal requirements than do exist. It is interesting to note that while Israel and Palestine have general wastewater treatment regulations, Jordan has separate regulations for domestic as opposed to industrial wastewater and also has different regulations for domestic wastewater that is treated through mechanical versus natural processes. A point that must be considered in the final recommendation and one that was alluded to earlier is that despite the existence of standards, all states fail to adhere to these standards 100% due to source water fluctuations and cost of treatment.

Table 4- Regulations for disposal of treated wastewater into rivers from Jordan, Israel, & Palestine.

Category	Parameter	Unit	Israel[f]	Jordan			Palestine[i]
				Domestic[g]			
				Mechanical	Natural	Industrial[h]	
	pH*		7.0-8.5	6.0-9.0	6.0-9.0	6.5-9.0	6-9
ONP	Biological Oxygen Demand*	mg/L	10	60	120	50[a]	--
ONP	Carbon Oxygen Demand*	mg/L	70	150	300	150[a]	200
ONP	Dissolved oxygen*	mg/L	>3	>1	>1	>1	>1
ONP	Nitrogen as Ammonium	mg/L	1.5				
ONP	Total Nitrogen*	mg/L	10	45	45	--	
ONP	Total Phosphorus*	mg/L	1	15	15	--	5
ONP	Faecal coliform*	CFU/100 mL	200			1000[b]	<1000
ONP	Residual chlorine*	mg/L	0.05	0.5-1.0	0.5-1.0		
ONP	E. Coli*	CFU/100 mL		500	1000		
ONP	Intestinal Helminthe Eggs*	egg/L		≤1	≤1		
ONP	Nitrate*	mg/L		45	45	12[c]	
ONP	Phenol	mg/L		<0.002	<0.002	0.002	
ONP	Nematodes	unit				<1	
ONP	Hydrocarbons	mg/L					1
ONP	Ammonia	mg/L				5	5
S/ONP	Sulfate*	mg/L		300	300	500	1000
S/ONP	Color					15	
S	Total Suspended Solids*	mg/L	10	100d	--	50	
S	Total Disolved Solids*	mg/L		1500	1500	3000[e]	
S	Bicarbonate*	mg/L		400	400		
S	Chloride*	mg/L	400	350	350	15	--
S	Sodium	mg/L	200	200	200	--	--
S	Magnesium	mg/L		60	60		
S	Fluoride	mg/L	n/a	1.5	1.5	1.5	
FOG	Anionic detergent*	mg/L	0.5				10
FOG	Mineral oil	mg/L	1				
FOG	FOG*	mg/L		5	5	5	
FOG	MBAS	mg/L		25	25	25	
M	Tin	mg/L				0.1	
M	Boron	mg/L	n/a	1	1	1	2
M	Arsenic	mg/L	0.1	0.05	0.05	0.05	
M	Mercury**	mg/L	0.0005	0.002	0.002	0.001	
M	Chromium	mg/L	0.05	0.02	0.02	0.1	
M	Nickel	mg/L	0.05	0.2	0.2	0.2	
M	Selenium	mg/L	n/a	0.05	0.05	0.02	
M	Lead**	mg/L	0.008	0.2	0.2	0.1	
M	Cadmium	mg/L	0.005	0.01	0.01	0.01	
M	Zinc	mg/L	0.2	5	5	15	
M	Iron	mg/L	n/a	5	5	1	
M	Copper	mg/L	0.02	0.2	0.2	2	
M	Manganese	mg/L	n/a	0.2	0.2	0.2	
M	Aluminim	mg/L	n/a	2	2	5	
M	Molybdenum	mg/L	n/a	0.01	0.01		
M	Vanadium**	mg/L	n/a	0.1	0.1		
M	Beryllium**	mg/L	n/a	0.1	0.1		
M	Cobalt	mg/L	n/a	0.05	0.05		
M	Lithium**	mg/L	n/a	2.5	2.5		
M	Cyanide	mg/L	0.005				

a Carbon Oxygen Demand (COD) and Biological Oxygen Demand (BOD) are monthly averages
b Geometric mean is used for calculations
c The quantity allowed is dependent on the nitrate level of concentration allowed in the affected water basin
d WWTP that use mechanical methods and have polishing ponds are allowed to exceed two times the standard
e Depends on concentration in the water resource supplying the industry and the water basin affected
f (Inbar, 2007)
g (The Institution for Standards and Metrology, 2006)
h (The Insitution for Standards and Metrology, 2007)
i (Samhan et al., 2010)
(*) Frequently regulated parameters in release of treated wastewater
(**) Metals usually indicative of anthropogenic sources

3. Impact of treated wastewater on the Lower Jordan & Dead Sea

In terms of partial stabilization we are interested in each of the aforementioned parameter sets for different reasons. As discussed in section 2.2, organics, nutrients, and pathogens (ONP) may cause algal blooms, eutrophication, or other ecosystem changes on the Lower Jordan River and the Dead Sea. Salts are important from an ecological standpoint and may impact the ecosystem of the Lower Jordan River. Fats, oils, and greases (FOG) usually consist of contaminants that are typically not found in the natural environment and may have unforeseen consequences for the environment and for people who use these areas recreationally, whereas metals may impart unintended health impacts due to toxicity.

Based on current data and country specific existing standards only, it appears that release of treated wastewater to the environment for the purposes of revitalizing the Lower Jordan River are possible with current and/or planned technologies in all states. Albeit, additional systems or expansion of current systems need to be built to handle the issue of overloading the existing technologies across the board. It is emphasized that treatment standard attainment is essential.

3.1 Dead Sea water column structure & limnology stabilized with treated wastewater

It is clear that additional inflow volumes (of any water salinities) will result in a water level rise of the Dead Sea. In the case of an increase of 300-400 MCM/yr of treated wastewaters (with any treatment level) dilution of the surface water and the development of stratification will occur. Once stratification develops, the surface density and salinity will drop continuously. The precipitation of halite (aka salt) from the epilimnion will likely cease due to the effect of dilution. Treated waters, as opposed to seawater or recycled brine, will not contribute any significant salts to the upper waters. Therefore, use of treated wastewater will result in the dilution of the Dead Sea waters. This dilution will result in a greater evaporation rate that will slow the water level rise.

In the past during hydrologically anomalous wet winters (e.g. 1991-1992) when the freshwater input reduced the level drop, a relatively fresher surface layer developed in a similar manner that is expected if treated wastewater is introduced. In this scenario aragonite ($CaCO3$) will likely precipitate out of solution (Barkan, et al., 2001; Belmaker et al., 2019). Based on historical conditions, when the surface level exceeds 400 mbsl (Bookman, et al., 2004), the deposition of the Dead Sea will switch from seasonal halite deposition (Sirota et al., 2016), to carbonate deposition (Stein et al., 1997). However, given the complex composition of treated wastewater, additional studies must be conducted to determine potential impacts of secondary and tertiary treatments on the chemistry of the Dead Sea waters and mineral crystallization.

In the Dead Sea, biologically available inorganic nitrogen is abundantly found in the form of ammonium ions, the concentration of which have not changed considerably over time. The average concentration of ammonium ions in the water column was reported to be 5.9 mg/l in 1960 and 8.9 mg/l in 1991 (Nissenbaum et al., 1990; Stiller and Nissenbaum, 1999; Gavrieli et al., 2011). Studies have estimated the dissolved phosphate concentration in the Dead Sea water column to be around 30mg/L, with an additional 10-50 mg/L of particulate phosphate (Nissenbaum et al., 1990; Stiller and Nissenbaum, 1999). While raw wastewater tends to have high phosphate concentrations, compared to the standards set by the three states, even the least restrictive value of 15 mg/L total phosphate is less than that found in the Dead Sea which leaves room for error in WWTP.

3.2 Impact on microbial life in the Dead Sea waters

Although quite a high concentration relative to other water bodies, phosphate is still a limiting nutrient for primary production in the Dead Sea. The limited availability of phosphate is thought to be due to the unusual ionic composition of the brine (Gavrieli et al., 2011). Currently, concentrations of sulfates in the Dead Sea are low and do not allow for deposition of gypsum ($CaSO_4 \cdot 2H_2O(s)$), which would adsorb and co-precipitate phosphate. Hence, phosphate that enters remains and can trigger microbial blooms, especially in the Dead Sea where phosphate is a key nutrient for Dunaliella and halophilic Archaea (main organisms) in the Dead Sea (Oren, 2010). Even though the limits for sulfate in treated wastewater are relatively high, typical wastewater has generally lower sulfate concentrations, so with treated wastewater we can expect potential blooms. Furthermore, wastewater can potentially introduce other halophilic bacteria (high salinity-thriving), so it is important to study the influence of other halophilic bacteria on the Dead Sea and the Jordan River environments.

Recently there has been a global increase in harmful cyanobacterial blooms, many of which are formed by invading species (Huisman et al., 2018). Furthermore, cyanotoxins are known to be involved in cyanobacteria function under changing salinity (Holland & Kinnear, 2013; Liebe, 2012) and hyper-saline environments promote the formation of more toxic strains. Since salinity is one of the most important abiotic factors affecting cyanobacteria distribution, it must be carefully studied in the case of the Dead Sea.

3.3 Physical and ecological effects due to increased water discharge

In the case of discharge of treated waters of 300-400 MCM through the Jordan River, it is expected that the level retreat drop will reduce (full stabilization needs a 2-fold increase in discharge). The rate at which the process will occur and be maintained has significant physical and ecological implications. A too high rate of level rise can induce shore erosion. Therefore, it is recommended to gradually increase the discharge to the Dead Sea and monitor the impact on the coast in the initial stages.

Additionally, if the water level rises too quickly, it could impact the ground water level and spring systems. When the Dead Sea level dropped, it resulted in a massive change of the shallow groundwater and spring system and subsequent alteration of aquatic habitats that endangered the ecological systems, some of which are endemic to the Dead Sea (Goren & Ortal, 1999). Unconventional mitigation strategies were used to revive the ecosystems. A quick rise of the level could interact with the previous mitigation strategies to cause even greater harm. Thus, the interaction of an increased water level with surrounding stream and groundwater ecosystems must be reviewed.

As the Dead Sea shrinks today, topography-driven fresh groundwater that flows from the surrounding highlands penetrates the coastal shallow aquifer and replaces the retreating brine. Fault lines that ruptured the underlying silt and clay conduct the fresh groundwater across the aquiclude layers and dissolve a thick salt layer formed in dry geological times (Stein et al., 2010). The rise in level and shoreline landward migration, subsequently will also drive subsurface brine migration and may stop the fresh groundwater flow into the subsurface salt layer, which was previously immersed in the Dead Sea brine (Yechieli et al., 2006).

Alternatively, there is also potential that the sinkhole formation may increase, as wastewater is significantly less saline than seawater or brine. With the inflow of the treated wastewater, the hydraulic gradient between the lower and shallow aquifers will decrease such that the fresh-saline interface will migrate and restrain dissolution (Gavrieli et al, 2011). The long-term stratification of the Dead Sea water body and the complex flow interactions need to be studied and modeled to better understand the effect of increasing Dead Sea level with low salinity water on sink hole formation.

4. Comparison between Brine and Wastewater

Wastewater and brine are effective opposites. Brine composition depends on the feed water as well as the specifics of the Reverse Osmosis (RO) process but is essentially a concentrated form of the original source water with the addition of any chemicals utilized in the process. Sodium chloride and other dissolved salts in brine exist at a similar ratio to, but more concentrated than, the feed water with total dissolved solids (TDS) as high as 65000-85000 ppm with seawater feed. For reference, this is six times more than the ocean (TDS ~10000 ppm) and about half the TDS of the Dead Sea (TDS ~330000 ppm). Further, due to a higher level of alkalinity, the pH of brine is often higher than that of the feed water. RO membranes reject heavy metals proportionally to calcium and magnesium and also reject 95% of organics, leaving these residuals in the brine. Chemicals found in the brine may include chloride, iron, sulphates, and polymers as well as antiscalants which can include polyphosphates, phosphates, and/or polycarbonic acids.

In contrast, wastewater will tend to have higher organic content, a lower salt content but a potentially higher trace metal content. The process used to treat the wastewater will ultimately determine the quality and composition of the treated wastewater with primary, secondary, and tertiary treatment processes increasingly removing organics and salts and to a lesser degree smaller polymers and trace metals.

Unlike less saline wastewater, the use of brine would potentially introduce harmful compounds into the ecosystems of the Lower Jordan River and the Dead Sea.

5. Calculated Available Treated Wastewater by 2050

Calculations presented in the EcoPeace Jordan Valley Master plan estimated a present outflow into the Dead Sea of 90 MCM/yr. The Master Plan proposed that a total flow of 300 - 400 MCM/yr into the Dead Sea is possible with additional combined input of desalinated water (from Israel) and/or treated wastewater from the larger Jordan, Palestinian, Israeli regions.

However, as earlier noted, stabilization of the Dead Sea requires 700-800 MCM/yr flow into the Dead Sea (EcoPeace, 2015). In later EcoPeace policy briefs, EcoPeace has proposed to source 300-400 mcm/yr treated wastewater to flow from the lower stretches of the Jordan River into the Dead Sea and 300 MCM/yr to be saved from reduced evaporation due to proposed changes in mineral extraction practices of the private sector in Israel and Jordan. EcoPeace has identified the need to research and invest in the potential use of membrane technology for Dead Sea mineral extractions in order to reduce the present evaporation of Dead Sea waters by as much as 300 MCM/yr.

For the purposes of this study, we calculated a number of possible factors considering wastewater available for diversion into the Lower Jordan and Dead Sea in 2050. The calculations demonstrate that there will be enough wastewater produced to achieve >400MCM/yr, as appears in Table 5. A description of how the calculations were conducted and an example of the calculations are presented in the appendix. The calculations are dependent on large-scale desalination continuing to be developed in the region and supplied to all three populations in order to produce enough wastewater. Specifically, if there is not enough water utilized then there will not be enough wastewater for Jordan River rehabilitation and Dead Sea stabilization.

Table 5 - Calculated available wastewater for stabilization of Lower Jordan River and the Dead Sea in 2050 (MCM) assuming per capita water demand of 220 l/c/d with different agricultural water demand growth values for Israel and Jordan and 24.6% growth for Palestine based on the NGO master plan.

Israel & Jordan Agricultural Water Demand 0.00% Growth	Israel & Jordan Agricultural Water Demand 0.20% Growth	Israel 0.06% & Jordan 0.00% Agricultural Water Demand Growth
1405.9	1290.3	1168.0

5.1 Assumptions & Rational for Assumptions

These assumptions are based on each countries projected numbers and are consistent with the EcoPeace NGO Master Plan.

1) **Wastewater will be conveyed to the Lower Jordan from outside the Jordan River Valley. These regions cover east of Zarqa, Jordan to the Mediterranean and from north of Ashkelon, Israel and north of Madaba, Jordan (Figure 4).**

   Malkawi and Tsur (2016), performed simple calculations of shuttling water from the Mediterranean to the Dead Sea rather than from the Red Sea to the Dead Sea. They demonstrated that either tunneling water from the Mediterranean to the Dead Sea from Ashkelon to Qumran (90 km) or by transporting desalinated water from Atlit to Naharayim/Bakura (70 km) are both cost effective in relation to the costs of the Red Sea-Dead Sea conveyance (discussed briefly in the appendix). Thus, transporting currently unclaimed wastewater from the larger cities in the north and center of Israel to stabilize both the Lower Jordan and the Dead Sea are possible.

2) **All treated wastewater from urban areas in Figure 4, are treated to at least the minimum requirements defined by each state for release to the natural environment.**

   Urban areas are more densely populated than rural areas and therefore are more easily connected to sewer systems while treated wastewater from rural areas are more likely to have septic or other improved wastewater systems.

3) **82% of all treated wastewater is allocated to agricultural use**

   In Israel currently, 82% of irrigation demands are met with treated wastewater. As such, this assumption was applied to all areas in this assessment and leave a margin of error to account for leaks or other lost water that might occur.

4) **Agricultural water demand increased 24.6% for Palestine from 2020-2050, 0 or 0.2%/yr for Jordan, and 0 or 0.6%/yr for Israel from 2020-2050.**

   The NGO Master Plan assumed a 0% increase in irrigation needs in Israel and Jordan. However, Israel currently has a 0.6% increase per year in agricultural water needs and projects this growth to continue into 2050 (Avgar, 2018). It is more realistic that Jordan will also increase its yearly irrigation needs and that Israel may not attain a 0.6% increase. As such, we also included a calculation that was in between 0 and 0.6% for both Israel and Jordan at 0.2%.

5) 220 l/c/d was used as the universal water consumption quantity

The EcoPeace NGO Master Plan assumes 220 L per capita per day for each of the three states and we used the same assumption.

6) All per capita water demands will be met.

In agreement with the EcoPeace NGO Master Plan.

Figure 4 - Area included in the calculations for available wastewater for stabilization of the Lower Jordan and the Dead Sea

5.2 Costs

Based on the cost calculations conducted by Malkawi and Tsur (2016), the cost of conveyance of desalinated water (USD \$0.50/m^3) from the north of Israel to the Jordan (Figure 4) river is negligible compared to profits obtained from stabilization of the Dead Sea and generated hydropower with the conveyed water. The cost of construction, maintenance and use of desalination plant tend to be greater than the cost for a wastewater treatment plant (Kotagama, Ahmed, & Al-Haddabi). Hence, the use of treated wastewater of high quality for stabilization of the Lower Jordan River and the Dead Sea would cost even less once the value of stabilization and irrigation used by this treated wastewater are accounted for. Malkawi and Tsur, 2016, claim the conveyance of water along this northern route would cross valuable land. As such, it is necessary that the wastewater in this region be of the highest quality..

Similarly, Malkawi and Tsur (2016), estimated the cost of transporting water from the Mediterranean along a southern route of 90 km (Figure 4) via a tunnel was also more cost effective than the Red Sea Dead Sea conveyance especially if hydropower is harnessed. For wastewater coming from this area or from the same distance in the west, there will be additional value added to the water conveyance by the possibility of irrigation water as well as wastewater treatment in general for areas in Palestine.

Similarly, based on the EcoPeace NGO Master Plan, treated wastewater conveyance from Amman to the Jordan Valley is already included in cost analysis and the addition of wastewater treatment plants will be negligible with the added value of treated wastewater, irrigation, and possibly even hydropower.

7. Recommendation

Treated wastewater appears to be a potential and viable option for partial stabilization of the Lower Jordan River and Dead Sea. However, essential criteria must be fulfilled, and additional information must be collected. If state regulations are met it seems that the effluent is usable. However, current WWTPs are not attaining these goals and research is not available for the environmental impacts of lesser treated water.

Additional research in the form of modeling or laboratory experiments must be completed to assess the impacts of wastewater effluent on the existing groundwater systems and sink holes and to determine the impact of wastewater effluent of different qualities on the Dead Sea column structure, biota and ecosystem. The is especially important to understand organic and nutrient loadings and their potential to result in uncontrolled algal blooms.

8. Appendix

8.1 Alternatives suggested for partial stabilization of the Dead Sea

The Red Sea-Dead Sea (RSDS) Conveyance Project is the most studied attempt to stabilize the Dead Sea (et Bellier, 2012). Apart from the RSDS Project, two other Mediterranean Sea-Dead Sea Projects have also been proposed-a northern and southern conveyance (Malkawi & Tsur, 2016). Recently EcoPeace presented perhaps a more sustainable alternative that suggests using future treated wastewater.

The increase in the Jordan flow must also be accompanied by a reduction in Dead Sea water pumping by the Potash industries using a more efficient production process. These could be met according EcoPeace Middle East, if industry in the south of the Dead Sea were to replace their evaporation ponds with the use of membrane technology (EcoPeace, 2015), which is the most feasible of the options since the Red-Dead project is halted. These alternatives are presented in Figure 5

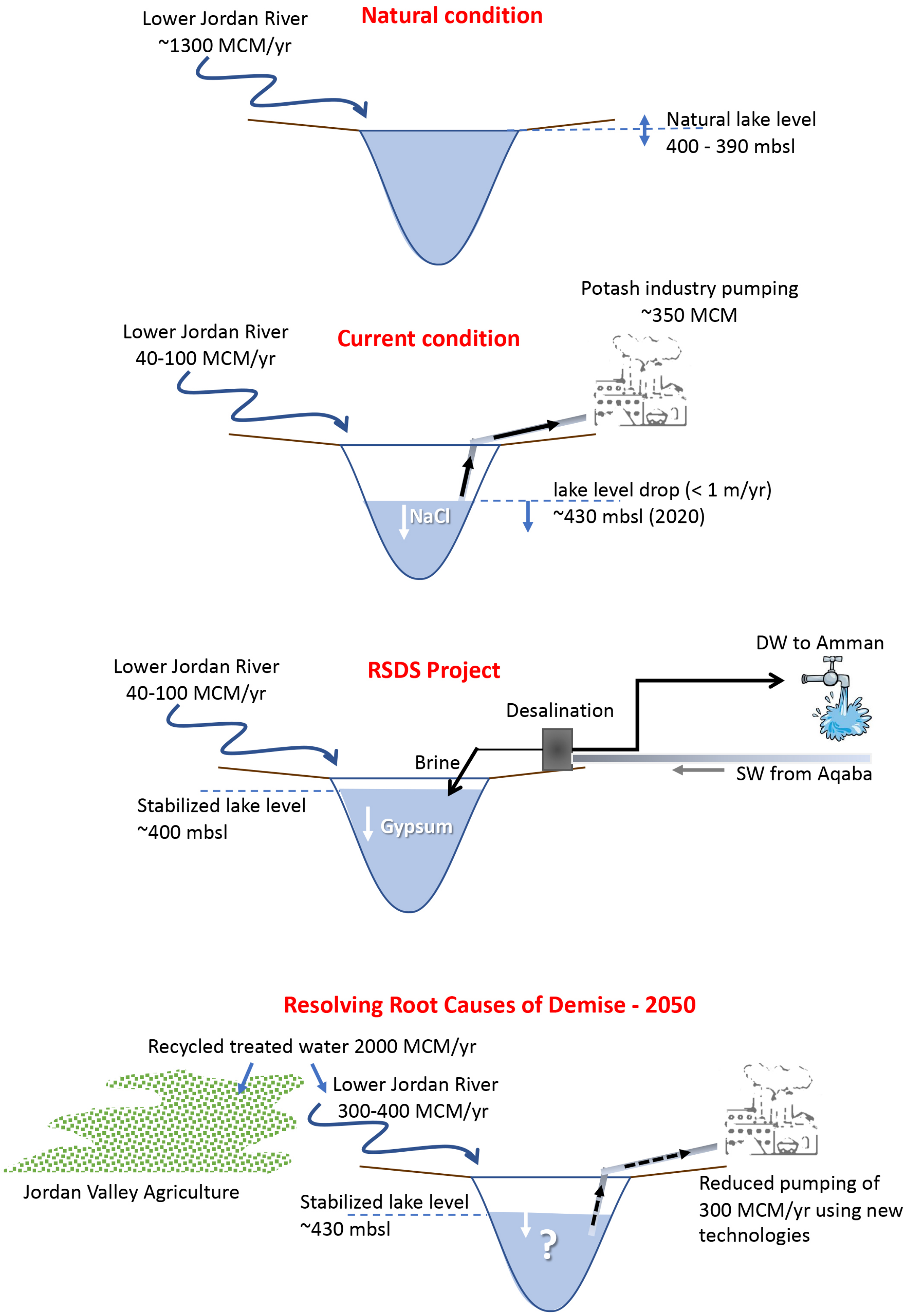

Figure 5- Schematic illustration of alternatives for the stabilization of the Dead Sea level. A combination of these different alternatives can also be proposed. Based on (Malkawi and Tsur, 2016).

8.2 Additional details of the 2050 available wastewater calculations

8.2.1 Method to calculate 2050 wastewater availability

The urban population was determined for the most recent year with the number of people outside the appropriate region (Figure 4) subtracted from the total population. The population growth in the region was averaged. Domestic water use was extrapolated to the future population. Agricultural demand was tabulated and then the appropriate percentage increase was calculated. Wastewater and agricultural needs already allocated for use in the Jordan Valley by the NGO Master Plan was subtracted for each region. All available wastewater available was summed across the riparian states and 82% of agricultural need was subtracted from it to account for an increase in agriculture. The remaining water is what is available for release into the Dead Sea. Table 6 provides the values used to complete the calculations

Table 6- Tabulation of how available wastewater for 2050 calculations were conducted

	Value	Base Year	Source	2050 Projection
Israel				
Population				
Total Population	8883800 people	2018	World Bank Database	16847957 people
Population Growth Rate	2%	Aver. 2015-2018	World Bank Database	
Urban Population	8210230 people	2018	World Bank Database	15570544 people
Urban Population Growth Rate	2%	Aver. 2015-2018	World Bank Database	
Percent of Population North of Ashkelon	86.7%	2018	Certal Bureau of Statistics	
Population North of Ashkelon§				14607179 people
Water Demand				
Domestic Water Demand*	263 l/c/d	2016	Israel Key Sector Report	
Agriculture				
Agriculture Water Demand	1287 MCM	2016	Israel Key Sector Report	
Water Demand with 0.2%/yr Increase				1372.208 MCM
Water Demand with 0.6%/yr Increase				1572.114 MCM
Jordan Valley				
JV Agricultural Water Demand			NGO Master Plan	158.708 MCM
JV Wastewater Reuse			NGO Master Plan	0.003871 MCM
Calculations				
Agricultural W.D. - JV Agriculture W.D.†				**1213.500 MCM**
Percent agriculture W.D. from WW				**82 %**
Agriculture W.D. from WW				**995.070 MCM**
Jordan				
Population				
Total Population	9956911 people	2018	World Bank Database	17712434 people
Population Growth Rate	1.8%	2018	World Bank Database	
Urban Population	9057879 people	2018	World Bank Database	17178094 people
Urban Population Growth Rate	2%	2018	World Bank Database	
Percent Population North of Madaba§	83.5 %	2018	Jordan Population and Family Health Survey 2017-2018	
Percent of Population in Urban Areas	91 %			
Population North of Madaba in Urban Areas§				13452361 people
Agriculture				
Agriculture Water Demand	700 MCM	2015	Jordan National Water Strategy	
Water Demand with 0.2%/yr Increase				750.756 MCM
Jordan Valley				
JV Agricultural Water Demand			NGO Master Plan	276.258 MCM
JV Wastewater Reuse			NGO Master Plan	0.007805 MCM
Calculations				
Agricultural W.D. - JV Agriculture W.D.†				**474.497 MCM**
Percent agriculture W.D. from WW				**82 %**
Agriculture W.D. from WW				**389.088 MCM**
West Bank				
Population				
Total Population	2860000 people	2015	Securing Water For Development	5759333 people
Population Growth Rate	2%	Aver. 2015-2018	World Bank Database	
Urban Population	2113540 people	2015	National Water and Wastewater Strategy for Palestine	4645339 people
Urban Population Growth Rate	2.25 %	Aver. 2015-2018	World Bank Database	
Agriculture				
Agriculture Water Demand‡	28.5 MCM	2013	Status of the Environment in State of Palestine	35.511 MCM
Agriculture Water Demand Increase			NGO Master Plan	24.6 %
Jordan Valley				
JV Agricultural Water Demand			NGO Master Plan	125.170 MCM
JV Wastewater Reuse			NGO Master Plan	0.002573 MCM
Calculations				
Percent agriculture W.D. from WW				**82 %**
Agriculture W.D. from WW				**29.119 MCM**

Table 7 - Table summarizing the function and status of WWTPs in Jordan. Italicized WWTPs utilize natural processes while the others utilize mechanical processes. Red indicates exceedance of standards. Unless otherwise noted data is from (Alfarra et al., 2011) and (Alzoubi, 2018).

Wastewater Treatment Plant	Treatment Technology	Design Capacity (CM/day) 2017a	Daily Influent (CM/day) 2017a	Cr	Al	Ca	Mg	Na	Cl	NH3	NO3	Phenol	TSS	TDS	COD	BOD	DO	PH	Repeated Violations
Al samra*[b]	AS	360000	344548.5	<0.02	<0.7	75	19	207	288	9	54	<0.002	9	935	41	6	4.1	7.53	
Kufrenjeh*[b]	TF	9000	3497	--	--	106	17	76	119	63	4	<0.002	266	680	1158	228	2.1	7.58	T-N
Wadi Hassan*	AS	1600	1262	--	--	83	28	163	206	7	4	<0.002	17	844	59	7	7	8.35	
Me'rad*	AS	10000	4397	--	--	117	23	196	275	8	<1.0	<0.002	71	996	315	46	6.3	7.38	
Aqaba-Mechanical[c]	AS	1200	12719	--	--	67	24	155	177	57	7	0.006	207	752	426	18	2.9	7.61	
Tafeileh[b]	IT & AS	1600 (7500)	1945	--	--	83	41	171	204	95	2	<0.002	53	988	456	97	0.3	7.46	BOD, COD, TSS, T-N, E.Coli
Karak	AS			--	--	121	16	191	279	186	1	0.01	330	1142	963	365	0.6	7.46	BOD, COD, T-N
Madaba*[b]	N/A	7600	7388	<0.02	<0.7	77	26	245	277	34	2	<0.002	15	984	76	15	3	7.79	
Jeizeh[b]	AS			--	--	93	37	194	257	106	<1.0	<0.002	34	1008	97	15	3.4	7.82	
Wadi Seer*[b]	WSP	1700	5040	<0.02	<0.7	89	9	112	155	68	3	<0.002	20	708	318	23	3	7.73	T-N
Fuheis & Mahes*	AS	2400	2928	<0.02	<0.7	100	21	125	166	<4.5	14	<0.002	96	784	125	11	2.4	7.62	E. Coli
Ramtha*[b]	AS	5400	4268	--	--	119	41	335	528	85	4	<0.002	23	1514	88	5	5.7	7.73	
Wadi Musa	AS	3400	2832	--	--	86	43	144	24	<4.5	43	<0.002	7	854	25	3	6.4	7.69	
Sheikh Hussien Bridge	AS			--	--	118	90	26	266	31	<1.0	<0.002	68	1079	104	37	3.6	8	
Swaqa	AS			--	--	103	36	207	311	89	34	<0.002	51	1108	236	36	3.3	7.54	
Karak Hospital[b]	AS	5500	1321	--	--	94	42	313	463	<4.5	146	<0.002	15	1388	45	10	4.6	7.46	
Aqaba-Natural	WSP	9000	7066	--	--	57	15	136	160	<4.5	2	<0.002	4	575	25	4	2.8	7.23	
Al-Bayt University	AS			<0.02	<0.7	55	41	71	156	16	58	<0.002	4	504	14		4.3	7.53	
Mutah University	AS			<0.02	<0.7	63	19	81	133	<4.5	212	<0.002	6	677	30	5	4.8	6.76	
JUST	Bio			<0.02	<0.7	64	35	137	147	<4.6	143	<0.002	6	722	34	9	4.7	7.78	
Al-Hussein Bin Talal University	AS			<0.02	<0.7	77	33	61	96	<4.5	23	<0.002	5	499	13	5	5.2	7.72	
Akeider*	WSP	4000	2087	--	--	110	40	395	1167	186	3	--	381	1962	2201	9	1.6	8.05	COD, TSS, T-N, TDS
Abu-Nussier*	AS	4000	3385	--	--	65	20	153	199	<4.5	55	<0.002	8	804	45	6	3.8	6.84	
Baqa'a*	TF			--	--	90	31	202	33	59	76	--	19	993	101	23	2.6	7.78	E. Coli
Salt*[b]	AS	2500 (7600)	8086	<0.02	<0.7	79	27	139	175	44	<1.0	<0.002	30	755	86	22	2.1	7.59	E.Coli
Irbid*	AS & TF	13350	8272	--	--	108	33	228	309	112	2	0.01	124	1272	361	115	4.5	7.77	COD, TSS, E. Coli
Wadi Al-Arab	ASa	20800	12683	--	--	108	30	195	230	53	<1.0	<0.002	31	1034	101	39	6.2	7.9	E. Coli
Mafraq[b]	WSP	5500	3731	--	--	90	37	243	187	98	40	0.02	109	1222	427	100	0.1	7.92	
Ma'an[b]	AS	7000	2324	--	--	90	37	243	287	98	40	0.02	109	1222	427	100	0.1	7.92	
Lajoun[b]	WSP	1200	712	--	--	106	87	398	564	10	18	<0.002	76	1964	267	23	11.8	8.41	TDS
Tal Mantah	TF + ASa	400	383	--	--	91	25	264	355	203	122	<0.002	39	1252	198	23	4.3	7.49	
Al-Karak Collage				<0.02	<0.7	70	23	142	181	<4.5	327	<0.002	25	868	29	5	5.8	7.58	
Al-Mansourah	WSPa	50	20	--	--	10435	225	258	73	3	<0.002	372	1212	1023	36	4.3	7.96		
Al-Shoubak	WSPa	350	153	--	--	109	44	260	295	<4.5	3	<0.002	11	1176	80	14	3.9	8.02	
South Amman*[c,a]	AS	52000	13517.5																
Wadi Shallaleh[c,a]	AS	13750	8421																COD, T-N, E.Coli
Mutah-Mazar-Adnaniyyah[c,a]	AS	7060	1369																
North Shouna[c,a]	WSP	1200	655																

a (Soud & Subah)
* Located in the Jordan Valley
b Upgraded after 2016
c New construction

(AS) = activated sludge
(WSP) = waste stabilization pond
(TF) = trickling filter
(MBR) = membrane bioreactor

9. References

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