PUMPED STORAGE IN ASSOCIATION WITH THE RED SEA TO DEAD SEA PEACE CANAL

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INTRODUCTION

We discuss pumped energy storage in conjunction with the proposed Red Sea to Dead Sea Peace Canal project or the Aqaba hybrid seawater and pumped storage scheme for cogeneration. As an ecological project, it would restore the surface area of the northern basin of the Dead Sea and preserve from extinction the Fauna and Flora on its shrinking shores. The water level is falling at a rate of 4 ft / year.

A combination of single purpose and dual purpose plants is proposed along the canal route providing a balance between the fresh water and electricity needs. This would address the areas acute fresh water shortage providing about 830 billion cubic feet of fresh water to be shared among Jordan, Palestine and Israel, and satisfies a focus of international cooperation and economic development for peace and confidence building which has developed in the aftermath of the "Treaty of Peace" between Jordan and Israel on October 26, 1994.

Figure 1. Receding shoreline of the Northern Dead Sea basin is apparent. Water level is decreasing by about 1 m per year.

GEOGRAPHY AND HISTORY

The Dead Sea is located on the northern part of the Great Rift Valley fault line which extends southward into the Red Sea and East Africa. The Jordan River flows down from the north until it reaches the lowest point on Earth at 1,370 feet under sea level. Fully 98 percent of the Jordan River's water is diverted by bordering countries, and more than half of that by Israel. Syria and Jordan share the rest; and the Palestinians claim about 5 percent. The inland sea there is flanked by the rift walls composed of the Judean Hills to the west and the mountains of Moab to the east.

The lowest point on Earth, named as one of the natural wonders of the world, is dying. The Dead Sea, commonly called the Salt Sea, is divided into two northern and southern basins. The two basins do not connect to one another. At the southern basin, the waters are rising as flooding threatens the well-being of the ecosystem. This portion of the sea is an extraction site by many chemical companies, who extract lucrative minerals from the lake. Taking chemicals out of the lake leaves tons of salt on the bottom of the sea, causing the water levels to rise nearly 8 inches per year.

At the northern basin of the Dead Sea, the water level is dropping. As Jordan, Israel and Syria all redirected the Jordan River and its tributaries for drinking and agricultural uses, the flow to the Dead Sea has been drastically reduced. The World Bank is considering channeling water through a canal from the Red Sea.

Magnesium, sodium and calcium chlorides salts are washed into the Dead Sea in the waters flowing from the Jordan River and other smaller rivers, streams and springs. The Jordan River alone deposits 850,000 tons/year of salts. Being at the lowest point on Earth, the water cannot drain out and is lost through evaporation. On a summer day, 7 million tons/day of water are lost to evaporation. The minerals and salts left behind from the evaporative process result in a water salinity of 30 percent; several times saltier than the world's seas and oceans. The volume of the sea is not increasing and is in fact shrinking, threatening an ecological disaster to the faunal and floral lives on its shores.

Over the centuries it has been called: the Stinking Sea, the Devil's Sea, and the Lake of Asphalt. In the Bible it is called: the Salt Sea and the Sea of Arabah (Genesis 14:3, Joshua 3:16). Legend suggests that the ruins of Sodom and Gomorrah are under its waters; so it is also called: the Sea of Sodom or the Sea of Lot; the prophet associated with their history and mentioned in both the Islamic Quran and the Christian Bible.

The Greek philosopher Aristotle reported that the Sea was: "so bitter and salty that no fish lived in it." The high salt concentration results in such a high water density that creates substantial buoyancy so that it is easy for swimmers to stay afloat. The historian Flavius Josephus tells a tale of how the Roman General Vespasian put this phenomenon to the test by throwing his prisoners into its waters. Upon exiting the water, swimmers would find their skins covered with an itchy layer of salts, unless promptly showered and washed out with fresh water.

It used to be a bustling trade route in the 7-5th centuries BC with ancient harbors such as the one at Engedi from the Roman times. On its receding shores two 2,000-2,500 years old wooden anchors that were preserved by the salt content were discovered; together with fragments of the ropes attached to them.

The shores of the Dead Sea are thriving with wildlife and constitute an important ecological system. In the sea water only simple organisms such as resilient forms of bacteria can survive. The surrounding region, even though considered as arid, possesses pockets of lands that stand as lush oases thriving out with fresh-water waterfalls and tropical plants.

The shores of the Dead Sea are recognized as a flourishing wildlife habitat. There exists 24 species of mammals living near its shores. This includes unique species such as the sand cat, the Arabian wolf and the ibex.

In ancient times, desert lions existed there. Balsam, a tree that used to grow in the area had been valued and used for cosmetic and medicinal purposes in antiquity and medieval times.

The Dead Sea is situated in the path of a major migration flight path from Europe and Asia to Africa. Over 90 bird species have been identified there including the black stork, the white stork, the griffon vulture and the Egyptian vulture.

In ancient times people used to drink its water, attributing to it some curative features. Today the salt water is thought to have a cleansing effect on the body. The low altitude is claimed to possess an oxygen-rich atmosphere. The high concentration of bromide in the atmosphere is said to have a relaxing effect. The mineral-rich black mud and hot sulfur springs along its shores are the basis of multiple health spas where a number of skin ailments and arthritic disorders are treated. Tourism draws each year thousands of people to its shores.

Arid regions of the world currently experience a fresh water shortage that is more prominent than electrical energy per se. In fact, the demand for fresh potable, municipal and agricultural water far exceeds the need for electricity in regions such the Middle East. The experience to be gained there would be applicable to other regions of the world.

Table 1. Major world depressions.

	Location	Elevation [m]	Area below sea level [km²]	Distance from sea or ocean [km]
Dead Sea	Jordan, Israel	-401	3,800	72
Lake Tiberius, Sea of Galilee	Syria, Israel	-212	-	50
Assal	Djibouti	-174	80	15
Turfan	China	-154	5,000	1,500
Qattara Depression	Egypt	-133	44,000	56

A most prominent prospect for the implementation of nuclear desalination and the establishment of agro-industrial communities is in conjunction with the Red Sea to Dead Sea area shared by Jordan and Israel in the Middle East region. Currently a pipeline project is under consideration for conveying water from the Red Sea to the Dead Sea for hydroelectric power generation and possibly some form of Reverse Osmosis desalination scheme.

The project for a canal linking both seas is under consideration with 11 firms commissioned to conduct feasibility studies. The USA, France, the Netherlands and Japan allocated $9 million for a 2 years study costing $15 million that was managed by the World Bank. The project is under consideration by a joint Jordanian, Palestinian and Israeli committee. Such a project could take 25 years to complete and cost in the range of $15 billion dollars. The project has been under consideration since Jordan and Israel signed a peace treaty in 1994.

Currently, to save $1 billion in cost the use of a pipeline instead of a canal is under consideration. The adoption of a canal alternative would, on the other hand, offer long term advantages of the possibility of the economical development of agro-industrial communities along the canal route, supplied with fresh water and electrical needs from future solar and single and dual purpose nuclear power plants.

On September 16, 2007, Jordan represented by Khaled Toukan, Minister of Scientific Research and Higher Education and the USA represented by Secretary of Energy Samuel Bodman, signed a memorandum of understanding on the sideline of a nuclear energy summit in Vienna, Austria, supporting the peaceful development of a nuclear program. Under the agreement, “the two countries will work together to develop requirements to appropriate power reactors, fuel service arrangements, civilian training, nuclear safety, energy technology and other related areas.”

Khaled Toukan envisions nuclear energy to provide 30 percent of the electrical energy produced in Jordan by 2030, with a possibility of exporting energy through a nascent Middle Eastern electrical grid system. Jordan’s Minister of Energy, Khaled Al Sharaydeh, suggested that Jordan possesses an estimated 80,000 tons of high grade uranium reserves and that its phosphate rocks constitute an additional low grade reserve of 100,000 tons of uranium fuel.

Figure 2. Enhanced satellite picture of the proposed Red Sea to Dead Sea canal location. The length of the canal would be slightly longer than the existing Suez Canal to the left. Source: Microsoft Virtual Earth, NASA photograph.

King Abdullah II of Jordan announced his intention to develop a peaceful nuclear program in January 2007, asserting that alternative energy sources were needed to generate electricity and desalinate water in the Jordanian kingdom. Jordan has signed the Non Proliferation Treaty (NPT) and has advocated a Middle East free of weapons of mass destruction. In fiscal year 2007, $454 million were allocated to Jordan as economic and military aid, supplemented with $78 million disbursed in September 2007 to boost its efforts to improve education and health services in communities that have been swollen by a fraction of a large influx of 2 million displaced refugees from neighboring zones of conflict.

DUAL BASINS OF THE DEAD SEA

The Dead Sea is divided into two northern and southern basins. These are located at different elevations, disconnected and miles apart. The water is rising in the southern basin and cannot pour into the higher elevation shrinking basin in the north. Heavy industrialization is causing the waters on the southern basin to rise. Chemical companies have built evaporation pools there to extract minerals from the lake, particularly potash. Large amounts of salt are left annually on the floor of these pools, causing the water to rise 8 inches per year.

A complex $2 billion tourism plan was conceived to dredge the salt and convey it from the part of the sea that is rising and send it by conveyor belt to the northern end that is dropping. Half of the 3.45 million tourists to Israel paid a stop there in 2010. Almost 200,000 stayed at the 4,000 hotel rooms along the lake. Local residents also flock there with more than 630,000, almost one in 10 Israelis spending time at the Dead Sea hotels each year. Dead Sea tourism revenue reaches about $300 million per year, propping up an industry that accounts for thousands of jobs in an area that offers limited employment opportunities.

The southern basin that is in danger of flooding nearly dried up before the chemical companies entered the picture. In the 1960s, The Dead Sea Works chemical company dug a 10-mile canal to convey salty water from the lake's northern basin into its parched southern end, turning it into a network of evaporation pools. This area is where the bulk of the Israeli hotels lie, and where tourists swim in water so heavy with salt and minerals that they float. As the water rises, it encroaches on the hotel beaches, where chunks of salt stick out near the shores and the salty sea floor sparkles in the water. At some beaches the stairs leading to the lake are half-submerged.

The exact opposite problem occurs at the Dead Sea's northern basin, where the water level is dropping and a barren, pockmarked moonscape has replaced sandy beaches. Old boardwalks that once led into the lake now stand in the middle of empty land. At one beach, bathers must ride a trolley to the lake's edge.

Israel, Jordan and Syria caused the northern Dead Sea basin's shrinkage: They have redirected the Jordan River and its tributaries for drinking water, drastically reducing the amount that used to flow into the Dead Sea. The Israeli and Jordanian industries also pump out water from the northern basin of the sea to their evaporation pools in the southern basin.

The World Bank considered a decades-old proposal to replenish the northern Dead Sea's basin waters by channeling water through a canal from the Red Sea, 100 miles south at a cost is estimated at $15 billion.

GEOLOGICAL AND ECOLOGICAL FEATURES

The Dead Sea is the most salty as well as the lowest point on Earth at over 400 meters below sea level. The Dead Sea as a terminal lake has a salinity of 250,000 ppm, which is seven times the salinity of the open ocean. The salt concentration is 33 percent compared with 3 percent in the Mediterranean Sea. It is fed mainly by the Jordan River.

It is shrinking in size with its water level dropping at a rate of one meter per year in the last 20 years. This is caused by solar evaporation and the upstream diversion for agricultural and municipal uses of the water of the Jordan River and its tributaries that feeds into it by Jordan, Israel and Syria. The Jordan River currently flows into the Dead Sea at 7 percent of its original rate. The Dead Sea level drops about 4 feet per year and has fallen about 20 meters over the last 50 years. The surface area has decreased by 30 percent in the last 20 years.

At the beginning of the century, the Dead Sea level was 390 meters below sea level; as of 1977 it was 411 meters below sea level. Its surface area was 950 km^2, it was 640 km^2 by 1977. Its volume was 155 km^3, as of 1977 it was 131 km^3.

Its dried sea floor has developed sinkholes as a concentration of minerals and salt that collapse into craters. Erosion is occurring at the banks threatening the potash extraction industries on both the Jordanian and Israeli sides. Tourism is affected in that hotels at resorts built on the Israeli side have to ferry tourists using buses more than one mile from the hotels sites to the receded shore line. Environmentalists foresee an entire drying of the Dead Sea and a disappearance of its surrounding ecosystem within the next 50 years if no remedial action is taken.

Figure 3. Enhanced satellite picture of the southern edge of the Dead Sea showing the north and south basins and the potash extraction works evaporation ponds in the southern basin. Israel's Dead Sea Works and Jordan's Arab Potash companies mine Dead Sea

waters for potash and other minerals, exporting them worldwide. Source: Microsoft Virtual Earth, NASA photograph.

Figure 4. Salt flats at the Dead Sea.

Figure 5. Dead Sea Works chemical extraction factory. Source: AP.

CURRENT CONSIDERATIONS

The Red Sea to Dead Sea Canal has been under consideration for several decades. Its route has been designated as the peace conduit.

The 400 meters drop at the Dead Sea has been proposed to be used for hydroelectric power generation as well as for reverse osmosis desalination. The pressure of 40-60 kg/cm^2 would be directly used to convert sea water for drinking purposes at an estimated treatment cost of about $1 per cubic meter. The hydro powered reverse osmosis desalination plant would include a pre-treatment unit, a pressure control unit, the reverse osmosis unit, an energy recovery unit, a post treatment unit, and regulating reservoirs for distribution.

Under consideration is a canal route starting at Aqaba in Jordan. Two other competing canal routes have been considered starting from the Mediterranean Sea. The main hurdle is a hilly elevation of 170 meters along the canal route from the Red Sea to the Dead Sea. Excavation, tunneling, or pipeline conveyance with pumping of the water flow must be considered along a 110 miles stretch of the proposed canal.

Under current consideration is the production of hydroelectric power from the water drop into the Dead Sea. At the point of connection to the Dead Sea, co-sited power and desalination plants have also been proposed. Part of the electricity produced would be conveyed back for pumping of the water above the 170 meters elevation. Another part of the electricity would be allocated to a desalination plant using membrane technology.

REVERSE OSMOSIS

The Reverse Osmosis process includes three phases: pretreatment, processing, and post-treatment.

Pretreatment

Before being desalted, the water must pass through three pre treatment steps to remove all solids that would clog the expensive desalting membranes if they were not removed. Pre-treating the water ensures a membrane life of three to five years. As the water flows into the plant, chlorine is added to prevent the growth of algae and other organisms. The water then goes through a grit sedimentation basin to remove heavy grit, sediment, and suspended sands in the water. The water is softened by removing some of the calcium. Lime and ferric sulfate are both used in solid contact reactors. Then dual media filters are used to remove any fine particles or organisms remaining in the water.

Processing

Reverse osmosis is the separation of one component of a solution from another in the present case, salt from water, by means of pressure exerted on a semi impermeable plastic membrane.

A total of about 6,750 membrane elements inserted into fiber glass pressure vessels will desalt the water. The pressure tubes are 6 m or 20 ft in length. Some membranes have a diameter of 30 cm or 12 inches, while the diameter of others is 20 cm or 8 inches.

The elements are made up of a number of sheets rolled into a spiral-wound membrane. The separation of salt is a chemical process as well as a physical diffusion process. The water will be forced through the walls of cellulose acetate or synthesized membranes by applying pressure at about 15-25 kg/cm^2, allowing only the freshly desalted water to pass through. This process will filtrate 75 per cent of the feed water and remove about 97 per cent of the salts from it. The fresh water will be forced by the downward pressure toward the central tube.

Post treatment

The water, with a salinity level of 300-500 mg per liter of Total Dissolved Solids (TDS), will then be treated to make it safe for drinking in accordance with the World Health Organization (WHO) standards. The water pressure in the brine reject which constitutes 25 percent of the feed water with 10,000 mg/liter salinity, will be used to generate electricity with a 1 MWe mini hydropower plant at the end of the reverse osmosis module circuit. After retrieving energy of 6.4 million kW.hr per year, the brine will be directly released into the Dead Sea, where it will mix with its extremely saline water body at 300,000 mg/liter of TDS.

TECHNICAL SPECIFICATIONS

The theoretical hydroelectric potential from exploiting the 400 meters head difference between the Red Sea and the Dead Sea with a volumetric flow of $56.7 m^3$/sec. or 1.6 billion m^3 per year of sea water is estimated to be 194 MWe. The hydroelectric power plant would produce 1.3 billion kW.hr per year of electrical energy with an installed capacity of 495 MW assuming peak power operation.

Figure 6. Enhanced photograph showing the cities of Aqaba and Eilat area along the Red Sea. Source: Microsoft Virtual Earth, NASA photograph.

Figure 7. Enhanced picture of the proposed Dead Sea to Red Sea canal route. It also reveals the existence of flat areas amenable to agricultural and industrial development with fresh water and electricity. Source: Microsoft Virtual Earth, NASA photograph.

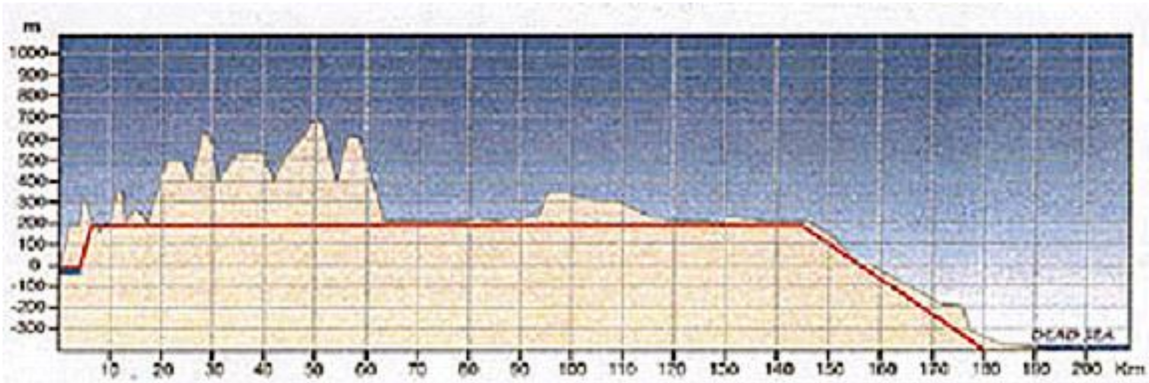

Figure 8. Ground elevation along proposed canal route.

If a booster pumping alternative is applied to make an effective head difference of 500 m, taking into account the operating water pressure at 50 kg/cm^2 and cheaper electricity during off-peak periods, the sea water diversion capacity is estimated to be 50 m^3/sec, consisting of 39 m^3/sec of intake water for the hydroelectric power unit and 11 m^3/sec of feed water for the desalination unit.

The hydropower unit would have a theoretical hydroelectric potential of 160 MWe to generate 1.2 billion kW.hr per year of electrical energy with an installed capacity of 480 MWe and operating at peak power for 8 hours per day. For the production of 100 million cubic meters (MCM) per year of permeate or water filtered through a membrane, the installed capacity of the reverse osmosis plant is estimated to be 322,300 m^3/day with a load factor of 85 per cent.

Marginal operation of the reverse osmosis system is designed to use the hydroelectric potential energy in a tunnel conduit with 481.5 m of effective head of water for 16 hours a day off-peak. The feed-water requirements to produce 100 MCM per year of permeate with 1,000 mg/liter of total dissolved solids (TDS) are estimated to be 333 MCM per year, assuming a 30 per cent recovery ratio. The brine reject of 233 MCM a year, whose salinity is 57,000 ma/liter of TDS, is then discharged into the Dead Sea. The energy recovery potential from the brine reject is estimated to be 28,280 kW.hr, assuming 20 per cent of frictional losses in the reverse osmosis circuit. The reverse osmosis plant is assumed to be operating for 16 hours per day.

The annual production of electricity from the reverse osmosis brine reject is estimated to be 168 million kW.hr with a load factor of 68 percent. The recovered energy as electricity would be used to supply electricity for the post treatment process or other purposes to save electricity on the national grid.

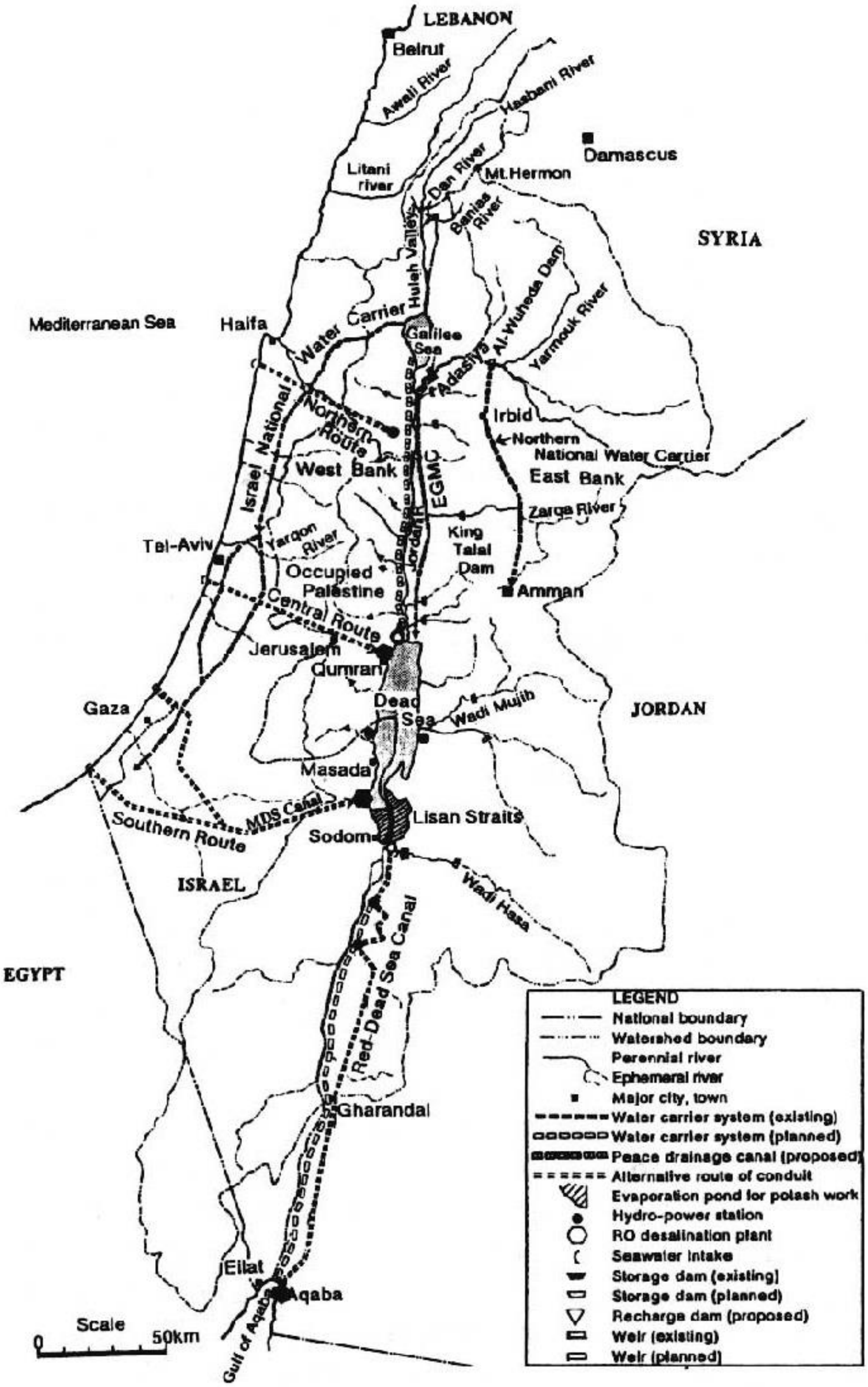

Figure 9. Proposed routes for Dead Sea canal projects.

PUMPED STORAGE ENERGY AND POWER PRODUCTION

The potential energy of a mass of fluid at a height h is given by:

$$E = mgh\,[Joule] \qquad (1)$$

where:

m is mass [kg]

g is the gravity acceleration constant $= 9.81[\frac{m}{\sec^2}]$

h is height or water head difference [m]

The theoretical hydroelectric power can be estimated from:

$$P = \frac{dE}{dt} = \frac{d}{dt}(mgh) = \frac{dm}{dt}gh = \dot{m}gh\,[\frac{Joule}{\sec}][Watt] \qquad (2)$$

where:

$\dot{m}$ is the mass flow rate $[\frac{kg}{\sec}]$

The mass flow rate can be expressed as:

$$\dot{m} = \rho\dot{V}\,[\frac{kg}{\sec}] \qquad (3)$$

where:

ρ is the water density $[\frac{kg}{m^3}]$

$(\rho = [1.03 - 1.05] \times 10^3 [\frac{kg}{m^3}]$, for salt water)

$\dot{V}$ is the volumetric discharge rate $[\frac{m^3}{\sec}]$

Substituting from Eqn. 3 into Eqn. 2 yields:

$$P = \rho\dot{V}gh\,[Watt] \qquad (4)$$

The electrical power production depends on the efficiency of the electrical conversion process as:

$$P_e = \eta\rho\dot{V}gh \times 10^{-6}\,[MWe] \qquad (5)$$

where: η is the pumped storage conversion efficiency in the range of 0.67-0.93

If the pumped storage facility is used for peak-load power generation, say for 8 hours per day, the required installed capacity would be:

$$P_{installed} = \frac{24}{8} P_e = 3P_e [MWe] \tag{6}$$

The yearly potential electrical energy generation per year would be:

$$\begin{aligned} E_{year} &= (365 \times 24) P_e \\ &= 8,760 P_e [\frac{MWe.hr}{year}] \end{aligned} \tag{7}$$

If a combined electrical generation and desalination facility is used, we can write for the electrical power generation:

$$P_e = \eta \rho \dot{V} g h \times 10^{-6} (1 - f_{des}) [MWe] \tag{8}$$

where: f_{des} is the fraction of electrical energy used by the desalination process

and for the electrical energy diverted to the desalination process:

$$P_{des} = \eta \rho \dot{V} g h \times 10^{-6} f_{des} [MWe] \tag{9}$$

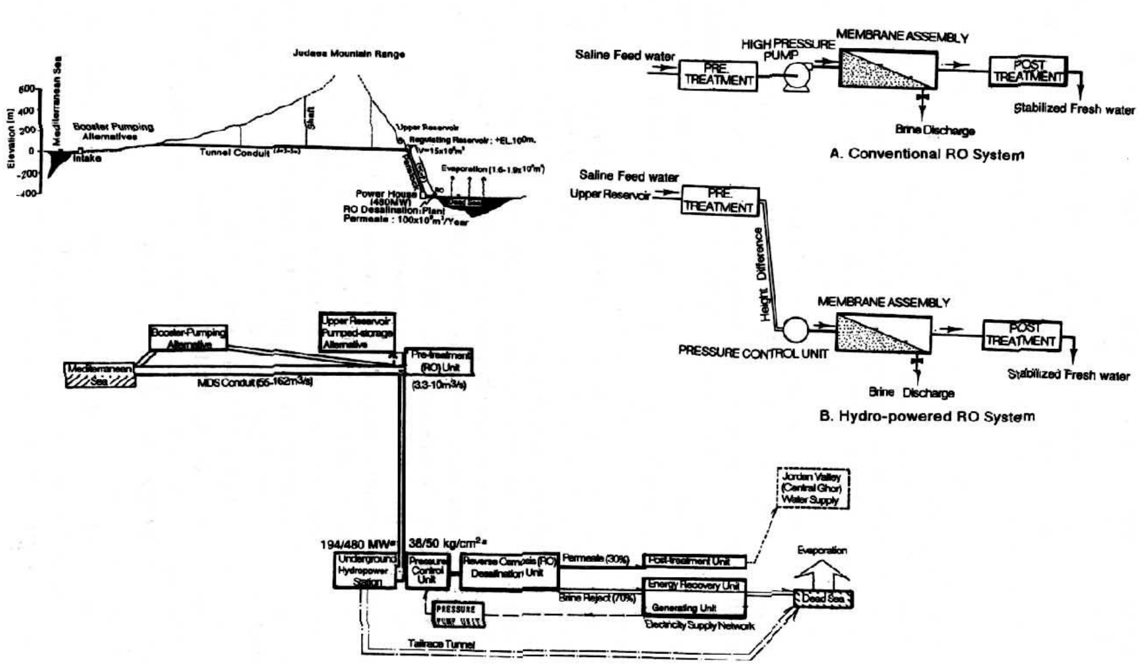

Figure 10. Proposed desalination alternatives for Red Sea to Dead Sea Canal.

COST ESTIMATES

The available cost estimates were reported in 1999 dollars assuming a plant lifetime of 20 years and 8 percent interest rate during 3 years for construction. The costs of the reverse osmosis unit are $389.4 million capital expenditure and $44.4 million per year for operation and maintenance. This assumes a membrane life and replacement time of 3 years. This includes the exclusion of the cost benefits from energy recovery, and the costs of source water and pipeline distribution system.

The water cost of hydro powered sea water reverse osmosis desalination to produce 100 MCM/yr is estimated to be $0.63/m^3. For comparison, the international water tariff and the estimated unit water cost is $0.85-1.07/m^3 in the "Peace Pipeline" project from Turkey, and the estimated unit water cost is $1.6/m^3 by conventional reverse osmosis desalination using electricity to create a pressure of 50-60 kg/cm^2.

PERCEIVED BENEFITS

The project's main advantage would be to protect the ecology surrounding the shrinking Dead Sea area by replenishing its evaporative water losses. There is presently no attempt at modifying the present ecology by enlarging its surface area possibly enhancing precipitation in an otherwise arid environment; even though such a prospect by itself is worth studying.

Restoring the Dead Sea surface area and water level to their original levels would preserve the existing potash extraction industries and curb erosion of its banks. These industries are important not just in terms of employment opportunities, but also in providing potassium as a fertilizers and food production ingredient. The Dead Sea water level would be maintained at a steady state level with some seasonal fluctuations of about 2 meters to sustain the seawater level between 402 m and 390.5 m below mean sea level, during which inflow into the Dead Sea should balance evaporation.

Maintaining the present shore line of the Dead Sea is important in preserving the existing resort and tourism industry, both on the Jordanian and Israeli sides.

The 400 meters below sea level hydrostatic drop from the Red Sea into the Dead Sea as the lowest point on Earth provides a hydroelectric power production capability proportional to the water flow needed to compensate for the evaporative water losses. As presently conceived this electricity, or alternatively the pressure drop of the water can be used in a membrane process such as Reverse Osmosis to produce fresh water. The potential energy due to gravity would not be sufficient by itself to drive the process, but it could be used to reduce the amount of energy used to pump the feed water through the membranes.

PIPELINE PROJECT

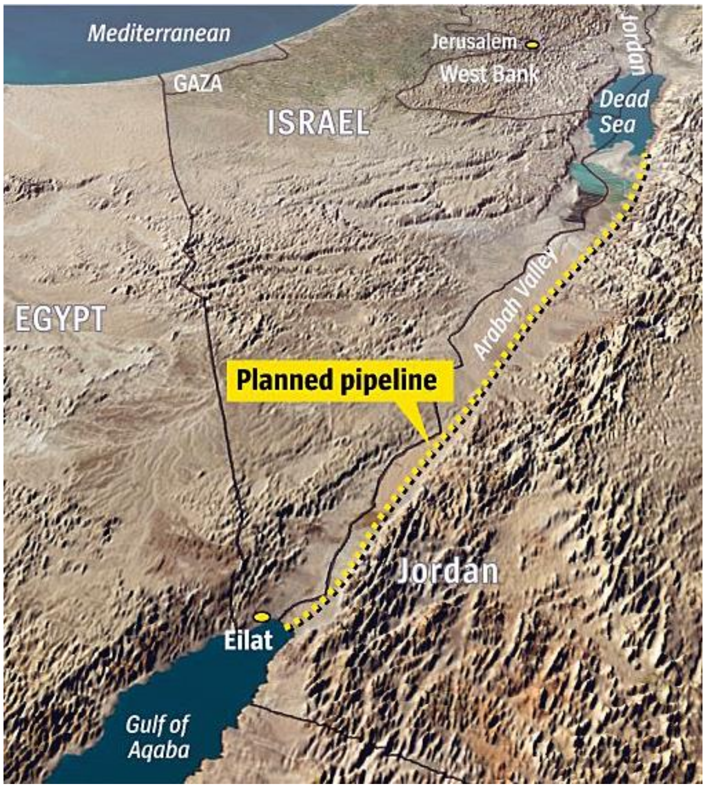

Figure 11. Proposed pipeline through Wadi Arabah. Source: Der Spiegel.

An agreement between Israel, Jordan and the Palestinians is supposed to save the shrinking Dead Sea. But some environmentalists believe the plan to pump brine discarded from a desalination plant could do more harm than good. In December 2013, Israeli Energy Minister with his Jordanian and Palestinian counterparts, agreed to a joint project which would prevent the Dead Sea from drying out and would secure water supplies for the notoriously arid region [8].

The plan is to build a desalination plant in the Jordanian city of Aqaba on the Red Sea, which will then supply both the neighboring Israeli city of Eilat and southern Jordan with fresh water. The brine that is created in the desalination process will be pumped 180 kilometers through a pipeline to the Dead Sea.

Numerous environmentalists and 20 Palestinian Non-Government-Organisations (NGOs) spoke out against the project arguing that the agreement is not a ground-breaking project to save the lake, but simply a water exchange. Israel and Jordan want to build up their water supplies, and the supposedly economically-friendly rescue action is an excellent way to attract international money to do so. The 200 million cubic meters of brine set to be pumped into the Dead Sea by 2017 at the earliest only make up about 10 percent of the water needed to halt the lake's retreat.

Experiments carried out by Israeli microbiologists on behalf of the Geological Survey of Israel show that the transfusion of water from the Red Sea could have ecological consequences for the Dead Sea. They could include: an uncontrolled growth of red or green algae; the proliferation of bacteria; the lake turning a rusty red color; and the formation of white gypsum crystals on the water's surface. It would also be possible that the water from the Red Sea would not mix properly with the water from the Dead Sea because of different densities, but would rather form layers. In the worst case scenario, microorganisms could establish themselves and convert the gypsum into noxious, putrid, stinking hydrogen sulfide. In addition, the brine produced as the product of desalination could be contaminated with scale formation inhibiting chemicals and copper.

DISCUSSION

The most relevant aspect of the Red to Dead Canal Project is its implications on sustaining peaceful cooperation and coexistence between the previously warring countries of Jordan and Israel. With already existing water shortage, crises worldwide are likely to cause more disputes than oil is presently causing. A joint effort that benefits equally both countries would foster a working relationship with each other.

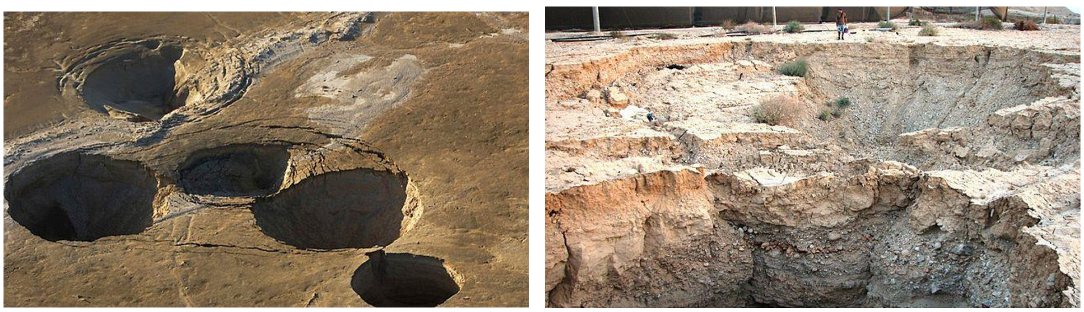

Figure 12. Sink-holes appearing along Dead Sea shores. Source: Univ. of Negev.

Fresh water and electricity production with a large network of canals, tunnels, and pipelines would foster economic development, food production and industries, providing jobs for their respective population. Along with the resulting generated income, fresh water would be available for irrigation in the region. The generated tourist business along the Dead Sea could be revived as the water level is returned to its historic level.

The Dead Sea is proposed as an entry in the International New Seven Wonders of Nature competition, which would generate the interest to protect it. The sharing of ownership and operation of nuclear and desalination facilities would encourage the creation of regional cooperation and inspection frameworks.

EXERCISE

1. Consider a pumped storage facility producing power from stored sea water at a discharge rate of 39 m^3/sec from a height of 500 m.
a) Calculate the theoretical power production of the station.
b) For a conversion efficiency of 85 percent, what would be the effective power generation?
c) Calculate the potential yearly energy production in MWe.hr/year.

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