Greening the Red Sea – Dead Sea Water Conveyance Project

Figure 1 – The shrinking Dead Sea

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On August 12, 2007, a well-attended public meeting was held by the World Bank, in Neve Ilan, near Jerusalem (other meetings were held later also in Ramallah, Jericho and Amman). The objectives of the meeting(s) were defined by the Bank as:

- to inform the public about the Bank's proposed and recently revitalized Study Program for the Red Sea – Dead Sea (RSDS) Water Conveyance project ("the Project"); and
- to obtain the views of all interested parties on the Study Program's Terms of Reference published two years earlier (on April 19, 2005).

Those attending the meeting witnessed a three-hour parade of Israeli opponents to the Project, each voicing, in differing degrees of eloquence and vehemence, their criticisms to both the Project and the Study Program as currently defined and specified. The speakers included mainly representatives of environmental protection groups (the "Greens"), Wadi Araba/Arava agricultural settlements, Red Sea and Dead Sea coasts tourist industry and the two Potash and other chemicals producing companies in Israel and Jordan, who expressed strong concerns about the potential risks to both the ecology and their livelihood that the Project imposes. Opposition was expressed also, by others, on religious and cultural grounds. Almost all speakers complained bitterly and forcefully that the World Bank's Terms of Reference did not include the examination of alternative schemes for saving the Dead Sea.

The main points and concerns raised by these groups, divided into the three zones to be affected by the Project, were:

1. Gulf of Aqaba/Eilat

- The large quantity of seawater to be sucked and pumped out (almost 2 billion m^3 per year) will impact seawater level and circulation over a wide stretch of the Gulf [1] and could have a negative influence on the sensitive coral reef [2].
- The huge pumping station that will be required will occupy a significant area of land at a site where the shore line is limited and short [2].
- Construction activities at the seawater intake will destroy benthic habitat at the site [1].

2. Wadi Araba/Arava

- The groundwater in the Araba/Arava Valley (currently exploited at a rate of 40-55 million m^3 per year) will be vulnerable to salinization due to constant seawater leakage from the conveyance facilities and/or large spills resulting from catastrophic damages thereto from flashfloods, tectonic activities and earthquakes (frequent along this section of the Syrian-African fault line) [1] [2].

3. Dead Sea

- The Dead Sea water column will become stratified with a relatively diluted upper water layer [1]. This will result in an increased rate of evaporation and given the wind regime that exists over the Dead Sea (from north to south) it can be expected that the humidity in the air above the northern section of the Dead Sea will be transported southward and decrease the rate of evaporation from the commercial solar ponds that produce Potash and other chemicals [4].

- Dilution of the surface water and the introduction of nutrients, as a result of the polyphosphate anti-scaling chemicals present in the desalination plant's brine, will result in microbial blooming, which can remain for long periods [1].
- The mixing of the calcium rich Dead Sea water and sulfate rich Red Sea water will result in gypsum precipitation that could lead to the whitening of the surface water [1]. The gypsum may also float on the surface of the water, as a suspension, thereby damaging evaporation rates in the chemicals producing solar ponds [4].
- The lower water layers will likely develop reducing conditions that will result in the release of hydrogen sulfide (H_2S). The hydrogen sulfide will increase the solubility and concentration of trace metals in the Dead Sea water and blanket the Sea with a malodorous toxic H_2S gas [1].
- The inflow of Red Sea water could introduce oil and petroleum pollution, as well as micro-elements and other contaminants that are not found currently in the Dead Sea. These, together with the chemical additives used to pretreat this seawater prior to its use as feed in the desalination plant and discharged with its brine will adversely affect the purity of the chemicals produced from the Dead Sea [4].

The <u>main</u> alternative schemes referred to by the speakers were:

1. <u>The Jordan River Alternative</u>

   Stopping the diversion of Sea of Galilee water to Israel and allowing this water to flow again to the Dead Sea through the Jordan River, just as it did before the Israeli National Carrier project was executed, revitalizing enroute the section of the River connecting the two Seas. To compensate for the loss of this potable water supply to the Israeli water system, new large seawater desalination plants will be constructed along the Mediterranean Sea. [1] [2]

2. <u>The Med-Dead Alternatives</u>

   Supplying the Dead Sea with Mediterranean Sea water through several alternative routes and desalination schemes. [2]

If the World Bank's representatives were surprised and/or frustrated by the strong opposition to the Project exhibited at the Neve Ilan public meeting, they didn't show it publicly. They certainly had every reason to be frustrated:

- They had already redefined the Project (in the Overview Section of the Study Program's Terms of Reference [3]) from an <u>economic</u> project meant primarily to take advantage of and utilize the potential energy difference between the two Seas to generate power and/or desalinated water (while restoring the rapidly decreasing Dead Sea water level) into an <u>environmental</u> "Saving the Dead Sea" project, with potential ancillary water and power supply benefits.

- They had also given the ecological issues of the Project independence and extra weight by separating them, along with the social aspects of the Project, from the main technical and economic feasibility study, and providing them with a separate, detailed TOR, which calls for a comprehensive and critical review by a different, specialized team of experts.

This shift in emphasis was well placed, but, as shown in Neve Ilan, it was insufficient. Also, the Bank's response to the call for examining alternative schemes turned out to be inadequate and unconvincing.

It is the contention of this paper that to win all the nay-sayers support or even only acquiescence, it will be necessary to go further and present the Project not only as a "Saving the Dead Sea" project with potential positive implications to the Sea and the stakeholders that surround it in comparison to the "no action alternative" (see consequences of this alternative in Figure 1, on the cover page, and Figures 2, 3 and 4) and all the alternative schemes promoted by the critics, but as a comprehensive environmental project that will have profound positive ecological and economic benefits to all stakeholders, including those along the route of the water conveyance system and even those north of the Dead Sea.

Right now, even after the above noted shift in emphasis, the goals of Project's environmental and social feasibility study appear defensive, trying mainly to identify, address and find ways to mitigate risks, e.g. how to minimize damage to the coral reefs in the Gulf of Aqaba/Eilat, how to minimize the risks of leakage and contamination of the ground water along the Wadi Araba, etc.

I believe that for the Project to succeed in winning the hearts and minds of all its current opponents, its designers and feasibility assessors must take an imaginative and creative approach and, besides performing all the tasks listed in the World Bank's TOR, suggest and examine several new, bold yet practical ideas and elements that have the potential to enhance the ecological, economic and social dimensions of the Project.

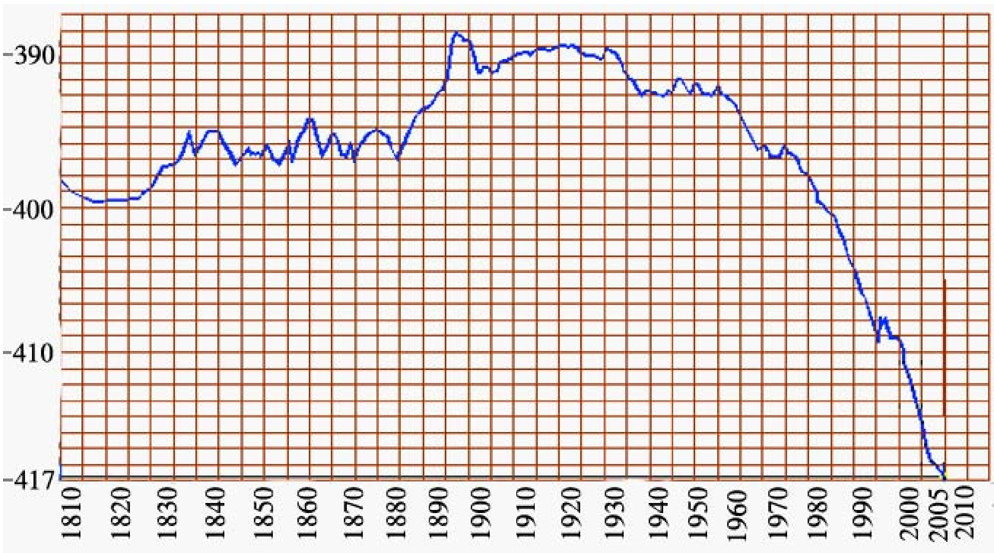

Figure 2 – Receding Dead Sea level

Figure 3 – Receding Dead Sea coastline

Figure 4 – Sink-holes development

In other words, as the title of this paper suggests, they must green the Project further.

To do this, the environmental and social issues will have to lead rather than follow the Project's goals and resultant systems designs.

The conventional thinking and practice ("wisdom") is that environmental assessments and impact analyses should commence only when a project's design has been optimized and finalized on the basis of a value analysis and cost-benefit studies. However, just like in modern reliability engineering practice, where reliability considerations do not wait for the system's design to be established on the basis of desired performance figures and cost-benefit analyses, and then, through a design review, changes are introduced to improve reliability, it is my opinion that dealing with the environmental issues should not be postponed until the Project's design is finalized, but, from the start, be an integral and critical part of the design process.

Right now, the reference point for the Project's design is the one adopted in the HARZA JRV Group's Prefeasibility Report which was commissioned by the Jordan Rift Valley Joint Steering Committee in 1995 and completed in 1997 [5]. The key elements of this design (see Figures 5 and 6) are:

- Abstraction of about 1.86 billion m^3/year of seawater from the Gulf of Aqaba/Eilat at a point located on the border between Jordan and Israel.
- Conveyance of this seawater, after minimal pretreatment (only settling of sand and chlorination, "as significant treatment is envisaged immediately upstream of the desalination plant at the Dead Sea") for about 11 kilometers, by an open canal, to a pumping station within Jordan, where it will be raised to balancing tank at an elevation of about 125 meters above sea level.
- Conveyance of the seawater over a distance of about 142 kilometers, in two free-flow drilled tunnels (121 kilometers) and an intermediate open canal (21 kilometers), all located entirely within Jordanian territory, to a point nearby the Dead Sea, at an elevation of 107 meters.
- Pretreatment of the seawater, by deep-bed filtration, de-chlorination, pH adjustment and micro-screening, to make it suitable for desalination by reverse osmosis.
- Delivery of the pretreated seawater through a pressure shaft and tunnel (15 kilometers) to the desalination facility, located near the Dead Sea at the lowest possible elevation (365 meters below sea level).
- Production of up to 2.3 million m^3/day (851 million m^3/year) of 300 ppm TDS desalinated water, in a reverse osmosis plant operating at a recovery ratio (product to seawater feed ratio) of 45%. Due to the beneficial contribution of the hydrostatic head of the feed and the use of energy recovery turbines, the energy consumption of the desalination plant, excluding the seawater intake pumping, will be only 140 GWh per year, or 0.16 KWh/ m^3 of product, and 970 GWh per year, or 1.14 KWh/ m^3 of product, including seawater intake pumping energy.

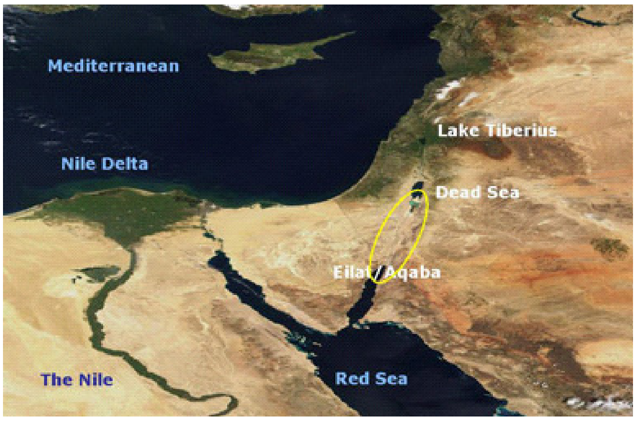

Figure 5 – Satellite view of the region and the terrain between the Red and Dead Sea

Figure 6 - Path and profile of the HARZA JRV Group's Project's design

- Transmission of the desalinated water, 570 million m^3/year to Amman and 280 million m^3/year to Hebron/Jerusalem, by pipes, pumping stations and terminal reservoirs. The energy requirements for these transmissions are 2,640 GWh per year, or 4.63 KWh/m^3, for Amman, and 1,320 GWh per year, or 4.71 KWh/m^3, for Hebron/Jerusalem.
- Discharge of the desalination plant brine along with any un-desalinated seawater in a 7 kilometers long canal leading to the Truce Line Channel, where it will join and mix with the Israeli and Jordanian Potash works' end-brines and flow with them, by gravity, for about 20 kilometers, into the northern basin of the Dead Sea.

This design, which resulted in a total required investment of almost US$ 5 billion at 1996 values, or about 6.85 billion including cost escalations during the ten year construction period, and in desalinated water costs, at their final delivery points, Amman and Hebron/Jerusalem, of 1.34 and 1.15 US$/$m^3$, respectively, can be improved not only from the critical environmental point of view, but also economically.

Some of the new ideas and elements, vis-à-vis the HARZA JRV Group's design, which should be considered in the new World Bank Study, are:

- **Applying Nanofiltration (NF) on part of the seawater at a site alongside its Red Sea intake to soften the total conveyed seawater stream and to remove contaminants and other undesirable elements.**

  Nanofiltration (NF) is a membrane desalination process that utilizes membranes with a higher molecular weight cut-off point than brackish water and seawater reverse osmosis (BWRO and SWRO) membranes. The NF membranes reject bivalent elements, such as calcium, magnesium, sulfates, almost as well as BWRO and SWRO membranes, but to a much lesser extent mono-valent ions, such as sodium and chloride (the rejection figures for the better NF membranes are 98% for sulfate ions, 85–90% for calcium and 94–98% for magnesium). They will also block the passage of heavy metals, nutrients and other contaminants.

  NF has therefore been used often, particularly in the USA (Florida), on hard and contaminated groundwater, to soften municipal water supplies and/or to remove organic and inorganic contaminants, such as tri-halo-methanes, heavy metals, color, etc. (See Figure 7).


Figure 7 – The large NF plant in Boca Raton, Florida

  Recently it has also gained favor, particularly in Saudi Arabia, Kuwait and the Emirates, as pretreatment to seawater desalination plants with difficult (i.e. contaminated) feed water and/or where long seawater intake lines are required, i.e. the costs of supplying the seawater feed to the plants are relatively high. In these plants the NF pretreatment of only a fraction of the feed (the exact fraction has to be optimized) has removed 96–98% of this fraction's total hardness and reduced its TDS by 55–65%. The resultant blended seawater feed has enabled the desalination plants, both thermal and membrane (SWRO), to operate at considerably higher conversion ratios, up to 65% compared to 40-45%, with no operational and maintenance problems and considerable savings in antiscalant chemicals' costs.

  The RSDS Water Conveyance Project could certainly qualify as potentially the longest and most expensive raw water supply system to any inland desalination plant site worldwide. The cost figures developed by the HARZA JRV Group for the investment in the seawater conveyance system to the desalination plant (including the intake sub-system, contingencies and engineering and administration) were US$ 1.66 billion in 1996 prices, and about US$ 2.28 billion if the cost escalations during construction are taking into account. These escalation calculations were based on a 3% per annum inflation rate, and if we assume that this rate has continued during the 11 years since they were made (a conservative assumption considering the 50% depreciation of the US dollar since 1997), then today's seawater conveyance system costs, in dollar terms, should be at least a third higher, or on the order of US$ 3 billion.

Using the HARZA JRV Group's capital discount rate of 8% and 40 year Project lifetime (i.e. a 0.08386 capital recovery factor), the capital cost component of the total seawater delivery cost to the desalination plant's battery limits should be today about 13.7 US cents per m^3 of seawater. Pumping energy costs, at 830 GWh per year and today's electric power cost of 8-9 US cents per KWh, will be in the range of 3.6-4.0 US cents per m^3. Other conveyance system operating costs, at 2.5% of the capital cost of the conveyance system per year, should add about 4 US cents per m^3, for a total of about 21.5 US cents per m^3.

For the RSDS Water Conveyance Project the application of NF will have the following potential benefits:

1. The HARZA JRV Group's study established the seawater optimal conveyance flow rate (60 m^3/s, or about 1.86 billion m^3/year) and the resulting sizes and costs of all the Project's works and items of equipment based on an optimization process and various design concepts and assumptions. Based on a conventional and conservative recovery ratio of 45%, 851 million m^3/year of desalinated water could be produced from this seawater feed. Increasing the recovery ratio of this same desalination plant to, say, 65%, will enable either a) to size down the capacity and dimensions of the project (for the same desalinated water output) by about 30% (abstraction and conveyance of only about 40 m^3/sec, or 1.3 billion m^3/year of seawater) and reduce its required investments and energy and operating costs by a similar, but, due to the loss of economies of scale, somewhat lesser percentage, or b) to eventually produce more desalinated water from the Project, about 1,225 million m^3/year instead of 851 million m^3/year.

   Both options will reduce the rates of flow of seawater and/or desalination plant brine into the Dead Sea and the pace of water level restoration, but so will the pace of Dead Sea water dilution and its effects on the chemical industries. In any case, these industries prefer restoring the Dead Sea's level to only -407, rather than to the HARZA JRV Group's Study's target level of -395.

   The HARZA JRV Group's Study projected, on the basis of the Dead Sea level, surface area, density, evaporation rate, chemical industries water withdrawal rate and other parameters that existed at the time (1995), and an algorithm developed by it, that with a seawater abstraction of 60 m^3/sec and a 45% desalination plant conversion ratio (its base design), i.e. a brine inflow to the Dead Sea of 1,040 million m^3/year, the Sea's level will rise by about 16 meters after 40 years of Project operation.

   On the basis of the same Study algorithm and data, if we maintain the seawater flow and conveyance system size but increase the desalination plant's recovery ratio to 65% (the second option), the situation will be more or less equivalent to a project with only a 40 m^3/sec seawater abstraction rate and a 45% recovery, i.e. an inflow of about 660 million m^3/year. As can be seen from Exhibit 7-2 of the Study (see Figure 8), the Sea level in this case will rise by about 9 meters in 40 years.

   However, since it is probable that the full desalination plants capacity with this second option, 1,225 million m^3/year, will be built up in stages, to meet the developing demand, there will be an initial stage where excess seawater, and not only desalination plants brine, will be introduced into the Dead Sea, raising its level at a much faster rate. The 660 million m^3/year of brine rejected from the desalination plants when they reach their final, full capacity, will then be sufficient to raise the Sea level to its final desired level within a reasonable time and to maintain it there, by matching the steady-state rate of surface evaporation.

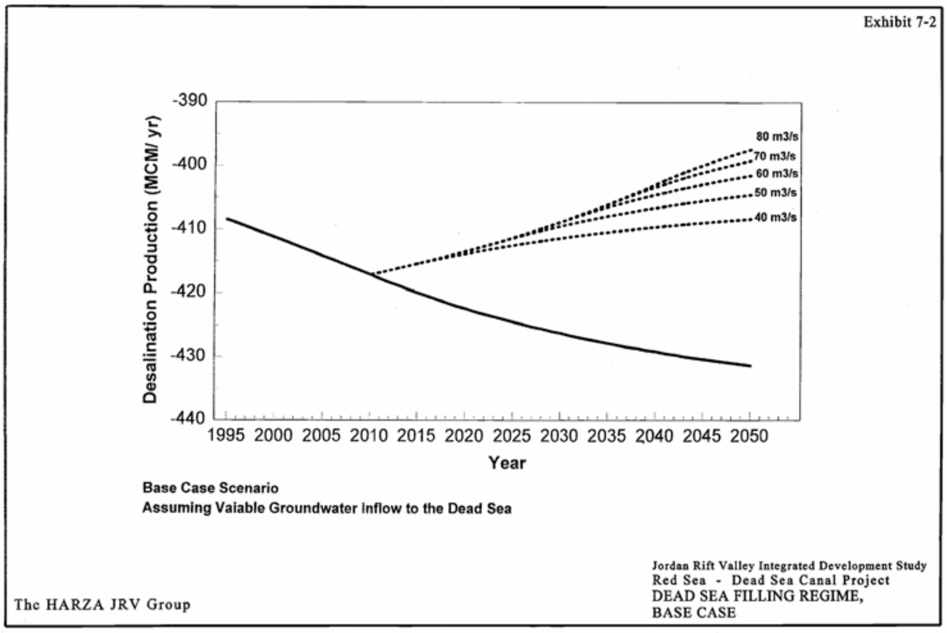

Figure 8 – Exhibit 7-2 in the Harza Group's study
– Dead Sea Filling Regime

Reducing the size of the conveyance system so that the same amount of desalinated water is generated at a 65% conversion ratio from only 40 m^3/sec of abstracted seawater (the first option) will result in only about 440 million m^3/year of brine entering the Dead Sea. This is well below the minimal quantity of inflow required, according to the Study, to avoid a further drop in the level of the sea, let alone raise it to the target level.

For this reason, and also since the water shortages in all three beneficiary entities, Jordan, Israel and the Palestinian Authority, has only increased since the Study was made, i.e. more desalinated water from the Project would be welcome, I believe that the second option, or, maybe, an even an option with higher rates of flow, should be chosen.

Using the above developed seawater supply cost figure, 21.5 US cents per m^3, to quantify the benefits of the increased recovery ratio, we see that, at 45% recovery, 2.2 m^3 of seawater feed are required per 1 m^3 of desalinated water compared to only 1.5 m^3 at 65% recovery. At 45% recovery, therefore, the seawater supply adds 47.8 US cents to cost each m^3 of desalinated water, compared to only 33.1 US cents at 65% recovery, a saving of 14.7 US cent per m^3.

The cost of the NF treatment per 1 m^3 of desalinated water will depend on the fraction of the feed that will be pretreated, but we can estimate it. The cost per m^3 of seawater filtrate (at, say, 70% NF system recovery) should be on the order of 25-30 US cents, and if, say, 30% of the seawater is treated, the cost of the softer and lower salinity feed to the desalination plant will be increased by 7.5-9 US cents per 1 m^3, and the cost of the desalinated water (at 65% recovery ratio) will increase by 11.5-13.8 US cents per 1 m^3.

The net savings, not counting the other benefits to the Project noted below, will be 0.9-2.2 US cents per 1 m^3 of desalinated water or, for 1,225 million m^3 per year, US$ 11-27 million annually.

2. The softening of the conveyed seawater will decrease the quantities of sulfate introduced into the Dead Sea and the precipitation of Gypsum, which could results in "whitening".

3. It will also eliminate the need to add polyphosphate based anti-scaling chemicals to the desalination plant's feed. These normally contribute 1-2 cents to the cost of each m^3 of desalinated water. The annual savings, for 1,225 million m^3 per year, would be US$ 12-24 million.

4. Equally important, the elimination of these additives will allay the fear that, as nutrients, they will induce algae and microbial blooming in the upper layers of the Dead Sea.

5. At a 65% desalination plant recovery, the concentration of the brine which would be introduced into the Dead Sea from the 3.6% TDS feed and would form the top layer in any density stratification, will be higher, about 10.2% TDS instead of about 7.6% (from 4.2% feed). This will reduce both algae and bacterial growth and evaporation rates at the surface.

6. The NF system will also reduce the concentration of organic matter and nutrients in the seawater delivered in the conveyance system. This will increase the effectiveness of its chlorination, thereby reducing marine organism growths on all conveyance structures and equipment and the risk of subsequent algae and bacteria blooms in the Dead Sea. Marine organisms growth within seawater supply lines has always been a major problem for desalination plants utilizing open sea intake systems, with and without chlorination (both continuous and shock treatments). In both the Ashkelon and Palmachim large SWRO plants, for example, this growth has led to the need to continuously carry out maintenance work on their seawater supply lines, including periodic scraping of pipe surfaces.

   The HARZA JRV Group's study ignored this potential but real problem, but it, nevertheless, exists and will have to be dealt with in the current World Bank study.

7. The generation of higher concentration brine in the desalination plant, with lower levels of calcium, magnesium and sulfates, will improve the economics and purity of table salt production at the Dead Sea.

- **Designing the seawater Intake system so that it will maximize the removal of pollutants of concern from Red Sea and the ecological benefits of the fresh seawater flow to its Eilat-Aqaba dead-end.**

Whereas, normally, intakes to seawater desalination plants are situated in areas of minimal pollution, in order to protect the desalination plants and minimize their feed pre-treatment costs, I believe that the act of abstracting seawater for the Project could and should be transformed from a cause of concern to the ecology of the Eilat-Aqaba into a positive "cleaning up the Gulf" operation.

The Study should opt, therefore, for a submerged intake system, as used, with intake heads that include coarse filters to prevent suction of fish, algae and large floating objects, for large seawater desalination plants (see Figure 9), rather than a surface configuration as utilized, typically, in large coastal power stations and as called for in the HARZA JRV Group's design (see Figure 10 for the surface intake system at one of Israel's Mediterranean Sea coast power stations. To put the Project's seawater abstraction rate in its proper proportions, it should be noted that this intake system provides 340,000 m^3/hr of seawater coolant to the power station, i.e. almost 60% more than the Project's 60 m^3/sec, or 216,000 m^3/hr, abstraction rate).

Some of these submerged intake points should be specifically be placed at sites where they will be able to suck up and withdraw as much pollution as possible (i.e. at the highest concentration point within any contaminant plume, as is done for contaminated groundwater pump and treat remediation). These sites should include not only known and identified day to day sources of

Figure 9 – A submerged type of intake used to supply seawater feed to a desalination plant in Cyprus

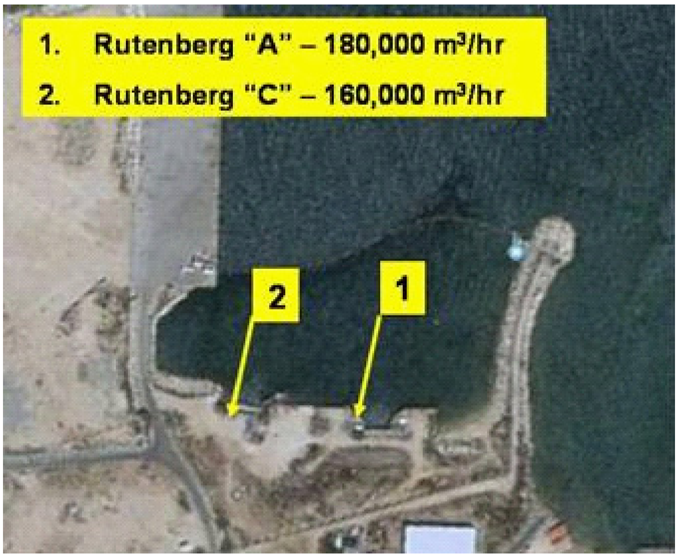

Figure 10 - A satellite view of surface intakes delivering 60% more seawater coolant to a power station than the total Red Sea intake flow

pollution (ports, fish cages, etc,), but also likely, though random, potential oil spill locations, where skimming equipment could be used.

This polluted stream would probably comprise only a small fraction of the total required seawater intake capacity and should be separated from the (non-polluted) balance of the seawater intake. The pollutants collected by it will be removed on shore, utilizing suitable facilities (beyond the minimal facilities envisaged in the HARZA JRV Group’s study), including sand filters and the NF system suggested above, and discharged to a suitable, approved disposal site (e.g. coastal infiltration basins, similar in design to the Soil Aquifer Treatment basins used in Israel to filter treated municipal effluents). The NF system would concentrate the polluted stream to 30% of its original volume, reducing the volume to be disposed of.

The Gulf seawater flow pattern resulting from the proposed layout of all submerged intake suction points will have to be modeled and optimized to benefit ecologically in the most cost-efficient and effective manner from the Project’s total seawater abstraction. It should aim to change the Aqaba/Eilat area from being the dead-end of a long and narrow gulf that continuously collects and accumulates pollution from cargo ships, tourist activities and commercial aquaculture into a body of water that is continuously “vacuum-cleaned” to remove both suspended matter and stagnant water, which is replaced by a steady inflow of fresh seawater, as clean and clear as that enjoyed by tourists in their favorite Sinai Red Sea coast beaches.

If this clean-up concept proves feasible, i.e. its benefits (as well as the mitigating effect of reduced total seawater abstraction if the Project is down-scaled as a result of the NF scheme) will outweigh the added costs of the submerged intake system (vis-à-vis a surface intake system), it should be well publicized by the World Bank and the Project's sponsors.

- **Increasing the social and economic benefits to the settlements along the Wadi Araba through enhancement of tourist projects.**

The conveyance of the seawater through the Araba/Arava Valley should be treated and, more importantly, presented to the public not as something dictated by the need to "Save the Dead Sea", a necessary evil whose potential threats and risks to the current livelihood of the Valley's residents will be mitigated by the best possible engineering, but as an opportunity to develop the region and boost its economy.

The residents of the Valley must be offered strong economic incentives to accept and support the Project, regardless of the risks that will, no doubt, remain even after all precautions have been taken and fault and failure events and consequences have been minimized.

The fact is that there is a strong potential market for new seaside and aquatic sports recreation sites by vacationers, locals and foreign tourists, from both Israel and Jordan. The two countries are currently short of free coastlines for such recreational activities. Jordan has only about 26.5 kilometers of Red Sea coast and the Israeli Mediterranean and Sea of Galilee coasts are already overbuilt and cramped. The tens of thousands of Israeli tourists, who are eager for such recreation, far from the crowds and tumult of these limited stretches of beach, and who cross every year into Sinai, could and should be lured into closer, safer and equally attractive newly developed sites along the Valley.

To create these there must be some diversion of seawater from the main conveyance system along the Jordanian highlands to the Valley. Some of this water should also be desalinated locally, at various points along the Valley, to support the tourist population and its service personnel without drawing from and even supplementing the meager natural water resources which are utilized fully to support existing agriculture.

In fact, to allay fears that leakage and catastrophic events could contaminate the groundwater currently used for agriculture in the Valley, it would not be unrealistic to include in the Project provisions for installing, in a worse case scenario, a desalination plant that will be capable of supplying, at a significantly better quality, the entire 40-55 million m^3 per year of groundwater currently in use. This quantity is less than 5% of the total Project desalinated water potential.

Jordan can allow this seawater diversion without detracting from its insistence that the main conveyance system, supplying the "raw material" for its vital new potable water source, lie, for security reasons, entirely within its borders. Most of the seawater will continue to flow in its territory and its own Valley citizens will also benefit from the diversion and its touristic projects.

I believe that such projects will draw the residents of the Valley, on both sides of the border, as they did the agricultural settlements in the northern Jordan Valley, into the tourism trade, which is immensely more profitable than agriculture. One of the key attractions of the northern Jordan tourism trade is rafting. It is my opinion that the Project should consider the seawater conveyance system as a means to sculpture lengthy and challenging rafting courses along the Wadi Araba that will compete with the best rafting courses in the world (e.g. the Colorado River in the U.S. – see Figure 11) and make them a global attraction for all rafting lovers.

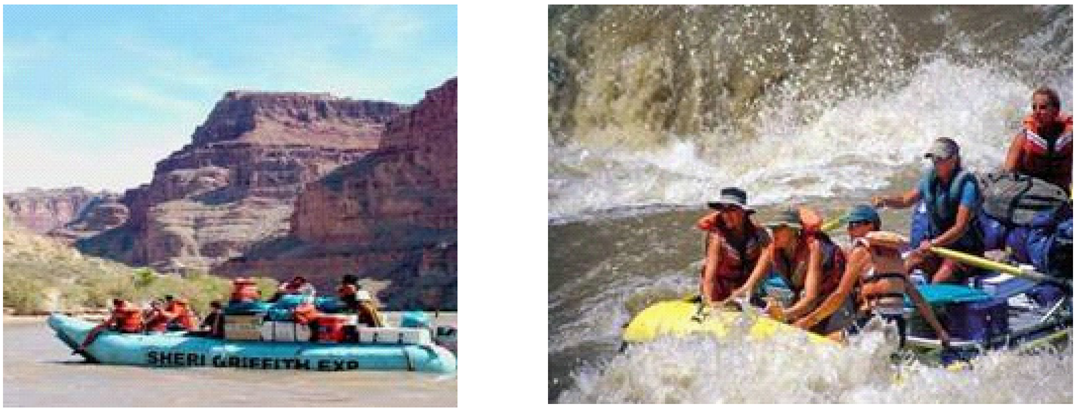

Figure 11 – Rafting courses in the Colorado River, USA

- **<u>Splitting and relocating the desalination plant(s) and generating hydro-electric power during peak power demand periods</u>**

  I believe that utilization of the hydrostatic height difference between the northern terminal point of the conveyance system and the Dead Sea should be separated from desalination, and utilized fully to generate electricity rather than to provide an initial head for the reverse osmosis desalination process.

  Furthermore, the Project's total desalinated water capacity should be broken up into two or more staged plants, which will allow the upstream plants to operate at lower conversion ratios and operating pressures, reducing total energy consumption. An overall recovery of 65% in one plant will anyway require its staging, for the sake of energy efficiency, since higher operating pressures than in a 45% recovery plant will be required.

  The first plant should be sized to provide only the Jordanian share of the Project's total desalinated water output, and be located at the conveyance system terminal, near its planned pretreatment facilities. The Israeli and Palestinian shares of the desalinated water should be produced in separate downstream plants located on the western side of the international border, closer to their main product using population centers, and operated by their nationals. At the large desalinated water capacities envisaged for the Project, all plants will continue to benefit from economies of scale.

  If the same formula for dividing the Project's total desalinated water output adopted in the HARZA JRV Group's study, 60% to Jordan and 40% to the Israelis and Palestinians, will apply, the Jordanian desalination plant will be able to operate at a 39% recovery, producing 725 million m^3/year of product from 1.86 billion m^3/year of NF treated seawater feed and discharging about 1,135 million m^3/year of brine.

  The Jordanian desalination plant will include operational seawater, product and discharge brine reservoirs. It, as well as the Israeli-Palestinian desalination plants, will be operated continuously, but their outputs will be maximized when low valley Time of Use (TOU) power tariff rates apply and reduced somewhat when high peak TOU tariffs apply. Likewise, the stored product will be pumped to its destinations as much as possible when valley TOU power tariff rates apply and the stored brine (and excess seawater if the desalination plants' capacities will be built up in stages) will be discharged through hydraulic turbines, located at the Dead Sea level, to generate electricity, only when peak TOU tariffs apply.

  This will minimize the Project's energy costs, that, at today's fuel and energy costs (which are considerably higher than those when the HARZA JRV Group's study and optimizations were carried out), will weigh heavier on the Project's profitability.

It will also simplify and reduce the size of the pressure shaft, tunnel and penstock in the HARZA JRV Group's design, and, if the Israeli and Palestinian desalination plants are sited by the Dead Sea shore, somewhere between Hebron and Jerusalem, will shorten the pressurized fresh water supply pipelines to these cities, at the "expense" of a lower cost unlined, open canal along side or even within the Dead Sea, which will deliver the seawater by gravity to the plants, like the canal bringing Dead Sea water from the north to the Dead Sea Works evaporation ponds.

More importantly, as will be discussed shortly, this will enable utilizing clean, renewable solar-energy desalination, using salinity gradient solar ponds and low-temperature Multi Effect Distillation (LT-MED) plants, and introducing the brine into the Dead Sea at its northern end, thereby minimizing and postponing its effects on the chemicals producing industries.

The fresh water lines to Amman from the Jordanian desalination plant will, likewise, be shortened, and the added energy consumption of this plant, due to its not being assisted by the seawater's hydrostatic head as in the HARZA JRV Group's selected location, will be compensated by the saving in its product pumping, from an elevation of +107 meters rather than -365 meters (using their Study's figures). This will allow eliminating several of the nine pumping stations envisaged in the Study for the fresh water transmission line to Amman.

- **Taking advantage of the Dead Sea's clean solar energy potential and instead of seeing the Project's resultant density stratification as a threat, utilizing it to create salinity gradient solar ponds for both power and desalinated water generation.**

Salinity (and density) gradient solar ponds were suggested initially by Dr. Harry Tabor, who also pioneered solar water heaters and developed the efficient flat, black surface solar energy collectors that made these home heaters economically viable. The ponds, which trap solar energy by suppressing convection-induced mixing and heat dissipation at the surface, generate a brine stream with temperatures as high as 95 degrees C. Most importantly, they possess, by virtue of the heated pool's depth and volume, a heat capacitance that enables continuous operation also during nighttime and cloudy weather.

The salinity gradient ponds were developed commercially in the early 1980's. Several demonstration ponds were built and operated along side the Dead Sea and within it ("floating ponds"), where solar insolation values are high (1,900-2,100 kWh/m^2/year).

The largest pond, with an area of 250,000 m^2, generated 2-2.5 MW of clean energy utilizing a low temperature, Organic Rankine Cycle (ORC) secondary fluid turbo-generator (see Figures 12 and 13). The project was suspended, however, since it was found that the generated electric energy was competitive with fossil fuel power only when the cost of oil was higher than 40 USD/barrel, and the fuel costs at the time were considerably lower. Needless to say, fuel costs, even after taking into account the depreciation of the USD, are considerably higher today and are expected to remain so throughout the life of the Project. Moreover, this 40 USD/barrel economic breakeven point was calculated for ponds built along-side of the Dead Sea, where the laying of insulating and leak protecting double-layer plastic sheets was necessary. If the ponds are built within the Dead Sea, on its shallow, currently exposed beds, it will be possible to save on this major investment cost.

The ORC turbo-generators, which are the most efficient method of generating power from low grade heat sources, have been scaled up and improved efficiency-wise since the 1980's and today are used extensively throughout the world for geothermal energy production.

Another potential application for the 95 degrees C heat generated by the salinity gradient solar ponds' hottest, highest density bottom layer is seawater desalination utilizing Low Temperature

Figure 12 – The large solar pond and ORC power station

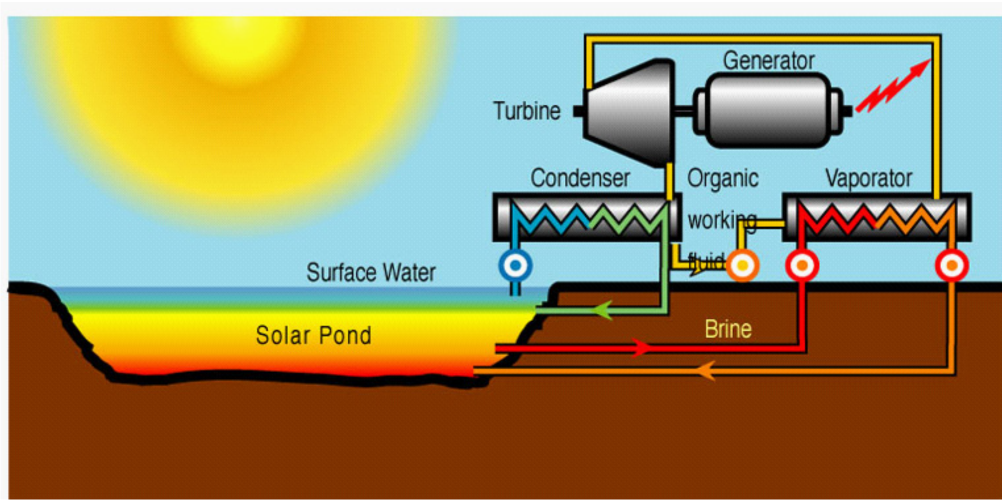

Figure 13 – Schematic of a solar pond driven ORC power plant

Multi-Effect Distillation (LT-MED) plants. These are the most efficient low grade heat input thermal seawater desalination plants in the world and recently larger scale single units have been developed (see Figure 14 for an early prototype test unit).

The LT-MED units will be the best choice for desalinating, as the last stage in the planned series array of desalination plants, the highest concentration feed resulting from an overall 65% recovery ratio. Their high quality, distilled product will be hardly affected by the higher salinity feed while the seawater reverse osmosis (SWRO) plants' product salinity will be. Also, the higher osmotic and required operating pressures associated with the higher salinity feed will affect the SWRO plants' operation more adversely than the corresponding higher Boiling Point Elevations will affect the LT-MED plants' performance and operation.

In a study performed for the Israeli Ministry of Energy and Infrastructures (today the Ministry of National Infrastructures) and published in Desalination Journal [6], it was found that the cost of desalinated water from LT-MED plants utilizing solar pond generated heat was lower than the cost of any other solar desalination system and was competitive with the cost of desalinated water produced with energy from conventional fossil fuel power plants when the cost of oil was 20-25 USD/barrel (2.7-3.8 USD/MBtu).

Figure 14 – An LT-MED seawater desalination plant prototype

More importantly, solar desalination using solar ponds was the only solar desalination system that could operate continuously (to minimize the desalinated water fixed cost components) also during night-times and cloudy periods, without fossil fuel backup. With all other solar energy collectors (that do not have such a built-in heat storage capacitance) up to 65-77% of their energy inputs, if continuous operation is desired, are derived through fossil fuel firing – definitely not a totally “clean” process.

Also important, in the context of the concerns about microbial blooming, is the fact that the designers of the solar ponds have developed techniques for dealing with such blooming, which for them is not so much an esthetical threat as a threat to the transparency of the ponds’ water layers. Such transparency is critical for the solar rays’ penetration of the upper (lower salinity) layers to the heat accumulating higher density bottom layers. These techniques should be studied and adopted.

Similarly, other techniques developed for maintaining the integrity and effectiveness of the solar ponds, techniques that are relevant also to maintaining the stratification of Red Sea water and rejected desalination plant brine on top of the mineral rich Dead Sea water, should be examined and adopted. This stratification is important to both the DSW and APC in that it delays and minimizes the expected decline in Potash production rates due to the effects of introducing water with a lower concentration and different composition of minerals into the Dead Sea.

The two most important other techniques are:

1. Avoiding mixing of the top, low-salinity gradient layers by wind induced currents, waves and turbulence – floating nets which attenuate and dampen these dynamics were developed. This calming of the surface layers, as well the entrapment of most of the solar energy within the lower, higher-salinity bottom layers, for subsequent useful utilization, will also reduce considerably the pond surfaces evaporation rates.

2. Drawing the bottom hot layer and reintroducing it, or most of it, at an appropriate intermediate layer, after its heat has been recovered and utilized for either or both power and desalinated water production, without disturbing the rest of the pond. Properly designed suction and discharge schemes and devices are critical to avoid turbulence and mixing that would destroy the sensitive temperature and salinity gradients. Needless to say, these techniques are

also critical to the successful drawing of the undisturbed mineral-rich bottom layers for the production of Potash and other chemicals by the DSW and APC.

The solar ponds would be installed on the shallow north-western shores of the Dead Sea that have been extensively exposed due to the drop in sea level and the receding coastline (see Figure 15) and partially in the sea itself ("floating ponds"). Figure 16, which shows the Israeli and Jordanian Potash companies' evaporation ponds on the southern end of the Dead Sea, illustrates what the solar ponds at its northern end would look like.

Figure 15 – The shallow coastal areas exposed by the sea level drop

Figure 16 – The Potash companies' solar evaporation ponds

- **Introducing the brine derived from the desalination plants at the northern end of the Dead Sea.**

According to the HARZA JRV Group's design, the Red Sea water, prior to and/or after its desalination by a Reverse Osmosis plant, would be introduced into the Dead Sea at its southern edge (or just north of the chemicals producing evaporation ponds) via the Truce Line Canal.

If the Israeli and Palestinian desalination plants, including any thermal desalination units operating on heat derived from the above noted salinity gradient solar ponds scheme, are located along the northwestern shores of the Dead Sea, near the population centers that will benefit from their desalinated water, it will be possible to have their brine discharged either to the salinity gradient solar ponds or direct to the Sea, via relatively short open canals, much further north.

Such northern points of entry, as requested by the Dead Sea Works, will delay and minimize its effects on the economically important chemicals production.

- **Expanding the Project to include the rehabilitation and revitalization of the Jordan River through a minimal flow of Sea of Galilee water, without its loss to the Dead Sea.**

  The proponents of "the Jordan River Alternative" are the most vocal opponents of the RSDS Water Conveyance Project. To neutralize their criticism, I propose examining and possibly including, as an annex to or as an integral part of the Project, a miniature scale version of this scheme that will achieve the same ecological benefits for the Jordan River and Valley, without the loss of 400-500 million m3/year of valuable fresh water. A loss of this magnitude would require an equivalent increase in the scale of seawater desalination along the Mediterranean Sea, at an incomprehensible annual cost of 260-350 million USD (a Present Value of 5.2-7.0 billion USD over 40 years at 4% interest), and the increase of air pollution from the 180-230 MW fossil fuelled power plants providing the energy required for this desalination.

  Under the proposed alternative scheme, an additional, but still relatively small amount of Sea of Galilee water, the minimum required to rehabilitate and revitalize the Jordan River, will be released and allowed to flow through it southward. This water, however, will not be released into the Dead Sea and lost, but will be dammed at the northern end of the Sea and diverted, perhaps also at several other points downstream of the Sea of Galilee, for irrigation (both agricultural and landscaping) and other economic development projects (e.g. tourism).

  If the quality of this water will be compromised by other (current) discharges upstream it will be used for domestic and tourist consumers only after pretreatment by gravity, micro or ultra filtration, as warranted. The salinity of this water can, in any case, be reduced by blending with high purity product from the nearby seawater desalination plants, avoiding the need for additional brackish water desalination plants.

  This scheme is not meant to and will not raise the Dead Sea's water level (this will be done by the Red Sea water, through the RSDS Water Conveyance Project), but to provide all the <u>other</u> features and benefits claimed by the Jordan River Alternative.

  Israel will be compensated for this Sea of Galilee water diversion by an equal or even slightly larger amount of additional desalinated seawater.

To summarize, it is proposed to modify and expand the Red Sea to Dead Sea Water Conveyance Project, as envisaged by the HARZA JRV Group, and transform it from a "Save the Dead Sea" project into a larger Jordan Rift Valley project that would be environmentally safe and will expand its benefits to all the stakeholders from the Sea of Galilee to the Gulf of Aqaba/Eilat. The new ideas and elements that are proposed in order to improve the Project's economics and make it more acceptable ecologically include:

- Changing the composition of the Red Sea water at its source (reducing the levels of sulfates, contaminants and nutrients) so as to make it more acceptable ecologically and commercially (to the chemicals producing industries) for mixing with the Dead Sea water.
- Increasing the amount of desalinated water that can be produced with the same amount of seawater abstraction and conveyance by 30%.
- Using the abstraction of this water to remove excess nutrients and accumulations of pollutants from the Gulf of Aqaba/Eilat.
- Diverting some of the conveyed seawater to the Araba/Arava Valley and utilizing it to create large-scale recreational and aquatic tourist attractions.
- Desalinating some of this diverted seawater also at one or more points along the Araba/ Arava Valley, to support these new activities and economic development, in general,

including making up for any loss of ground water resources that may result due to leakage or catastrophic events, thereby assuring the continuation the Valley's current hi-tech agriculture.

- Reducing the Project's energy costs by dividing its total desalinating capacity into several plants that will operate in series. The first plant, which will be situated at the higher elevation terminal conveyance point, above the Dead Sea, will provide only Jordan's share of the water and will include seawater and brine storage capacity. It will be operated in a regime which would minimize its output and electric energy consumption and maximize electric power production from the brine and excess seawater passing through a hydro-electric turbine located at the Dead Sea's level, when high peak demand Time of Use (TOU) tariffs apply, and increase its output when low valley TOU tariffs apply. This location and operating regime will also reduce the costs of the product delivery system and product pumping energy to Amman (shorter high pressure lines, less pumping stations and maximum use of valley TOU tariffs).
- Locating the downstream desalination plants which will supply the Israeli and Palestinian shares of the Project's water output at the northwestern shores of the Dead Sea, nearer to the population centers which will be served by this water (Hebron and Jerusalem). This will shorten and reduce the costs of their high-pressure product transmission pipelines. The plants will be operated by Israeli and Palestinian nationals in a regime that, like the Jordanian plant, benefits from the existing TOU tariff structure.
- Including within these desalination plants not only electricity consuming reverse osmosis units but, in a hybrid scheme, also high-efficiency, low-temperature thermal desalination units that will derive their energy from nearby salinity gradient solar ponds. The northern entry of these plants' brine into the Dead Sea will postpone and reduce the Project's effects on the chemicals industries in the north.
- Utilizing the salinity gradient solar ponds to generate heat not only for the thermal desalination plants but also for generating electricity, mostly during peak power demand hours, by Organic Rankine Cycle power plants.
- Achieving all the features and benefits claimed by the Jordan River Alternative, without paying for them through the loss (to the Dead Sea) of large quantities of fresh water, by releasing a relatively small amount of Sea of Galilee water into the Jordan River, as required to revitalize the Jordan Valley. This water will be dammed at the northern end of the Sea and used there for agricultural and landscaping irrigation and other economic development projects. Israel will be compensated for this water, on a one for one basis or by a larger share of desalinated water.

I believe that even if only some of these ideas and elements are examined thoroughly and adopted they will help overcome the objections raised by the Project's opponents and their benefits will contribute decisively to turning the whole Jordan Rift Valley into a Valley of Peace, Cooperation and Prosperity.

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