Department of Bioresource Engineering

Design of a Renewable Energy Powered Desalination System

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Abstract

The Kingdom of Jordan is the 10th water poorest country in the world and the 4th water poorest country in the Middle East. The natural water resources of the country are not sufficient to meet the demands of the population and because of this water rationing has been in place since the 1980's. Currently, the economically viable harnessing of surface water has been maximized, groundwater is being pumped at 160% of the sustainable yield, and non-renewable fossil water is also being utilized. A rapidly growing population and industrial sector threaten to exacerbate the water shortage in the very near future. Jordanian scientists in partnership with international organizations have determined that desalination of saline water will play the most important role in alleviating the country's water scarcity problems. This document will outline a design work for a desalination unit to using a slow sand filter as pre-treatment and an evaporation pond for the brine disposal. This technology will provide sufficient fresh water for the needs of a small rural community in Jordan at a small fractional cost to the government of Jordan.

1. Problem Statement; Jordan's Water Shortage

In countries with a high population growth rate and fast socio-economic development, water demand and wastewater production is steeply increasing and the gap between water supply and demand is getting wider. Fortunately, efficient technologies have been developed to treat wastewater and brackish water desalination for communities where fresh water is scarce. A number of such communities in arid regions have turned to desalination technologies because of it being a relatively feasible alternative for fresh water production.

Jordan's population reached 5.3 million in 2002 and continues to grow at an annual rate of 3.6%. This is a very high rate of growth when compared to Canada's 1.1% population growth rate (Statistics Canada). Annual rainfall ranges from 600mm in the highlands of North-western Jordan to 130mm or less in the deserts in the East and South, which make up 91% of the surface area of the country. This is a very small amount of precipitation when compared to Canada's range of 250 mm in the far North to over 900mm in the Atlantic Provinces. Due to very high evaporation rates in the Jordan, 85% of the rainfall is lost to the atmosphere. Of the remaining 15%, 4% goes towards the recharge of groundwater and the other 11% is equal to available surface water (Mohsen, 2007).

Jordan has three main sources of surface water, the Zarqa (Jakkob) and Yarmouk Rivers, which both drain westward to the Jordan River and eventually to the Dead Sea. The Jordan River forms the border between Palestine and Jordan while the Yarmouk River forms the border with Israel in the Northwest, to the South of the Sea of Galilee (Lake Tiberias). Farther upstream and to the Northeast, the Yarmouk also serves as the border between Jordan and Syria.

The Zarqa River water system is becoming increasingly polluted from the industrial area around the Zarqa-Amman region, where 70% of Jordan's industry is located, and its ability to provide clean water has been greatly diminished. Syria has built a number of dams on the Yarmouk in order to divert water for its own purposes. Perhaps an even greater strain on the surface water resources for Jordan has been the construction of the National Water Carrier by Israel in 1967, which takes water from upper Jordan River at Lake Tiberias. The construction of this project has significantly reduced the flow of the lower Jordan River (Mark Zeitoun). Unfortunately, Syria and Israel have taken advantage of their upstream riparian position without regard for Jordan's fair share of the water available from sources shared by all three countries (Mohsen, 2007).

Jordan's conflict with Israel was in part due to the issue of unfair water sharing practices. In 1994, Jordan and Israel signed a peace treaty which guaranteed an additional 215 million cubic meters (MCM) of water for Jordan through new dams, diversions, pipelines, and desalination plants. Even with this improvement, Jordan is still a very water poor nation.

Jordan has one of the world's lowest per capita water resources. Water scarce countries are defined as having access to less than 1000 m^3/year per capita. In 1996, Jordanians consumed an average of less than 175m^3/year per capita. In 1997, a total of 882 million cubic meters (MCM) of water was used in Jordan. Of this total, 225 MCM exceeded the sustainable groundwater yield and an additional 70 MCM was sourced from non-renewable fossil water. Fossil water is groundwater that was accumulated during a time of a dramatically different climate in the region and that has been sealed by geological processes for thousands of years. Without an increase in overall availability of water and a constant population growth rate, the per capita consumption of water could drop down to 91m^3/year by the year 2025 (Mohsen, 2007).This would relegate Jordan to absolute water scarcity status, the most severe level of water scarcity, recognized by the UN to be less than 100m^3/year per capita (Rijsberman, 2005).

It is also important to note that continual over-extraction of groundwater undermines the sustainability of these already limited water resources to provide fresh water into the future. Groundwater resources are being exploited for 160% of their sustainable yield. In some regions, over-extraction has lead to a 5 meter drop in water levels and a tripled salinity. If current trends continue, some of these over-exploited basins will run dry within the next few years. Dropping water table levels as well as the increasing salinity of groundwater are the direct result of over-extraction and imply increasing scarcity and a higher cost of fresh water in the future (Mohsen, 2007).

There are a number of factors which exacerbate the issue of water shortage in Jordan. The low availability of fresh water that can be pumped economically, in combination with large influxes of refugees and a rapidly growing population, improving standards of living, as well as the geo-political situation in the region are some of the factors that have caused the current condition of water scarcity in the region. Wastewater treatment plants operating beyond design capacity are becoming a significant source of pollution for groundwater as well. Inefficiencies in Jordan's irrigated agriculture systems have caused 70% of available water to be allocated to the agricultural sector. Increased effectiveness in irrigation will play an important part in freeing up more water for the growing domestic and industrial needs of the country. In addition, because the Kingdom of Jordan's priority is to provide potable water for domestic use, water resources will be allocated away from agriculture and towards the domestic and industrial sectors. This makes sense economically "since the product value of 1 m^3 of water consumed in industrial production is very much higher than for the same amount consumed for irrigating wheat fields or orchards. In Jordan, for example, productivity per unit of consumed water is 40 times higher in industry than in agriculture, and employment effect is 13 times higher" (Mohsen, 2007). For arid countries, the optimization of water use may imply that increased importation of food from nearby regions is necessary.

Though Jordanians currently consume about 175m^3/year per capita, domestic usage of water accounts for only 20% of the total and roughly amounts to 96L/day per capita. According to the UN, 100L/day per capita is the minimum requirement for a settled population to have proper sanitation and a reasonable standard of life. These figures shed light on the severity of the water crisis in Jordan, as unsustainable pumping of water resources is already occurring in order to keep quality of life at an adequate level. Access to water is highly limited to all sectors of the country and especially so during the summer months of May-September, during which absolutely no rain falls. During this time, the capital city of Amman has water access for a few hours once every seven days and rural areas receive a delivery of water once every twelve days (Denny et. al, 2008)

1.1 DESCRIPTION OF SITE AND PROPOSED SOLUTION

Jordan's potential water resources are estimated to be roughly 1000 MCM or 1200 MCM if the potential for recycled wastewaters is taken into account. Of this value, 750 MCM can be sustainably sourced from renewable ground and surface water. An additional 143 MCM can be supplied from the non-renewable fossil waters referenced earlier. It has also been determined that 50 MCM of fresh water can be sourced from the desalination of brackish ground and spring water that is available around the country. Although the brackish spring water sources are scattered and are difficult to exploit on a large scale, they will be able to supply desalted water for small, remote communities by utilizing solar and or wind energy (Mohsen, 2007). Additionally, the implementation of local energy resources to power the desalination process can lead to water and energy autonomy and consequent improvements in social conditions for the community under consideration (Eltawil et al., 2009).

A multi-objective analysis was performed to evaluate the relative importance of different non-conventional sources of water for Jordan and its results (see figure)show that desalination is the most feasible based on economic, technical, availability, reliability, and environmental factors (Jaber et al., 2001). More specifically, the desalination of brackish water is far more economical than seawater on a small scale. Since energy consumption in the process is directly related to the operating pressures, and operating pressure is directly related to the concentration of dissolved solids in the feed water, one can conclude that desalinating brackish water (1-10 g/L TDS) as compared to seawater (35 g/L TDS) would require less energy and the product would have a lesser cost (Mohsen, 2007).

Though Jordan is surrounded by many oil-rich nations it has very few of its own fossil fuel reserves and must therefore develop alternative sources of energy for its growing needs. A multi-criteria analysis was performed in order to analyse the feasibility of using different non-conventional energy sources to power desalination processes in Jordan, finding that solar energy may be economically used to produce water for domestic usage as based on criteria of environmental sustainability (Akash et. al, 1997). Average annual solar radiation on a horizontal surface in Jordan has been found to range from 5-7 kWh/m^2/day depending on location, making it one of the richest countries in the world in terms of solar resources (Abdallah, 2005). Although water demand is highest during the dry summer months, this is also the time period with the highest rates of solar radiation and sunshine duration, further solidifying the decision to utilize solar power for desalination of brackish water.

2. Objective and Scope

Clean drinking water is a critical resource for the development and maintenance of human communities. Dry Mediterranean and African countries, especially those undergoing development and with limited monetary resources, often find the task of providing clean drinking water to the population very expensive. Jordan's water shortage needs to be dealt with quickly before very serious environmental and social problems arise. Because of the unreliability and inefficiencies involved with the transport of treated water over long distances to remote communities in Jordan, this document will show a system design for a small scale desalination unit powered by a locally abundant source of renewable energy which can economically bring water autonomy to people.

Within the scope of this project will be the sizing of an appropriate:

- Desalination unit
- Renewable energy system
- Pre/post-treatment unit (pumps, storage tanks, etc.)
- Associated machinery
- Brine disposal system

More specific objectives include the following:

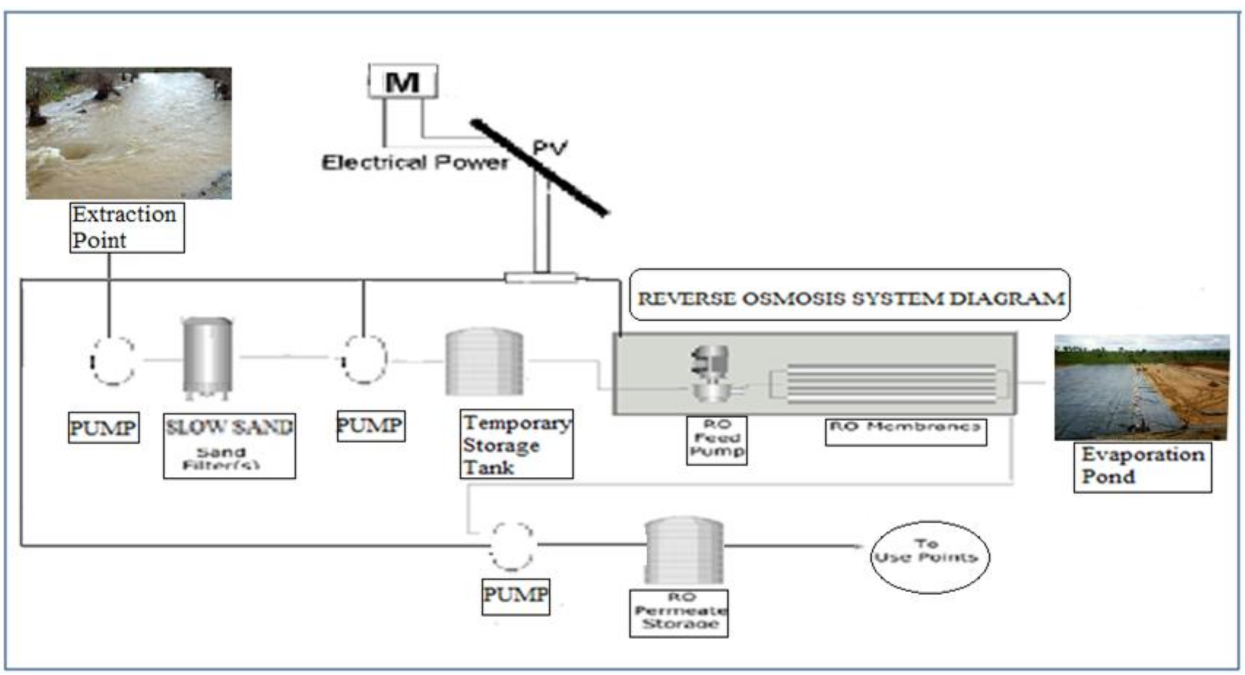
1) Collect information about the location, including the local climatic conditions, the water demand, the source of inflow, and the turbidity levels of the source water.

2) Develop conceptual structural drawing of a slow sand filter plant for a typical site. It will include details of structural requirements, and complete descriptions of required inflow and outflow piping systems, filter and underdrain systems, and filter controls.
3) Develop overall water treatment system design including storage tanks, pumps, and piping.
4) Develop a design for a solar energy system that will meet the electrical load requirements of the water treatment system.
5) Develop operation information on how to operate and maintain the main components of the system. This will include information on, when the filters need to be scraped, how to backfill the filters, and how to control the inflow and out flow from the filter. Notes on maintenance for the pumps and reverse osmosis unit will also be included.

Additionally, a cost evaluation and economic analysis of the designed system will be performed to determine the feasibility of such a project.

3. Design Elements

The design of this solar powered brackish water desalination system will closely follow the flow chart in Figure 1 seen below.



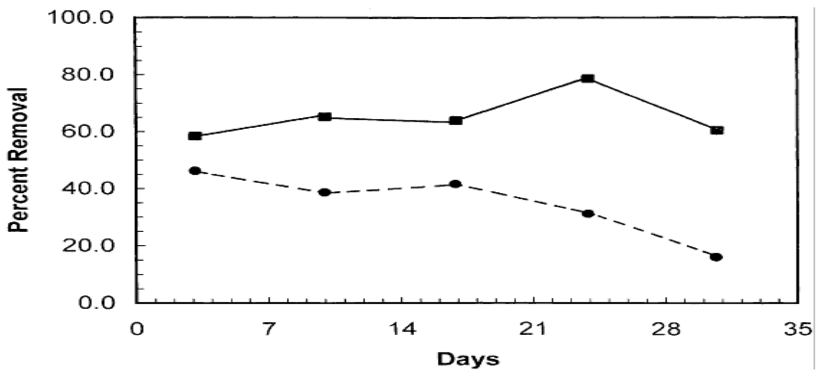
3.1 Slow Sand Filter Design

The simplicity, efficiency and economy of the slow sand filter provide appropriate means of water treatment, particularly for community of water supply in developing countries. With a community of 50 inhabitants desalination of the brackish water will require adequate pre-treatment before going through the reverse osmosis unit. A slow sand filtration system is one of the earliest processes used for eliminating contaminants from surface waters to produce drinking water. Slow sand filters (SSF) can operate at very low filtration rates; using very fine sand (0.2 mm-2mm) and usually operate without pre-chlorination. The decontamination of water passing through such filters is principally the result of filtering through the filter skin at the top few millimeters of sand, together with biological activity. Therefore, both physical and biological mechanisms are important in particulate capture in slow sand filtration (Haarhoff and Cleasby, 1991). This filtration process removes particles and microorganisms by the slow percolation of water through a porous sand media. Furthermore, as we know the reductions in BOD and COD across the coarse sand filter at a depth of 1.5m and a filtration rate of 0.19 m/h (10 l/min) is presented in figure below. BOD removal efficiencies range from 58.4 to 78.5%, averaging 65.4%, while COD removal efficiencies varied from 16.6 to 46.2% with an average of 34.9%. Effluent BOD5 and COD concentrations ranged (Nakhla et al, 2002).

As seen from Graph 1, the SSF will eventually mature and eliminate most unwanted contaminants in the water. In slow sand filters, biological processes are considered to dominate the uppermost region of the filter bed (Haarhoff and Cleasby, 1991; Ellis 1995). A layer termed the “schmutzdecke”, literally translated as “dirty skin” (Hendricks, 1991), forms on the surface of the filter bed and is thought to contribute to the removal of water impurities.

As seen in Table 1, the removal efficiency increases as we increase the thickness of the sand bed. The treatment technology must be economical to build, and simple to operate and maintain given the adverse economic and environmental conditions of this remote location. In order to provide the necessary amount of water to the people we have decided to use the United Nation’s standard of hygienic living that every person requires 100L / day of fresh water. Now we have added to this value a safety factor of 1.5 which gave a total amount of 7500 L/day for the whole community. Since a typical efficiency of a slow sand filter would be about 60% efficient [1], therefore the initial feed water required to be pumped into the SSF is 7500/0.6=12500 L / day for 24 hour continuous flow. The initial pumping of the water will be for a constant 7 hours of time, since power will be provided by photovoltaic cells only during 7 hours of a day. Parameters of the dimensions of the slow sand filter can be seen in Table 2.

Graph 1. Percent removal of BOD and COD



Temporal variation of BOD_5 (■: avg. infl. = 5.1 mg/l) and COD (●: avg. inf. = 44.2 mg/l).

Table 1. Biological characteristics of filtered water produced by slow sand filters

Parameter	Pretreatment step	Sand filter depth			
		50 cm sand	60 cm sand	75 cm sand	60 cm sand + membrane
Chlorophyll ‘a’	84	98	92	80	98
Blue-green algae	86	100	86	100	100
Diatoms	81	93	90	98	99
Total algal count	91	92	89	96	98
Total bacterial					
Counts at 22 °C	90	71	99	96	98
37 °C	91	91	98	95	91
Total coliforms	93	93	93	93	98
Faecal coliform	92	92	92	96	100
Faecal streptococci	85	93	85	93	90
Yeast	95	98	99	97	95
Candida albicans	100	100	100	100	100

Table 2 Design Parameters of SSF

Design Parameters of Slow Sand Filter	
inhabitants	50
Quantity of water per person per day	100L
Permeat Flow rate	7500 L/day
Recovery Rate	60%
Feed Water	12500 L/Day
filtration rate	0.5m/h
Area per filter bed	240 m^2

As depicted in the AutoCAD drawing in Appendix A, the SSF has many required aspects to it for its proper function. At first the recommended 1.5 inch inflow pipe will have attached to it 1.5 inch water meter to monitor the volume of water in use every month. There is also the need of a drain and a flush pipe for the required maintenance of the sand filter by backwashing with water when or scraping the sand when needed. The gate valves will assure a constant level of water input in the SSF, while the piezometers will help in determining any head loss through the SSF which may cause lower filtration rate. As shown in Appendix A, the piezometers connected to the filter's outflow pipe will have a function of determining when a filter will need scraping.

There will be an installation of 1 gate valve at each end of the sampling hose attached on the 8 inch outflow pipe. The first valve is to adjust the flow of water going into the water meter while the other valve is used during sampling of the water. Now the SSF consists of one circular concrete tank 3.05 m high and 8.7 m in inner radius and 9m outside radius. The thickness of the concrete could be found using the typical formulation.

Thickness is assumed to be 0.3 meter which includes a large safety factor. The SSF is constructed on 6 inches thick gravel compacted above sub-grade level. The total amount of concrete for the SSF and the foundation layer will be as follows.

$$\frac{D_o^2 * pi * t}{4} = 19\,m^3$$

Total Volume of Concrete

Total volume of compacted foundation gravel is 39 m3 using the same above formula for the volume. Total of 58 m3 of concrete required for the SSF installation. The inside of the filter consists of porous media of graded granular sand layer (1.25m) thick placed on a 4 gravel layers of total 30 cm thick. Appendix B in the appendices will represent the dimensions of the SSF and volume of the required sand and gravel size can be found in the Cost tables.

3.2 Selection of the Reverse Osmosis Unit

In order to limit most of the other contaminants in the water that have not been filtered by the SSF, then the need to purchase the right type of Reverse Osmosis Unit (ROU) would be a critical point. According to Lenntech supplier of water treatment and purification technology, the best ROU that will accommodate our need to desalinate brackish water that contains 4000ppm of total dissolved solids would be the Small Brackish water reverse osmosis unit (SBWRO) seen in Appendix C and D. Appendix D represents the parameters and description of the SBWRO. Most notably, it requires 5.5kW of AC electricity and will force 1238L/h of brine through its membranes, producing drinkable water at a rate of 1000L/h. Although this amounts to 7000L/day which is below our intended goal of 7500 L/day, this is acceptable because it is still above the 5000 L/day calculated by UN standards, lowering the safety factor to 1.4 from 1.5. The ROU produces 238 L/h of brine which includes 25% of solids approximately and the ROU has 80% in recovery as seen in diagram Appendix C.

3.3 Evaporation Pond Design and Construction

Since the increase in desalination plants in land areas, of many countries there have been an increase in the salinity of surrounding lakes, river, ponds, spring water and ground water as well. This is simply caused by the disposal of waste water or (brine, rejected water) from the desalination unit towards these local water areas. A common new practice suitable for the disposal of reject brine or potash has been used over the past decades.

While evaporation ponds have long been used for salt production in many parts of the world, the disposal of concentrate from desalination plants in inland areas using evaporation ponds is of much significance both economically and environmentally (Ahmed.,2000). The evaporation ponds can be successfully used as means to dispose of the brine especially in warm, hot weathers places, with high evaporation rates and availability of lands. It is said that Jordan has abundant solar energy sources with an annual daily average of global solar irradiance ranging between 5 and 7 kW h/m*day on horizontal surface (Hrayshat et al, .2004).

Figure 5 represents the monthly average global solar radiation in Jordan, calculated depending on records of daily values of global solar irradiance on horizontal surface for a period of 10 years (Hrayshat et al,.2004).

After carefully selected the site for our installation of the evaporation pond, according to the flow rate of brine rejected of 1700L/day or 238 L/h, the following formula was proposed for calculating the open surface area of the evaporation pond:

A open= V*f1/E

Where V=1.7m^3/day volume of rejected water

F1 is a safety factor of 1.5

A is the open surface area to be calculated

E is the evaporation rate (m/d) which is according to (Lensky et al 2005), which ranges from 1.1 to 1.2 m /year for the Dead Sea region. Therefore we assumed that our evaporation rate would be 1.2 m/year or 0.0033m/day at our location.

From this we calculated our Area to be 770 m^2 with length of 31.5m and width of 25m.

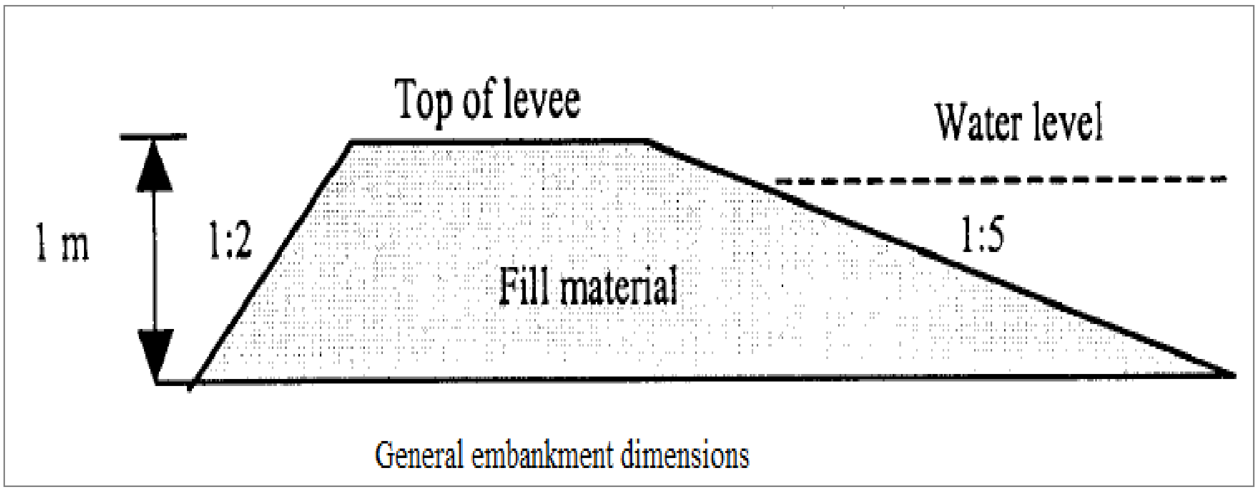
The depth is calculated using the formula given by (Ahmed et al., 2000) to be

D min= E*f2 where f2 is the effect of winter factor time in days. The start of winter in Jordan is approximately in 1st of November until March. F2 is found to be 30days*4=120 days. Minimum pond depth would be 0.0033*120=0.4 m with a recommended freeboard of 200mm or 0.2m.

From this we conclude that it is unnecessary that evaporation pond remain wet at all times, therefore we can be reassured that with the average annual evaporation rate exceeds the depth of water that would have to be stored in the pond which is of minimum 0.4m.

The schematic of the dimensions of the evaporation pond is shown in Figure 2. The walls of the pond are constructing above ground level, first by eliminating the top soil the banks should be 1meter in height and 2.4 meter wide at the crest to allow the movement of vehicles. To minimize bank erosion and absorb much of the wave energy the inside slope is of 1:5 as recommended by (Ahmed et al., 2000).

Figure 2. Dimensions of the general embankment of the evaporation pond



After the banks have been compacted with sheep roller, the installation of the polyethylene liner can be done. The polyethylene liner is mechanically strong and impermeable able to withstand stress during salt cleaning. Sand is then placed on top of the liner to facilitate the salt removal after the first year only when a hardpan is developed at the bottom which will help in the removal of the salt in due time. All liners will be sealed according to the manufacturer since sealing of liner joints is crucial as leakage takes place along joints (Ahmed, et al 2000).

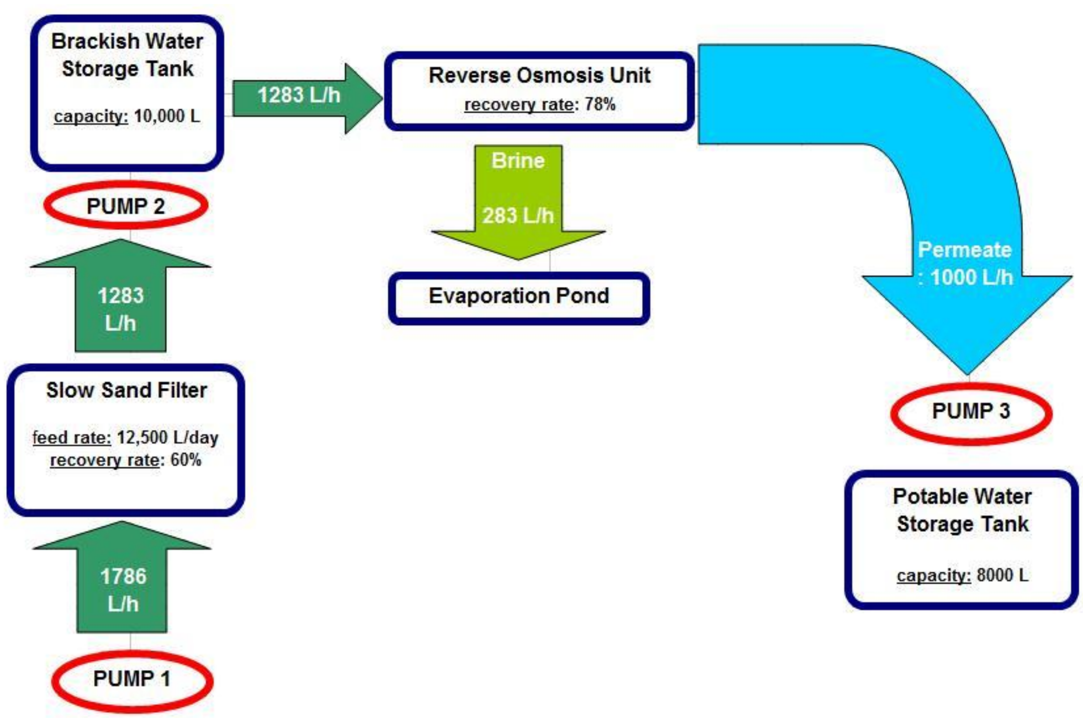
3.4 Storage Tanks

In an effort to minimize the cost of the solar energy system by reducing battery storage, this water treatment system is designed based on the premise that electrical devices will generally only operate during the 7 hours of the day which experience peak solar radiation and not continuously throughout 24 hours. Because of this system characteristic, the difference in rate of production vs. rate of consumption of the SSF and the RO unit, respectively, as well as the need to ensure a reliable daily production of fresh water, two storage tanks are employed in this system design.

Although the SSF does produce enough filtered water for 7 hours of reverse osmosis treatment, its output for these 7 hours occurs continuously over the full 24 hour period that it is servicing. This is necessary because for optimal functioning of a SSF, it must always be experiencing a flux of water. Thus, the total amount of feed water needed is pumped into the SSF over 7 hours, remaining there as supernatant water which slowly filters through before collecting in the bottom of the tank, where it rests until the 7 hours of daily operation begins. At that point, Pump 2 (see Figure 3) begins moving water from the bottom of the SSF and into the intermediate brackish water storage tank, from where the ROU begins to take feed water that was produced during the previous day.

The brackish water storage tank is located immediately after the SSF and the potable water storage tank is located immediately after the RO unit.

Figure 3. Water Flow Rate Chart



The start-up procedure, which ensures that the brackish water storage tank is full at the beginning of the 7 hour active pumping period, requires that the storage tank must be large enough to contain the full quantity of brackish water to be treated daily. The RO unit is fed at a rate of 1283 L/h. Thus, the brackish water storage tank volume = 1283 L/h * 7 h = 8981 L. Assuming the storage tanks are cylindrical and vertically orientated a storage tank with a 2m diameter would require a height of 3.2m in order to achieve a total capacity of 10,000 L with a freeboard of 20cm for the design conditions of 8981 L of brackish water. This storage tank will be elevated 0.5 m from ground level.

Permeate from the RO unit is produced at a steady rate of 1000 L/h throughout the 7 hours of active pumping time, thus achieving a production of 7000 L throughout a single day. To be safe, we will assume a worst case scenario of no water being used by the community throughout the production time and size a potable water storage tank to hold at least 7000L. Based on a diameter of 2m and a height of 2.55m, total capacity for this cylindrical storage tank will be 8000L, with a freeboard of approximately 30cm for design conditions.

In order to prevent damage to the system components, sensors should be installed in the storage tanks to detect when the vessel is full which would automatically shut off the pumps.

3.5 Selection of Pumps and Piping

This system requires the use of three pumps apart from those associated with the ROU. Due to the small scale of this water treatment plant, the flow rates are relatively low when compared to conventional plants, and thus our system design was limited by the availability of appropriate water pumps. It was deemed desirable to use high quality, industrial strength water pumps for increased reliability and resistance to corrosion from the brackish water. Only the smallest industrial pumps were remotely feasible to use in this application. Lowara, an Italian pump manufacturer with a distribution and service center in Amman, Jordan was selected and their smallest centrifugal, self-priming pump, the SP5 model, was chosen. Because the flow rates required in our treatment system range from 1 to 1.79m^3/h, the SP5 is used for all 3 pumping applications. Technical specifications for the Lowara SP5 can be found in Appendix F.

As seen in Figure 3, Pump 1 must supply 12500 L/ 7h = 1786 L/h to the SSF. As can be seen from the head-flow curve in Appendix F, the SP5 provides 20.7 m of head at this flow rate. The elevation head for this pumping situation is the sum of the height of the SSF and the elevation from the water source. Assuming that the brackish water is pumped from surface water 5 m below the SSF, the total elevation head for Pump 1 is 3.05m + 5m = 8.05m. Assuming 1" PVC pipe, the three 90^o elbows have an equivalent pipe length of 3 * 0.762m = 2.286m and the one gate valve has an equivalent pipe length of 0.183m for a total of 2.47m. Total pipe length for this section of the system is determined by Hazen-Williams equation:

$$h_f = L\left[\frac{V}{kC}\left(\frac{4}{D}\right)^{0.63}\right]^{1/0.54}$$

where V is flow velocity of 1.122 m/s in this case, k is 0.85 for metric units, C is 150 for PVC (Engineering Toolbox), L is pipe length in m, D is pipe inner diameter of 0.02375m, h_f is set as head provided by the pump minus elevation head. Therefore, total pipe length for this section is calculated to be 56.9m. Subtracting the equivalent pipe length for head loss associated with fittings, we arrive at a total pipe length of 54.6 m. Since 3.05 m is used up in lifting the water to the top of the SSF tank, then we can conclude that the SSF must be placed approximately 50m from the source of water under the proposed design conditions.

As show in Figure 3, pump 2 is placed after the SSF and pumps the pre-treated brackish water into the intermediate brackish water storage tank. The flow rate of this pump must match the inflow and outflow from this storage tank during ROU operation. The ROU has a feed rate of 1283 L/h and therefore that is the flow rate required from Pump 2 – another Lowara SP5 model. Once again, from the head-flow curve in Appendix F, it is seen that the pump provides 29m of head at a flow rate of 1.283m^3/h. As described in the previous section, the brackish water storage tank is 3.2m tall with a 0.5m stand, giving a total of 3.7m for elevation head. This section of pipe contains four 90^o elbows and two gate valves (see Appendix A) which, with 1" Schedule 80 PVC piping, results in a friction loss pipe length equivalent of 4 * 0.762m + 2 * 0.6m = 4.248m. The same procedure as for pump 1 is followed with the Hazen-Williams equation but with the different characteristics of this second section of the system (h_f = 29m – 3.7m = 25.3m, V = (1.283m^3/h)/3600s/(Π * (0.02375m) ^{2} / 4) = 0.8045m/s). Pipe length for this section is calculated as being 158.6m – 4.248m (friction loss) = 154.35m. This is quite a large quantity of pipe and, depending on the distance from the water source to the final destination of the heart of the community this may not be appropriate. As the pump port size is 1", a reducer may be installed after the pump and a smaller diameter pipe used. The reduction in pipe diameter will increase friction head loss and shorten pipe length. For the sake of this analysis, it is assumed that 1" piping is used throughout.

Pump 3 is used to lift the potable permeate from the ROU into the final storage tank in the system at a rate equal to the production rate of the ROU, 1000L/h. At this flow rate, the Lowara SP5 provides 34m of head. The permeate storage tank is 2.55m tall on a 0.5m stand, resulting a total elevation head of 3.05m for this section of piping. Once again, the pipe diameter can be modified based on the needed pipe length to the final destination of the water, the permeate storage tank but for the sake of this analysis 1" Schedule 80 PVC pipe will be utilized. There are four 90^0 elbows in this section resulting in 4 * 0.762m = 3.05m of friction loss pipe length equivalent. Thus, the effective head provided by the pump is 34m – 3.05m = 30.95m. The velocity of water for this section, $V = (1.0m^3/h)/3600s/(\Pi * (0.02375m)^2 / 4) = 0.627$ m/s. All other parameters are the same as for the previous sections, resulting in a calculated pipe length of 249m. Subtracting the friction loss pipe length equivalent, 3.05m, the total pipe length for this section is determined to be 246m. Once again, this distance can be reduced by reducing the pipe diameter as needed. Less powerful, non-industrial pumps could be used to reduce this distance but this compromise may come at the expense of reliability.

3.6 Solar Photovoltaic Energy System Design

The renewable energy system (RES) is designed to meet the energy demand from the desalination unit and the associated pre/post-treatments as well as the pumps needed to run the process. To appropriately size the energy system, the first step is to sum the electrical requirements of all of the desalination system components.

- The ROU electrical requirement is 5.5 kW, 3 phase x 400 V, 50 Hz
- Each of the three pumps requires: 0.78 kW, 3 phase x 220-240/380-415 V, 50 Hz

Total power required = 5.5 kW + 3 * (0.78 kW) = 7.84 kW

The electrical components of the system are operational for a duration of 7 hours throughout each day, therefore the electrical energy required = 7.84 kW * 7 h = 54.88 kWh

This value represents the energy input required by system components, but to find the power that needs to be generated by the solar photovoltaic (PV) array the efficiency of various components within the RES needs to be taken into account. These components are the sin-wave inverter, the battery charge regulator, and the batteries themselves and their efficiencies are taken from technical literature as shown below:

- Inverter: 97% (See Appendix H)
- Charge regulator: 97% (See Apendix I)
- Batteries: 80% (Mahmoud, 2003)

Therefore, the electrical energy that must be generated by the PV is = 54.88 / (0.97*0.97*0.80) = 72.9 kWh. Now the peak power required from the PV generator can be calculated as (with a safety factor of 1.25):

$$P_{\mathrm{PV}} = \frac{(1.25 \times E_{\mathrm{PV}})}{\mathrm{PSH}}$$

The Peak Sunshine Hours (PSH) is the equivalent number of sunshine hours over the course of a single day if insolation was to be evenly distributed and is calculated as:

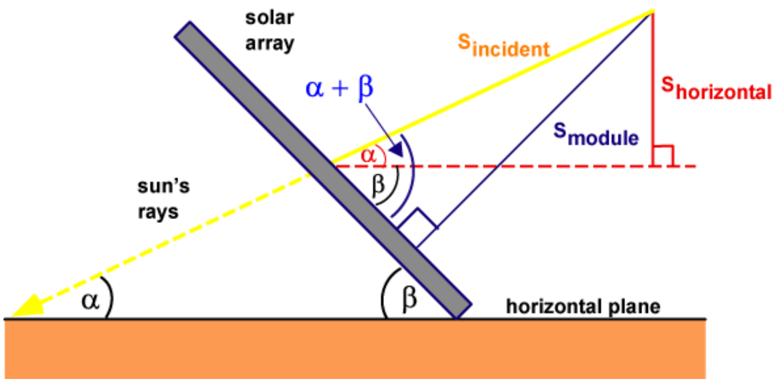
$$\mathrm{PSH} = \frac{E_{\mathrm{sd}}}{G_{\mathrm{o}}}$$

E_{sd}, the daily average of solar radiation intensity

G_{o}, the peak solar radiation intensity

The average annual solar radiation on a horizontal surface for Jordan is calculated to be 5.5 kWh/m^2/day (Hryashat, 2009). (See Figure 5 and 6 at end of section) The average value is used because using the worst case scenario would result in an over-designed system that would produce far too much power during the majority of the year and have very high costs. Using the average solar radiation value for system sizing optimizes production and cost. Peak solar radiation varies from location to location but a general value of 1000 kW/m^2 is an accepted value for this region (Mahmoud, 2003).

The amount of solar radiation that lands on the PV array is maximized by tilting the array up from the horizontal to an angle of β to more directly meet the rays of the sun, which are incident to the Earth's surface at an angle of α. (See Figure 4 below).



From these trigonometric relationships, the measured horizontal insolation can be related to the insolation on a tilted surface by the following equations:

$$S_{horizontal} = S_{incident} \sin \alpha$$

$$S_{module} = S_{incident} \sin(\alpha + \beta)$$

$$S_{module} = \frac{S_{horizontal} \sin(\alpha+\beta)}{\sin \alpha}$$

Where **$\alpha = 90 - \phi + \delta$**

And **ϕ = latitude, $\delta = 23.45^0 \sin[360*(284 + d)/ 365]$**

And **d** is number of days since January 1.

Because Jordan is located near the 30^0N latitude line, the solar array will face directly south (azimuth of 0^o) and will be tilted up at an angle $\beta = 30^0$.

Because the PV array is designed for the annual average conditions, and **δ** varies from $+23.45^0$

to – 23.45^0 in the course of a year, the average will be taken as a zero value.

Therefore, the solar radiation incident on the PV array, S_{module} = 6.35 kWh/m^2/day, showing that installation of the PV array on an angle of 30^0 increases capture of incident solar radiation by 15%. In this setup, PSH = 6.35 hours and peak power required from the PV, utilizing a safety factor of 1.25 for miscellaneous losses and climatic variability, is 14.35 kW.

The Siemens SP-150 is the PV module of choice for this project as it is the most efficient model offered by Siemens, a reputable manufacturer in the PV industry (see Appendix G). Energy delivered is 150 W (rated peak power) * 6.35 hours (PSH) = 0.9525 kWh / module. The number of modules needed is 14.35 kW * 7 hours (daily energy use) / (0.9525 kWh / module) = 105.5. The number of PV modules must be an even number in order to have proper voltage when wired together, implying that 106, SP-150 modules must be used, thus bumping the safety factor from 1.25 up to 1.385.

Each of the modules has an area of 1.32 m^2, thereby requiring a total of 140 m^2 of PV modules. The 30^0 tilt saves some of this space, effectively reducing the area to ~120 m^2.

The output voltage of an SP-150 module is 24V. The arrangement of modules is such that there are 2 strings of parallel-wired modules, resulting in a net output at 48V going to the charge regulator which steps down the voltage to 12V to charge up the battery bank. The chosen charge regulator is an OutBack Power Systems FLEXmax, which protects the battery bank from spikes in voltage and from being overdrawn, thereby extending their life and ensuring safety (See Appendix I).

The battery bank was sized using the following equation for 2 days of autonomy (Mahmoud, 2003):

$$C_B = [(E_{PV} + E_{RO})/(\mathrm{DOD} \times \zeta_B)] \times N_a$$

where

C_B = storage capacity of the battery block in kWh
E_{PV} = energy required for pumping of brackish water.
E_{RO} = energy consumed by the RO-system.
N_a = days of autonomy.
DOD = depth of discharge = 75% which is the maximum allowable discharge percentage of battery block full charge.

$C_B = [(72.9 \text{ kWh})/ (0.75 * 0.80)] * 2 = 243 \text{ kWh}$

The chosen batteries will then be 5, Concorde SunExtender PVX-2580L.

A Siemens SINVERT PVM 17 inverter is placed next in the circuit where it converts DC to AC electricity needed for running the pumps and the ROU. If the community is connected to the national electric grid in the future, the inverter will synchronize the PV generator with the grid.

Figure 5: Mean monthly variation of the recorded global solar radiation for Jordan, 1994–2003

(Hrayshat, 2009).

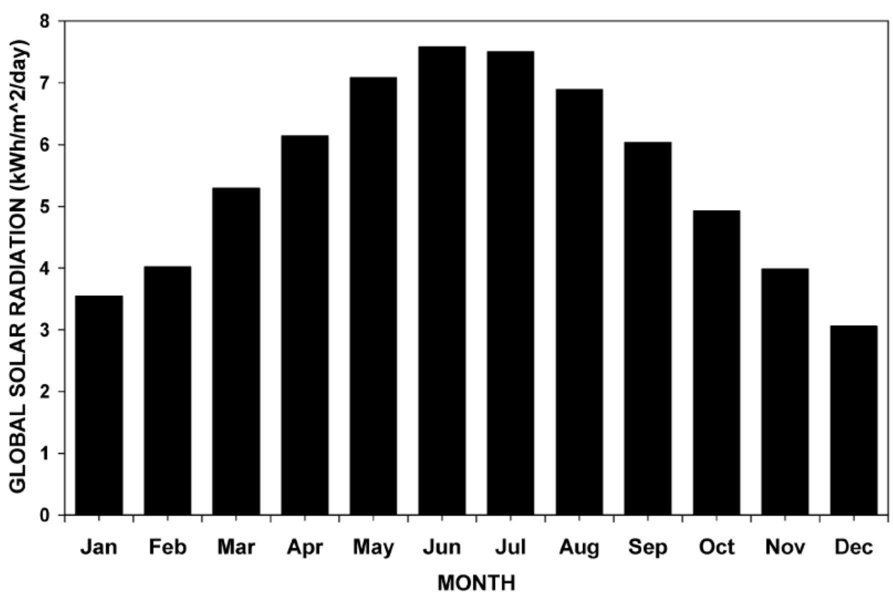
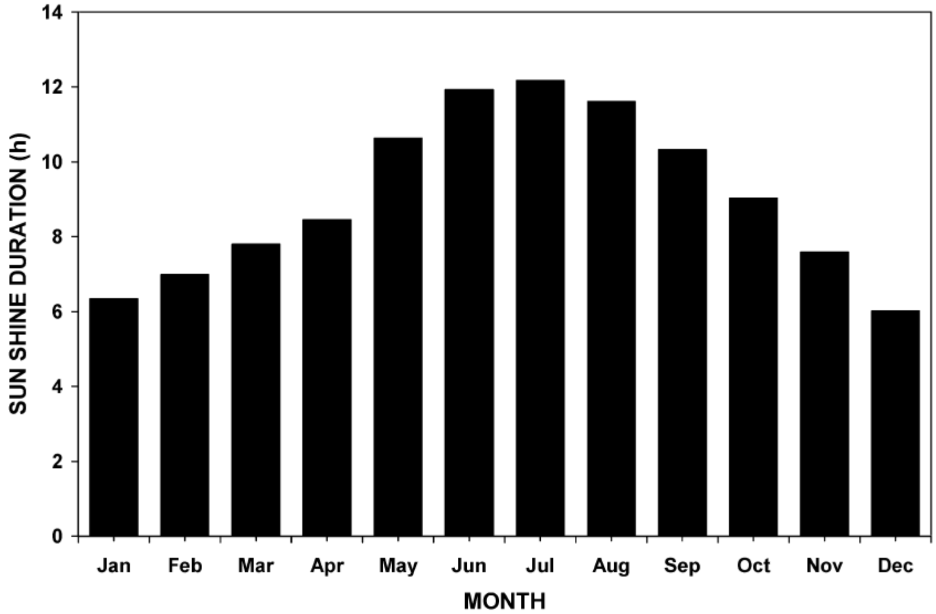


Figure 6: Mean monthly variation of the recorded sunshine duration for Jordan, 1994-2003 (Hryashat, 2009).



4.0 Maintenance

4.1 Maintenance of Slow Sand Filter

Maintenance of the SSF requires several steps, after noticing critical low filtration rate on the pizometers, and then we are required to backfill the sand bed.

In order to displace the air pockets within the sand bed media, the bed should be saturated by slowly backfilling the sand media from the bottom of the filter with raw water. The rate of backfilling should be in the range of 0.1-0.2 meter of bed depth per hour or 0.3-0.6 ft/hr, (Hendricks, 1991). With this we can conclude that it will take about 6.5 hours to backfill with 1.25meters of bed media. The backfilling will starts when we close the gate at the outflow of the filter, and letting the flow to go upwards in the sand while the gate valve is open and the water will go through the drain pipe. After the displacement of the sand media, the maturation or the development of the Schmutzdeske layer or biofilm layer after 24 hours to several months (Khosrowpanah, et al., 2001).

Furthermore, in order to insure that the filter is operating effectively, scraping is done when we can notice that the headwater rises to the overflow level. The recommended scraping time is after 45 days of filtration. (Khosrowpanah, et al., 2001)

The steps to undergo scraping the filter are;

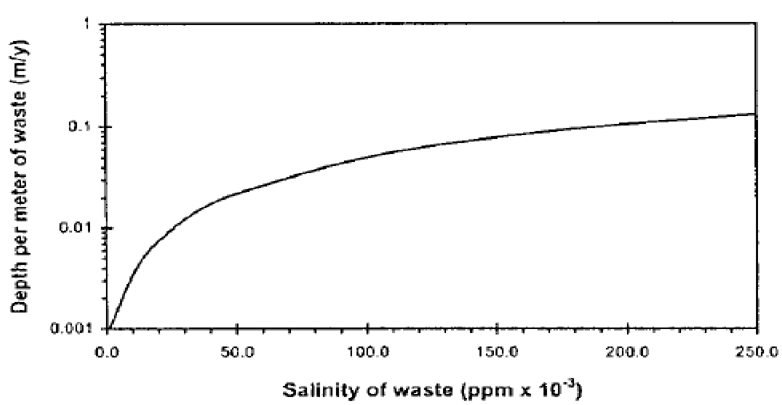
1. Removal of floating material
2. Slowly draining water level to just below the level of sand
3. Removal of scraped sand from the filter
4. Wash the filter walls if needed.

By closing the inflow to the filter and opening the outflow we can reduce the level in the slow sand filter. The time required for the scarping is dependent on the depth of sand removed. According to most peer reviews, scraping of the top few centimeters should be done accordingly. A typical slow sand filter facility normally consists of two identical filter tanks that supply the community with treated water. During the time when filter scraping is required, one filter will be shut down and scraped while the other remains in service.

4.2 Maintenance of Evaporation Pond

It has been recommended that no salt should be removed from the pond for the first year or two of operation in order to prepare for a hardpan development at the base of the evaporation pond. This hardpan will give provide support when cleaning the basin. The hardpan can only develop if the pond is completely dried during the hottest month of the year. Furthermore, when leaving the salt for too long in the pond, it will reduce the storage volume and may cause spill if ignored. According to Graph 3 it provides an estimate of precipitate have been produced to show that each foot of wastewater discharged there is an exponential increase in the depth per meter of waste in the evaporation pond.

Graph 3. Depth of precipitate



4.3 Maintenance of ROU

It is clear that the RO unit maintenance requirement should be high in order to maintain excellent quality of purification water after treatment. According to the manufacturer Lenntech there is a 10 year warranty on the system and all critical problems or mishaps that could happen during and maintenance or after installation as well as while in operation, the company would send technicians for repairs.

5. Cost Evaluation and Economic Analysis

The budget for this project is split into two parts: the water treatment system and the PV energy system. The detailed costs for each system are outlined below:

Table 3. Water treatment system detailed cost

No	Item	Quantity	Unit	Unit Cost	Total Cost
1	8'' PVC pipe perforated	40	FT	$25.00	$797.70
2	8'' PVC pipe	20	FT	$19.94	$398.80
3	8'' PVC sched. Coupling	5	EA	$31.25	$156.25
4	8'' PVC Sched Elbow 90 degrees	4	EA	$40.00	$160.00
5	6''to 8'' PVC Reducer	4	EA	62.5	$250.00
6	8''Gate Valve Brass	6	EA	$687.50	$4,125.00
7	8'' gavanized pipe	6	FT	29.11	$174.66
8	8''solid sleeve joint	8	EA	$225.00	$1,800.00
9	1/2 " PVC pipe	155	FT	$0.50	$77.50
10	1" PVC pipe	560	FT	$1.00	$560.00
11	Storage Tanks	2			$3,000.00
12	Concrete (3000psi)	25	CY	312.5	$7,812.50
13	Bedding sand	1268520	Lb	$0.01	$12,685.20
14	Gravels base course	157324.2	Lb	0.01	$1,573.24
15	compaction	2	LS	$1,250.00	$2,500.00
16	excavator Backhoe,powershovel	1	LS	$55,000.00	$55,000.00
17	Gravel underdrain	12177.6	Lb	$0.02	$243.55

18	Gravel bedding	133760	Lb	$0.03	$3,344.00
19	Pizometers	3	EA	$435.00	$1,305.00
20	water meters 8''	2	EA	1250	$2,500.00
21	Pipe adhesive plugs, Misc,Fittings	1	LS	$1,000.00	$1,000.00
22	Plastic foam cover	2568	FT^2	0.46	$1,181.28
23	stainless steel ladder	2	EA	$1,000.00	$2,000.00
24	Small tools Misc. equipement	1	HR	1500	$1,500.00
25	Labor	3000	HR	$15.00	$45,000.00
26	Supervision	375	HR	$30.00	$11,250.00
27	Land Surveying	1	LS	$5,000.00	$5,000.00
28	RO Unit	1	EA	$22,000.00	$22,000.00
29	PE Liner HDPE	8285.2	FT^2	$0.53	$4,391.15
30	Pumps	3	EA	400	$1,200.00
31	Total maintenance Cost per year				$3,000.00
	Subtotal				$195,985.83
	With Overhead, Shipping, Taxes (10%)				$215,584.41

Table 4. Solar PV energy system detailed costs

No	Item	Quantity	Unit	Unit Cost	Total Cost
1	OutBack Charge Regulator	1	EA	$ 749.00	$ 749.00
2	OutBack Battery Temperature Sensor	1	EA	$ 29.00	$ 29.00
3	Siemens SP150 PV modules	106	EA	$ 690.00	$ 73,140.00
4	Siemens SINVERT PVM17 Inverter	1	EA	$ 6,730.00	$ 6,730.00
5	Batteries	5	EA	$ 580.00	$ 2,900.00
6	Cabling, Mounting Racks, etc.			$ 1,000.00	$ 1,000.00
	Sub Total				$ 84,548.00
	Grand Total with Overhead, Shipping, Taxes (10%)				$ 93,002.80

http://www.e-pumps.co.uk/lowara-sp5-self-priming-pump-200-p.asp

http://www.usplastic.com/catalog/item.aspx?itemid=23979&clickid=redirect

http://www.chargeregulators.com/outback_power_systems_mx60.html

http://store.solar-electric.com/pvx-12255.html

http://www.innovationhouse.com/products/solar_siemens_sp150.html

http://www.who.int/water_sanitation_health/publications/ssf4.pdf

http://www.areamulchandsoils.com/price%20list%20gravels.html

The total cost of the project is estimated at a grand total of $308,587.21 USD. The water treatment and renewable energy systems accounts for 70% and 30% of the total cost, respectively.

Assuming a salvage value 20% of the original project cost and maintenance costs averaging at $3000 per year for the lifetime of the system, 25 years, the total cost to own and operate this system will be $321869.77. Assuming the system is operational 95% of each annum, producing at the design rate of 7000 L of potable water every day, lifetime production is 60,680 m^3 of potable water. Thus, the unit cost of producing potable water at a village scale with this design is $5.3/$m^3$. Current water costs in the capital city, Amman, are 25 Jordanian Dinars for 6 m^3 (Ladenhauf et al.). This is equivalent to $5.88 USD / m^3.

If we assume water prices in the rural community to be the same as in the city, then each year the net cost-benefit of producing water as opposed to purchasing delivered water is $1408. At this rate, the payback period would be 220 years. It would be realistic to assume that rural water prices are 20% higher than city prices, but the payback period under this scenario is still very long at 72 years. As this payback period is longer than the expected life of the system, we conclude that the desalination of brackish water at this scale is not feasible without subsidies from the Jordanian government.

Conclusion

The Kingdom of Jordan is a country in which the desalination of brackish water has been determined to have the greatest potential to alleviate the current condition of water scarcity (Jaber et al., 2001). Because the problem is so severe in Jordan, we have finalized the development of the system design for a small-scale desalination project for a rural community in this country. This Turnkey project will be able to deliver a proper functional system to provide sanitary and required water to the location in Jordan area. Although the price of desalinated water increases with smaller scale projects, the need for decentralized water treatment is reinforced by the extremely high losses associated with the current water distribution network and by the increasingly high cost of water transport to remote locations.

There are factors which we did not quantify that would shorten the payback period, including decreased healthcare costs for the community members that are experiencing an improvement in water quality thereby improving health. Although the designated purpose of the water is for domestic use, it is quite possible that community members may be able to exploit some portion of produced water for economic activity. Both of these factors could contribute to shortening the payback period.

Although a brief economic analysis shows that under current water pricing schemes the project is not feasible to undertake if it was only community-funded, it would be wise for the Jordanian government to invest in decentralized desalination systems at a somewhat larger scale than the proposed design in order to reduce production costs. This decentralized production will be essential as transport fuel and water prices grow in the near future. As the water scarcity issues become more serious in the country, it is inevitable that eventually the government will have to increase the prices for water which are currently artificially held low. If these projections for the future show themselves to be true, it will quickly become much more feasible for this project to be implemented without government subsidy. Still, we do maintain that it would be prudent not to wait for the dire circumstances before acting on this issue and that the Jordanian government should live up to its stated priority of ensuring domestic water supply by making investments in the healthy future of its citizens.

AKNOWLEDGEMENTS

We would like to acknowledge the following people for their invaluable guidance during the conceptualization and development of this design project:

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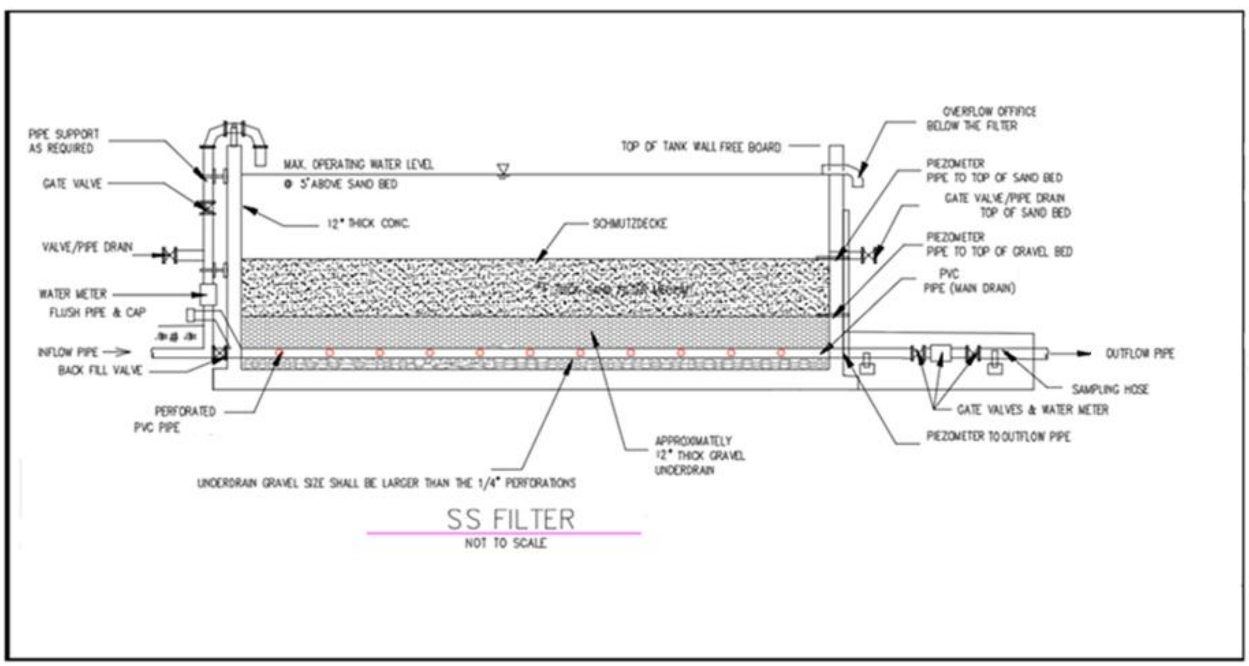
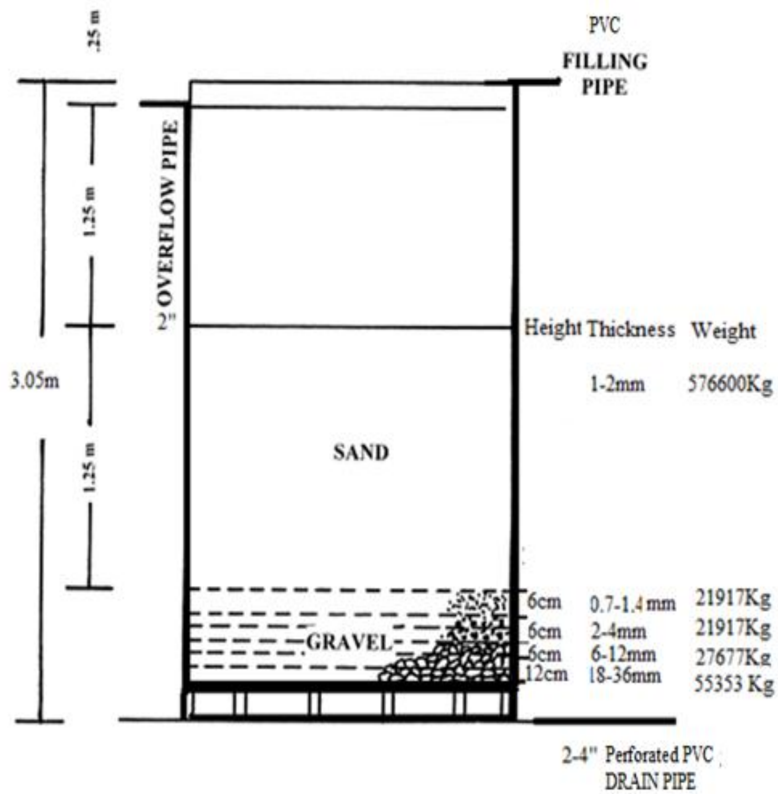
Apurva Gollamudi, Brace Center for Water Resources Management
Mousa Mohsen, Department of Mechanical Engineering, Hashemite University, Jorr.
Mark Zeitoun, School of International Development, University of East Anglia, UK

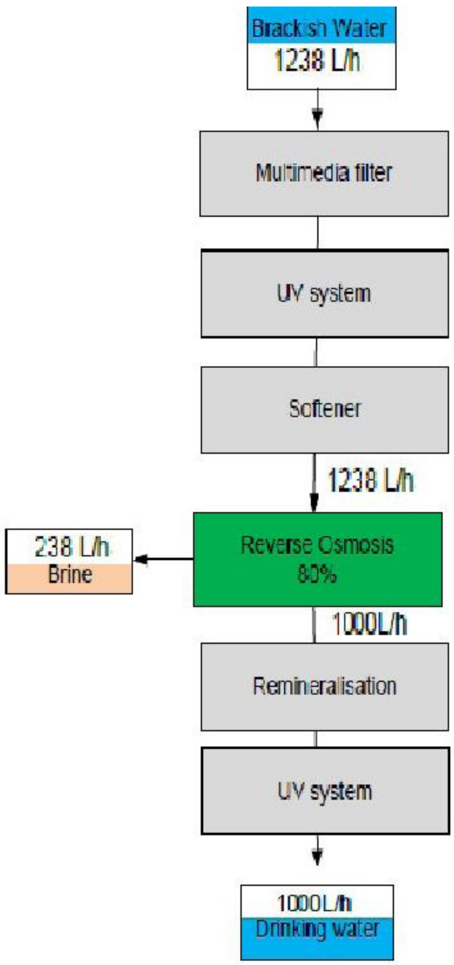
Appendix A. Autocad Drawing of SSF



Appendix B. SSF SIDE VIEW



Appendix C. Flow diagram of ROU Lenntech Water Treatment and Purification



Appendix D. Small brackish water RO Lenntech inc.

Appendix E. Lenntech RO Description

Lenntech Water Treatment and Purification

Equipment description

- Prepressure pump 1238 L/h3 bar, 0.37 kW

Pre-treatment
- 1 self cleaning filter 50 microns
- 1 filters GRP 334 mm diam

Filtration rate: 4.5 m/h
Media: 100L (70% sand, 20% anthracite, 10% gravel)
Fleck distribution head
- 1 UV system – 30W
- 1 softener – Fleck 5600

Instrumentation

Reverse Osmosis
- 5 microns cartridges filter
- High pressure pump 790 L/h 22.8 bar
- 2 membranes AG4040
- 2 pressure vessels 450 psi
- post disinfection UV system – 8W
- post remineralisation Calcite filter
- Valves, piping
- Instrumentation
- Skid mounted
- Control cabinet

Total installed power 5.5 kW

Price: EUR 13.200,-

Prices are ex-works.
VAT 19%, not inclusive.
Offer validity: 3 months

Kind regards,
Aurelie Jimonet
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Rotterdamseweg 402M
2629 HH Delft, The Netherlands
Tel: +31(0) 15 275 57 04
Fax: +31(0) 15 261 62 89
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Lenntech delivers according to the Orgalime S2000 conditions.

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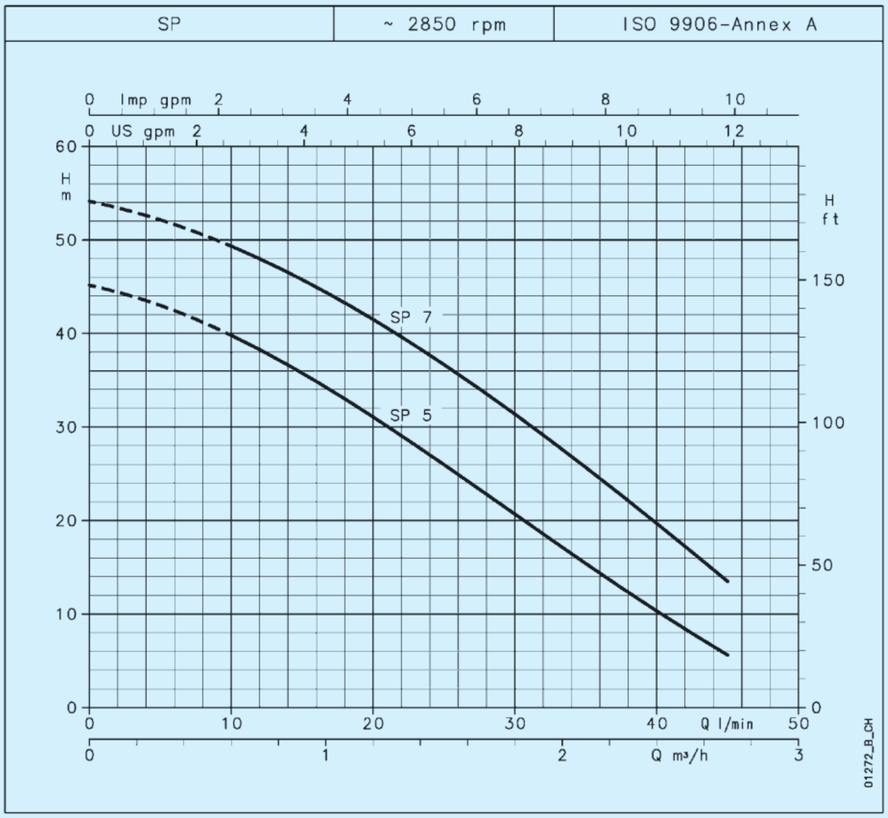
info@lenntech.com / http://www.lenntech.com

LOWARA

SP

SP SERIES
OPERATING CHARACTERISTICS AT 2850 rpm 50 Hz



PUMP TYPE	RATED POWER		Q = DELIVERY								
			l/min	0	10	20	25	30	35	40	45
			m³/h	0	0.6	1.2	1.5	1.8	2.1	2.4	2.7
	kW	HP	H = TOTAL HEAD METERS COLUMN OF WATER								
SP5(T)	0.55	0.75		45.2	39.8	31.1	26.0	20.7	15.4	10.3	5.7
SP7(T)	0.75	1		54.1	49.3	41.5	36.7	31.4	25.7	19.7	13.5

These performances are valid for liquids with density ρ = 1.0 kg/dm³ and kinematic viscosity γ = 1 mm²/sec. sp-2p50_a_th

PUMP TYPE SINGLE-PHASE	INPUT POWER* kW	INPUT CURRENT* 220-240 V A	CAPACITOR μF / 450 V
SP5	0.87	4.21	16
SP7	1.00	4.60	20

PUMP TYPE THREE-PHASE	INPUT POWER* kW	INPUT CURRENT* 220-240 V A	INPUT CURRENT* 380-415 V A
SP5T	0.78	2.67	1.54
SP7T	0.98	3.53	2.04

* Maximum value in specified range

sp-2p50_a_te

Lowara
ITT Industries

Appendix G. Siemens SP150 PV module specs.

Solar module SP150

Electrical parameters		(24 V)
Maximum power rating P_{max}	$[W_p]$ 1)	150
Rated current I_{MPP}	[A]	4.4
Rated voltage V_{MPP}	[V]	34.0
Short circuit current I_{SC}	[A]	4.8
Open circuit voltage V_{OC}	[V]	43.4
Thermal parameters		
NOCT 2)	[°C]	45±2
Temp. coefficient of the short-circuit current		2.06 mA / °C
Temp. coefficient of the open-circuit voltage		-.077 V / °C
Qualification test parameters 4)		
Temperature cycling range	[°C]	-40 to +85
Humidity freeze, Damp heat	%RH]	85
Maximum permitted system voltage	[V]	600 V (1000 V per IEC 1215)
Wind Loading	PSF [N/m²]	50 (2400)
Maximum distortion 3)	[°]	1.2
Hailstorm / hailstones	inches [mm]	1.0 (ø 25)
	MPH [m/s]	52 (v = 23)
Weight	Pounds [kg]	32.6 (14.8)

1) W_p (Watt peak) = Peak power

Air Mass	AM= 1.5
Irradiance	E= 1000 W/m²
Cell temperature	T_C= 25 °C

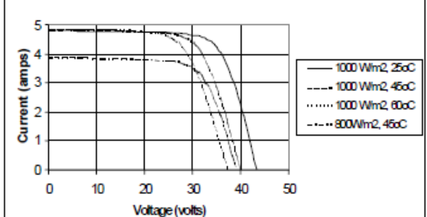
2) Normal Operating Cell Temperature at:

Irradiance	E = 800 W/m²
Ambient temperature	T_a = 20 °C
Wind speed	v_W= 1 m/s

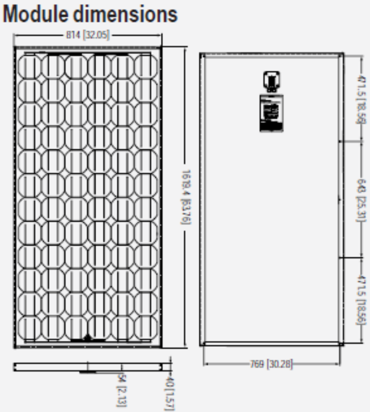
3) Diagonal lifting of the module plane

4) Per IEC 61215 test requirements

Voltage-Current Characteristic
SP150 (24 volt Configuration)



Module dimensions

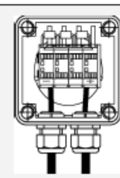


Hole diameter 0.26 inch (6.6 mm)
Hole dimensioning referred to hole center

Sp J box

Maximum cable diameter: 4 mm²

Degree of protection: IP54



Your address for photovoltaics from Siemens Solar:

Appendix H. Siemens SINVERT PVM Inverter Technical Specs.

	Type		PVM10	PVM13	PVM17
DC	U MPP min	V	380	420	525
	U MPP max	V	850	850	850
	U DC max	V	1000	1000	1000
	I DC max	A	29	30	32
	Overvoltage protection		Type 3		
AC	P rated	kW	10.0	12.4	16.5
	P max	kW	10.0	12.4	16.5
	I max	A	18	18	25
	Grid interface		3AC 400 V; 50/60 Hz		
	cos phi		0.9 i to 0.9 c		
	THD I	%	< 2.5		
	eta max	%	98.0	98.0	98.0
	eta EU	%	97.4	97.5	97.7
	Infeed starting at	W	20		
	Own consumption at night	W	< 0.5		
	Overvoltage protection		Type 3		
Ambient conditions	T min	°C	–25		
	T max	°C	55		
	T max for P rated	°C	50	50	40
	Cooling		natural convection		
	Max. installation altitude	m	2000		
	Operating noise	dBa	< 45		
	Width (approx.)	mm	530		
	Height (approx.)	mm	600		
	Depth (approx.)	mm	265		
	Weight (approx.)	kg	40		

Appendix I. OutBack Power Systems FLEXmax Charge Regulator Specs.

	FLEXmax 80 - FM80-150VDC
Nominal Battery Voltages	12, 24, 36, 48, or 60 VDC (Single model - selectable via field programming at start-up)
Maximum Output Current	80 amps @ 104° F (40°C) with adjustable current limit
Maximum Solar Array STC Nameplate	12 VDC systems 1250 Watts / 24 VDC systems 2500 Watts / 48 VDC systems 5000 Watts / 60 VDC Systems 7500 Watts
NEC Recommended Solar Array STC Nameplate	12 VDC systems 1000 Watts / 24 VDC systems 2000 Watts / 48 VDC systems 4000 Watts / 60 VDC Systems 5000 Watts
PV Open Circuit Voltage (VOC)	150 VDC absolute maximum coldest conditions / 145 VDC start-up and operating maximum
Standby Power Consumption	Less than 1 Watt typical
Power Conversion Efficiency	97.5% @ 80 Amps in a 48 VDC System - Typical
Charging Regulation	Five Stages: Bulk, Absorption, Float, Silent and Equalization
Voltage Regulation Set points	10 to 60 VDC user adjustable with password protection
Equalization Charging	Programmable Voltage Setpoint and Duration - Automatic Termination when completed
Battery Temperature Compensation	Automatic with optional RTS installed / 5.0 mV per °C per 2V battery cell
Voltage Step-Down Capability	Can charge a lower voltage battery from a higher voltage PV array - Max 150 VDC input

REFERENCE

Abdallah, S. et al. ‘Performance of a photovoltaic powered reverse osmosis system under local climatic conditions’. Desalination. (2005) 183: 95-104

Akash, Bilal A. ‘Multi-criteria analysis of non-conventional energy technologies for water desalination in Jordan.’ (1997) 41,9: 883-890

Denny, Elaine et al. ‘Sustainable Water Strategies for Jordan’. International Economic Development Program, University of Michigan, Ann Arbor. (2008)

Haarhoff, J. and Cleasby, J. L.1991, Mechanisms in Slow Sand Filtration, in Slow Sand Filtration, American Society of Civil Engineers, New York, p. 19.

Gamila E. El-Taweel and Gamila H. Ali. 1999, Evaluation of Roughing and Slow Sand Filters for Water Treatment. Water Pollution Control Department, National Research Center, Cairo, Egypt.

George Nakhla Shaukat Farooq .2002, Simultaneous nitrification–denitrification in slow sand filters Journal of Hazardous Materials B96 (2003) 291–303

Hendricks, D. W. and Bellamy, W.D. 1991, “Microorganism Removals by Slow Sand Filtration”, In G.S. Logsdon (Ed), Slow Sand Filtration: A report prepared by the Task Committee on Slow Sand Filtration. New York: American Society of Civil Engineers.

E. Hrayshat and M. Al-Soud. 2004, Renew. Sustain. Energ. Rev., 8 193–200.

E. Hrayshat and M. Al-Soud. 2004, Renew. Energ, 29 1393–1399.

Eltawil, Mohamed A. et al. ‘A review of renewable energy technologies integrated with desalination systems’. Renewable and Sustainable Energy Review. (2009) 13: 2245-2262

Engineering Toolbox. ‘Hazen-Williams Coefficients.’ Accessed 20/3/2010.

Jaber, Jamal O. et al. ‘Evaluation of non-conventional water resources supply in Jordan’. Desalination, (2001) 136: 83-92.

Khosrowpanah, S., L. Heitz, and Colette Beausoliel, 2001. “The Application of Slow Sand Filtration Technology for Kosrae State, the Federated States of Micronesia, A Pilot Project”, Technical Report 91, May 2001, UOG, WERI.

Ladenhauf, J.C., Liven, I. “Water Shortage in Jordan”. Goethe-Institut Jordan. http://www.goethe.de/ins/jo/amm/prj/ema/far/whj/enindex.htm

Lensky, N.G., Y. Dvorkin, and V. Lyakhovsky.2005, Water, Salt, and Energy Balances of the Dead Sea. Water Resources Research, Vol. 41.

Mahmoud, Marwan M. 'Solar electric powered reverse osmosis water desalination system for the rural village, Al Maleh: design and simulation'. International Journal of Sustainable Energy, (2003) 23,1: 51 — 62.

Mohsen, Mousa S. ’Water strategies and potential of desalination in Jordan’. Desalination, (2007) 203: 27-46.

Mushtaque ahmed, Walid H.Shayya , davaide Hoey, Arun Mahendran, Richard Morris,Juma Al-Handaly. 2000, Use of evaporation ponds for brine disposal in desalination plants, Desalination Elsevier 130 -155-168.

Rijsberman, Frank R. ‘Water Scarcity: Fact or fiction?’. Agricultural Water Management. (2006) 80: 5-22

Zeitoun, Mark. ‘The Roots and Future of Water Conflicts in the Middle East’. Presentation at Macdonald Campus, Nov 23, 2009.