Australian Nuffield Farming Scholarship Trust.

The multiple use of saline water; turning an under utilised resource into a viable one.

Neil Smith, 2000 Scholar.

Sponsored by the Grains Research and Development Corporation.

GRDC
Grains Research & Development Corporation

TABLE OF CONTENTS

TABLE OF FIGURES

EXECUTIVE SUMMARY

With Western Australia set to lose up to 6 million hectares of arable land (one third of total arable) to salinity between now and the years 2050 and 2070, new forms of agriculture must be developed to utilise these changing farming conditions. The concept of turning saline land into a resource must be constantly encouraged instead of perceiving salinity as a problem.

Worldwide 131 species of halophytic plants are presently being studied. Potentially 250 commercial halophytes could be developed from the 10 000 salt tolerant plants that are known to exist. Opportunities are present and we must as individuals and as an industry explore them further. Australia has a huge biodiversity that is under developed and under researched. Many other countries are exploiting these resources in their quest to support their farm sector. We must continually ask how we support these "potential" crops or industries in Australia.

A farming system that includes halophytes and aquaculture on saline land has a synergistic benefit to present grain production practices. New shrimp farming ventures in the USA are conservatively estimated to return 38% (IRR) including establishment costs. Inland aquaculture has the benefit of disease and pest freedom, a processing industry that can employ people in declining rural communities and the proximity to grain for food.

ACKNOWLEDGEMENTS

I would like to thank the Australian Nuffield Farming Scholarships Trust for the opportunity that was given to me, and I am truly thankful for the experiences and knowledge that I have acquired in undertaking this scholarship. I hope that Australian Nuffield Farming Scholarships Trust and its sponsors the Grain Research Development Corporation and QANTAS with their travel support will receive sufficient return in this report for the investment placed in me.

I would like to thank my family Brian, Barbara, Matthew, and Elizabeth Smith for working the farm in my absence, and their invaluable support in enabling me to travel on this scholarship.

I would like to thank the people I met in my travels that were courteous enough to meet and discuss what they were doing with me. Particular thanks must go to Rachel Guy at the University of Ben Gurion at Sede Boker for organizing a weeks visits in and around Sede Boker, Jeremy Levy from the Israel-Australia Chamber of Commerce for contacts throughout Israel, and Nick and Susannah Yensen for their hospitality in guiding us around Arizona, especially into Mexico for three days.

I must acknowledge a friend in Harry Perkins (OAE N.Sch) who said "have a go", and especially to my wife Rosemary who navigated and escorted me throughout my travel time with constant encouragement and love.

OBJECTIVES

The topic I selected for my Nuffield Study was turning saline land and water into a profitable resource rather than a problem. I also started looking at high value grain production systems with the intention of adopting cropping techniques and new crops suitable for low rainfall environments. The cropping techniques segment dissolved after a week in Israel when I learned the technology in place there seemed no more advanced than Australia, and only 9 farmers were using no-tillage techniques over an area of 5000 ha. Except to say a researcher was developing a seed coating for crops that inhibited germination until 30 mm of rain fell. This could be very useful given that timeliness of seeding in broad acre cropping is possibly our most limiting factor to yield improvement.

Our grain production system in Western Australia is limited by water. Strangely enough the valley floor of our catchment has too much water and is affected by salinity and waterlogging. Several neighbours were seeking to drain our Nukarni Catchment. I had reservations about the success of this proposal due to the clay valley floors and little slope to move water. Deep drainage has had limited success in the Eastern wheatbelt and has so far not proven cost effective on many properties. What other options are available to us given that the wheatbelt in Western Australia is set to be one third salt affected between 2050 and 2070? This is a question that farmers and researchers alike have been grappling with for the last two decades. At a recent GRDC salinity workshop in Canberra participants from a range of farming, research and extension fields were asked where government money needed to be prioritised. The outcome of that survey was:

Expenditure	Area
23%	Agronomy/plant breeding/farming systems solutions
22%	New and profitable perennial plant options considering salinity and waterlogging
16%	Making better use of salty land and water
11%	Technology transfer to get high adoption
10%	Engineering solutions
8%	Economic policy issues
10%	Other

This evidence shows the need for new technology that enables farmers to be profitable in a resource-limited environment. Consequently I focussed my study on the multiple use of saline water, turning an under utilised resource into a viable one, through groundwater pumping for aquaculture, algae production, desalination, salt harvesting, power generation, halophytes, saline irrigation and gene modification.

INTRODUCTION

My Nuffield trip started in February with my fellow scholars for a trip through Asia and Europe. This was a dynamic time, which challenged the way I looked at everything, particularly considering the global situation. At the end of the United Kingdom tour I returned home for my brother's wedding, seeding and to organize my own study tour.

The topic I selected was turning saline water into a profitable resource rather than a problem. I began searching for possible uses for saline groundwater (seawater quality). Israel and the USA offered the most in terms of agriculture based on a stressed environment, particularly growing crops in the desert and industries utilising salt water as a resource. My study travel began in August with Rosemary my wife, a hydrologist in the Department of Agriculture of WA. We travelled to Israel for 5 weeks, then Spain for 5 days, onward to the UK for 4 days and then the United States of America for 5 weeks with a short journey into Mexico.

Israel is a very dry country with 60% of the land area classified as desert. As a guide to the scarcity of water, Israel has 0.4 m^3/person/day available compared to Australia having 18.3 m^3/person/day and a world average of 12 m^3/person/day. Their water resources are limited coming from the Sea of Galilee and coastal aquifers. Consequently their potable water comes from this source and recycled town/city wastewater. A lack of water in the last three years has caused the farm sector to have its water allocation cut by 25%, 40% and 50% respectively. The reduced water allocation has resulted in a decrease in the area sown to broadacre crops such as cotton. Horticultural crops are grown in preference, due to the higher produce value. Farmers are also seeking to acquire more treated sewage wastewater to augment water supplies for cotton production. A further dilemma exists in that if the Israeli farmers do not work the land in the Negev Desert the Bedouin people will effective resume the land as a squatter settlement. The demand for water resources is increasing, considering the population growth in Israel is also the fastest in the world due to immigration. The soils are generally very sandy and allow deep percolation of the applied water. The water tables in Israel are very deep; for example, in the Arava region the water is from deep bores (300 m) with a salt content of 5 500 ppm and is used for date production.

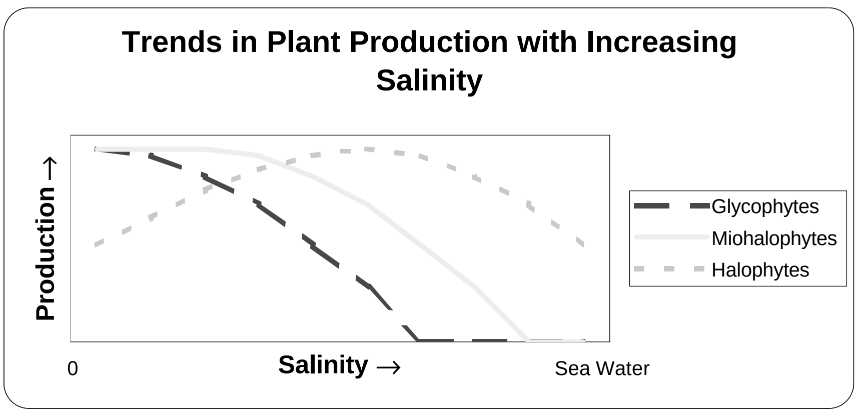
Spain offered a chance to see an enterprise that was mixing water to increase the volume of water available to Intercrop Iberica. Spain like other countries is facing increased pressure on its water resources. Manager Richard Smith (English Nuffield Scholar 1996) is using well water at 4 000 ppm to mix with the fresh river water from the north of Spain (less than 500 ppm) to obtain an irrigatable supply at 1 500 ppm. At this salinity it is suitable for all their crops of baby lettuce, endive and herbs for the fresh cut salad market. Water is sprayed using micro sprinklers from Israel, to obtain a more even droplet size that is more resistant to evaporation through a large orifice that does not clog. They are considering the use of a service called SALTMED, which offers a reliable water/salt/crop model by way of genetic material with improved salt tolerance and information from other crops generally applicable.

The United States of America had lots to offer in many integrated systems utilising saline water. I travelled in Texas, New Mexico, Arizona, Nevada and California. U.S.A. had many issues relating to saline agriculture. The San Joaquin Valley was perhaps the most salt-affected area. It receives its water from a system of canals that conveys the water from the mountains on the eastern side of the valley. Irrigation brings over 2.84 million tonnes of salt into the area and only 355 000 tonnes drains away in the San Joaquin River. The remaining salts go into the soil profile. In many ways the Californian situation is most similar to salinity in Western Australia.

Most farms implement irrigation using flood methodology with an increasing reliance on drip and spray systems. The increased water consumption keeps the salts leached out of the root zone of most plants. The accumulation of salts in the soil profile led to the implementation of a drainage collector system in 1976 throughout the valley, disposing of the water into the Kesterson Reservoir. Due to the unforeseen accumulation of selenium from the drainage water in an artificial wetland (greater than 1 ppm of Selenium in water is considered toxic), wildfowl chicks had birth defects. Environmental groups considered eight percent of chicks with deformities unacceptable. As a result the drainage system and its wetland were shut down in 1986. Drainage Districts in the San Joaquin were then required to do something about the problem. Planning solutions included reducing or avoiding the environmental impact, then rectifying or compensating for that impact. Some of the practical resolutions were: more evaporation basins, which served only in spreading the wildfowl problems over a greater area; losing the land to salt accumulation; using an Integrated On-Farm Drainage Management scheme; or scaring the birds away and providing an alternative compensation habitat for the bird-life. The Tulare Lake Drainage District (TLDD), which is the biggest drainage district in the USA, decided to scare the birds away from existing evaporation basins and create an artificial wetland (compensation habitat) for the birds elsewhere. They have had incredible success in the survival of birds in the compensation habitat that they can sell portions of their habitat to other drainage districts. The evaporation basins are at present only just handling the volume of water that is being sent to them and they have a stipulation that no more tile drainage can be implemented, due to the quantity of water that is delivered. Several farmers are very keen to tile drain more land.

HALOPHYTES

A plant in a non-saline environment absorbs water through its roots where the salt content of the plant is greater than the soil solution (osmotic differential). When exposed to saline conditions, water is removed from the soil solution up to a certain salinity threshold before the salt dehydrates the plant causing reduced growth or death. Using this threshold the plant kingdom could be broadly broken up into three groups, salt sensitive (glycophytes), salt tolerant (miohalophytes) and salt resistant (halophytes). Glycophytes ("glyco" means sweet as in sweet water and "phytes" means plants hence fresh water plants) are defined as plants that grow in less than 4 000 ppm salinities. Plants that tolerate the range between 4 000 ppm and 10 000 ppm are salt tolerant plants sometimes known as miohalophytes ("mio" meaning middle). Halophytes are plants that use salt water ("Halo" means salt) and grow in solutions greater than 10 000 ppm. Typically glycophytes lose production with increasing salinity, miohalophytes resist salt up to a given level then lose production with rising applied salts. Halophytes increase in production with increasing salinities then drop after a threshold is reached. See the chart below. The peak of this trend may vary with different salinities for the same plant due to the composition of the solution, such as a high level of an ion.



Given that halophytes can withstand higher salinities and still produce, the potential for agricultural systems based on these plants is only just beginning. Nick Yensen in Arizona a breeder and marketeer of Nypa ® grasses worldwide, believes that of the 10 000 salt tolerant plants some 250 may be potential halophytic crops. A student that he is supervising is working with medicinal halophytes particularly ones with benefit to cancer and diabetes. The products that halophytic plants may produce include:

- Forage for stock. Fodder from *Atriplex nummularia* (Old Man Saltbush) yielded in excess of 8 t/ha from seawater irrigation which is greater than some lucerne in freshwater. Although the salt is accumulated in the leaves of Atriplex species its grazing value increases after rain when this salt is exuded from the leaf. Nypa ® Forage yielded around 18 t/ha dry weight when irrigated with 32 dS/m quality water (See Figure 1). It exudes salt from its leaves and sheep tend to graze the new growth tips. The Red Rock Ranch in California showed some of the results of different species in the salt tolerant grasses and halophytes, the digestibility and rate of absorption is in the following table (Courtesy of Vashek Cervinka). The salicornia was the most digestible and most readily absorbed, with many plants better than lucerne for digestibility.

Rumen Apparent Digestibility

Absorption of digestible material (%)

Sample	Ave.%(24hrs)	12hr	24hr	48hr
Lucerne (control)	46.8	62	75	82
Salicornia	56.1	87	92	93
Iodine bush (young)	53.7			
Atriplex	50.4	69	72	80
Iodine bush	37.2			
Nypa ® Forage	34.9	28	46	55
Creeping wild-rye	24.7			
Jose tall wheat grass	24.4			

Figure 1: Pictures of Nypa ® Forage (*Distichlis palmeri*)

- Biomass for heating/wood products. Atriplex is known to produce large quantities of biomass and in Mexico it gave good test results for laminated lumber. Methanol can also be produced from biomass and compete with fossil fuels.

- Food. Salicornia is perhaps the best food source halophyte known at present. This plant can be ground up for vegetable salt, the new shoots eaten like an asparagus (available in The Netherlands as a wild food), and also as an oilseed crop with a vegetable oil high in unsaturated fatty acids (See Figure 2). Breeding is currently underway to increase seed size (from 1 mg), reduce the level of saponins (soap like oilseed component), increase the seed yield, and improve harvest ability (some harvest loss from shattering, combine harvested crop). This crop has been grown in Saudi Arabia and Mexico under seawater irrigation and achieved yields in excess of 2 t/ha of seed. The trial also found that salicornia used more water than saltbush (*atriplex barclayana*), which is interesting given the present state of saltbush use in Australia. Nypa ®Wild Wheat has a grain for flour that has better taste characteristics than wheaten bread and yields above 1 t/ha at 20 000 ppm. *Atriplex nummularia* (Old Man Saltbush) leaves can be eaten like a spinach or vegetable salt.

Figure 2: Pictures of Salicornia (S*alicornia bigelovii*), plant and flowers.

- Industrial crops. This area is of great interest given that the biodiversity of halophytes on coastal estuaries are under threat from population growth. The area of nutraceuticals is a high value industry based on natural products for human consumption. For instance maltose was extracted from aloe vera plants and succulents (like many halophytes) contain fructose ($3 000 /kg) both of which are plant sugars that can replace sucrose for people who cannot consume sugar. A crop called guayule is a perennial plant that when crushed, a resin extract forms a rubber compound, used for making injection bottle rubber and gloves. It is more impervious than latex and ideal for people that are hypersensitive to rubber. The plant residue can be used in timber products to improve resistance to termites. Guayules salt tolerance is rated at twice that of barley in soil at 15 dS/m.

- Remediation of soils. Saline soils are often totally devoid of vegetation, and because of the sodic nature, lacking in soil structure. The establishment of plants can give benefits as simple as aesthetic, or growing something to improve soil structure. As opposed to bioremediation (the use of plants to remove salt), which cannot transport the volumes of salt that exist in the soil or are transported onto it. Nypa ® grasses (Wild Wheat, Forage, Turf and Reclamation) have been shown to lower the watertable in waterlogged saline conditions. The extensive root systems of the *Distichlis* genus can grow without oxygen from the soil and change a sodic soil structure to "Swiss cheese" like. With the opening up of the soil salts can leach deeper with rainfall, replacing drainage in some cases. The amelioration of some soils in this way has allowed miohalophytic crops to be re-established.

- Ornamental With many areas going saline, a garden that can combat desertification has advantages in many social situations. Some halophytes are grown as ground covers already in our gardens. The value of garden nursery based agriculture is substantial.

- Effluent treatment Dr Nick Parker from Texas Tech University operates a water circulation system to handle the effluent from aquaculture or feedlots. The system uses halophytes (in saltwater) and duckweed as a feed source for the livestock industry (in freshwater). Halophytes are very successful in using the phosphorous (99% total P removed) and nitrate (98% total N removed) from animal waste according to an Environmental Research Laboratory trial in Tucson. More polyculture systems will occur in the future with growing regulatory conditions on intensive animal production systems. In the western side of the San Joaquin Valley where selenium is a considerable problem it was found that salicornia volatilised more selenium than bare soil, Nypa ® Forage, and evaporation basins.

ALGAE PRODUCTION

The growth of algae in saline water is technically feasible using highly saline water. It has a synergy with solar gradient ponds, desalination, evaporation basins and salt harvesting. Algae production requires salinities in excess of 31 000 ppm in water and up to sodium chloride saturation point (350 000 ppm), they can also tolerate high temperature conditions (up to 40^{o}C). Specifically *Dunaliella salinas* perform well in high salinities as a source of Beta Carotene and aquaculture food, they fit into a production system where a brine source (such as a salt evaporation facility) exists to harness it economically. Another algae *Spirulina* (*platensis* and *maxima* species) are used as a vitamin supplement but when processed yields a meal in excess of 84% protein suitable for animal feed. I tried to view a Spirulina facility in Israel and discovered that it had gone bankrupt so the economics are very fickle. Ben Gurion University of the Negev in Israel had a green algae (*Haematococcus pluvialis*) in experiments that when exposed to sunlight yielded a rich brown pigment (*Astaxanthin*) for colouring food and white salmon flesh from fish farms. Algae production may be an option for an add on industry to complement an existing salt utilising business.

IRRIGATION WITH SALINE WATER

Irrigating with saline water would make many people quiver at the thought of it. It has seen many irrigation areas put at risk of environmental damage but where fresh water is limited in supply, saline irrigation is a real choice. When I was in Israel I observed date production at Kibbutz Lotan, they were using 10 dS/m water from a saline aquifer. This would be used at a rate of 2 400 L per palm per irrigation. The drip irrigation would run for 12 hours every third day, to allow sufficient leaching to occur, for the plants to absorb the water and not be overly influenced by the salt accumulation. The area receives only 32 mm/yr of rainfall but the soil is sandy and the watertable is deep. Kibbutz Lotan would get a yield of up to 450 kg of dates per palm using this system.

Tomatoes and some fruit are regularly irrigated in Israel with slightly salty water to obtain a sweeter taste. Most of Israel's marginal wastewater is conveyed underground (40 cm down), in drip systems so that water does not come in contact with the leaves of plants and burn off growth. Bacterial contamination (*E.coli*) is also an issue with water on the surface. The subsurface drip irrigation schemes were being used in a variety of situations from irrigating lawns to putting more water onto a soil than could be furrow irrigated, mainly to reduce evaporation (compared to other irrigation systems).

In Texas where furrow irrigation occurs, every second row is flooded so that the salts move towards the unirrigated row in water up to 8 dS/m. With this level of salinity in the irrigation water plants must be carefully selected.

California pushed the introduction of pistachios as a measure for productive use of its saline land in the early 1980's due to the slight salt tolerance. Hence the pistachio industry is quite large. Some selection in Israel has found that the native *Pistachia atlantica* rootstock is less seasonal in its bearing and more salt tolerant that other types.

I observed the use of blended water in Spain (Intercrop) and Israel (Moshav Kardesh Barnea) to increase the volume of water available without sacrificing the quality totally. Irrigation has taken place with seawater directly from the ocean in Mexico (Puerto Penasco), Kuwait, Morocco, Tunisia, Eritrea, and Saudi Arabia (Jabail). The halophytic plant salicornia (S*alicornia bigelovii*) was the crop of choice in each of these countries. It had a zero tolerance to drought in Saudi Arabia where plants were wilting, between the 6 hourly irrigations from the centre pivot sprinkler system in the heat. Labour was required to unblock seaweed that regularly caught in the irrigation nozzles over the 50 ha plots. This system was useful in desert areas where glycophytes crop production is limited, sandy soils that freely drain and close access to excessive quantities of seawater existed. Seawater irrigation was successful where irrigation drainage can freely drain back to the ocean.

SERIAL BIOLOGICAL CONCENTRATION

Serial Biological Concentration (SBC) in Australia is similar to Integrated On-Farm Drainage Management (IFDM) in the USA. IFDM is a process of using plants to transpire the water from reused drainage water concentrating the salts in the solution. This system is used successfully on John Diener's Red Rock Ranch. In 1985 John had a problem of salt accumulation making 259 ha of his land uneconomical to farm. He made a decision not to loose the land but to reclaim it. In 1991 the 259 ha was split into five areas:

- Salt sensitive crops. This area represents 73.4% (190 ha) of the total and receives canal or well water to irrigate vegetables. The soil EC dropped from 11.3 dS/m in 1995 to 0.8 dS/m in 1998 in the top 30 cm of soil. This area is tile drained with the discharge water going to the salt tolerant crops.

- Salt tolerant crops. 20.3% of the area or 52.6 ha grows lucerne, cotton, wheat, canola, etc which can handle 9.9 dS/m irrigation water. The soil salinity dropped from 10 dS/m in 1995 to 0.7 dS/m in 1998 in the top 30 cm of soil. The drainage water was then used to irrigate the salt tolerant grasses.

- Salt tolerant grasses. Representing 2% (5.3 ha) of the total area, this was set aside for a trial of different grasses such as Bermuda grass, Jose tall wheat grass, Puccinellia, Creeping wild rye, and several others. They were selected on the basis of tolerating between 8 dS/m and 15 dS/m water. The Bermuda grass and Jose tall wheat grass performed best, although the digestibility of the wild rye and wheat grass were very low (see table in halophyte section). This received 9.4 dS/m quality water for irrigation and discharged 14.8 dS/m.

- Halophytes. Plants were chosen for a trial in this area if they tolerated above 15 dS/m. The plants selected included Nypa ® Forage (*Distichlis palmeri*), 3 forms of *Atriplex* (*nummularia, lentiformis,* and *canescen*), iodine bush (*Allenrolfea occidentalis*) and salicornia (also known as *Salicornia bigelovii*). The halophyte area covered an area of 2 ha or 0.8% of the farmland.

- Evaporation basin. An evaporation basin of 0.86 ha (or 0.33% of the section) received an estimated salt load of 75.5 t, 51.5 t, 42.3 t, and 30 t in 1995 through to 1998 respectively. This evaporation basin was considered toxic in Selenium, with a concentration exceeding 1 ppm.

Red Rock Ranch had the highest Selenium level as compared to surrounding farms. Hence the evaporation basin was closed recently and the drainage water is going only as far as the halophytes. John believes this is not sustainable in the long term (greater than 10 years) and would like to evaporate the water in a basin if possible once the bureaucratic problems are sorted out. The process uses over 90% of the drainage water, with leakage intercepted by rows of eucalyptus trees on the low side of the salt tolerant grass, halophyte and evaporation basin as well as the boundary with the neighbours. The drainage water is collected into sumps in the corner of each field and pumped out via flood irrigation to the appropriate area.

The farm uses 1 485 Ml/yr; 22% less water than conventional farms that require 1 895 Ml/yr. Of this water 472 Ml/yr is sequentially reused and 14 Ml/yr made its way into the evaporation basin.

The farm is economically successful considering that US$1 500 /ha was spent to establish the system. The land value went from US$1 850 /ha producing wheat, cotton, and lucerne to an average of US$5 940 /ha producing vegetables and wheat went from 2.5 t/ha to 10 t/ha.

This project was the first of its kind in California and several other farms are using the same system in a larger capacity. The IFDM on John Diener's farm has demonstrated that the drainage water from the farm will not contribute to the regional drainage problems of a high water table and poor ground water quality.

Several IFDM schemes are in place in the San Joaquin that use trees as a soak for all the drainage water. Typically eucalyptus is selected with the occasional casurina as the tree of choice. Some species are specifically selected but still have difficulty handling the quantity of water delivered, with many dead areas in the bays that receive this water. This type of IFDM will not be a long- term solution as the area is relatively devoid of trees outside of the horticultural crops.

AQUACULTURE

Aquaculture appears to be one of the most promising uses of saline groundwater. The Outback Oceans Project run by the Department of Agriculture is a great driver for change in Western Australia and needs further development. The use of aquaculture in inland W.A. has the advantages of low disease, low predator numbers, salty (since salt water fish taste better), cheap land (relative to elsewhere in the world), isolated from coastal river systems, synergy with evaporation basins, and close to Asia for a market. Initial development of processing facilities could be done in conjunction with ocean based fisheries presently in existence.

The systems of production are as varied as the species available. I observed aquaculture in Israel, USA, and Mexico in my travels. It varied in size from a small shed growing catfish in Israel to 600 ha of shrimp in Mexico using ocean water. Marketing is important when considering integrating aquaculture into an existing farming enterprise. Are we raising low valued aquaculture species that have economies of scale or developing a niche to compete with ocean-based fisheries?

Yankele Yogev at Kibbutz Revivim was supplying almost the entire catfish market in Israel from a small shed where the water was recycled to irrigate lucerne. Catfish are not a kosher fish since it has no scales, hence his limited production of 1 200 kg/month to the non-Jewish market. Catfish however can be stocked at incredibly high rates of 100-300 kg/m^3 (fish to water volume). At this density not a lot of water is in the tank and thus the flow through rates of water need to be extremely high. Catfish are also very good at stirring the sludge that develops on the bottom of fish ponds since they are bottom feeders.

I observed closed systems that were operated under green igloo structures in Israel that used barramundi as the fish of choice, supplied from Thailand. The extra 4 hours in airfreight from Australia made a significant difference to the mortality of fingerlings so they were not sourced at home. The green cover limited algae growth in the water, lowered evaporation rates in the hot climate and warm water (24^{o}C) and stopped bird predation.

At the National Centre for Mariculture (NCM) in Eilat (Israel) high capacity pumps with a low lift (30 cm) and highly monitored water conditions used oxygen injection to show the ultimate in technology. This facility conducts feed trials, with different species, and different operational systems for educational and commercial purposes. The NCM conducted a fish meal replacement trial using lupins from Australia (Warra cultivar from NSW) and it proved very successful. The reason for this study was because of the declining supply of fish meal as a protein source for aquaculture. One of its water recycling system experiments was using shrimp, a sea lettuce called ulva and abalone whilst another system used fish, abalone, sea urchins and ulva. In both systems the first step was fish or shrimp fed a commercial feed mix and the waste transferring to the next species as a feed and so on. The ulva was the last step in both systems, acting as a biofilter removing the nitrate waste from the water before recirculating the water back to the fish/shrimp. Financially the sea lettuce production is at breakeven levels, unlike the other aquaculture/mariculture products that are very financially rewarding. The ulva is processed for agar, and other seaweeds can be processed for beta carotene. The mariculture products would take several years before marketable size was achieved.

The flow of water from one species to another in both Israel and USA on commercial intensive farms relied on tilapia as a cleaning agent. This fish can withstand extremes of temperature and poor water quality. The tilapia species (see Figure 3) are very forgiving of conditions, but they are a fish that the Australian industry presently does not allow to import. Perhaps a catfish could serve this purpose where multiple use of water is planned.

Figure 3: Picture of Tilapia in an intensive tank system.

The extensive pond system at Kino Aquaculture in Mexico used ocean water pumped through a coastal dune into 5-8 ha ponds. The managers were running water replacement at 10% of pond volume per day, with the waste being gravity fed back to the ocean. Kino was massive in all terms with a turnover of more than US$25 million of shrimp per year. The ponds were harvested once per year even though it was only stocked for 4 months in the summer. Shrimp production increased by 100% by placing an aerator on the surface of the water. Kino was interested in growing halophytes to stabilise the dunes and banks between ponds.

DESALINATION

Desalinisation is the process of removing salt from an off quality water source to leave water of a given quality and brine as a waste product. At present several methods exist in desalinating water, these being multi-stage flash (MSF), multi-effect distillation (MED), Reverse Osmosis (RO), Electro-Dialysis (ED), Filtration or Capacitative Deionisation Technology (CDT). These are broadly placed in two categories: thermal desalination (MSF and MED) and membrane (RO, ED, CDT and filtration) technologies. The cost of which is dependent upon the capital cost of the technology, the cost of energy, the quality of the water that you input; the output quality, the quantity required and most importantly brine disposal.

- Multi-stage flash uses the heating of the saline water to a high temperature, as it is gradually introduced to a low-pressure chamber, causing the volatising of steam to the top of the chamber. A series of closed pipes with cool water flowing through them act as a heat exchange, removing the heat and causing the steam to condense and be pumped out as a final product. The remaining water is then passed through more of these chambers until a concentrated brine and water are the remaining products. MSF is typically high energy consuming, and does not handle suspended materials very well. The finished water is usually around 50 ppm Total Dissolved Solids (TDS), although better quality is possible, it is restricted by the salt collecting on the condensing tubes at the top of the chambers. This technology has been operating commercially for more than 30 years and is used in more than 48% of plants worldwide generating greater than 4 000 m^3/day of water.

- Multi-effect distillation while similar to MSF can use low temperature and pressure steam as the energy source. The system uses input steam to heat the low quality water in a series of pipes, making steam, which is condensed with the initial input brine, and heating it in the process. The system usually goes through eight to sixteen stages. The system continues as long as the temperature difference exists between the input steam and the input water temperature. Typically MED can give a ratio of 15 tonnes of water produced per 1 tonne of steam, whereas MSF is limited to a ratio of 10:1. A new plant in California using this system in a vertical format is maintaining a ratio as high as 24:1. The El Paso Solar Pond (Texas USA) uses its heat for MED and produces 16 000 l/day in a small sized unit, shown below in Figure 4.

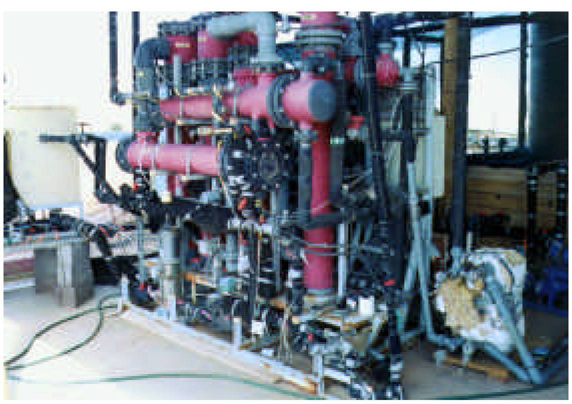


Figure 4: Multi-Effect Distillation desalinator at El Paso solar gradient ponds.

- Reverse Osmosis uses a pressure difference between sides of a membrane. Fresh water permeates through the barrier leaving the saline brine behind. The membrane barrier is made of synthetic polymers in thin layers adhered to a thick support layer. The brine is washed away due to the flow through nature of the process. The water conversion can be as high as 90-95% in brackish water and as low as 35-50% in seawater RO operations. Suspended materials can have a significant impact on the membrane lifetime, as it can block the membranes permeability. Many different sized units are commercially available now, although used in 22% of large-scale plants worldwide (ie generating >4000 m^3/day of water).

- Electro-Dialysis is where ions are forced to pass through a semi-permeable membrane, leaving a diluted solution on one side and a concentrated solution on the other. ED is used mainly for brackish water desalination but is not widely used.

- Capacitative Deionisation Technology is a process where a small DC current (like that of a capacitor) is passed through a saline solution causing the ions to move to their opposite charged side of the solution and onto the power inputs in the solution. The poles are coated with a carbon aerogel, which increases the surface area of the pole by up to 60 000 over the plain pole at a thickness of 0.02 mm. The aerogel resists acids, alkalis and heat in the solution. This is a new process that still requires more research and is on going at the Lawrence Livermore National Laboratory in the USA. The aerogel is pulsed with a reversal of the current and the ions move back into solution during a cleaning cycle. The process is limited by the time taken to remove the ions from the solution, and seawater poses the greatest difficulty for CDT with the number of flushing cycles required. The energy requirement for CDT is the least of all the promising technologies as demonstrated below.

CDT Process:	5.5 Watt-hours/litre
Reverse Osmosis:	7.7 Watt-hours/litre
Electrodialysis:	16.5 Watt-hours/litre
Thermal Evaporation:	600 Watt-hours/litre

- Filtration is primarily used before some of the other desalination techniques for the removal of material in the saline water. It involves the passing of the saline water through a membrane and collecting the suspended material in or on the membrane. Three main techniques are used: Nano-filtration to remove heavy salts; Ultra-filtration to remove bacteria and viruses; and Micro-filtration for suspended particles like clay and algae. These processes can also handle nitrates in polluted waters.

- Other desalination techniques exist like solar evaporation but many have failed the scrutiny of time. For instance solar evaporation requires 250 m^2 of collecting membrane and pond for 1 m^3 of fresh water, consequently this is too high a land requirement. One desalination technique that Nick Yensen discussed was the use of algae (*Pheridia tenuis*) that sequester the salt in their bodies removing the salt from a solution. A bucket of seawater with the algae if left to grow will be turned relatively fresh. Where the development of this technology is taking place I do not know.

Desalination typically takes place as close to existing energy sources such as a power station or a source of heat such as a mining operation, utilising waste thermal energy. Hence a large proportion of large desalination facilities exist in the Persian Gulf (50% of world usage) where there is an excess of energy. The cost of each technique is broadly illustrated below.

	MSF	MED	RO	RO*
Installation costs US$/m^3/day	1200-1500	900-1000	700-900	1000-1350
Water output cost UScents/m^3	110-125	75-85	68-92	45-56

Based on seawater desalinating and power @US6-7 c/kWhour (*- proposal in Tampa Bay Florida) (Figures courtesy of Rafi Semiat). The cost can reduce significantly if brackish water (6000 ppm) is considered, RO would drop to US 25-28 cents/m^3. To use desalinated water for agricultural crops the returns must be significant to return the cost of the water input. Cotton for instance in Israel has a water cost component of its production running at 30%, whilst tomatoes are at 8%, the farmer would have to endure a doubling in the cost of the water he is receiving with desalinated water, consequently the tomato grower can endure the rise in his cost of production.

All of the desalination processes have a waste product of concentrated brine, usually in higher concentrations than seawater. The handling of this brine is perhaps the most serious issue facing a potential desalination plant. Some methods of dealing with this include delivering it back to the sea, deep injection into an aquifer, delivery to an evaporation basin, or to a solar gradient pond. Only the last two in an integrated system will return something to an investor. Irrigation onto crops is restricted as the salinity is above the threshold for most halophytes.

Unless the cost of the technology reduces significantly or we alter our production system to include higher value agricultural commodities, desalination will remain in the industrial or domestic usage scale.

SALT HARVESTING

I observed salt harvesting in several places, the Dead Sea Works in Israel, Tulare Lake Drainage District and Rainbow Ranch both of which are in California. The minerals in the water largely determined the profitability of salt harvesting. In California sodium sulphate was being precipitated. This was being used in the dying of fabrics, although the process used 95% purity (US$200 /t) the farmers could only achieve 92% purity and faced a lower price for their product.

Development of methods to increase the evaporation rate included timing sprinklers to create smaller droplet sizes, and shallower pools to raise the temperature of the water. A pool 1.8-2.1 m deep took 2 years to dry out in Rainbow Ranch's case. This had the potential to make the process an occasional harvest of salt. The Dead Sea Works uses 1 m of evaporation per year and in California they use 2.5 m. But this is working on a fresh water pan evaporation rate. Several people indicated that evaporation rates decreased with increasing salinity but a distinct lack of quantative information on these rates existed in published literature.

The Dead Sea Works is a huge facility that covers 150 km^2, specialising in producing potassium (for fertiliser), magnesium (for car parts), magnesium chloride (for de-icing) and bromide salts for fire retardants and electronics. The potassium fertiliser and the bromide sections are the economic mainstays of their business. Sodium products extracted at the Dead Sea works include fine and coarse grade refined salt for the food industry, SalKal® (a low sodium salt substitute for human consumption), water softening products and beauty products. This company started with one pond in 1952, and now has a turnover greater than half a billion US dollars. Unlike most salt harvesting businesses they collect the salt crystals in a liquid form. Floating harvesters similar to a combine harvester pump the slurry to the processing plant several kilometres away (worth approximately $12 million each see Figure 5 below). Originally the salt was harvested in a dry format with dynamite, but new slurry techniques made harvesting more viable.

Figure 5: Dead Sea Works salt harvester on evaporation pond

Any salt harvesting venture must consider very carefully the production, marketing and government regulations of harvesting salts. The sodium sulphate salt accumulated on Rainbow Ranch was scraped up and placed in one pond because a market for its salt did not readily exist, even though the possibility existed for the salts use in the textile industry. At both Rainbow Ranch and the TLDD, selenium was concentrating in the evaporation basins and endangering wildlife. The TLDD found that 70% of the amount of selenium is being volatilised away by algae that grow in the evaporation basin. It was discovered that this selenium volatising process is highest in ponds that have brine shrimp in them.

POWER GENERATION

Solar gradient ponds work to produce electricity through the collection of solar heat in a vertical column of saline water. The process relies on saline solutions of differing concentrations. The more concentrated brine hence increased dense material stay on the bottom with less concentrated/dense solutions on top. The surface must remain still from wind movements to prevent surface circulation and dilution of the brine. Solar heat warms the bottom strata of brine in the pond but because of the difference in the density no vertical circulation currents will distribute the accumulated heat. The temperature difference can be substantial. Whilst at the El Paso Solar Pond in October the surface temperature was 24^{o}C and at 1.8 metres depth the temperature was 74^{o}C. Temperatures can get higher than 80^{o}C on the bottom. A heat exchanger can then by way of a low temperature boiling liquid, create movement of gas and then turn a turbine and a generator to produce power. El Paso had a 100kVA generator for the 3 350 m^2 of surface area. This was too large a generator for the pond size and was only run on a limited time daily. The pond will effectively produce electricity 24 hours a day (when pond and generator size are matched correctly). During the winter of 1987 the surface of the pond froze and the bottom of the pond remained at 68^{o}C hence batteries are not required given this thermal storage (see Figure 6 below).

Figure 6: Picture of Solar Gradient Ponds at El Paso, Texas. Note the netting on surface.

Before I received my Nuffield Scholarship I also viewed the Pyramid Hill Salt Companies facility in Victoria in 2000. They were in the process of building a solar gradient pond, which they have since completed in 2001.

The pond technology while simple offers a heat source that is very efficient costing around two thirds of the energy requirement of fuel. The greatest benefit of the ponds is heat production. This could be used for a multitude of uses, such as the heating of water for aquaculture in winter to stop thermal cold shock and the heat exchange can cool a pond in summer. El Paso was going to use the heat for the tomato processing facility within 300 m of the plant. The Dead Sea Works in Israel was of the opinion that the area required for a unit of power was too great to run their power requirement of 112 MW/h. They would need considerable more ponds than they presently have of 150 km^2 to use solar gradient power.

DRAINAGE

As part of a farming systems long-term survival it is sometimes necessary to do some engineering works to handle the volumes of water that are in the profile. If flood irrigation is in place then drainage is more likely to be required than sprinkler and drip irrigation systems. This also depends upon the nature of the soil (ie clay or free draining sand) and the quality of the water. A drain can be deep and open as in most Western Australian deep drainage or a closed tiled drainage system. The tiled system consists of slotted, corrugated PVC pipe usually 100 mm diameter surrounded by gravel placed at depth in the soil. The pipe functions to intercept water moving in the ground and convey it to a disposal drain or sump in an IFDM's case.

Israel had very limited drainage facilities as their soils are sandy in the south of the country and drip irrigation systems are in place over 95% of all irrigated area and this does not add excessive amounts of water. The watertable was in excess of 50 m in most areas. Israeli farmers were more concerned with getting the water rather than the drainage.

The San Joaquin Valley is extensively drained considering the soil is clay and flood irrigation is used. This was implemented by the Federal and State governments consequently District Drainage Management offices are in place throughout the San Joaquin. Each district has both water supply and drainage boards to regulate usage and disposal. Principally the area has supply channels to farms and drainage channels from farms. The drainage channels are linked and are at the end of most fields. The TLDD has a perched watertable that is at 0.9 m causing waterlogging. The TLDD covers an area of 94 980 ha of which 9 966 ha is under tiled drainage. Initially the drainage was constructed at 2.4 m deep on 120 m spacings, but this was then changed to 1.2 m deep on 30 m spacings to reduce the cost of the excavation process. This also served to reduce the amount of drainage water that was being delivered/pumped to the evaporation basins as the evaporation basins are at present only just handling the volume of water that is being delivered to them. The shallower drains intercepted less drainage water in the soil profile than the original design. The tiled drainage scheme keeps the root zone of shallow crops like cotton free from waterlogging.

The seawater irrigation schemes previously mentioned in Saudi Arabia and Mexico were not drained but were on coastal dunes being free draining back to the ocean. The sand did not hold a large volume of water and drained readily with the large volumes of water applied.

GENE MODIFICATION

A Dr. Edwardo Blumwald from the University of California recently had success in inserting a saline gene into canola, tomato and arabidopsis (experimental research plant). This is a great breakthrough for agriculture that may push the boundaries of where crops can be grown. It also creates many questions like the tolerance of the genes and where we can use these new plants. A salt tolerant tomato already exists that can withstand extremely high salinities but is of acrid flavour and extremely small fruit size.

CONCLUSIONS

Aquaculture has the greatest potential for the saline waters of Western Australia. The melding together of evaporation basins and aquaculture to use the water and remove the salt gives the most promising multiple use of saline water. I would estimate that 36 000 ha being 0.2% of arable area (18 million ha) in the SW of WA set aside for evaporation basins and/or ponds may have a significant impact on the rate of salinisation in WA and be large enough for an inland fish industry in its own right based on extensive stocking rates at 1 kg/10m^2. Many niches also exist in intensive style aquaculture so that farmers can differentiate their products to not compete with one another.

Several new forms of desalinisation are being developed including Capacitative Deionisation Technology and algal treatment, these have potential as low cost desalination processes but will not compete in the short term with Reverse Osmosis. Desalinating offers water mainly for high return users such as for industrial or domestic water and is presently cheaper to desalinate than convey water in the Goldfields Pipeline Scheme in Western Australia. The cost of desalination is prohibitive for irrigation without government assistance. Algae desalination may be possible in the future.

Solar Gradient Ponds are best used as a low cost heat source rather than power production. Power would be cheaper to come from conventional sources although biodiesel or biomass (from halophytes) burning may be alternatives that should be evaluated.

Drainage may have a role to play in some circumstances in Western Australia particularly tiled closed systems, if the economics of high value crops can justify the investment in salinity control measures. Cheaper surface water control measures and agricultural methods can be used to overcome freshwater waterlogging than drainage.

Nick Yensen has four laws that he likes to quote when talking of saline agriculture. These are:

1. First law - protect fresh-water crops from salt.
2. Second law - develop salt-tolerant varieties.
3. Third law - develop local halophyte species.
4. Fourth law - introduce domesticated halophytes.

These do have some credence considering Australia's record with introduced species. This methodology has merit in the problem solving process considering plant based solutions to salinity.

The best halophytes I observed overseas were Nypa ® Forage (*distichlis palmeri*) and salicornia (*Salicornia bigelovii*). Nypa ® Forage may do the same job of drainage by using water in a waterlogged saline soil and providing fodder more so than a saltbush in bare scolded areas. The salicornia offers high water use, and a multiple use crop with the products being vegetable salt, oilseed and a vegetable.

We need a multifaceted approach, integrating new techniques and crops into our farming system because no magic bullets exist in tackling the salinity issue.

Israel took 16 years to develop the pitaya cactus fruit, no market existed for this fruit, but it now retails for US$9 /fruit. They needed a drought tolerant plant for their desert conditions and this is what they found. More research is going on for new crops (even eucalyptus) that will be released shortly. It begs the question how much work is being conducted on potential crops for Western Australian conditions. We have a wide and varied biodiversity, and the current focus on lucerne whilst good should not be at the detriment of future developments. The cost may be great in the short term but any new industry developed can only benefit agriculture. Instead of being totally reliant on cereal grain production a niche can provide economic sustainability for many farms.