

**Saline Groundwater Pumping Water Change Water Quality and Management In Dry-Lands:
An Experimental and Numerical Assessments**

Ahmed Hasson, Research Officer, Department of Agriculture and Food, WA,
ahasson@agric.wa.gov.au

Abstract

This involved pumping saline water to shallow ponds, reducing pond evaporation, diluting salt levels with winter rain water and then using this water for irrigation and livestock water supplies. Studies were conducted at two sites in Iraq and in Western Australia. These sites all have a similar climate and share the similar salinity problems. It was found that there was a reduction of 70%, 72% and 82% of the evaporation from the ponds in Iraq and Western Australia respectively. In Upper Euphrates and Babylon the subsequent dilution with winter rainfall changed the water quality from highly saline level to moderately saline, brackish, suitable for irrigation and livestock. Environmental parameters were used to compare the applicability of this technique for the Western Australian wheatbelt. Water pumping were 32% for Upper-Euphrates, 35% for Babylon, and 33% for Moora-Katanning.

Introduction

Water is a scarce resource in many countries. The optimal water requirement per capita is estimated to be around 1,700 m³/year. However, in many countries in West Asia, the available water is less than 500m³/capita/year. The situation will deteriorate further during the next two decades as populations increase. Agriculture is the biggest consumer of water. About 80% of the renewable water resources are used for agricultural irrigation. Traditional methods such as furrow and surface irrigation are highly inefficient. Only one third of the applied water is transpired by the crop (Moutonnet and Heng (2002). Crop yield is strongly correlated with the level of evapotranspiration, a reduction in which results in a loss of yield. Internationally, there is great need to increase the availability of water and improve irrigation management in drylands, such as Iraq and Australia (Barrett, 1985).

Groundwater and land clearance are contributing factors to increased salinity in agriculture in both Western Australia and Iraq. In rural Western Australia there is 14 giga litre a year flowing from ground water systems. However as most of this is saline it is not presently used by agricultural. This saline ground water represents a significant resource if its salt content could be reduced.

In southern region of Iraq water scarcity is common, especially during the dry season. Irrigation with river water is widely used but leads to a build up of salt in the soils due to poor soil drainage. This has resulted in the storage of a huge amount of salt in the lands.

Ground water pumping from aquifers can control rise water tables and help to prevent salinity. Pilot projects in Western Australia have been evaluated. However, conventional salt water pumping systems are expensive and result in no commercial returns.

Saline ground water can be disposed of by pumping it into evaporation ponds. Evaporation increases the saturated salts in evaporation ponds, especially in hot, windy conditions of Iraq (Hasson, A. and AlSajir, 1989). Evaporation rates decline as the salt concentration approaches brine levels. Once water in the ponds becomes hyper-saline the evaporation ponds stop being effective.

Most ground water is pumping is done using electric pumps. This can be expensive and access to an electricity grid is not always available. Solar electric driven pumps using photovoltaic cells (Hasson and AlSajir, 1990) is a more sustainable option. On-site water pumping and storage is the most inexpensive method. The viability of this option is dependent upon the land topography. In Sigh and Christain, (1999) studies they considered basin sizes of 2-30ha to be small and 30-200ha large.

Leany and Chrestain (2000) reported that leakage from basins can vary from 0.5 – 5.4mm/day with acceptable losses set a 0.5 – 1.0mm/day. Also they showed that the leakage with more than 3mm/day is unviable.

Evaporative losses from open storage can be minimized by using a cover or a floating mat. The mats can absorb short-wave solar radiation and convert it to kinetic energy depending on the mat surface reflectance (Kaisy and Hasson, 1992).

In this paper, the use of solar energy for water pumping and water storage, dilution of salinity using winter rainfall and the use of floated covers to reduce the potential evaporation rates are investigated. Economical benefits were also analyzed. Comparison of the region between the Tigris and Euphrates rivers in Iraq and that with South-West region of Western Australia is primary interest of this investigation.

Environment

Iraq is characterized by an arid to semi-arid climate, being arid in the Eastern part and less so in Mesopotamia. The Iraq region is a broad central lowland that provides most of the country's agricultural production. Rain seasons are short with annual means varying from 150 to 400 mm. Almost all rain falls during winter, December to February. The region has clear skies during most of the year, and potential evaporation rates are high at >2000mm in summer because the high net solar radiation. Ambient temperatures range from 7 to 20 C in winter and 30 to 38 °C in summer.

The Western Australian wheat belt region has around 400 mm total rainfall in with 1500mm of average pan evaporation (Moora to Katanning). This region also has clear skies during most of the year, and potential pan evaporation rates are similar to those in Iraq.

The majority of Iraq soils are Aridisols, Inceptisol, Vertisols, Milisols. In the Euphrates valley soils of sandy clay loam with gray sandy surface and high salt storage are widespread. The lowland region dips gently to the southeast with sediments becoming generally more fine-textured in the delta lands south of Baghdad.

Due to low levels of vegetation wind erosion, mainly in eastern region, and water erosion, mainly in the southern region, occur frequently. Materials eroded by surface water flow are deposited in small desert playa lakes.

The soils in southern part of the Central Wheatbelt and Great Southern, including Katanning, are mainly Grey or Yellow/brown deep sandy duplex. These are seen mainly as a grey or yellow brown sand over clay or reticulite (mottled loamy sand to sandy clay loam) subsoil at 30-80cm. An in depth description of these soils can be found in the Department of Agriculture, Western Australia, Technical Report, 246(2005). The environmental and soil classification in Western Australia and Iraq are similar.

Experiment Site

Two sites were chosen for this detailed study . They are Upper Euphrates Valley (34.30 N; 42.10 E), Babylon (32.40 N; 44.40 E). These are regions where the national electricity grid is not available to power groundwater pumps.

Groundwater is more saline due to slow to moderate groundwater through flow. Salt-tolerant perennials are grown in these areas. Less salt-tolerant annual crops, annual and perennial pastures, and small grains are traditionally farmed in the areas of Upper Euphrates and Babylon where groundwater gradients are relatively high. This allows for good lateral groundwater flow and flushing of the salt from the soil.

The position of these Iraq sites represents the northern equivalent of the Western Australian of Moora (33.27 S, Log. 118.43E) and Katanning, 33.41S, Log. 117.40E.

Recharge to groundwater varies between the experimental sites. It is higher in deep soils and locations with poor water holding capacity, but less in soils with high water holding capacity moderate texture soils of the Babylon. All sites studied have very low groundwater gradients and consequently very low rates of lateral groundwater flow.

Effective soil water content and soil bulk density were determined gravimetrically for undisturbed 7.6cm diameter core samples taken from the ponds. Specific heat of the soil was 0.35 cal/gm/day.

Water Pumping

The water table was tested using a piezometer 5 cm in diameter. Total solar radiation was measured at the sites over ten years. Monthly averages were calculated determining the amount of water able to be pumped, Figures 1 and 2, at the Upper-Euphrates, Babylon and Moora-Katanning locations.

The photovoltaic optimized surface area was determined as 27m² based on daily climatological parameters.

$$S = P / (R_s \times \eta_c)$$

Where S is the surface area of the photovoltaic system (m), R_s is total solar radiation, (MJ/m²/d), η is the photovoltaic efficiency (10%) and P is the pump power.

The pumping (hydraulic) energy required to deliver a volume of water is given by

$$E_h = \rho_w g V H$$

Where E_h is the required hydraulic energy, V the required volume of water, H the total head, ρ_w the density of water and g the gravitational acceleration.

The input energy for the pumping system undergoes several conversions before it is made available as useful hydraulic energy (Figure 3). The input energy requirement for pumping is generally greater than the useful hydraulic energy output because of the energy losses associated with each conversion. The power required to lift a given quantity of water depends on the length of time that pump is used, Figure 4. It is given in the form

$$P_h = P_w gHQ$$

The total head comprises the sum of the static head and the head loss in pipes, which depends on the pipe diameter and flow rate.

Automatic data acquisition control equipment Model 3054 A was synchronized to provide the components of the energy balance at daytime hourly intervals.

Pond and Water Change

The Upper Euphrates valley pond was approximately 150m in diameter. It was located amongst 5,000 ha of land used mainly for annual and perennial pasture, alfalfa and date-palms. The slope of the pond sides was approximately 5 – 6%. The greatest pond depth was 4m and the least 0.5m. The pond volume was approximately 884,000m³.

At the Babylon site there were two connected artificial ponds. They had a W cross-section with each pond diameters of 95 and 70m. These were located within 3500ha farmland used mainly for small grain crops. The land slope was approximately 4.0 – 4.5 per cent. The deepest point is 2.8m while 0.35m is the shallowest. The ponds volume is approximately 1,180,000m³.

These ponds stored water from pumping water and fresh surface rainfall run-off. Rainfall runoff is collected from the surround surface water catchments. The ponds were dug in a silty clay of low permeability. During construction the bottom of the ponds were machine compacted to prevent the water leakage. The ultimate leakage rate was less than 1 per cent.

The ponds were covered with 2.30 -3.50mm thick floating mat made of date-palm leaves or bamboo to reduce the potential evaporation rates. The mats are very light and compact. They absorption is very little water, reflect more than 55% of the light, cost around \$0.25/m² and can be used for a period of 5 years. Alternative mats made of artificial materials are available in Australia markets (e.g. RefTex, AquaCap).

Daily micro-climatologically parameters were measured at, Babylon, Euphrates and Moora-Katanning. Pluviometers were used within the around the ponds in Iraq to record the rainfall. The national electricity grid is not available to power groundwater pumps for the experimental sites in Iraq.

The pond water levels and pan potential evaporation were measured at weekly intervals. The electrical conductivity of the water was measured from different sides of the ponds and at a range of depths on weekly intervals.

Solar energy pumping was use to top up the dams as required throughout the year.

Salt Accumulation

The monitoring in Iraq showed that the valley land was exporting an average of 376 tones per year of salt during the experiment period. This salt load came from both groundwater and runoff following rain. The valley receives 350 tonnes salts from groundwater. A further 36 tonnes of salts came from a mean annual rainfall of 400mm/year rainfall, with 7.5 mg/L salt. The pond received approximately 294,000m³ from pumping. Figure 5 illustrates the water volumes and salinity from the bores.

At Babylon, the average of annual steam flow into the ponds was 294,000 m³. Groundwater pumping contributed 212,000m³ of water with an Electrical Conductivity (EC) of ~2200mS/m and Total Dissolved Salts (TDS) of ~6000mg/L. This is a high level of salinity. 4400- 5000mg/L is rated as moderate to brackish for salinity. Rainfall contributed 81000 m³ of which run-off water accounted for 36000m³). Rainfall and run-off has salt content of approx. 7.5mg/L TDS and EC of 800-860mS/m.

For the Upper Euphrates there was 236,000m³ of pumped ground water and 32,000m³ from rainfall and 6,875m³ from run-off. This gave a total of 275,000m³ with an average EC of 1,800mS/m and 10, 000mg/L TDS for ground water. The runoff water was 980mS/m EC and

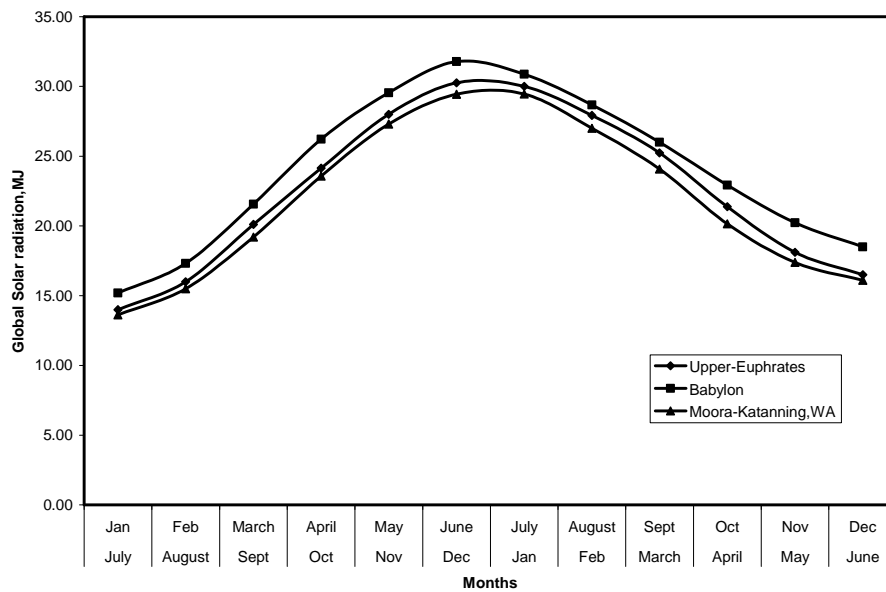
5,000mgL TDS. The Upper Euphrates water was marginally more saline than Babylon because of a lower volume of run-off .

Salt contents of 1,200mS/m EC are classified as saline. Rainfall plus surface run-off of 450 – 650mm/year diluted saline water to approximately 850mS/m which classified as moderate /brackish water. Crops that can tolerate this level of salinity are date-palm, alfalfa, clover, barley and forage sorghum. This water is also suitable for animals to drink.

Results and Discussion

The monthly average daily total solar radiation is shown in Figure 1. Short-wave net solar radiation recorded for the Upper- Euphrates, Babylon and Moora-Katanning sites is presented in Figure 2.

Fig.1. Long-term monthly average of daily mean global solar radiation at the studied sites.



In terms of solar irradiance, the Iraq sites have the most potential. The annual average total solar radiation and net solar radiation densities are 23.3 and 15.8MJm² /day, respectively.

Fig.2. Long-term monthly average of daily mean short-wave net solar radiation at the studied sites.

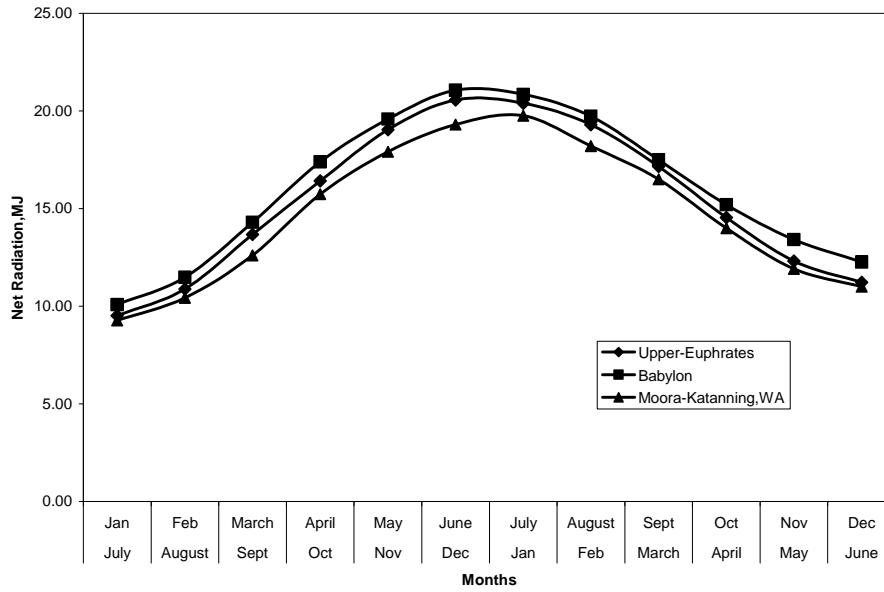
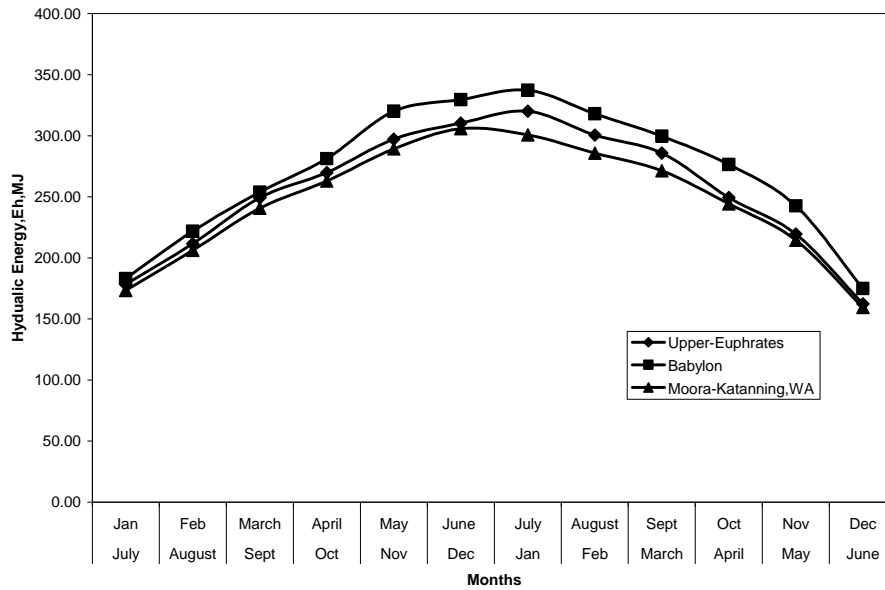


Fig.3. Monthly average of daily mean maximum hydraulic energy required to deliver a volume of water from 7m depth at the studied sites.



As the maximum input energy presented by Figure 3 and Figure 4 with an average is 58.6MJ, The annual amounts of water that can be pumped to a height of 7m are shown in Figure 5. The annual water output is 1,110m³/day during August in Iraqi sites and during January in WA.

Fig.4. Monthly average of daily mean maximum daily power required available for pumping at the studied sites.

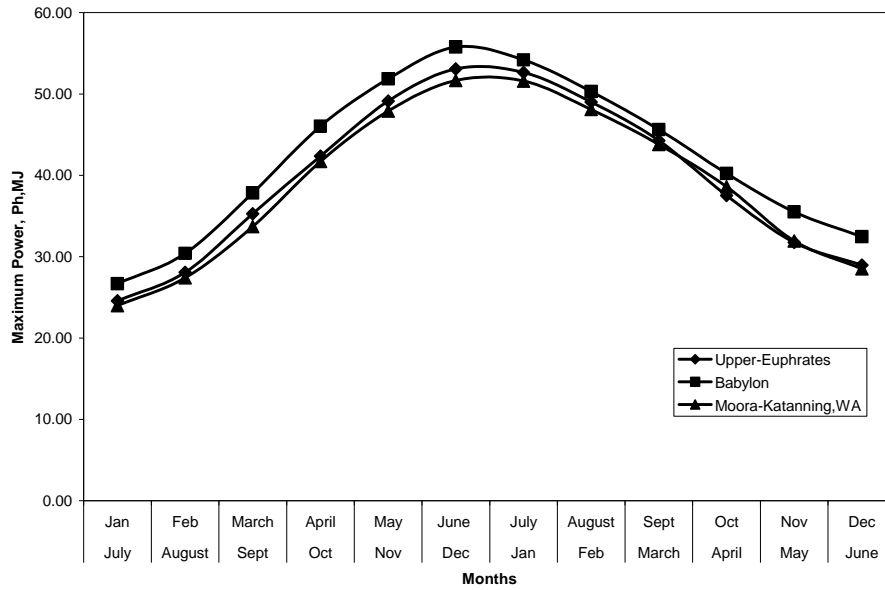
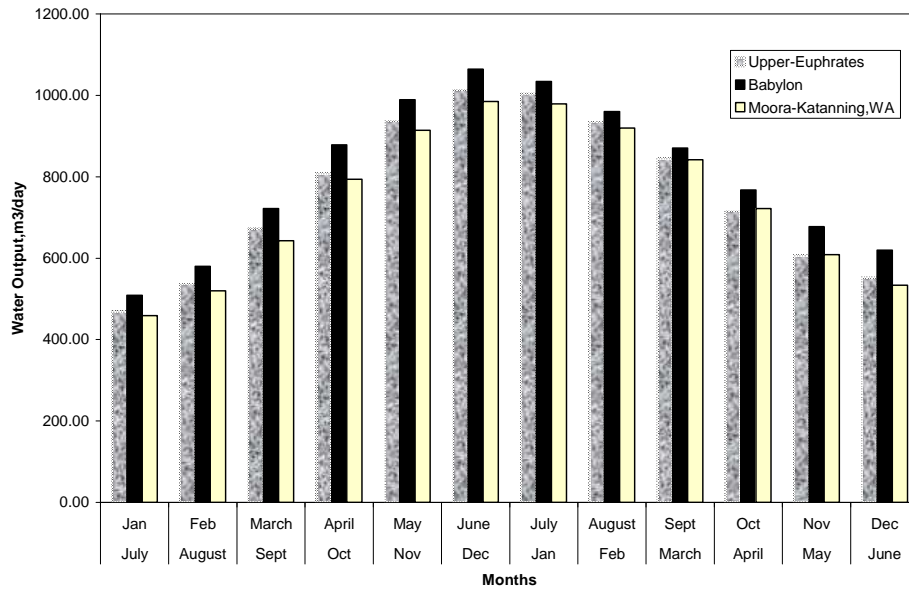


Fig.5. Monthly average rates of water output from 7m depth in the studied sites.



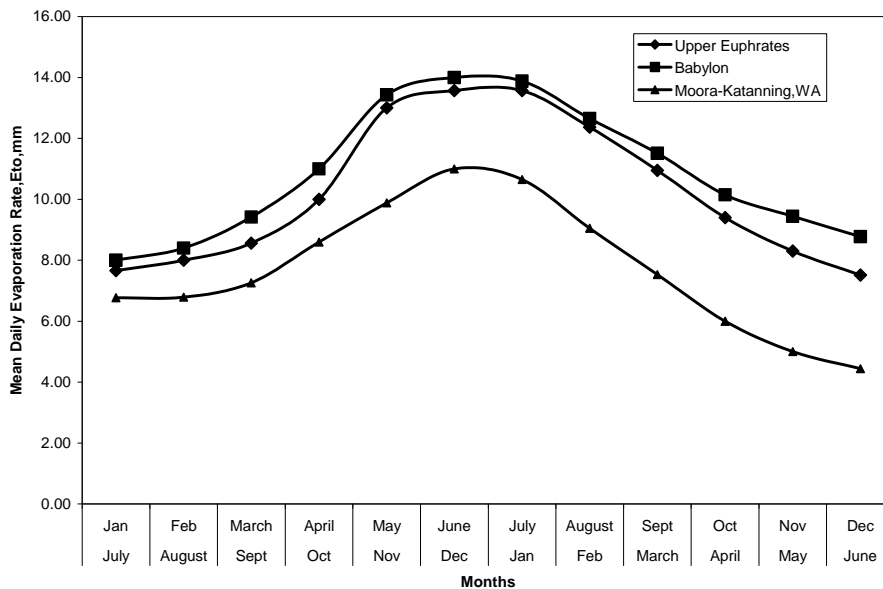
Based on the mechanical energy produced from solar energy, Babylon is favorable solar sites for water pumping.

The meteorological data of both countries are similar. The monthly average of daily total solar radiation in Latitude, 30°S Western Australia is between 10 to 30 MJ/m²/d, while for Iraq at Latitude of 30° N it is between 11 to 32 MJ/m²/d.

By using the environmental comparisons between Western Australia and Iraq it is possible to predict the actual maximum mechanical energy available to pump water in Western Australia. Based on total solar radiation, solar water pumping is possible during summer months, rather winter, in both Iraq and Western Australia. These months are considered the dry months when water consumption is highest and needed the most. At these locations solar powered pumping system would be viable and a better alternative to electrical pumping (Hasson and Peck,2004).

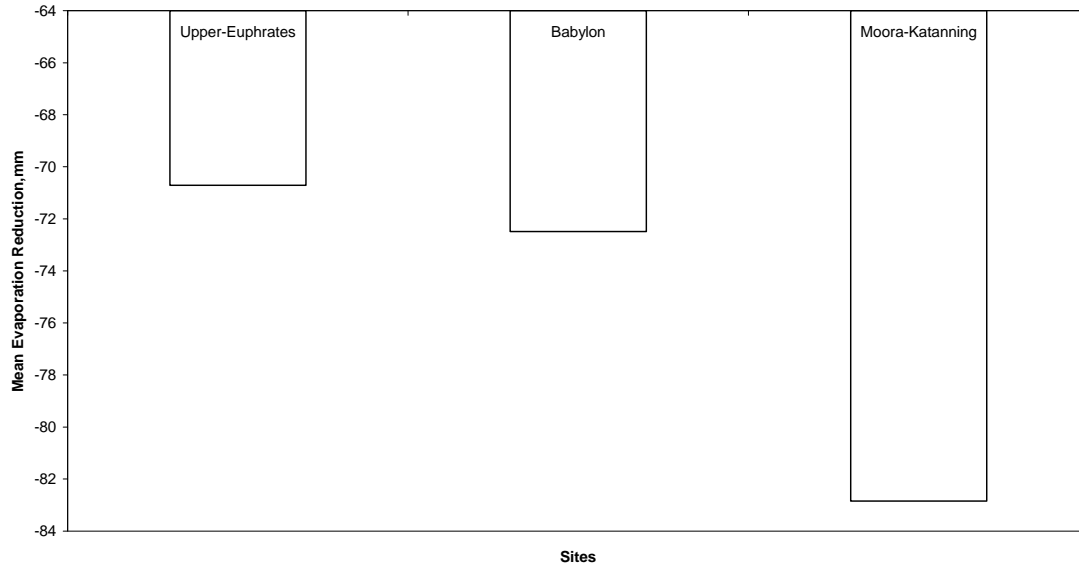
The potential evaporation rate is calculated assuming that the only restrictions on the evaporation is imposed by the net radiation at the evaporating surface. A mat on the pond surface will reduce this evaporation (Figure 6).

Fig.6. Mean daily evaporation rates from Class A pan at the sites



The mat of date-palm leaves can reduce the evaporation rate by 29 , 27.51 and 17.5% for Upper-Euphrates, Babylon and Moora-Katanning sites respectively. The potential evaporation rates bases on pan evaporation is between 17 – 20mm/day. The net evaporation rate from the pan on land near the pond is exceeds the rate from the pan in the middle of the pond. This is because the air over the pond have a higher Relative Humidity than the over land. Thus the wind by its advective action over the ponds, tend to slightly moderate the extremes of the air and the surface environment.

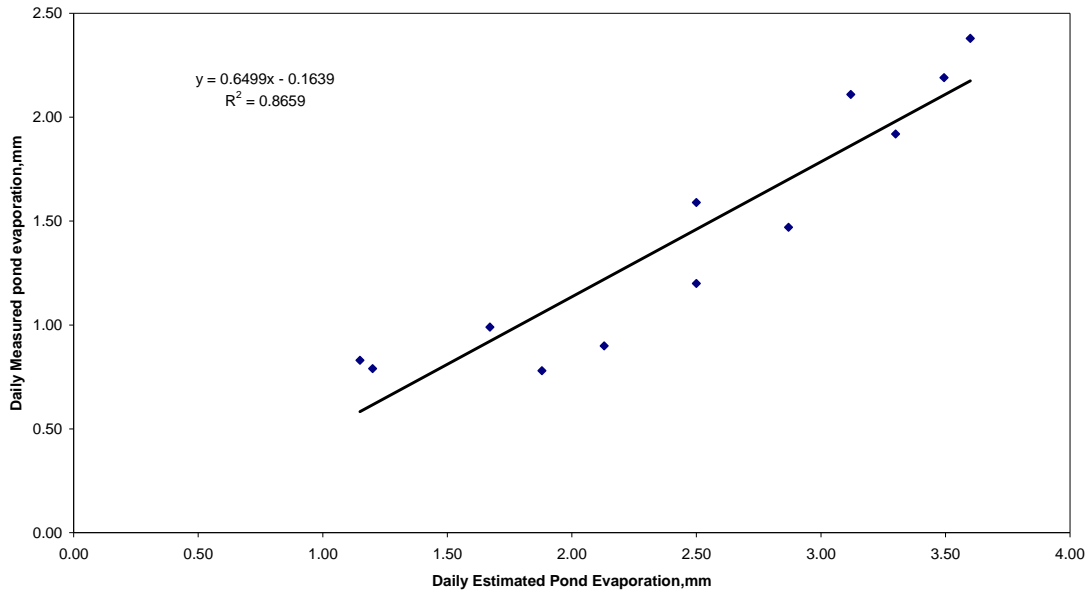
Fig.6. Annual average of reduction in evaporation from covered ponds at Upper-Euphrates, Babylon and Moora-Katanning sites.



At the Babylon site the evaporation was reduced more than at other sites because Babylon has higher humidity year round. Also the trees, date palm, alfalfa and citrus, help reduce wind speed. The date-palm mat was thicker and finer textured compared than the mat in Upper-Euphrates. The rate of evaporation in WA was close to Upper-Euphrates which has open fields, Bamboo mat textile is coarse. The Moora-Katanning evaporation was estimated based on the local climate and an assumption that Bamboo mat would be used to cover the pond.

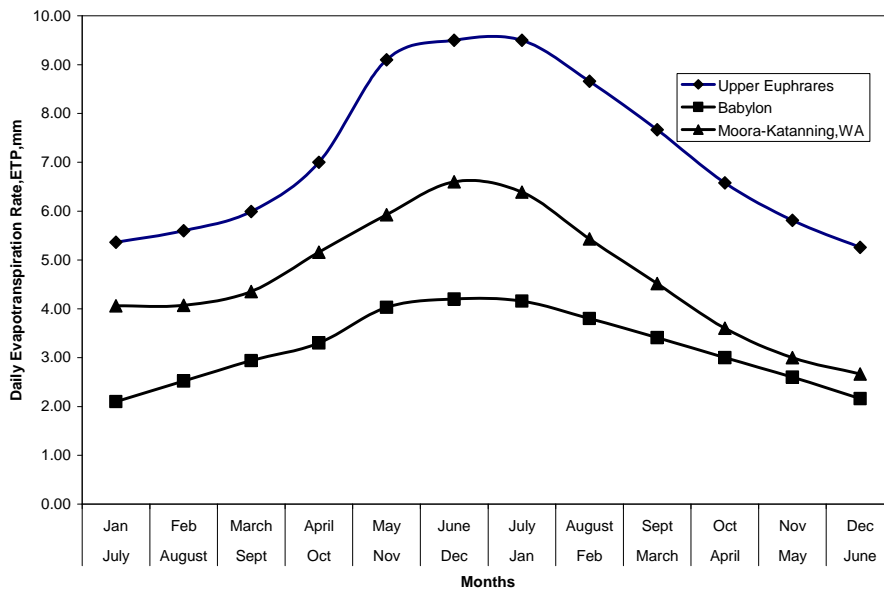
A linear relationship between pond daily values of measured and estimated evaporation has been derived by pooling the data obtained during the recording period and calculations based on micro-climatologically parameters of the WA site. There was a significant correlation coefficient of $r^2 = 87$ (Figure 7).

Fig. 7. Relationship between daily measured and and estimated covered pond evaporation



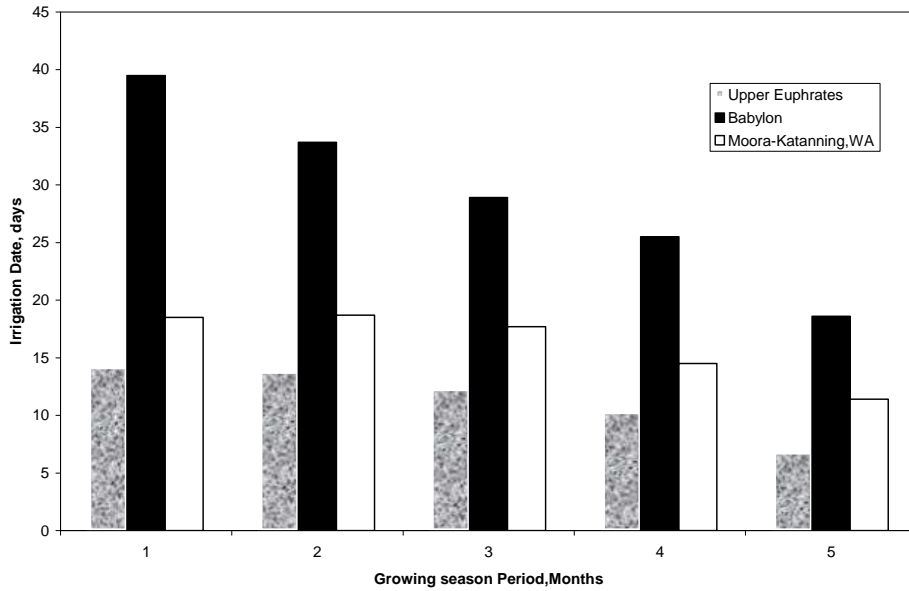
Daily evapotranspiration of all sites is presented in Figure 8.

Fig.8. Mean daily evapotranspiration rates at the sites.



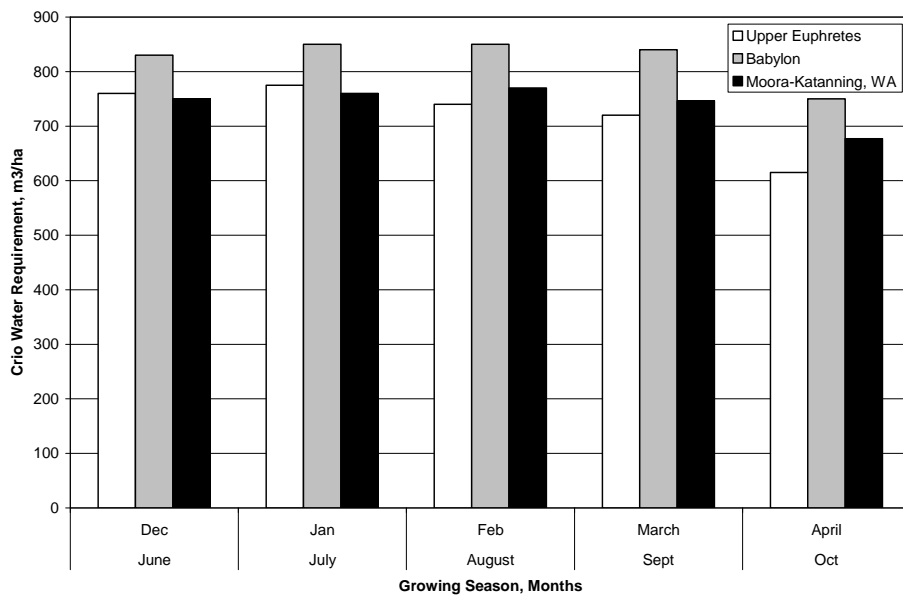
The number of days of irrigation required to deliver 61 to 77mm, 75 to 83mm and 68 to 75mm for crops in Upper-Euphrates, Babylon and Moora-Katanning is shown in Figure 10. This assumes the rainfall is < 300mm/a 320mm/a and 350-400mm/a in Upper-Euphrates, Babylon and WA sites respectively.

Fig.9. Irrigation dates needed in the sites.



The total days of required irrigation are listed in Figure 9, calculated from the known soil parameters. Assuming an irrigation efficiency of 79%, an irrigation of half of the crop water requirement, Figure 10, plus rainfall would fulfill the requirement for crops at the sites.

Fig.10. Crop water requirements for the sites.



The root zone moisture balance can be calculated on a day to day basis by recording daily rainfall and daily evapotranspiration (ETP) throughout the growing season period. Summer rainfall events of less 25mm are seldom effective and can be ignored (Thomas and Moore, 1968).

The total water outputs were 275,000, 194,000 and 277,000m³/year in Upper-Euphrates, Babylon and Moora-Katanning, respectively, (Figure 5).

The discharge water was stored in natural ponds and mix with rainfall water to be used for the irrigation of salt tolerant crops such as alfalfa, barley or stock water. The water was adequate as salinity levels were ~1200mS/m EC. Water was pumped to polyethylene lined ditches and flowed naturally the 300m distance to the pond on a slope of 2.25%. The rainfall water mixed in pond to lower salinity. The bamboo or date-palm mats reduced the evaporation, and thus reduced the concentration of salts in the pond. Under this system the rainfall provided 1.5% of the water supplied per hectare.

This is an efficient technique for conserving water and increasing crop production. There was a 70% increase in efficiency of use of irrigation water based on crop yield. This technique reduced water needed for irrigation by 40% when compared with traditional water-management practices.

Economic Assessments

Economic considerations are important when comparing methods. Solar PV pumps and reuse of pumped water for agricultural purposes are technically viable, but the evaluation of the alternatives must include both economic as well as technical considerations. There are three common techniques that are used for making an economical evaluation. They are payback period, rate of return and life cycle costs. An economic analysis should also calculate the cost per unit of water.

A socio-economic evaluation considers all gains and all losses of solar water pumping systems and pumped water reuse. This analysis would include the financial, social, cultural and ecological impacts. Cost-benefit analysis is the most widely used method for economic analysis. A socio-economic benefits and costs analysis must also consider the impacts from the field of welfare economics in addition to data provided by the cash flow sheets.

The Analytic Hierarchy Process (AHP) can be used as a practical approach for addressing these cost-benefit application issues (Saaty 1985). It has been effective in structuring many types of complex multi-criterion problems. The AHP has been applied to evaluation of energy systems, choosing areas of R&D programs, and water polices Gout and Jellet (1986) and Gout (1983).

The economic analysis used compared the costs of the major alternative pumping and evaporative pond methods. The calculations included the use of discount rate, which reflects the cost of capital (Hamand,1999).

A preliminary cost estimate for has been developed for an average of 282,280m³/year scheme to determine 1) the cost of pumped saline water and 2) the economical benefits of the system. A published paper for brackish water desalination indicated that the cost of the treatment is between \$0.5/kL and \$0.8/kL (Halim et al., 2002).

Our analysis includes the following cost assumptions:

Photovoltaic Panel cost =	\$7,000
Batteries =	\$3,000
Pumps =	\$6,000
Pipes =	\$2000
Mats =	\$5000
Installation =	\$10,000
Maintains =	\$10,000
Total =	\$53,000

The average of water volume pumped from the three sites was 282,280m³ at a cost of \$0.50/m³ resulting in a total cost of \$141,140 to desalination of seawater to brackish water.

The total cost of the system is \$53,000. It was assumed that the system would operate at 30% efficiency for an at least 10 years and that PV system would last that time also.

The Present Benefit was calculated at \$141,140 per year giving \$1,411,400 over the 10 years.

Net Present Value, NPV = Present Value Benefits – Present Value of costs,
i.e. NPV \$1,358,400 = \$1,411,400 – \$53,000

Benefit Cost Ratio (BCR) = Present Value Benefits, PV / Present Cost
BCR 25.6 = \$1,358,400 / \$53,000

The benefit-cost analysis framework allows the selection of economically viable options according to a minimum return on investment.

The analysis suggests that it may be economic to use brackish water for irrigation to increase from productivity. Pumping from saline water tables under this system would also help reduce soil salinity.

In reviewing existing surveys on financial evaluation methods for solar water pumping systems, some limitations were apparent. There were problems in calculating revenues, setting the interest rate for discounting, the cost calculations for solar water pumping systems, estimation of lifetime of solar water pumping components, lifespan of the ponds and irrigation infrastructure. Previous studies were not based on the reuse pumped water instead of evaporative method for salt collection.

Conclusion

Solar energy is abundant in most regions of Iraq and Western Australia, Pilots studies in Iraq shows solar powered water pumping compares favorably to conventional pumping methods. Water scarcity is a common problem in both regions. The maximum solar pumping capacity occurs during June in Iraq and January in Western Australia. Solar pumping can deliver more than 1,000m³/day, from 7m heads. Fresh winter rainfall can be used to dilute saline water pumped from the ground. This enhanced ground water could be used for irrigation to deliver economic and environmental benefits.

Using the solar water pumping system for multipurpose, groundwater discharge and re-pump storage water for irrigation is viable in dry climates.

In a forthcoming paper the Analytic Hierarchy Process (AHP) will be used for evaluate the feasibility of solar water pumping systems and reuse the discharged saline water and mixing with rainwater for agricultural applications.

Acknowledgments

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