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Report

Report

Water Resource Management and Desalination Options for Small Communities in Arid and Semi-Arid Coastal Regions (Gaza)

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ETSU
Harwell
Oxfordshire
OX11 ORA
Telephone 01235 433128
Facsimile 01235 433213

Report Manager	Name	Miss G T Wilkins
Checked by	Name	Dr W B Gillett
	Signature	W B Gillett
	Date	5.11.96
Approved by	Name	Dr D J Martin
	Signature	D. J. Martin
	Date	6/11/96.

PREFACE

This report was commissioned by the ODA and was jointly funded by three departments within ODA (Engineering Division, Natural Resources and West Asia Departments). The team of consultants and specialists involved in producing this report comprised ETSU, The Institute of Hydrology, The British Geological Society, Richard Morris and Associates, Dulas Ltd and Light Works Ltd.

The report aims to assess the viability of water management and desalination options for small communities in arid and semi-arid coastal regions and to identify any necessary developments required for the successful introduction of such options in these areas.

Chapter 1 outlines a range of water management options and identifies those which are suitable for small communities in arid and semi-arid coastal regions. An outline methodology is given to aid water management strategy development and to improve the success of schemes.

Chapter 2 describes the desalination processes which have been developed and possible energy resources which could be used to power the plant, giving a brief outline of suitable desalination technology and energy technology combinations.

Chapter 3 compares the economics of selected desalination technology and energy technology combinations.

Chapter 4 outlines some of the background requirements for undertaking a water management review and establishing where small-scale desalination plants would be appropriate.

Chapter 5 is a brief case study on water management options for Gaza. Two specific desalination technologies were assessed for their viability with respect to Gaza (the Seawater Greenhouse - Light Works Ltd and PV powered reverse osmosis - Dulas Ltd). Economic assessments of these technologies can be found in Annex A and Annex B respectively.

Chapter 6 contains general conclusions and recommendations for small arid and semi-arid communities in coastal regions and summarises the specific conclusions and recommendations which were made for Gaza in Chapter 5.

REVIEW OF WATER MANAGEMENT AND DESALINATION OPTIONS FOR SMALL COMMUNITIES IN ARID AND SEMI-ARID COASTAL REGIONS

EXECUTIVE SUMMARY

Background

This report was commissioned by the ODA and is jointly funded by three desks within the ODA (the Water, Energy and Palestine desks). The report aims to assess the viability of water management and desalination options for small communities in arid and semi-arid coastal regions and to identify any necessary developments required for the successful introduction of such options in these areas. A case study has been done on Gaza with an economic assessment of two specific desalination technologies (a Seawater Greenhouse - Light Works Ltd and a PV powered reverse osmosis plant - Dulas Ltd).

Summary

Water scarcity in semi-arid areas may often reflect poor water management and economic constraints rather than a shortage of water resources. An integrated water resources management strategy appropriate to local circumstances can often reduce demands by making more effective use of existing sources of supply. Although a wide range of measures are available, implementing such a strategy may depend on institutional, legal or other reforms which may require a decade or more before significant improvements can be made.

In the past, increased water demands were usually met by developing new surface water and groundwater supplies. However, this has often had adverse impacts on the environment and sustainability. Due to the rapid increase in population, rising living standards, industrialisation and the degradation of existing sources, water resources management must also consider the role of less conventional sources of supply, such as desalination, or importing supplies from elsewhere. Valid cost comparisons between conventional and non-conventional sources should take account of the water resources available to future generations.

There are a variety of technologies available for the desalination of seawater or brackish water using renewable energy (RE) sources. Numerous research and demonstration plants have been built with a view to overcoming the problems of matching a discontinuous energy source to a desalination process, which in all cases are best suited for continuous operation. However, there is still much to be done before such plants can be classed as being commercial.

Seawater is much more expensive to desalinate than brackish water. The cost of water produced by desalination technology using conventional fossil fuels is usually much higher than most economies can afford and much higher than naturally occurring water. Hence the only countries that have invested seriously in desalination are the oil rich Gulf countries. The cost of water produced by desalination using a renewable energy source is normally more expensive than using a conventional fossil fuel if an electric grid is already in place. However, renewable energy driven desalination can be competitive in remote areas where there is no developed electrical grid or where fossil fuel prices are high. The energy efficiency of desalination processes is improving and the costs associated with renewable energy are falling, and are expected to continue to fall, which will make RE powered desalination plant more viable in the future.

In the absence of grid electricity or waste heat, the most likely renewable energy sources to be coupled to desalination plants using current technology are wind, solar energy and combustion of municipal solid waste or agricultural waste (biomass). Solar energy plants tend to cover large areas which can be a problem on small islands or in areas where land prices are high. The availability of biomass is questionable if there is a lack of water for agriculture, as given the cost of the water produced by desalination systems it is unlikely that it can be used for agriculture. But, there can be a good market for small desalination plants using renewable energy sources in specific remote locations. In remote coastal communities, without access to alternative water supplies and without access to grid electricity, the PV/wind reverse osmosis (RO) and the Seawater Greenhouse concepts developed for desalination using alternative energy may prove cost effective. Longer term, vapour compression (VC) processes could be developed with lower energy consumption than RO. The viability of the Seawater Greenhouse will depend on the specific topography of the coast, its climate and local demand for, and pricing of, horticultural produce. Oceanic islands with seasonal demand from tourism will probably be currently the most appropriate targets for the technology. As the technology is developed they may have wider application.

General Recommendations

Whether water scarcity is already existing, occurring occasionally due to drought or due to foreseeable rising demands, it is recommended that:

* an integrated water resources management strategy should be developed for areas subject to water scarcity in order to reduce demands. An integrated strategy makes more efficient use of existing water resources, and considers the potential contribution from less conventional and external sources of supply. The integrated planning and management strategy should cover the following areas: fiscal policy, legal matters, institutional structure, infrastructural needs, environmental management, water demand and supply issues and the availability and costs of energy for water pumping and treatment.

* the strategy should identify any constraints on its implementation, a timescale for its introduction and take account of cost-benefits, the equitable distribution of supplies and intergenerational transfer of resources.

* whilst a range of demand reduction and water supply management measures are available, further work is needed to identify the cost-benefits and water savings for individual measures as well as combinations of measures. A water management planning manual containing information on these aspects, on the factors to be considered, and the planning steps to be taken would aid those responsible for water management in developing countries. It would also be useful to include contact details for organisations and institutions able to provide further advice and information on water management strategies.

* a selection of in-depth case studies should be carried out on existing schemes to identify the critical success factors for water management strategies in developing countries. This would help planners to assess their specific situation and learn from the experience of others.

* the case study on Gaza included in this report would be complemented by similar case studies for representative oceanic islands which may be more appropriate locations for deploying renewable energy desalination systems.

* R&D is needed to overcome the problems with desalination technologies associated with intermittent running of plant.

• R&D is needed for combining renewable energy technology with desalination plants such that there is suitable energy back up and switching technology for a steady power supply.

* R&D is needed to optimise energy efficiency (use of energy) in small to medium sized RO plants using RES.

• R&D is needed on PV as a power source combined with VC desalination technology (including developments in VC energy efficiency).

* A survey of the potential market for renewable energy powered desalination plants needs to be undertaken in order to give commercial companies the confidence to invest in product development.

The recommendations marked with an asterisk should be given priority.

Gaza

The combination of climate, topography, population pressure and politics give Gaza unique water scarcity problems. Existing water resources are already overexploited, leading to quantifiable degradation of the aquifer. Demands from all sectors are increasing. The legacy of occupation has been a laissez-faire institutional environment without incentives for conservation or effective management of water resources.

Given the scale of Gaza's problems any solution will need to be based on both supply management and demand management measures. The supply management options are limited to the import of water from outside Gaza, the exploitation of wastewater or the desalination of water within Gaza. While there is some scope for managing domestic and industrial demand through programmes of leak reduction and the installation of water efficient appliances, the bulk of demand is generated by the agricultural sector. The replacement of inefficient irrigation practices by modern methods and crop substitution could reduce demand, but in practice farmers will often seek to recoup investment in efficient irrigation technology by increasing the area irrigated, and high value crops use large quantities of potentially polluting agrochemicals.

Significant resolution of water scarcity in Gaza will require the reallocation of water, allowing transfers of water from low return agriculture to high return domestic and industrial use, coupled with integrated resource management to protect the aquifer from further deterioration. This will require institutional and legal developments that can only be addressed by the Palestinian authorities.

Desalination is one technology that is under active consideration within Gaza to augment supplies. Desalination of seawater would provide a genuinely new source of water. Desalination of brackish water, while cheaper than desalination of seawater, needs to be managed carefully if it is not to precipitate further aquifer degradation. There are no power generation plants in Gaza at present, the electricity grid is powered from generation plant in Israel, so combining desalination plant with existing power plant in Gaza is not an option.

Given the current and foreseeable price of renewable energy, it is unlikely that PV RO or other renewable energy based RO options will have a role of any significance within Gaza in the short to medium term. The factors mitigating against this are:

- low wind speeds
- high cost of land for solar collection
- developed grid for both electricity and water
- plans for power generation using gas from Egypt

The Seawater Greenhouse is possibly a feasible option for Gaza, although its viability depends to a large extent on prices in a highly volatile agricultural market. The low cost option, which does not rely on a long pipeline to extract cold seawater, would be most appropriate, but would produce a relatively small amount of fresh water purely for agricultural use, while demanding significant areas of expensive land.

Recommendations for Gaza

* The ODA should discuss with the Palestine Water Authority potential water projects within Gaza with a view to selecting projects that are consistent with the authorities' development of an integrated water resource management plan.

- If the effectiveness of investment in the water sector in an area of great scarcity is measured by the production of water at low cost, then the development of leak reduction programmes, the installation of water saving devices and the treatment of wastewater are the most attractive options for investment.

- Present local conditions mitigate against PV desalination as an option. It should not be pursued until costs come down sufficiently to make it a competitive option.

- Disposal of solid waste in Gaza is a problem. Solid waste combustion with associated power generation and desalination should be investigated in greater detail.

* The greenhouse option may be viable, but within an agricultural context rather than as a substantive water supply project. A more detailed study should be carried out for constructing a commercial sized plant in Gaza, addressing issues of land cost and real agricultural returns.

* Investigate options for combining the planned gas fired power station in Gaza with a desalination plant.

The recommendations marked with an asterisk should be given priority.

GLOSSARY

Aquifer	A geological formation, or part of a formation, that contains sufficient saturated material to yield economic quantities of water to wells and springs
Dunum	Unit area of land equivalent to 0.24 acres (0.1 hectare)
Drip irrigation	Piped irrigation distribution system in which water is delivered either above or below ground via small holes in pipes
dS/m	deci-Siemens/metre (conductivity)
Ec_e	mean soil salinity
Economic analysis	A cost-benefit analysis done by converting market prices to efficiency, or shadow prices, typically undertaken when market prices are judged to be a poor estimate of economic value
Financial analysis	A cost-benefit analysis done using market prices
Furrow irrigation	System of irrigation in which water flows in open channels between rows of plants
l/p/d	litres per person per day
Marginal cost	The incremental cost associated with producing one more unit of output
Medusa bag	large synthetic bag towed behind a ship to transport fresh water
Opportunity cost	The benefit foregone by using a scarce resource in one use instead of its next best alternative use
Sprinkler irrigation	Piped irrigation distribution system delivering water via a variety of arrangements of pressurised spray nozzles

CONTENTS

1. WATER RESOURCES MANAGEMENT OPTIONS

1.1 Introduction

Population increases and higher living standards in developing countries will result in considerably increased demands for water and consequent pressures on available resources, especially in arid and semi-arid regions where the water resources are often limited and vulnerable to drought.

In all areas, rapidly increasing water demands need to be addressed both by good water resources management practices to reduce water demands, and by more effective use of existing water sources. In recent years, there has been a realisation that addressing the demand side is as important as the corresponding supply side of water scarcity. However, where there is limited scope for improvement, existing water sources may have to be supplemented by non-conventional sources such as importing supplies into the area or by converting seawater or brackish water into potable water using modern desalination technology.

Industrial processes for the desalination of seawater have been used for the past three decades in some water-starved countries with sources of cheap energy. This has been the case in some oil-rich countries in the Eastern Mediterranean, notably Saudi Arabia. However, since the early seventies considerable efforts have been made to develop viable renewable energy resources. Some of these, wind in particular, have reached the stage of being commercially viable under certain circumstances. Coupled with this there have been useful developments in the field of desalination technology and in the development of less energy intensive desalination processes that can be used with renewable energy sources. A number of small demonstration plants have been constructed and tested.

Future technology developments and associated reductions in costs will make desalination powered by renewable energy an increasingly viable option in some areas. Areas that will be able to exploit this are those with good renewable energy resources and acute water shortages. The water that such systems produce will still be relatively expensive and if used for irrigation will have to be used to produce high value crops.

Chapter 1 presents an outline of water resource management options that could be applied in semi-arid regions to reduce water demands and to make better use of existing sources. Chapter 2 describes modern desalination technologies alternative energy options and combinations of energy sources and desalination technologies.

1.2 Water Management Options

Water management is concerned primarily with finding an acceptable balance between the benefits of water use and the costs of supply whilst taking into account socio-economic factors, the intergenerational transfer of resources and protection of the environment.

The two main components of water resources management are:

a) <u>demand reduction measures</u>, which attempt to reduce demands in each water sector and provide a more equitable distribution of supplies;

b) <u>supply management measures</u>, which aim to make better use of existing sources as well as identifying other possible sources of supply.

Some of the more common management measures are listed in Table 1.1.

Table 1.1 Water Management Measures

I Demand Reduction Measures

A. Agriculture

1. Reduce area under irrigation.
2. Improve irrigation efficiency.
3. Encourage low water use crops, more appropriate cropping patterns and methods to reduce evaporation losses in horticultural areas.
4. Scaled water tariffs, metering of supplies and government controlled schemes.
5. Reduction in livestock numbers.

B. Industry

1. Introduce licensing and scaled water tariffs.
2. Encourage low water use industries.
3. Introduce incentives for water recovery and re-use.
4. Leakage minimisation, target and monitor consumption.

C. Domestic

1. Reduce system leakage and illegal connections.
2. Introduce scaled water tariffs, water meters and efficient revenue collection.
3. Raise public awareness for water conservation by publicity campaigns.
4. Encourage and support domestic water saving appliances, whilst discouraging high water use appliances.
5. Reduce garden or patio watering.
6. Reduce water pressure or provide supplies on a rota basis.
7. Provide basic water requirements (BWR) only.

Other municipal measures include reduced watering of streets, roadside verges and public parks.

II Water Supply Measures

1. Conjunctive use of surface water and groundwater supplies.
2. Artificial recharge of surplus surface water.
3. Use of brackish groundwater.
4. Re-use of wastewater and irrigation drainage water.
5. Small dams in upland areas for local, short-term supplies
6. Saline intrusion control methods.
7. Freshwater 'skimming' in coastal areas.
8. Small-scale non-conventional sources (e.g. rainfall harvesting).
9. Small and large scale desalination.
10. Large-scale import of water from water-rich areas.
11. Blending of fresh and poor quality water
12. Groundwater abstraction control measures.
13. Transfer of water rights from agriculture to urban use.

Benefits derived from improved water management include (UN, 1991):

- postponing investment in new sources.

- a more equitable allocation of supplies and economic efficiency. Government policy or pricing and various restriction methods can promote water use in some sectors while discouraging it in others, usually in order to improve the economic return to water.

- generating water sector revenues. Through the analysis of water use and adoption of appropriate tariff structures, revenues derived from the water sector can be used to improve supplies and data collection.

- drought management. Reducing demands can lower the risk of disruption and costs resulting from water shortages and water can be allocated to the more important users during droughts.

- reduction in wastage. Metering, pricing, leak detection and monitoring of the distribution system to identify illegal connections can improve the operation and maintenance of the whole water distribution system.

1.2.1 Water Demand Reduction Measures

a) Reducing agricultural water demands

The agricultural sector usually accounts for 75 to 90% of the total water demand in many semi-arid countries, which generally need to rely on irrigation for crop production. Many of these countries have agriculturally based economies and a high proportion of the labour force in the agricultural sector. Measures to reduce irrigation water demands in particular can release significant supplies for other users, although other agricultural water demands can be important, for example the daily water requirements for cattle are about 30 l/head.

Examples of the average per capita water requirement for food production are shown in Table 1.2 (Barthelemy, 1993):

Table 1.2 Average Water Requirements for Food Production

Per Capita Water Requirements	Egypt	Tunisia
Total daily water input l/p/d	3242	2964
Percent of water needed to produce meat in diet	21.4	26.9
Percent of total daily input met by irrigation	69.0	57.3

Improving irrigation efficiency

Various irrigation methods and sources of supply are used in semi-arid countries. These range from traditional methods (such as spate irrigation) to modern, integrated drip irrigation schemes. The choice of system depends mainly on climate, availability of water and labour, costs, simplicity of installation and operation and tradition (i.e. what people are familiar with and used to using).

Water use efficiencies using subsurface and drip irrigation methods are reported to be 80 to 90% compared to 50 to 70% for sprinkler irrigation and only 30 to 40% for flood irrigation. However, in practice irrigation efficiencies are often lower than indicated by these figures (world average 37%).

Traditional irrigation systems typically lose 20-30% of the water supply in the distribution system, which can be reduced by low cost measures, such as the lining of secondary canals. Modern systems that deliver water more directly to the root zone result in less salt deposits, higher crop yields and reduced water demands (Shalhevet, 1994). Poor water scheduling often results in the inefficient use of water and for this reason modern irrigation systems may incorporate tensiometers or other equipment to monitor and improve water application.

In Jordan considerable success has been achieved in replacing the traditional 'dowaleeb' (or furrow) irrigation method by drip irrigation systems to produce high value crops with export potential. However, the water saved by improving the irrigation efficiency has been used to expand the area under irrigation in order to increase the economic return. An economic analysis of the benefits of modernising an irrigation system in Jordan showed that whilst the net income of a 40 ha plot increased tenfold after modernisation, this was due in part to a change in crop mix. It was estimated that traditional crop yields would increase by 50% whereas an increase in yield of 100% would actually be required to justify the investment in modernisation (Regev *et al.*, 1990).

Other government assistance to promote better water use could include government-controlled unified water collection systems (e.g. groups of boreholes linked to a covered reservoir or tank) and drip irrigation systems fitted with meters at the farm turnout to allow cost recovery. This type of scheme has been implemented for example in the Messara Valley in Crete to reduce groundwater abstraction.

Low water use crops

At the farm level, the choice of crop tends to be determined by market prices as well as the availability and quality of water. Vegetables and fruits generate a higher income than more traditional field and forage crops, but have a higher water requirement. However, agricultural water demands can be reduced by converting to lower water use crops where possible.

Self-sufficiency in food production and agricultural employment are major issues for governments in developing countries. Hence, whilst importing cereals or high water use crops may be desirable from a water management point of view, this may be unacceptable politically due to foreign exchange considerations or concerns for food security and employment.

Price controls

Excessive water use for agriculture often reflects the lack of an appropriate pricing structure, a reluctance by government to levy a realistic price for water supplies, or the lack of an organisational framework to collect revenues. Pricing (or water tariffs) can improve the efficiency of water use as well as encouraging a more equitable use of water supplies, although revenue collection is not always easy to achieve or enforce.

The use of energy prices to regulate water demands may be applied on an energy unit basis, especially for groundwater abstraction schemes. In Gujarat, India, electricity charges for running irrigation pumps are based on an annual fee related to pump horsepower (Moench, 1992). However, once the fee is paid the farmer has no incentive to invest in either electrical or water efficiency so that the more water the farmer uses, the lower the cost per unit volume of water. Pump energy efficiencies measured in the field in Gujarat typically range from only 13 to 27% as opposed to more than 50% usually found elsewhere in the world (Patel, 1989).

The price elasticity of water demand varies from place to place and therefore so does the effectiveness of price adjustment on the quantities used. Taxes, or prices based on energy consumption, could be used in water short areas. In Gujarat, some farmers use diesel pumps whose running costs are much higher (and a direct function of water use) and consequently efficiency in water use in these areas is much greater.

If energy pricing is impractical or does not have the desired effect, fees could be based on the area irrigated, by crop type or by the volume of water delivered. Charges could also be levied on the operation and maintenance costs, the ability of the farmers to pay or the value of the crops grown.

Each pricing arrangement will have a different impact on water allocation efficiency, distributional equity, ease of fee collection and cost of implementation. It may also be beneficial to impose additional costs if the farming activities cause water logging, salinization or pollution.

Other possible measures to reduce water demands in the agricultural sector include:

- research into alternative irrigation methods (e.g. bubbler systems)
- removal of subsidies or import controls that might promote higher water use
- low cost loans to farmers to purchase drip or other modern irrigation equipment
- improved agricultural extension services
- improved marketing and infrastructure
- preferential minimum prices for low water use crops
- import of high water use agricultural produce
- transfer of water rights to low water users.

b) Reducing demands in municipal areas

The population growth rates in many less developed semi-arid countries are amongst the highest in the world, and are increasing faster than improvements can be made to water availability. Demands will increase further as living standards improve.

Domestic water use depends on climate, living standards, water charges, water availability, and the distance to the supply. In dry regions of developing countries rural household water use ranges from 30 to 40 l/p/d with public standpipes to 60 to 80 l/p/d with house connections (but without flush toilets or gardens).

Recommendations for drinking water and sanitation needs vary from 20 to 40 l/p/d (USAID, World Bank, WHO), increasing to about 100 l/p/d in water scarce regions if bathing and cooking needs are included (Falkenmark, 1991). However, it has been suggested recently that a basic water requirement (BWR) of 50 l/p/d should be adopted for drinking, cooking, cleaning and sanitation needs (Gleick, 1996).

Domestic water demands in urban areas can be reduced by a range of measures. These include metering of household supplies, scaled water tariffs, reducing the number of illegal connections, reduced water pressure, leakage reduction and publicity campaigns.

Most household water savings are accomplished by some type of device. Appliances, water closets and showers can be adjusted or changed resulting in less water being used while accomplishing the same task. Promoting the implementation of these measures results in lower demand and may include:

- Shower spray nozzles which restrict the flow of water while increasing the velocity can reduce the water use significantly. In the UK, showers use on average 35 litres per use compared to 80 litres per use for baths (NRA, 1995).

- Clothes washers where water requirements for a standard load varies between 144 and 261 litres (UN, 1991). A dishwasher wastes comparatively less water than a clothes washer, using only 25 litres per use compared to 17 litres per day using a sink (NRA, 1995).

- Using a smaller cistern on a toilet reduces the flush volume, or a simpler measure is to insert a displacement device in the existing cistern. A dual flush fixture allows for a low-volume flush for liquid waste. Up to 3.5 litres per flush may be saved with this technique. In the UK the average rate of use is 10.5 flushes/household/day.

- Some countries such as Hong Kong, Saudi Arabia and parts of the US have dual systems whereby sea water or treated wastewater is used for flushing toilets or garden watering. In Venice, Florida, water demand was reduced by 20% by introducing a dual distribution system (NRA, 1995).

- Some countries use water-based evaporation air conditioning systems which would work equally effectively with non-potable water.

Examples of effective demand management programmes in municipal areas include [World Bank, 1993]:

- In Mexico City the replacement of 350 000 toilets by smaller six-litre models saved enough water to meet the household needs of 250 000 residents.

- In Beijing, China, a new pricing system linked to the amount of water used contains regulations that set quotas on consumption and impose fines on excessive use.

- Water use in Jerusalem was reduced by 14% over two years by the introduction of water-saving devices, a programme of leak detection and repair, and more efficient irrigation of municipal parks.

- In Bogor, Indonesia, water consumption was decreased by 29% following an increase in water charges of 30%. A subsequent campaign aimed at heavier users (>100 m^3/month) which included advice and water-saving devices produced a further decrease of 29% in three months.

Significant losses occur in urban water supply systems throughout the world (Khadam *et al.*, 1991). Losses in pressurised potable water supply networks may vary between 5 and 50% depending on local conditions, and rise exponentially with increasing water pressure. Common causes of pipe leakage include poor construction, corrosion and pressure variations. Besides being a direct economic loss and a loss of often scarce resources, there may be indirect economic losses from damage to structures as well as environmental problems. In general, losses exceeding 25% of the water supplied at source are considered unsatisfactory whilst losses of less than 15% are considered reasonable. Leakage control can be cost-effective in reducing demands at source. Measures include:

- reduced pressure at times of lowest demand
- routine leak detection and repair

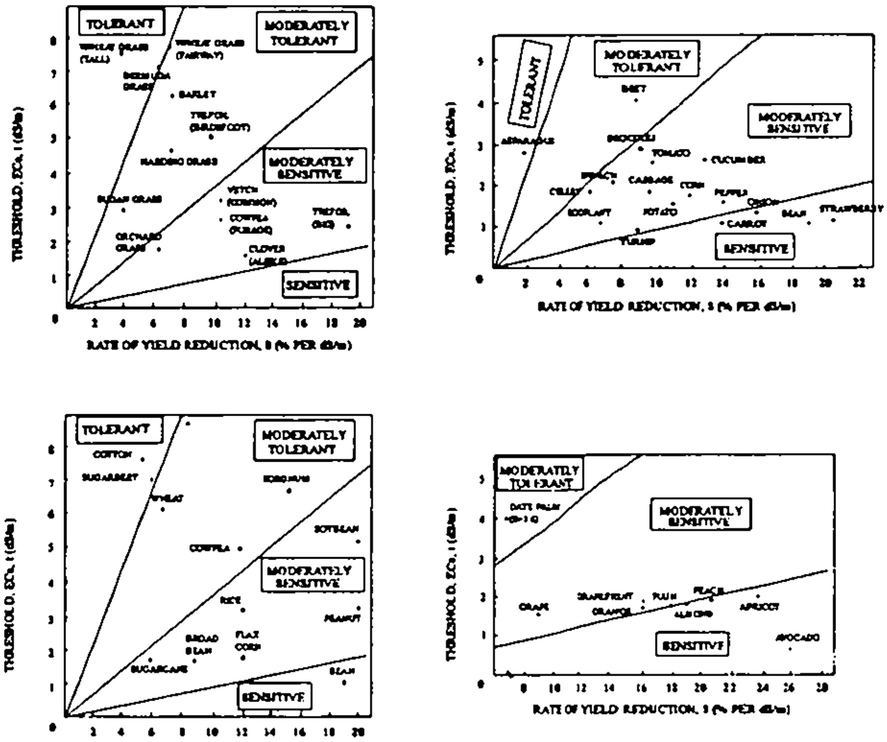


Figure 1.1 Salt tolerance ratings of selected crops. [Maas 1986; Shalhevet,1994]

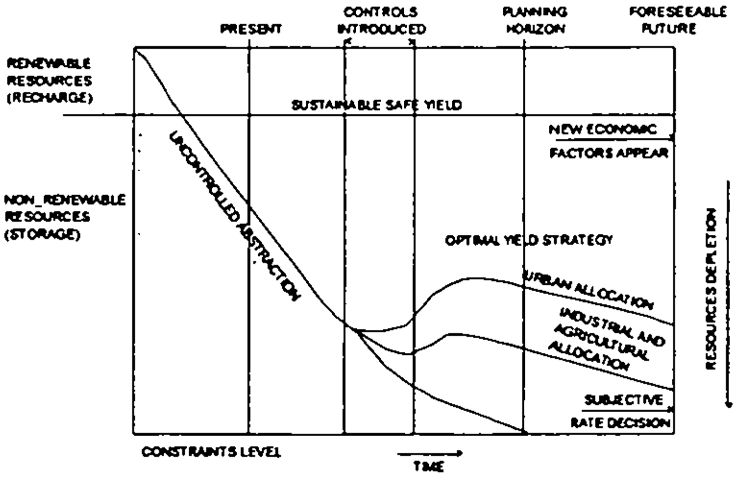


Figure 1.2 Example of optimal yield groundwater management strategy (Lloyd and Bradford, 1993)

- installation of `district meters' to detect abnormal changes.

Industrial water demands in most semi-arid countries are still relatively low but increasing rapidly. Supplies may be derived from individual boreholes or from the urban supply network. Water quality and supply requirements of different industries show a wide variation.

Measures to reduce industrial water demands include scaled water tariffs, incentives for water re-use and discouraging high water use industries, such as food canning.

1.2.2 Supply management options

Often more effective use can be made of existing water resources. Examples include conjunctive use of surface and groundwater supplies, re-use of urban wastewater and irrigation drainage water, groundwater abstraction control measures, and artificial and enhanced recharge. Various techniques are also available to optimise the use of fresh groundwater in coastal areas at risk from saline intrusion, such as scavenger wells and artificial recharge.

Use and re-use of poor quality water for irrigation

Crop yields are partly determined by water quality. However, water with quite high salinity levels can be used for irrigation if the following changes in the normal irrigation practice are applied (Oster, 1994):

- selection of appropriate salt-tolerant crops
- improvement in water management and, in some cases, the adoption of innovative irrigation technology
- proper maintenance of soil physical properties.

The relative tolerance of various crop types to salinity concentrations is shown in Figure 1.1 where the EC threshold is expressed in terms of deci-siemens per meter (conductivity) denoted by ds/m.

Sources of poor quality water include urban wastewater, low salinity (<2000 mg/l) irrigation drainage water or poor quality groundwater, all of which could be blended with freshwater supplies. In Egypt, where water from the Nile is recycled three or four times over in the eastern part of the Nile Delta, government controlled drainage re-use schemes provided 4.7 billion m^3/y of irrigation water in 1990 and there are plans to increase this to 7.0 billion m^3/y by the year 2000. Improvements in irrigation efficiency would, however, reduce the amount of drainage water.

In Teheran, Iran, road runoff is collected in `jubes' and canals and used to irrigate vegetable crops in the adjacent Varamin Plain. Where wastewater is collected in a unified sewerage system, there is the possibility of water re-use. Treatment involves the removal of sediment using screens and filters, breakdown of biodegradable materials and removal of contaminants to minimise the health risk. A large number of projects have indicated that waste water re-use is feasible with minimal health risks. The cost of treating wastewater (at 1996 prices) is of the order £0.17/m^3, but only an additional £0.07/m^3 is needed to produce water of sufficient quality for irrigation (including additional storage, pumping and treatment costs) (Assaf *et al.*, 1993).

Groundwater abstraction control measures

Groundwater supplies are widely used in semi-arid areas, in part because they provide more controlled and secure sources of supply. These supplies may be obtained from springs, river baseflows, horizontal galleries, dug wells and boreholes. Over the past 40 years the introduction of motorised pumps and modern drilling techniques has resulted in a rapid increase in the number of boreholes and often uncontrolled groundwater development.

A variety of groundwater management measures are available to reduce groundwater abstraction. These include:

- phasing out subsidies on diesel fuel and credit facilities for pumps and well materials
- restricting the size of pumps or introducing minimum spacing between wells
- establishing groundwater control zones where a ban on drilling of new wells or the deepening of existing wells is strictly controlled
- obligatory licensing of wells, fitting of water meters and scaled water tariffs
- introducing penalties for non-licensed abstraction
- licensing of drilling companies
- introducing low cost loans for water saving measures (e.g. plastic hose).

Public awareness campaigns, particularly through farmer cooperatives, can also assist in regulating abstraction.

Ideally the amount abstracted should not exceed the long-term, average safe yield of the aquifer. However, in semi-arid areas this may provide limited scope for development and recharge estimates may be uncertain. There may also be overriding socio-economic or political reasons for using groundwater in aquifer storage, which is often referred to as an 'optimal yield' groundwater management strategy.

Figure 1.2 shows one approach to groundwater management in these circumstances where over abstraction is taking place and there are competing urban and agricultural demands. Continued depletion of storage would eventually result in a reduction in abstraction due to increased pumping costs or water quality constraints. Alternatively, after introducing groundwater abstraction control measures and giving first priority to abstraction for domestic supplies, the amount of abstraction allowed for agriculture and industry would be decided by the controlling authorities depending on the rate at which they would allow storage to be depleted (Lloyd and Bradford, 1993).

Non-conventional sources

By providing additional supplies of water in water-short, arid regions, non-conventional water resources may offer an opportunity for development previously considered impossible.

Non-conventional sources of larger scale supplies include the import of water from water-rich areas perhaps from outside the country by pipeline or tankers, and large-scale or small-scale desalination techniques (see section 1.3).

A number of schemes have been proposed in the Middle East for the international sharing of water resources from water-rich countries (e.g. Turkey) using pipelines, water conveyors or tankers. For example, a 200 Million m^3/y pipeline from the Nile to Gaza would cost £0.32/m^3 of water delivered. A canal conveying water at the same rate would cost of the order of £0.11/m^3 (Assaf, 1993). However, in general the cost of such supplies can be high and this option may not be politically acceptable for water security reasons.

A UN seminar on non-conventional water resources in developing countries also concluded that (UN, 1985):

- the costs of non-conventional water resources technologies are difficult to determine with accuracy and are not comparable from place to place.
- no particular non-conventional solution is suitable to all water-short areas.
- in any situation where a conventional source of water can be developed, it will almost always be preferred to a non-conventional source.
- non-conventional sources are usually more complex to develop and operate than conventional sources, and are almost always more expensive.
- selection and implementation of a non-conventional water project should be carried out with caution since most require large capital expenditure, long term technical and financial support, chemicals and spare parts.

Where conditions permit, it may be feasible to supplement local supplies by various less conventional techniques, such as the following:

- water 'skimming' techniques using shallow drainage systems in coastal areas (e.g. at Rafah on the Mediterranean coast of Sinai in Egypt).
- directing local runoff to water cisterns for livestock use (e.g. western Egypt)
- terracing in upland areas for irrigation (e.g. Yemen)
- collecting run-off from roofs (e.g. New Zealand)
- mist nets (e.g. Chile) and dew collection in upland areas (e.g. central Sinai)

Table 1.3 presents some typical costs of various non-conventional water sources.

Table 1.3 Costs of selected non-conventional water supplies

Source	Cost range/m^3*
Sea water desalination	£0.73 - £1.00
Brackish water desalination	£0.10 - £0.47
Reclaimed wastewater (agriculture only)**	£0.10 - £0.27
Import by long-distance pipeline***	£0.07 - £0.27
Import by tanker or 'Medusa' bag	£3.20 - £4.00

* All currency figures are in 1996 £UK. Some figures have been modified to the 1996 baseline rate based on average unit value (quantum) indices for exported manufactured goods of developing nations. This is obtained from "Commodity Markets and the Developing Countries", International Monetary Fund. 1996.

** Note that these figures are reduced if some form of waste treatment is already taking place. The cost in this case is closer to £0.07/m^3.

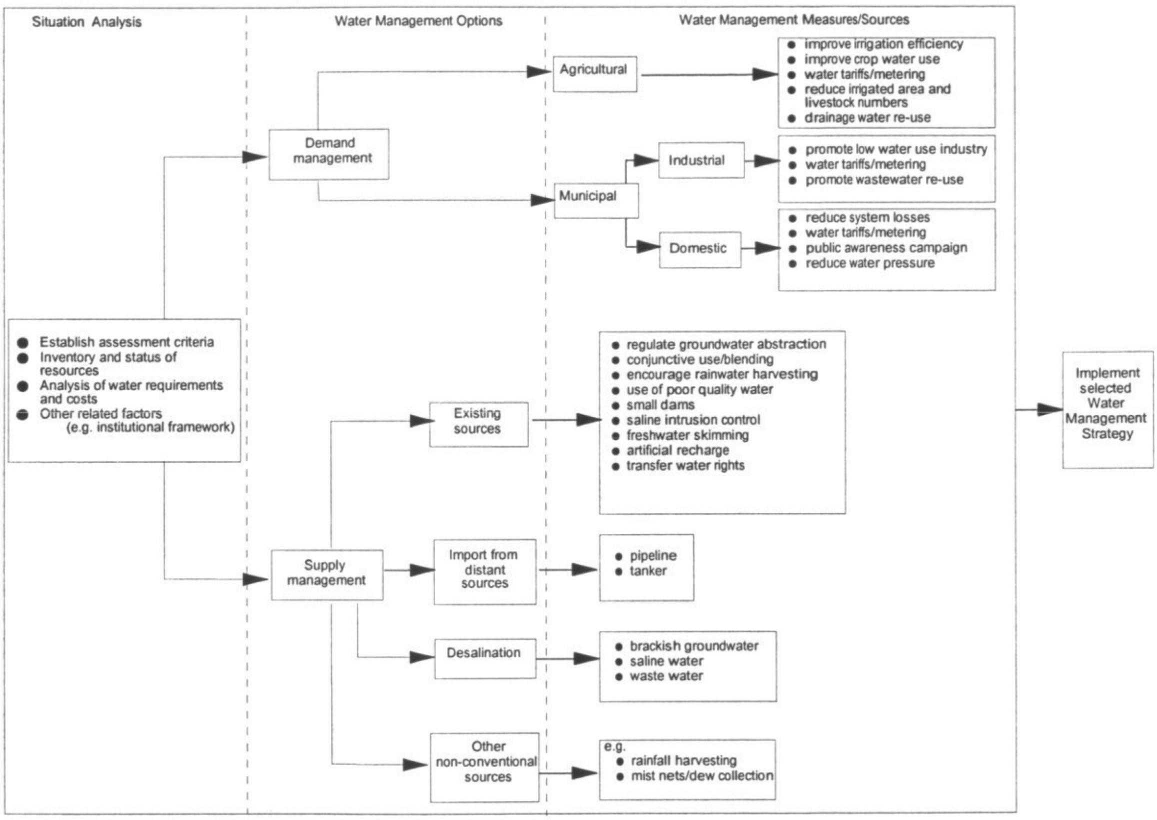
*** Pipeline schemes in Eastern Mediterranean countries.

(UN, 1985; Assaf, 1993)

1.3 Outline Methodology for Introducing a Water Management Strategy

A water management strategy should be selected that is appropriate to a particular location where demands exceed supply and adverse consequences of overexploitation are occurring. A simplified procedure for developing such a strategy is shown in Figure 1.3. It should be stressed that management options and associated measures for reducing demands, improving the use of existing resources or for introducing new or non-conventional sources of supply need to be considered simultaneously.

Figure 1.3 General Procedure for Selecting aWater Management Strategy



The following background information is usually required to select the most appropriate combination of management options for a particular area:

- an inventory of the resources available from existing and potential sources (both conventional and non-conventional)
- an assessment of the current level of exploitation of each source, gaps in information and of any adverse trends
- the availability and quality of monitoring information
- analysis of present water use and projections of future water demands
- an assessment of the occurrence and reasons for any water shortages
- an analysis of trends in the real price of water and cost recovery.

Other relevant considerations include government policies, inequalities in distribution, cost-benefits, existing national, religious and local laws, and the planning horizon. The success of water management measures may also depend on legislative and institutional reforms and progress in other related aspects, such as reducing the rate of population growth. Allowance should be made for the time required to implement and benefit from water management measures.

The successful introduction of water demand management options usually requires the following actions:

a) identify the current situation, data availability, planning horizon and future water demands (based on current water use)

b) identify locations and reasons for excessive demands, and when and where water shortages occur

c) consider where savings can be made in water use and which measures would produce the greatest saving in water demands for least cost and maximum economic benefit

d) identify any constraints on the introduction and success of the selected water management options, taking into account the costs and time required for the water management measures to produce water savings, other relevant government policies, technical feasibility, environmental benefits etc

e) instigate any necessary reforms in the institutional framework, legislation, water tariff structure or other relevant aspects in order to allow water saving measures to be introduced

f) establish the necessary monitoring and institutional requirements to make any future adjustments or improvements in the adopted strategy.

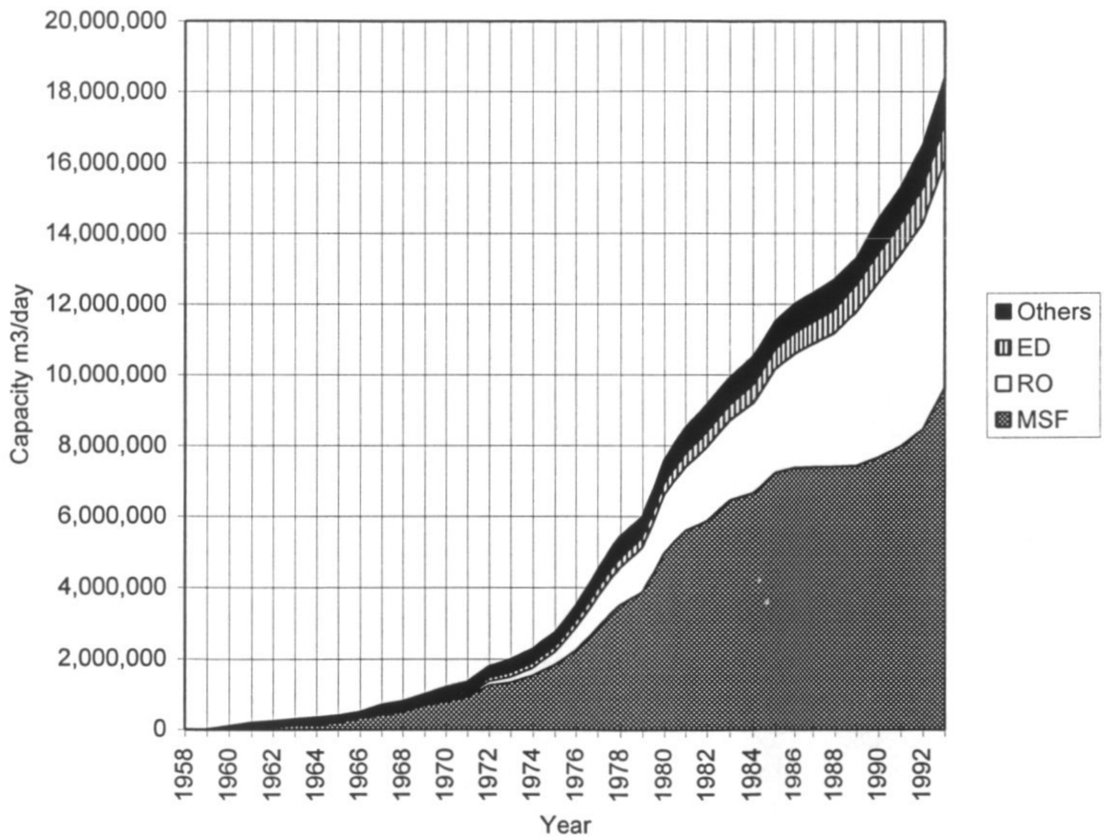
The criteria, appropriateness and applicability of each option depends on location and the particular circumstances at that location. Each option is likely to involve a different combination of measures and possible alternatives depending on the existing sources of supply, future water demands, socio-economic and political factors and seriousness of the situation. The overall methodology can be applied at different scales.

2. TECHNICAL OPTIONS FOR WATER RESOURCES - DESALINATION

Introduction

During the last 25 years there has been an explosive growth of desalination plants as shown in Fig 2.1. Most of this growth has been in the oil rich Middle East and is based on distillation technology. However alternative processes, most notably reverse osmosis (RO), have also been developed during this time. Reverse osmosis has grown spectacularly over this period and now dominates some sectors of the market, particularly the small plant sector. Given that we now have the technology to produce fresh water from seawater in significant quantities and that we have abundant supplies of seawater, why do we still have water shortages in arid areas ?

Figure 2.1 World Desalination Capacity



IDA Desalting Plants Inventory. Wangnick 1994

The answer is twofold. Firstly, the equipment is expensive. However this is a once off cost and can be recovered in many instances. Secondly, there is the cost of energy. All seawater based desalination processes require significant quantities of energy to achieve the separation of the potable water. This is more significant as it is a recurrent cost which few of the water-short arid areas of the world can afford. The Middle East is a unique arid area in that, because of oil income, it has enough money to invest in the desalination equipment and to run the energy consuming equipment. In this region, oil, or its associated gas, is the energy source used to drive the plants.

Many other arid areas of the world have neither the cash nor the indigenous fossil fuel resources to allow them to develop in a similar manner. These countries do however often possess significant renewable energy resources which advancing technology may allow them to use to produce potable water from seawater or brackish water.

Desalination Processes

One convenient and useful way to classify desalination processes is to separate them into those which involve a change of phase to separate the pure water from the feed water and those which accomplish this separation without a change of phase. The phase-change processes include:

a) Multi-Stage Flash (MSF) (a distillation process)
b) Multi Effect Boiling(MEB) (a distillation process)
c) Vapour compression(VC) (a distillation process)
d) Solar Distillation (a distillation process)

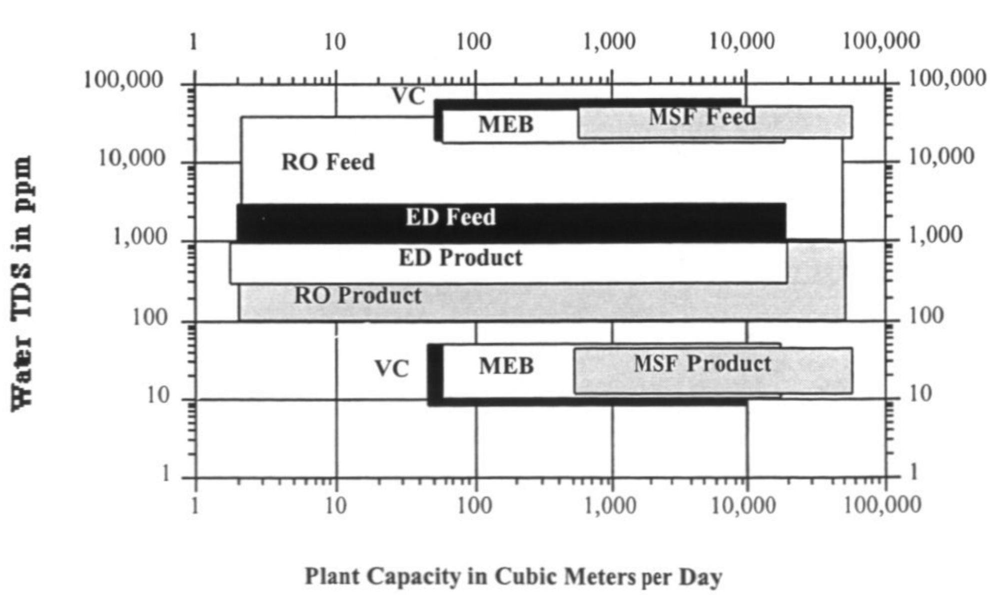
Those in the single-phase category include:

e) Reverse Osmosis (RO) (a membrane process)
f) Electrodialysis (ED) (a membrane process)

Energy requirements for thermal processes are normally defined in terms of units of water produced per unit of steam consumed. This is known as the performance ratio (PR). For power-consuming processes the energy consumptions are usually expressed in kWh/m^3. Processes involving a phase change are normally more energy intensive than those not requiring one.

Process Choice.

Figure 2.2 Desalination Process Applicability Ranges



The ranges of applicability of the various desalination processes are shown in Figure 2.2. From this figure it can be seen that, in general, the phase change processes tend to be used for the treatment of high salinity waters, particularly seawater, while the membrane processes are used over a wide range of salinities from brackish water to seawater. Ocean seawater has a salinity of around 35,000 ppm (parts per million) total dissolved solids (TDS). Brackish water is usually defined as having a TDS of up to 5000 ppm. Application of the electrodialysis process is limited to brackish water applications. With the membrane processes, energy consumption is directly related to the salinity of the feed water.

2.1 Brief Comparison Of Desalination Processes

Generally speaking, in all of the above phase separation processes there are few restrictions on the type of water which can be treated. The only effects that increased feed water salinity have on the process are:

1) the boiling point elevation (or freezing point depression) is increased

2) the permissible concentration ratio to avoid scale formation is reduced

Consequently, the cost of the energy to drive the separation processes at economic rates is only loosely related to feed water salinity. Whereas in the membrane processes the product water costs are very definitely related to both the feed water salinity and the desired product water purity.

2.1.1 Thermal Distillation

There are two ways in which vapour can be generated from a liquid at its boiling point:

either	heat can be added	BOILING
or	pressure can be reduced	FLASHING

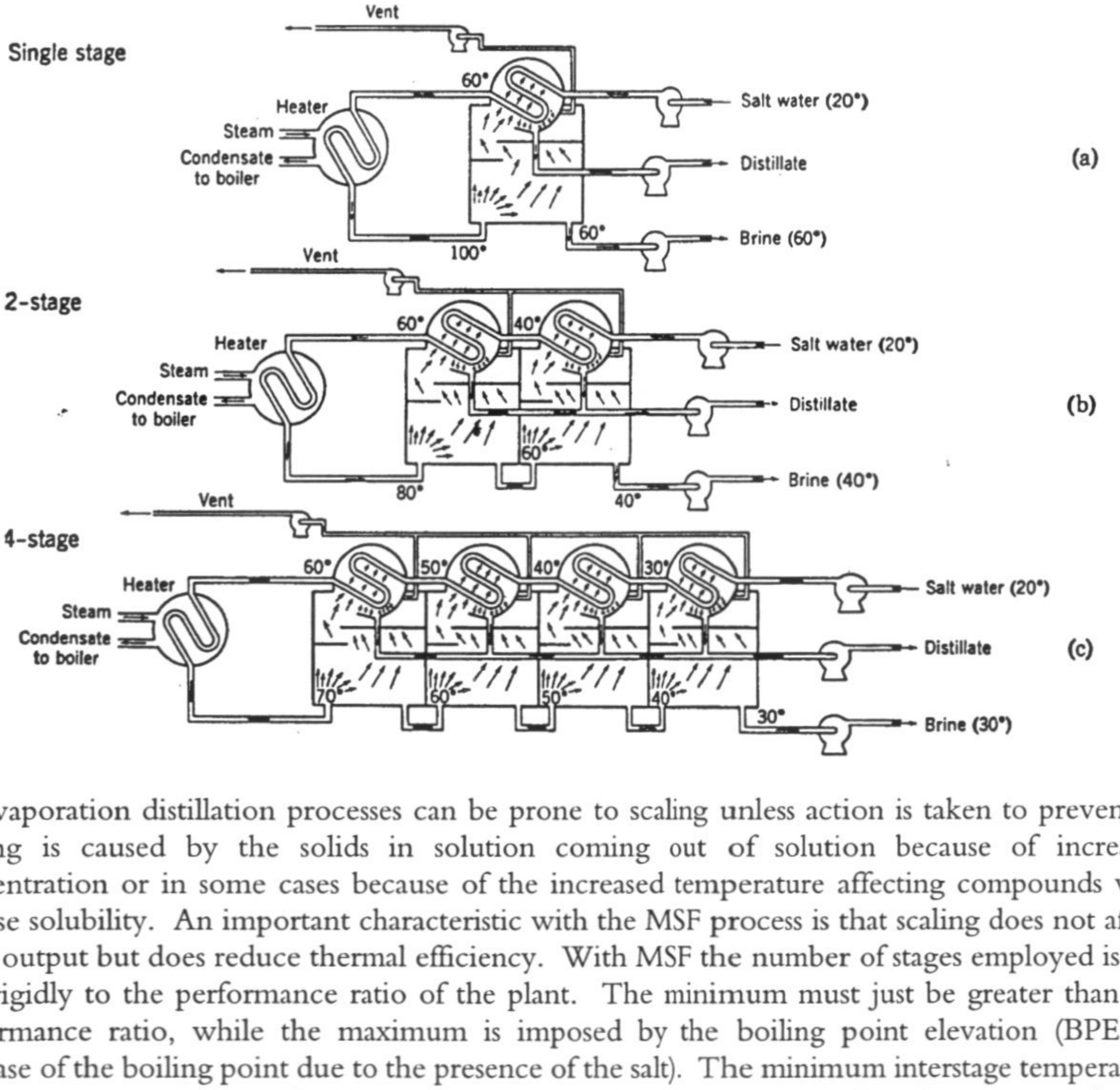
On this premise two types of evaporator have been developed - Multi-Stage Flash (MSF and Multi-Effect Boiling (MEB). The thermal processes are normally driven by low pressure steam (most typically pass-out or back pressure steam from a power plant) but can equally well be operated with other hot fluids available at similar temperatures. Because of chemical scaling problems distillation processes operate up to 120°C maximum.

2.1.2 Multi Stage Flash Evaporation (MSF)

The principle of the MSF process is illustrated in Figure 2.3. In this process seawater is taken into the plant and fed through a series of Heat Recovery Sections. This water is passed through a series of heat exchangers, raising its temperature. After passing through the last of these, the water enters the brine heater and is heated further, by the supply steam or heating fluid, to the top brine temperature.

The water then enters the first recovery stage through an orifice and in so doing undergoes a decompression to a pressure below its saturation pressure. As the water was already at the saturation temperature for a higher pressure, it becomes superheated and has to give off vapour to become saturated again at the lower pressure. This is known as 'flashing'. The vapour produced passes through a wire mesh (demister) to remove any entrained brine droplets and thence into the heat exchanger where it condenses, giving up its energy to heat the upcoming brine flow. This process of decompression, flashing and condensation is then repeated all the way down the plant by both the brine and distillate streams as they flow down through the subsequent stages which are at successively lower pressures. The process illustrated in Figure 2.3 is known as the once through process. As shown in Figure 2.3-a,b,c the process can have any number of stages. Large modern plants usually have between 14-20 heat recovery stages. It is the simplest form of the MSF process and is favoured for small plants. The process efficiency can be enhanced by recirculating some of the brine discharge and mixing it with the incoming seawater. This requires the addition of a heat rejection section (2-4 stages) and a brine recirculation pump. All of the large plants are of this type.

Figure 2.3 Multi-Stage Flash Process



All evaporation distillation processes can be prone to scaling unless action is taken to prevent it. Scaling is caused by the solids in solution coming out of solution because of increased concentration or in some cases because of the increased temperature affecting compounds with inverse solubility. An important characteristic with the MSF process is that scaling does not affect plant output but does reduce thermal efficiency. With MSF the number of stages employed is not tied rigidly to the performance ratio of the plant. The minimum must just be greater than the performance ratio, while the maximum is imposed by the boiling point elevation (BPE-the increase of the boiling point due to the presence of the salt). The minimum interstage temperature drop must exceed the BPE for flashing to occur at a finite rate. Within these limits, one is free to vary the number of stages. This is advantageous because as the number of stages is increased, the terminal temperature difference over the heat exchangers increases and less heat transfer surface is required, with obvious savings in plant capital cost.

MSF is the most widely used desalination process, in terms of capacity. This is in part due to the simplicity of the process, the performance characteristics and scale control. The process is the basic workhorse of the Gulf countries where reliability and simplicity count for more than thermal efficiency. The process normally uses pass-out steam from power generation steam turbines.

The maximum performance ratio that can be obtained from this process is around 13 units of water per unit of steam. In practice this is seldom achieved. Most large plants currently in operation (10,000 - 50,000 m^3/day) have performance ratios of 8-10.

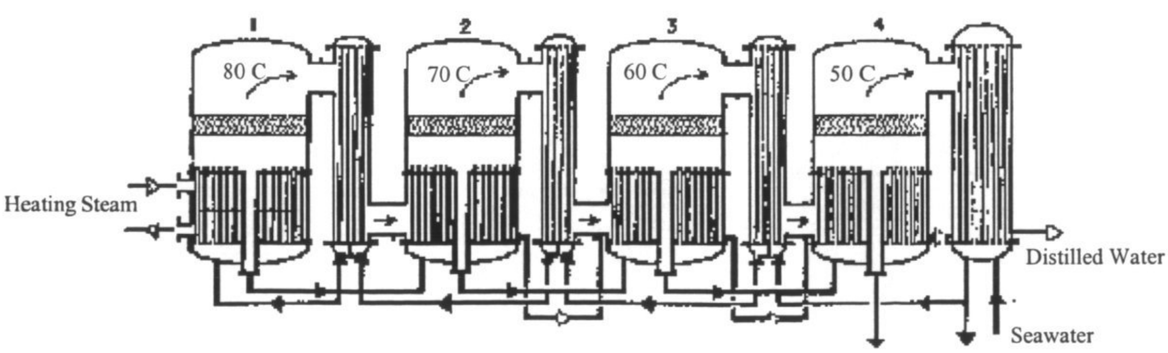
Small MSF Plants

The process is relatively simple to operate and once set up is stable in operation. Because of the thermal inertia of the plant and vacuum considerations the process is best suited for continuous operation. For continuous operation using an intermittent renewable energy source would require a substantial investment in energy storage. The equipment is usually robust. As seawater is corrosive to carbon steel, there is an increasing tendency to construct plants, particularly small ones, using stainless steels and copper nickel alloys. The process is not usually deemed suitable for very small capacities although some small units of 10 - 20 m^3/day have been constructed to operate in conjunction with solar collectors. Once through plants of 250 m^3/day are commercially available. Small units with large numbers of stages are expensive to construct and to maintain unless made of expensive materials which drive the cost up further.

2.1.3 Multi-Effect Boiling

The MEB process is used widely in the chemical industry where the process was originally developed. MSF has replaced MEB as the most important thermal desalination process. However, the MEB process still accounts for a significant number of installations. The process has the potential of giving higher performance ratios. PRs of 20 have been achieved.

Figure 2.4 MEB Evaporator 4 Effects



In this process vapour is produced by two means, by flashing and by boiling, but the majority of the distillate is produced by boiling.

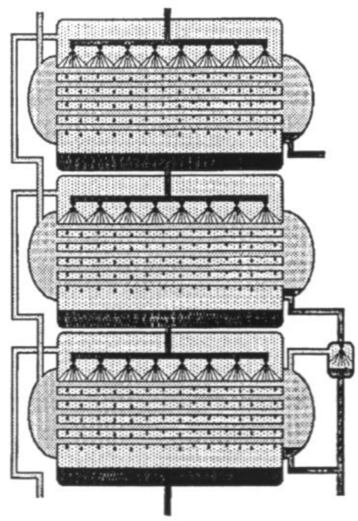
The MEB process usually operates on a once through system having no large mass of brine recirculating round the plant. This reduces the pumping requirements and has a major (beneficial) effect on the scaling tendencies in the plant.

In an MEB plant, the incoming feed passes through a series of feed heaters (which also serve as partial condensers for the vapour) and after passing through the last of these, enters the top "effect" where the heating steam brings it up to its boiling point and then evaporates a significant portion of it. The vapour produced is then condensed, in part, in the feed heater and in part by providing the heat supply for the second effect which is at a lower pressure and receives its feed from the brine of the first effect. This process is repeated all the way down the plant. The distillate also passes down the plant. Both the brine and the distillate flash as they travel down the plant due to the progressive reduction in pressure.

Unlike MSF, the performance ratio for an MEB plant is more rigidly linked to, and cannot exceed, the number of effects in the plant. For an instance, a plant with 13 effects might typically have a performance ratio of ten. However, an MSF plant with a performance ratio of ten could have 13 to 35 stages depending on the design. There are many possible variations of MEB plants, depending of the combinations of heat transfer configurations and flowsheet arrangements used. Early plants were of the submerged tube design, and only used two or three effects, and so had small performance ratios. Modern systems have got round the problem of hydrostatic head by making use of thin film designs with the feed liquid distributed on the heating surface in the form of a thin film instead of a deep pool of water. Such plants may have vertical or horizontal tubes. In the long tube vertical, LTV, plants the brine boils inside the tubes and the steam condenses outside. In the horizontal tube falling film design the steam condenses inside the tube with the brine evaporating on the outside.

The use of horizontal tubes lends itself to a stacked design where effects are built one on top of the other with gravity providing the motive force to transfer liquid to successive effects. A typical arrangement is shown in Figure 2.5. Such designs are suitable for small capacity high performance units.

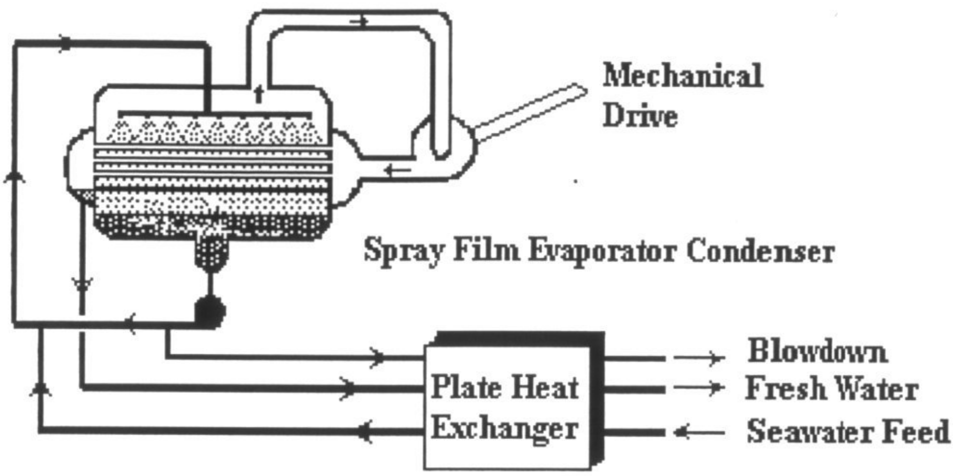
Figure 2.5 Stacked MEB Distillation Plant



MEB plants commonly have performance ratios as high as 12 to 14 but can be made higher. Actual performance ratios are determined by optimising capital cost against operating costs. Small single and multiple effect units are available. As with all thermal processes, it does not lend itself to intermittent use. For use with renewables, energy storage is required. High performance units require many effects which increases manufacturing costs. The process usually requires interstage pumps to transfer the brine through the plant. This increases the maintenance costs.

2.1.4 Vapour Compression

Figure 2.6 Mechanical Vapour Compression Distillation

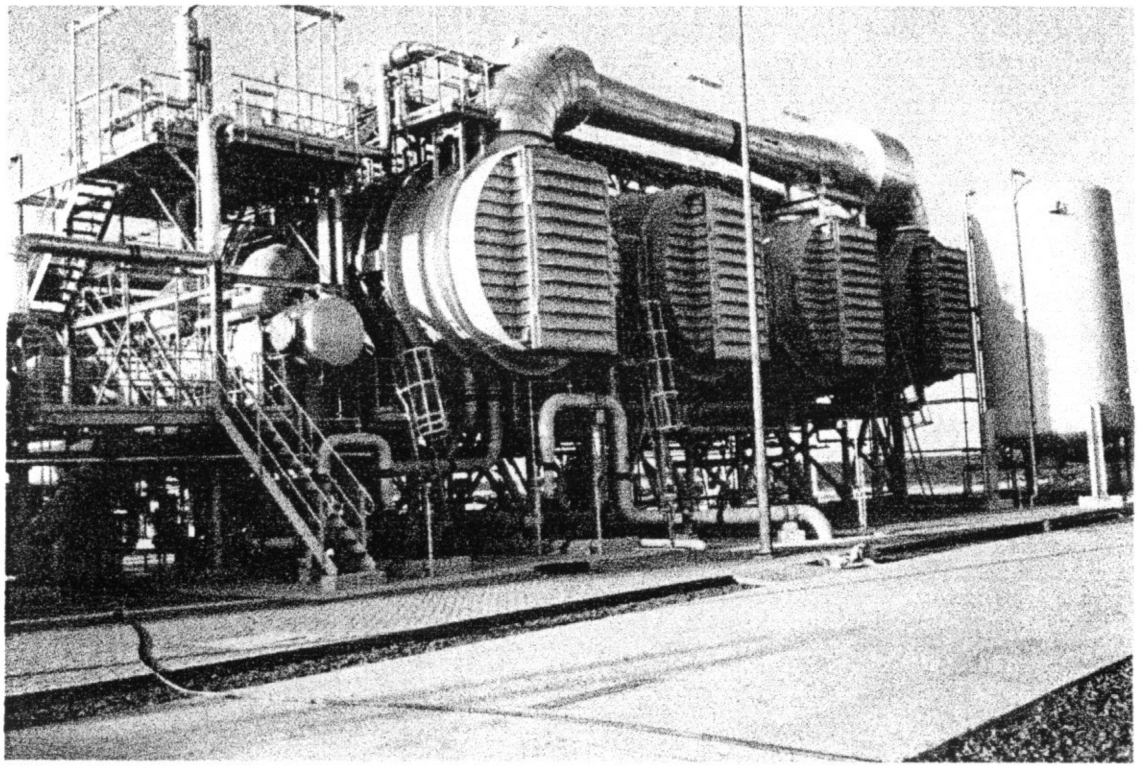


In the MSF and MEB processes, the energy input to drive the distillation was accomplished by simply heating one end of the plant and cooling the other, whereas in the vapour compression process this input is accomplished by using a heat pump to upgrade the low-temperature energy rejected from the distiller and to recycle it back to the hot end as the energy input. The heat pump may take the form of either a mechanical compressor (see Figure 2.6) or a thermo-compressor (see Figure 2.7). Vapour compression can thus be referred to as mechanical vapour compression (MVC) or thermal vapour compression (TVC).

Typically the inlet feed is initially pre-heated in liquid/liquid heat exchangers by the blowdown and product streams and may be further warmed by thermal rejection from the compressor engine. It then enters the evaporator/condenser (or the top effect in a multi-effect plant). The arrangement shown is based on the Horizontal Falling Film Evaporator but any other type of boiling evaporator can be used. As in a conventional MEB system, in multi-effect systems the vapour produced in the first effect is used as the heat input to the second effect which is at a lower pressure. The vapour produced in the last effect is then passed to the vapour compressor where it is compressed, its saturation temperature being raised in the process, before being returned to the first effect. The compressor represents the major energy input to the system and as the latent heat is effectively recycled around the plant, the process has the potential for delivering high performance ratios. It is not, however, a straight-forward matter to compare the performance ratio of a vapour compression plant with that of an MSF or an MEB plant. In these latter cases, the required input is 'thermal' energy which costs about one third of the price of the 'mechanical' energy used by vapour compression plant.

The process is particularly suited for relatively small output plants. Plants of 25 m^3/day are commercially available. One of the largest plants built to date is shown below in Figure 2.7. The thermo-compressor can be seen running along the top of the plant from the last to the first effect.

Figure 2.7 5000 m^3/day 4 - Effect Thermo Vapour Compression. (Sidem Ltd)



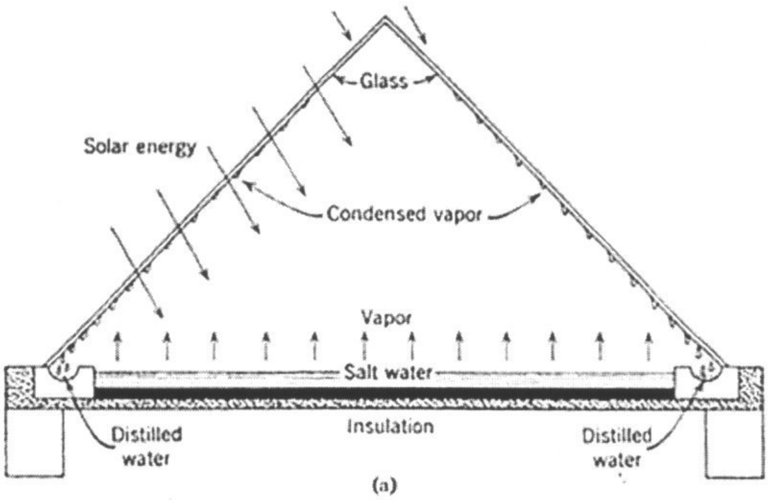
Mechanical compressors are expensive but can be relatively efficient. Thermo-compressors are cheaper but less efficient and require high pressure steam as the motive fluid. Both types are extensively used. Fairly large (5,000 m^3/d) thermo-compression plants are now being installed as single purpose water producing stations. Mechanical VC has limitations in the size of the plant due to compressor capacities.

Small units are commercially available but usually have high energy consumptions. Energy consumption is directly proportional to the temperature difference across the heat transfer surface. Lowering this means increasing the surface area to produce the same quantity of water. Historically the compressors have been expensive and troublesome, particularly with small units where compressor speeds are often very high (8 -12000 rpm). Designs have been proposed (Grimes *et al.*, 1996)with very low energy consumptions (2-3 kWh/m^3) but no viable plants have yet been produced.

2.1.5 Solar Distillation

Solar distillation has been used for many years, usually for comparatively small plant outputs. Over 100 years ago a plant producing 27 t/day was built in Chile but it was not until the 1950's that substantial research was started into improving the efficiency of the process. This research work has been carried out in many parts of the world particularly Australia and the US. Solar distillation utilises, in common with all distillation processes, the evaporation and condensation modes, but unlike other processes energy consumption is not a recurrent cost but is incorporated in the capital cost of the solar collector. The solar still is basically a low "green-house" providing simplicity of construction and equally importantly, simplicity of maintenance. Obviously it is most suited for those areas of the world with high solar radiation intensities and plenty of low cost land area.

Figure 2.8 Simple Solar Still



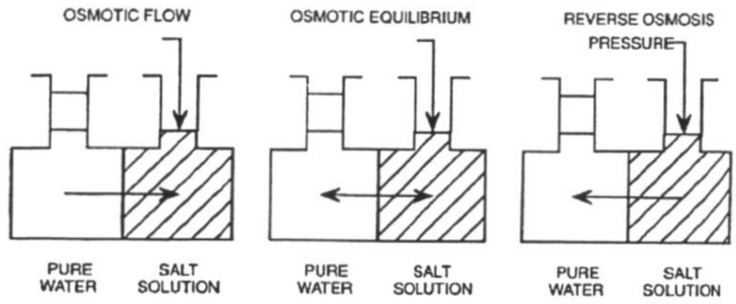
The principle of operation is based on the fact that glass and other transparent materials have the property of transmitting incident short-wave solar radiation. Thus this 'visible' radiation passes though the glass into the still and heats the water. However, the re-radiated wavelengths from the heated water surface are infra-red and very little of it is transmitted back through the glass.

This style of desalination system is only suitable for small product rates as the output rate per unit area of the still is small. Large capacity plants, although having practically no energy running costs, would cover large areas. So capital, land and civil engineering costs would be high. Well designed units can produce around 2.5 l/m^2 per day with a thermal efficiency of 50%. The equipment is very simple to construct and to operate, which lends itself to remote installations. Consumption of electrical power is minimal. Drawbacks are the large amount of space required, high civil costs and high capital costs. Keeping the glass clean on both sides is a recurring maintenance problem. Evaporative trays and pipe work also have to be kept clean.

2.1.6 Reverse Osmosis (RO)

Reverse osmosis utilises semi-permeable membranes through which water is forced under hydraulic pressure. Water is transported through the membrane in this pressure driven process, excluding ions and most organic molecules. When one places solutions of two differing concentrations on either side of a semi-permeable membrane, water passes through the membrane toward the more concentrated side in an effort to equalise the concentrations. The equilibrium reached is termed osmotic equilibrium. If mechanical force is applied to the more concentrated side, once the osmotic pressure is overcome, water is transported though the membrane (Figure 2.9). This phenomenon is called 'reverse osmosis' and may be used to separate pure water from brackish or saline solutions. The energy required is directly related to the salinity of the water being treated.

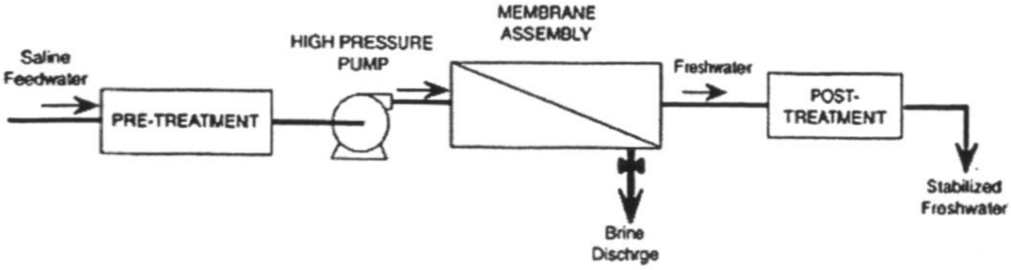
Figure 2.9 Reverse Osmosis Principle



Advances in Reverse Osmosis have been directly linked to advances in membrane technology. A good membrane should be able to pass a high flow of water (high flux) and limit the amount of salt flow (good rejection). Before the formation of the Office of Saline Water in the US in 1952, membranes generally gave low fluxes and low rejections. With the aid of a large amount of sponsored research, commercial membranes were developed which could first of all desalt brackish water and then later seawater. The first commercial seawater RO plants are commissioned in the late 1970's.

As shown in Figure 2.10, purification by RO consists of placing a semi-permeable membrane in contact with a saline solution under a pressure higher than the solution osmotic pressure, typically 50 to 80 atmospheres for seawater. The feed is pressurised by a high pressure pump and is made to flow across the membrane surface. Part of this feed, the permeate, passes through the membrane which removes the majority of the dissolved solids. The remainder together with the rejected salt emerges from the membrane modules as a concentrated reject stream, still at high pressure. In large plants, the reject brine pressure energy is recovered in a turbine or pressure exchanger. The pre-treatment required is a function of the scaling tendency of the water and the level of undisolved solids. The key to the successful operation of this process is in the pre-treatment section.

Figure 2.10 Simple Reverse Osmosis Plant



Important considerations in reverse osmosis are salt rejection, flux and membrane life and energy recovery. Usually, high salt rejection is achieved at the expense of low flux and vice versa. The membranes themselves can be purchased in a variety of forms. The major module configurations being of hollow fibre (Figure 2.11) or spiral wound (Figure 2.12). The membranes, being in effect very fine filters, are very sensitive to fouling, both biological and non-biological. To avoid fouling, careful pre-treatment of the feed is necessary before it is allowed to come into contact with the membrane surface.

Figure 2.11 Hollow Filament Reverse Osmosis Module Detail (Du Pont)

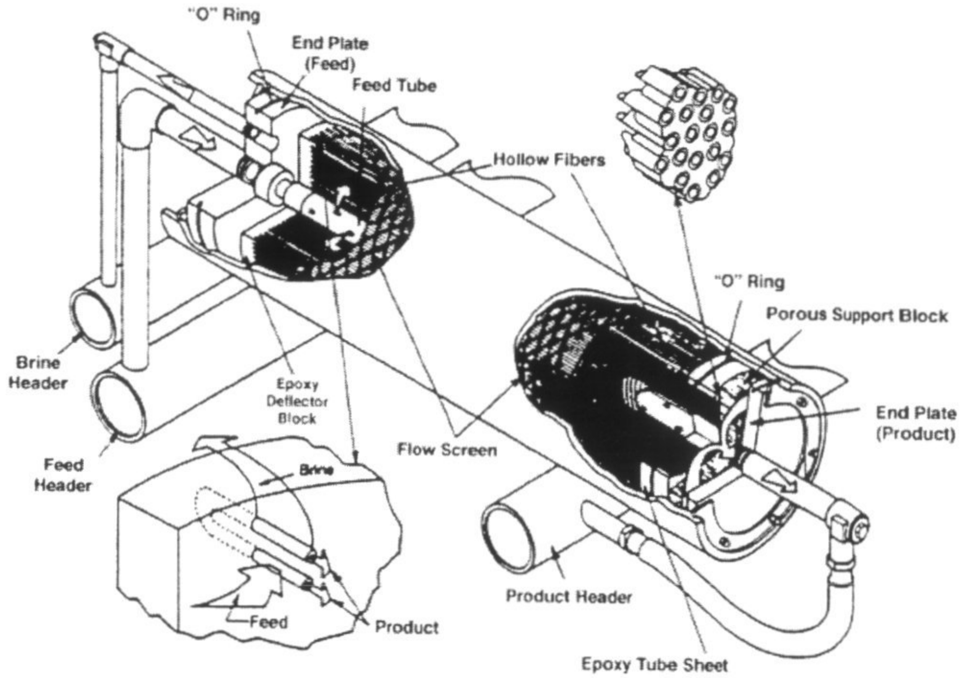


Figure 2.12 Spiral Wound Membrane

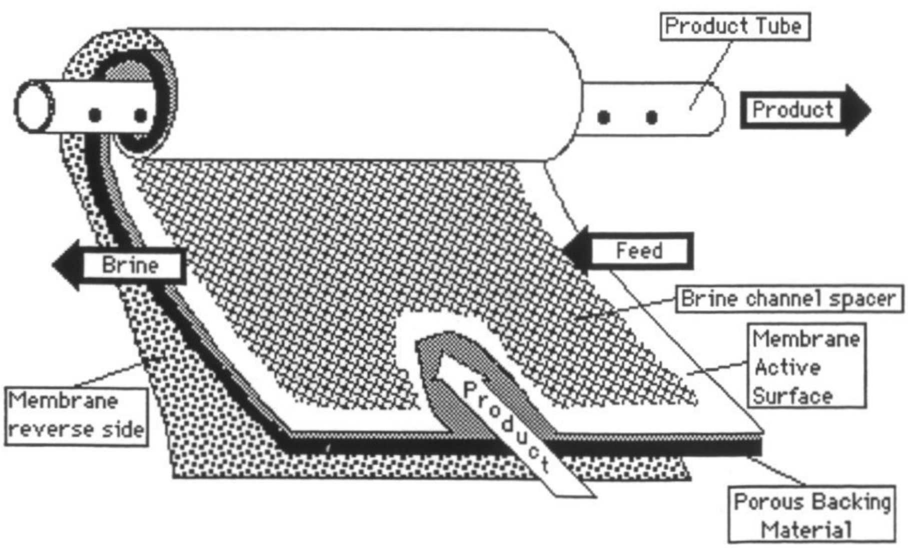
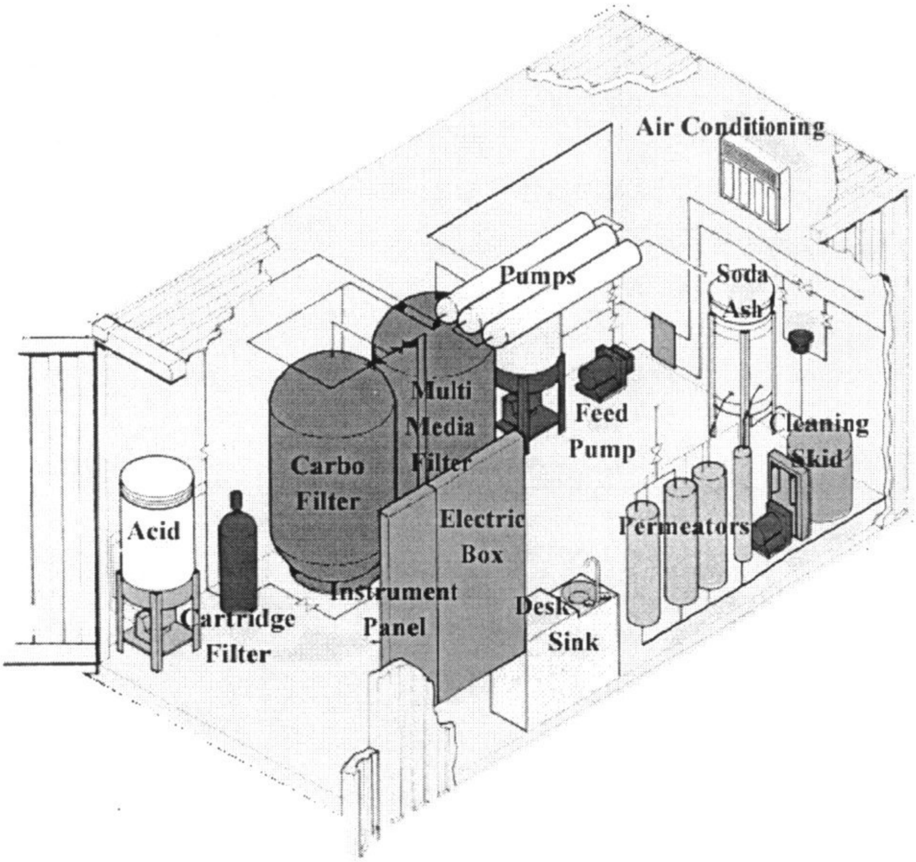


Figure 2.13 shows a small containerised unit which contains everything necessary for the operation of the plant except an electrical supply. Reverse Osmosis plants are of modular construction with modules being connected in parallel to give the required output. Manufacturers produce a range of module sizes. Large plants are made up of hundreds and occasionally thousands of modules

which are accommodated in racks. Very small units are also available for marine purposes in small sailing craft where the output may be down to 0.1 m^3/day.

Figure 2.13 Containerised R.O. Plant



Because of the modular construction, the capacity of the process is very adaptable. It is also a very energy efficient process which is important where energy is expensive. This tends to be the case with renewable energy sources. It is important to maximise the water produced for a given quantity of electricity. The energy economy of the plant can be improved by adding a water turbine to extract the energy from the discharge brine stream which leaves the plant at full pressure. In sea water plants, the brine discharge is usually around 70% of the feed flow. Energy recovery turbines are expensive and the decision to include one must be based on economics. The process is not as sensitive to stopping and starting as the thermal processes which is a distinct advantage when using renewable energy. The process uses mechanical energy usually translated into electrical power although there is no reason that a plant could not be driven directly by a wind turbine.

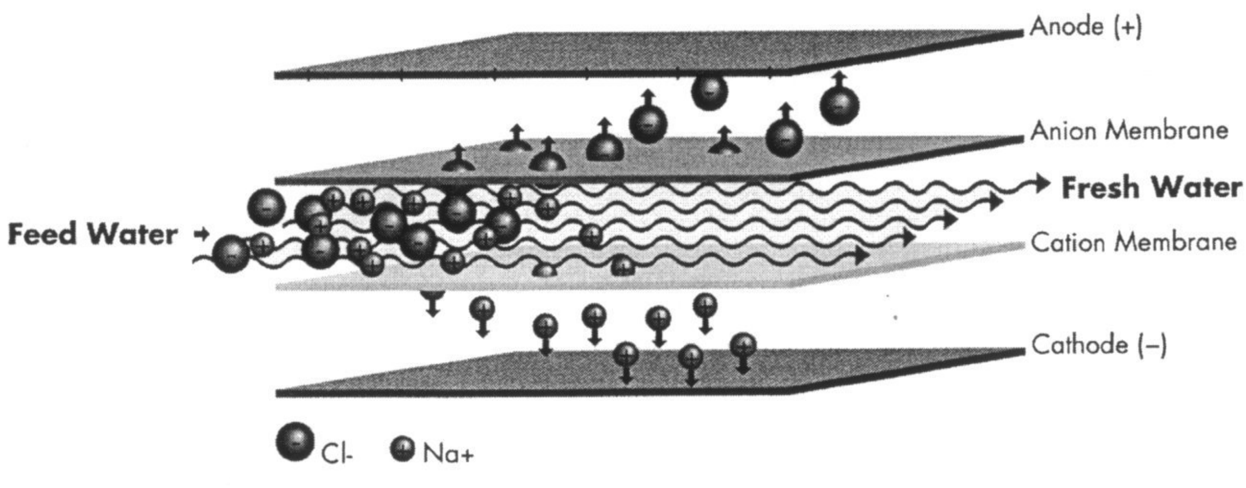
The process is straightforward in operation and unskilled operatives can be trained to operate such units. However satisfactory management of RO does require a knowledge of chemistry. The instrumentation is critical and requires the attention of competent personnel for maintenance. The membranes are relatively fragile and cannot be cleaned physically. They have to be cleaned chemically. The technology of cleaning is improving, but some fouling conditions are difficult to overcome. Membranes can be replaced but are expensive comprising some 10% of the overall cost. Membrane life is typically in excess of 5 years. In badly maintained plants it can be a great deal shorter. The feed pump has to develop around 60 bar pressure when running on seawater and can require frequent maintenance.

2.1.7 Electrodialysis

ED is the only desalination process which uses electricity as the fundamental process energy. If a D.C. current is passed through an ionic solution, cations, positively charged ions, will migrate to the cathode and anions, negatively charged ions, will migrate to the anode. Now, if between the anode and the cathode a pair of membranes are placed one of which only allows the passage of cations and the other of which only allows the passage of anions, then a region of low salinity will be created between the membrane pair, see Figure 2.14. This is the principle of the process known as 'electrodialysis'.

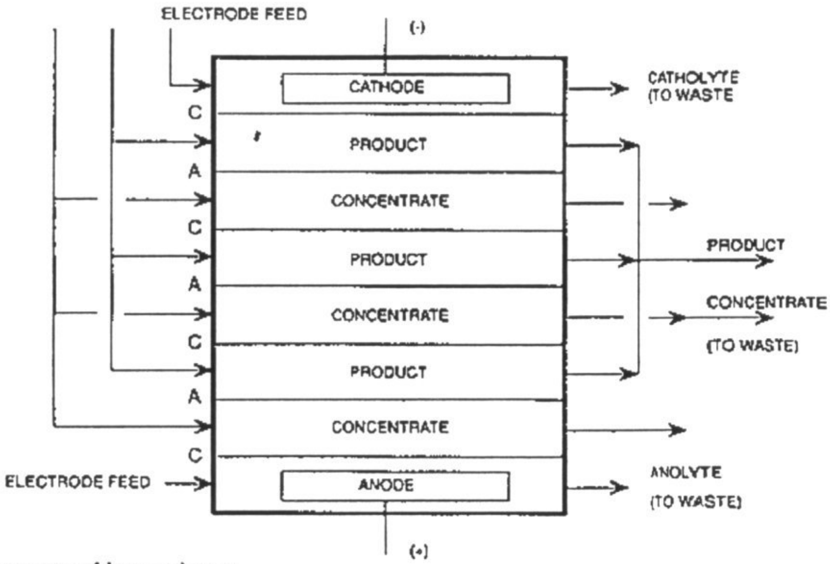
The principles of the process were known from the beginning of this century, but the membranes used were only slightly selective and so the process was only used for pH control. Developments progressed slowly with synthetic membranes being produced in 1940. With the formation of the Office of Saline water in the USA (0.S.W) and the further research into membranes, commercial plants for the treatment of brackish water began to be introduced from 1954. These were usually of standard packages up to about 1000 tons/day. These have rapidly grown in size and several plants of 40,000 tons/day have been built.

Figure 2.14 Electrodialysis Cell



The basis of any electrodialysis plant is the 'cell pair', around 300 of which may be located in a plant separated by spacers for support (Figure 2.15). The membranes are normally about 1 metre square and are very thin to minimise the electrical resistance of the 'stack'. As in any membrane process the feed water has to be very carefully pre-treated before entry to the stack to prevent fouling of the membranes.

Figure 2.15 ED Process



C = cation permeable membrane
A = anion permeable membrane

Previous limitations on this process were due to the energy cost being directly proportional to the amount of salt removed and so it was principally used for brackish water applications. Recent developments in high temperature membranes and polarity reversal, which goes a long way towards reducing fouling, have extended the range of applicability of the process to higher salinity levels. The viability of the process has been significantly increased with the development of EDR (Electrodialysis Reversal). In this process the polarity of the electrodes is changed after a given time period. This reverses the flow through the membrane and has the effect of negating any tendency for the membrane to foul. There is a slight loss in productivity immediately following the change but this is more than offset by the increased flow from the membranes.

Manufacture of the systems is limited to only a few companies which include, Asahi Chemical Industry Company, Japan and Ionics Incorporated from the USA. The process is not as widely used as RO partly because of the limitation of salinities that it can be used with and partly because of the fact that only two companies supply these membranes. Unlike RO membranes EDR membranes are very robust and can be scrubbed clean. It is an attractive process for small applications treating brackish water of low salinity. Operational and maintenance requirements are similar to RO save that with EDR the membranes are less sensitive to fouling and there is no high pressure pump to maintain. Another important factor is that with EDR no scale prevention chemicals are required. Limited scaling is allowed to develop and the process is reversed removing any scale. This is an important advantage as getting chemicals to remote locations can be expensive. The membranes can be physically cleaned if necessary.

2.1.8 Energy Consumption of Desalination Processes

Table 2.1 below compares energy consumption for different desalination plant processing seawater.

Table 2.1 Energy Consumption of Desalination Processes using Seawater

Process	Performance Ratio	Heat to Process kJ/kg	Consumption kWh/m3	Prime Energy Consumption	
				Single Purpose kJ/kg	Dual Purpose kJ/kg
MSF	8	290.6	3.9	380.9	175.8
MED/TVC	8	290.6	2.7	368.9	163.8
MVC	-	-	11.0	110.0	-
MVC	-	-	8.0	80.0	-
RO	-	-	9.5	95.0	-
RO+ERT*	-	-	6.5	65.0	-

Boiler Efficiency - (Single Purpose) 0.85 *Wade 1992*
Power plant Efficiency -(Dual Purpose) 0.36

*ERT - Energy Recovery Turbine

The single purpose plant produces only heat which is turned into steam, i.e. no waste heat. The dual purpose plant produces electricity and the waste heat from this process is converted into steam to drive the desalination plant.

2.2 The Energy Sources

As indicated in the previous section the, different desalination processes require energy in different forms, notably electrical, mechanical or thermal. As will be shown later, the commercial viability of a desalination process is to a large extent dependent on energy costs. For this reason, desalination processes are often compared on their energy consumption. However this is only half the story, the 'quality' of the energy is also important. High grade energy in the form of electricity is much more valuable than the same quantity of energy in the form of low grade heat. Therefore it is important to recognise that energy consumption is not the most important criteria for selecting a desalination process.

The basic problem in coupling a renewable energy source (RES) to a desalination process is the variability of the power output of the RES and its availability over time. This problem applies to wind, solar and wave energy but not to geothermal energy or energy from biomass which can be regarded as firm. But, as water can be stored relatively easily, the intermittent production of water is not a problem from a water supply point of view. If desalination technology can be run satisfactorily (technically and economically) with regular periods of shut down, then renewable energy resources could play a major role in supplying energy to desalination plant.

In this section we propose to examine the following energy sources:

- Grid Electricity
- Solar
- Wind
- Wave
- Waste Heat
- Biomass

- Batteries
- Diesel

2.2.1 Grid Electricity

Grid delivered electricity can be regarded as a high grade fuel. In developing countries it is usually obtained from the burning of hydrocarbons, and if oil or gas is used the conversion efficiency is typically around 35%. Grid electricity based on fossil fuel generation is usually cheaper than electricity produced from renewables, although this is not always the case, particularly where electricity transmission costs are high, for example in remote locations.

Where easily accessible, grid electricity is presently the preferred source of energy for desalination processes based on electrical or mechanical energy, (namely RO, EDR and MVC), in that it is usually relatively cheap and it is firm, i.e. it is available constantly. Grid electricity costs vary considerably from country to country dependent upon the price of the fuel used to generate it and distribution costs. A typical generation cost for grid supplied electricity which is widely used as a benchmark is 4p/kWh (around 6 cents/kWh).

2.2.2 Solar

Solar energy can be used in two forms. Either as thermal energy by heating a fluid or as electricity by converting it using photovoltaic arrays (PV). Solar energy is a relatively diffuse source of energy which can require large collector areas to deliver significant quantities of energy. Cost effectiveness is strongly influenced by the amount of solar radiation available at the site. However, most developing countries have a high availability of solar radiation.

Solar Thermal
With a simple still, it is possible to combine the energy capture with the distillation process (see section 2.1.5). This is simple, relatively cheap but not particularly efficient. Alternatives have been developed to produce higher grade energy in the form of hot fluids which can then be used to drive more thermally efficient desalination processes such as MSF and MEB. These are deep solar ponds and concentrating parabolic collectors. In all of these, the energy collected is proportional to the area of the collectors and the efficiency of the device. Energy storage of the thermal energy is relatively cheap in the form of a hot fluid in insulated tanks or in the case of solar ponds - within the solar pond. This is important if it is connected to a continuously operating desalination process.

Solar - Photovoltaic
In this process, the sunlight is converted into electricity using (typically silicon) PV cells. These are deployed in arrays and can be either static or tracking. Static devices are cheaper and by far the most common, but tracking devices are obviously more efficient at collecting energy. PV is widely deployed as a battery charging source for radio and telephone relay stations where the energy consumption is usually small. Typical costs are now around £3-5 per peak Watt of installed capacity (around $5-8), however, the costs of PV devices continue to fall and costs of less than £1 per peak Watt have been projected for the year 2010. Energy storage in batteries is really only practical for relatively small amounts of energy due to the cost of the batteries.

Solar energy in whatever form has the drawback of being only available for a fraction of the time. This means that any device using solar energy has to have back-up storage or it has to shut down at night. However, many areas which are short of water have very good solar energy resources and it tends to be highly predictable.

2.2.3 Wind

Wind can be used to supply either electricity or mechanical power, electricity being the usual output. Wind generators can be supplied in any capacity from a few kW to 750 kW, although MW scale prototypes are under development. They come in a variety of configurations, however, most designs are for horizontal axis with either two or three blades. They can be deployed singly, in clusters or in farms. Good wind energy is often available on an intermittent basis in arid areas, particularly islands. As electricity is the normal output, the desalination processes suitable for use are RO, EDR and VC. For continuous desalination plant operation some other form of generation, such as a diesel generator is required as a back up.

The last twenty years have seen considerable developments in wind turbine technology. Wind turbines have fallen in price (now approximately £800/kW installed capacity) and increased in size and reliability. In the UK wind turbines are generating power at around 4p/kWh for large schemes (>1.6 MW) based on 15 year NFFO contracts and in areas where the mean annual wind speed is in excess of 8m/sec. This is close to being commercially viable in the UK and at this price would make wind energy viable in many areas of the world, especially in remote locations without grid supply.

2.2.4 Wave

Several types of wave energy device have been deployed, albeit most of them have been not been commercial schemes (Thorpe, 1992; ETSU, 1992). Some of the most noteworthy schemes are outlined below:

- Perhaps the most successful wave energy device to date is the Norwegian Tapchan (Mehlum et al, 1988). A scheme with an output of 350 kW was built in 1985 and operated successfully for several years before being blown up. However, this type of device places stringent requirements on the coastline topography and tidal range, resulting in limited replication potential.

- ART in Inverness built a 2 MW near shore device in 1995 (Thorpe 1995) but this suffered catastrophic structural failure soon after deployment. It is understood that a new 2 MW device will be deployed in 1997, which will also include a 1 MW wind turbine. The output energy will be in the form of electricity but could be in the form of pressure energy.

- The Queen's University of Belfast built a prototype shoreline device on the island of Islay (Whittaker et al, 1987). This was rated at 75 kW but never achieved its theoretical performance. A new, more widely applicable design for a shoreline device has since been produced but, as yet, it has not been built.

- A wave energy device has been built into a breakwater in Vizhinjam Fisheries harbour, near Trivandrum in India (Raju, et al, 1991). The original device was lost during deployment but a new one has since been deployed and is operating successfully.

As can be seen from these examples, wave energy is not yet at the stage where it can be exploited commercially either for power generation or for desalination.

2.2.5 Waste Heat

This is the normal source of energy for MSF plants, which in many cases use the waste heat from power generation systems, this is also true of many MEB plants. If thermo-compression VC or MEB is involved then this is less likely to be the case. Thermo-compression requires high pressure steam which is not usually classed as waste heat as it can be usefully used in a number of industrial applications.

If there is an available high grade source of waste heat and no demand for electrical power, this can be used to generate steam or a hot fluid which dependent on quality could be used to drive a distillation process.

In Gibraltar, municipal solid waste is burnt in an incinerator, the heat is used to produce steam which is then used to generate electricity. Pass-out steam is then used in a five effect MEB process to produce potable water.

2.2.6 Biomass

This is unlikely to be a common option in small arid and semi-arid communities in coastal regions, as availability of biomass suggests that water is available for growing the biomass and therefore a desalination plant is not required. However there may be circumstances where biomass is available and potable water is in short supply. In this event a biomass combustion based energy conversion process could be used to produce firm electrical power. Biomass tends to be seasonal but it would be possible to stockpile material for use out of season, at a cost.

2.2.7 Batteries

Commercially available battery systems have very limited capacity and are a relatively expensive way of storing energy. They are therefore not practical as a primary source of energy for desalination. However, batteries can be used on small scale units in conjunction with renewables to provide backup power. For example, they can be used to power the instrumentation system when the energy plant is down or may be used to smooth the power supply in small systems. In small plants they can also be used to run the system for short periods when the renewable energy source is not available.

2.2.8 Diesel Generators

Diesel generators can provide a continuous supply of electricity. In this sense, a desalination plant coupled to a diesel generator is equivalent to being coupled to a grid supply. i.e. it is firm power. They are therefore a perfectly acceptable source of energy for a desalination plant. As electricity is the principle output, desalination plants using electricity are appropriate. These are EDR, RO or VC.

Diesel generators normally run with an efficiency of around 33%. The rest of the energy is dissipated in the exhaust (33%) and in jacket cooling water (33%). If the generator is large enough it may be possible to run a thermal process (MSF or MEB) using this waste heat. The jacket cooling water is the easiest to use.

Diesel generators can be used in conjunction with a renewable energy driven process to supply energy during the periods that the renewable source is unavailable. An interface is required to enable the diesel to cut in and out matching supply and demand.

In remote areas, diesel fuel can be expensive because of shipping costs. For example electricity generated by diesel in island communities varies in cost from 5-20 cents/kWh (around 3-13p/kWh).

2.2.9 Summary

All desalination processes use electricity in their operation, both for plant monitoring and control and most importantly for water pumping. Quite often water pumping can use a significant amount of the total energy consumption. For all desalination processes it is better if the plant can be operated continuously rather than intermittently. Thus a firm power supply in most cases is preferable to a variable power source, unless the variable source has adequate energy storage or a suitable backup system.

Table 2.2 summarises information relating to the different energy sources discussed above.

Table 2.2 Energy Sources Summary

Energy Source	Form of energy		Steady supply	Location specific	Resource constraints
	Electricity	Heat			
Grid	✓		✓		transmission distance
Solar PV	✓			✓	solar regime
Solar Thermal		✓		✓	solar regime
Wind	✓			✓	wind regime
Wave	✓			✓	wave regime
Waste Heat		✓	✓*	✓	proximity to industrial plant
Biomass	✓	✓	✓*	✓	availability, storage and transport of suitable biomass
Batteries	✓				size
Diesel	✓		✓*		transport of diesel

* Steady supply can be achieved with good resource management.

2.3 Review of Combinations of Desalination Technology & Energy Sources

Energy Options

There are a number of possible energy source/desalination plant combinations. A selection of combinations are shown in Table 2.3

Table 2.3 Different Energy Source and Desalination Plant Combinations.

Grid Electricity	Reverse Osmosis EDR Mechanical Vapour Compression
Solar Thermal	MSF MEB Direct Solar Still
Solar PV	Reverse Osmosis EDR
Wind Energy	Reverse Osmosis EDR MVC
Waste Heat	Multi-Stage-Flash Multiple-Effect-Boiling
Biomass	MSF MEB

Looking at these in turn:

2.3.1 Grid Electricity

Commercially proven equipment for RO, EDR and VC can be obtained which can be connected to a grid supply and which will operate satisfactorily with no more than the normal problems associated with such plants. For these processes this should be considered as the base case.

2.3.2 Solar

Solar Thermal Energy

Direct Solar Stills

As stated earlier thermal energy can be used in a simple direct solar still. They use very large areas of flat ground. Land can be expensive even in arid areas and can often be expensive to level. Once the ground has been prepared they are easy to construct and simple to operate. A number have been built by enthusiastic amateurs. Some universities continue to research them as they are technically interesting and cheap to construct. There are no companies manufacturing units for commercial purposes. A study carried out in North America Manwell *et al*, 1993 suggested that the process was attractive for small domestic usage in remote areas. Given the high per capita consumption of water in North America this could be extrapolated to include villages in remote areas in third world countries.

Concentrating collectors and Evacuated Tube Collectors

Higher grade thermal energy can be collected using either concentrating solar collectors, which normally employ parabolic reflectors, or evacuated tubular collectors. The energy is collected as a hot fluid, either hot brine or hot oil depending upon the temperature. This can then be used in conjunction with MSF or MEB plants. A number of plants have been constructed using these technologies. Although it is possible to obtain higher performance ratios with MEB plants, most of the units constructed to date have been MSF plants. This is largely because they are more readily available. The main problems associated with these plants are the cost and size of the collectors, and the operating and maintenance costs of the collector field (concentrating collectors need to track the sun during the day, and must therefore be fitted with motorised mountings and controls). Most commercially available evacuated tubular collectors employ heat pipes which are designed to heat water to temperatures below 100°C. To work at higher temperatures, they need to be filled with different fluids. Whilst such collectors have been built for research purposes, little operating experience is available with full scale systems.

Deep Solar Ponds
Some work has been carried out in Israel on the use of deep solar ponds in connection with desalination (Posnansky, 1989), where construction costs have been quoted at around $20/m^2. (The cost of the land has to be added to this figure.) Deep solar ponds have the advantage of having in-built energy storage which facilitates continuous operation of the desalination plant. However, the long term operation of such ponds has been dogged by problems associated with the stability of the temperature stratification, caused either by storms and wind or by the growthy of algae and other pollutants.

Flat plate Collectors
Flat plate collectors are cheaper to construct and provide heat at lower temperatures. A number of manufacturers design MEB plants to operate at 70°C or lower. Such plants could be coupled to flat plate collectors.

Photovoltaic/RO - EDR

Electricity provided by PV is expensive and hence should only be used in conjunction with processes which have high energy efficiencies. This means RO for seawater and EDR for brackish waters. A number of PV-RO plants have been constructed, notably in Cadarache (Maurel, 1991) France , Lampedusa, Italy (Palma, 1991)and Almeria, Spain (Andujar Peral, A. *et al.*,). All of the plants proved to be reliable. Other plants have also been built elsewhere. Generally all of these plants have been for small scale production.

PV plants are virtually maintenance free. However, the surface of the cells should be kept clean and free from dust. If cleaning is not carried out it can lead to problems in dusty arid areas. The plants will operate in diffuse sunlight but output drops. The RO plant requires the attendance of an operator with some training and some knowledge of chemistry. Most of the problems with RO plants stem from inadequate pre-treatment of the feed water. This results in membrane fouling which reduces the output of the plant. This can be remedied by replacing the membrane element but this is a last resort and is expensive. The system requires the provision of an interface control. As power output varies throughout the day a number of control scenarios have been developed. One solution has been to split the plant into 3 modules with each module having its own high pressure pump. The number of modules in operation being related to the available power.

EDR plants are less common and there is therefore less experience with PV-EDR. However there is no reason to suppose that this is not a perfectly viable combination. Membranes for EDR are substantially more robust than RO membranes. If they become fouled, which is unlikely because of the flow reversal, they can be cleaned physically by removing them and scrubbing them with chemicals and detergents.

2.3.3 Wind

Wind/RO - EDR

The cost of wind energy has dropped considerably over the last 15 years. Large machines (up to 1 MW are now available. There have been a number of wind/RO plants constructed.

In 1982/3 GKSS from Hamburg coupled an 11 kW wind turbine to a small RO plant with an output of 2.64 m^3/day on a small island in the Baltic. A major problem was the erratic nature of the wind causing frequent start-ups and shut-downs. This caused mechanical damage to the plant. This was reduced by building in a requirement for the wind to exceed the cut in speed for 20 minutes before allowing the RO plant to be brought on line.

In 1982/3 the CEA in France operated a 4kW wind turbine coupled to a 0.5 m^3/day RO plant. Frequent stopping and starting was again a problem. This was solved by installing batteries to smooth out the fluctuations in the wind speed.

In 1988 a 1.2 MW wind turbine was coupled to a 960 m^3/day RO plant on the island of Helgoland. The unit was later dismantled after repeated damage by lightening.

Obviously these systems have all of the problems associated with their specific technologies.

The problems associated with wind turbines are being reduced as time goes by. The reliability of wind turbines has improved considerably over the last 20 years. However there are the usual maintenance requirements that such machines have. In particular the electronic controls of these machines requires skilled technicians which may not be readily available in the locations where this type of plant is deployed.

RO desalination plants require trained operators to maintain the equipment in good operational order. Many of the problems with seawater RO stem from the quality of the water being passed to the membrane. If this is not in good condition then the membrane will foul and the output will fall. Fouling can be either chemical or bacterial. Irreparable damage to the membrane can easily take place. Membrane cleaning systems can sometimes overcome these problems but not always.

The main problem in combining the two technologies lies with the rapid change of power input to the system that can occur. Start up and shut down of the system put strains on many of the pressure components which may ultimately result in mechanical failure. There is a particular problem when the wind speed is around the cut-in speed for the wind turbine. Unless action is taken this can result in the system switching on and off with sufficient frequency to cause fatigue damage to the membranes. To overcome this it has been suggested that the system should not be switched on until the wind speed has been in excess of the cut-in speed for 20 minutes. During operation the power output will also vary as the wind speed varies. Various energy storage systems have been tried in order to smooth this out. These include, flywheels, batteries storage or pumped hydro power. All of these add to the cost of the system. System shut down also requires the membranes to be flushed out with fresh water, otherwise conventional osmosis will take place within the membrane module which may rupture the membrane. If the membranes are shut down for long periods then the membrane may need to be filled with a preserving fluid to prevent biological growth on the membrane surface. Some wind RO systems have included a diesel back up. When this is done it effectively means that the RO plant is grid connected.

Wind/EDR

No wind powered EDR plants have been built as far as is known. The combination should be simpler to operate than wind RO as the system would not require to be flushed out at every shut down. EDR should be an attractive option to couple to wind to desalinate brackish water.

Wind/MVC

This is an unusual combination. Wind turbines and mechanical vapour compressors have many similar characteristics in that they are both involved with compressible fluid flow. This combination copes well with the large changes in power output that are associated with wind turbines. A prototype plant capable of producing 48 m^3/day using a 70 MW wind turbine was built on the German island of Borkum in the North Sea.(Bier, R *et al.*, 1991). Since then a larger plant with a rated output of 300 m^3/day has been constructed on the island of Ruegen (Germany).

As has been stated earlier, MVC has the potential of very low energy consumption, even lower than RO, hence this is a very interesting process. Units with energy consumption of 10 kWh/m^3 now becoming available. Units with energy consumption of between 2-3 kWh/m^3 are being discussed for use with Seawater.

2.3.4 Waste Heat

Many chemical processes produce large quantities of waste heat. Usually this is discarded using cooling towers or other devices. Depending upon the temperature and the form of the waste heat, it may be possible to utilise it for desalination. Hot water down to 80°C is potentially useful.

Oil refineries produce large quantities of low grade thermal energy and many of these situated in arid areas use this to produce clean water using either MEB or MSF plants.

The major desalination plants around the Arabian Gulf utilise the waste heat from power generation. The production of water and electricity is closely linked in all of the Gulf countries usually through a combined Ministry of Water & Electricity. Many of the power stations use gas turbines (gas being less exportable than oil in most of these countries) which operate with efficiencies of around 30%. The waste heat in the exhaust gases from the gas turbines is used to produce HP steam. This is passed through steam turbines to produce electricity and the pass-out steam is then used to provide the energy for the desalination plants. Almost without exception these are MSF plants. In these, the brine is heated to a temperature between 90 -115°C. Thus the steam from the turbine has to have a condensing temperature some 5-10°C above this. While this is referred to as waste heat this is not strictly accurate. The extracted steam could have been used to produce more electricity. However, within the region it is often referred to as waste heat.

In Gibraltar an incinerator has been constructed to burn municipal solid waste (MSW). The reasons for building this were two-fold. Firstly there was a problem in disposing of MSW. There were no landfill sites. The MSW was being dumped directly into the sea which was environmentally unacceptable. There was also a water shortage. No water was being imported from Spain because of political problems.

The waste heat from the incinerator is used to fire a boiler to produce medium pressure steam. This in turn is passed to a steam turbine to produce electricity. Pass-out steam is extracted from the turbine and used in a six effect MEB plant to produce potable water. There were a few problems in the commissioning of this plant but it is now understood to be operating normally with few problems. In the absence of MSW, auxiliary oil firing of the boiler can be undertaken. The technology is conventional and there are no problems in linking the energy technology to the desalination plant.

2.3.5 Biomass

Biomass can be used as an energy source by combusting it to produce heat and thus steam and electricity to drive desalination processes. Combustible municipal solid waste (MSW) can also be burnt to produce steam and electricity. Suitable biomass, such as Bagasse, is usually seasonal, so storage of biomass is important if a biomass combustion plant is to operate all year round. Biomass transport and storage are important factors in the total energy cost.

2.4 Discussion and Conclusions

2.4.1 Operating Problems in Desalination Processes

MSF

This is a mature technology and if the materials of construction are selected carefully should give few problems in operation. The process is simple to operate and plants are usually stable in continuous steady state operation. Most plants are designed to operate at full load and are unstable at low flow outputs. i.e. <50%

MEB

This is also a mature technology but there are more variants available. Selection of materials of construction is very important with consequent effects on capital cost. The process is simple to operate and has much better turn down characteristics than MSF. The performance ratio can be higher than with MSF but the capital cost is increased.

VC

There are only a few manufacturers of MVC plants. Some of these have been more successful than others. The key to success is in the compressor designs coupled to cheap heat transfer surfaces. Small units often involve very high speed compressors which give problems and have high maintenance costs. Such units are not attractive for use in remote locations. MVC has the potential of having lower energy costs than RO but to date no one has produced a design that is practical and economically viable. There is renewed interest in this area and a number of companies are attempting to develop designs which will compete with RO.

RO

This is the process that has been most frequently coupled to wind or PV. The process can be started up quickly and shutdown quickly but frequent stoppages can result in premature failure of many components due to the large changes in pressure involved. Most of the problems with RO plants involve inadequate pre-treatment of the feedwater. The process requires the attention of trained operatives preferably with some knowledge of chemistry. The process requires chemicals for feed treatment which can be expensive to transport to remote locations. Experience with plants in remote locations suggest that they are prone to failure through lack of attention and inexperience of the operators. For example the RO plant supplied by Israel to Gaza at Dir El Ballah to desalinate brackish water has only been in occasional use through lack of chemicals.

2.4.2 Conclusions

There are now available a variety of renewable energy (RE) systems that can be considered mature and that can be coupled to a desalination process. A variety of desalination processes which can be matched to some of the RE systems are also available.

Most parts of the world which have water problems have access to some renewable energy sources (RES). Solar energy is likely to be the most common RES.

Some experience has been gained in coupling RES to desalination processes. This has usually been on a small scale. The most popular combination has been either wind or PV with RO. The combinations in Table 2.4 may be attractive for some locations.

Photovoltaic powered VC is not included in Table 2.4, as it has not received much attention. However, as VC has the potential to become a much more energy efficient technology, PV VC may be a viable option in the future.

Table 2.4 Summary of Energy and Desalination Technology Combinations

Energy Source	Desalination Process	Energy Storage	Back-up
Solar			
Thermal Systems Parabolic collectors Flat plates Evacuated tubes Deep ponds	MSF MEB MEB-TC	Hot fluid in insulated tanks	Oil or gas
Electrical Systems			
Solar thermal electric power generation	EDR RO	Batteries & or insulated tanks	Grid or diesel
Photovoltaic	RO EDR	Batteries	Grid or diesel
Wind			
Wind turbine	RO EDR MVC	Batteries Fly wheel Pumped storage	Grid or diesel
Wave			
Wells Turbine	RO EDR MVC	Batteries Fly wheel Pumped storage	Grid or diesel
Waste Heat & Biomass			
Thermal	MSF MEB MEB-TC		Oil or gas
Thermal electric power generation	RO MVC EDR		Oil or gas

Note: MEB-TC refers to MEB using thermal compression

3. ECONOMICS OF DESALINATION

The design of renewable energy powered desalination plants is complicated and is dependent on many factors. The optimisation of such plants is beyond the scope of this study. A complicating factor in the design of such plants is the variation of the energy source both in terms of duration and intensity. Other factors are the amount of energy storage required to ensure steady power, or alternately whether or not to install a diesel back-up or grid connection. The size of diesel generator installed can range from being just large enough to keep the system ticking over, to the point where the diesel is the principal energy source with the renewable contribution reduced to a fuel substitution role.

Cost figures for desalination have always been difficult to obtain. Even when data is available it is often difficult to make sensible comparisons as prices are site specific in many cases. Figures published in 1992 (Wade. N) give a cost comparison for water produced by large power and water plants which is still valid. This paper gave the costs MSF 1.44 \$/m^3, MEB 1.31 \$/m^3 and RO 1.39 \$/m^3, which are for large plants (i.e. 15,000m^3/day).

On the island of Malta, where 45% of the water is produced from seawater reverse osmosis plants, the production cost of water is estimated at \$1/m^3. Elsewhere in the literature desalinated water costs using conventional energy sources vary from 80c to \$8/m^3.

There is little information in the literature concerning the cost of water from renewable energy driven desalination plants. This is largely because almost all of the renewable energy powered plants were built for R&D purposes and thus have higher costs than if they were commercially deployed and manufactured on a large scale.

The cost of water and the price that individuals are prepared to pay depends largely on how much of it that they need and what they propose to do with it. Hotels in remote locations can afford to build their own desalination plants producing water at \$2/m^3 on the basis that it is a small overhead in the hotel costs. Individuals drink bottled water from \$0.5/litre to \$1.50/litre (or \$500/m^3 to \$1500/m^3) on the basis that they drink very little of it. It follows therefore that in order to decide whether or not desalination by renewables or any other means is economic, there has to be some insight into what the water is going to be used for.

3.1 Desalination of Seawater

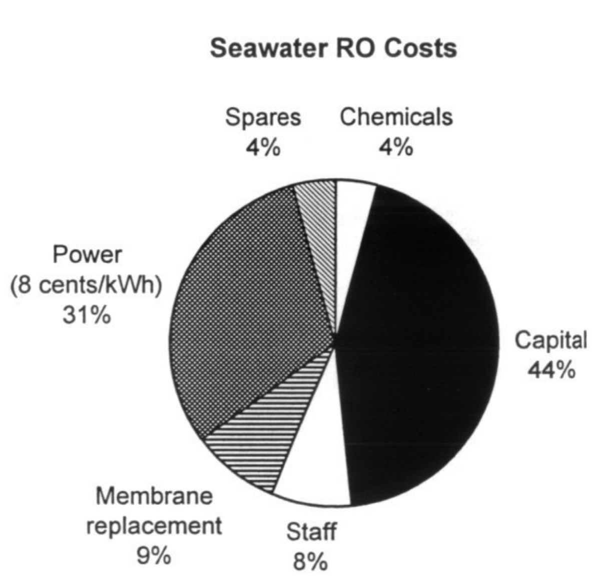
Reverse osmosis is regarded by many as the most cost competitive desalination process. Most of the renewable energy powered desalination plants use this process. For this reason the costs of this process will be used as an example.

The table and chart in Figure 3.1 above give a reasonable idea of the cost breakdown of a seawater RO plant operated by electricity at 8 cents/kWh. If the source of the electricity is a renewable source then most of the power cost is capital related.

The cost of PV will vary from location to location. The values in Figure 3.2 above have been adjusted to reflect the climatic conditions in Gaza. They do not take into account land prices which in the case of Gaza would increase the cost. As can be seen from the chart above the cost of electricity from PV with an 8% discount factor is around 15-20 cents/kWh. On this basis it is unlikely that PV can compete with a grid system operating at any reasonable scale. In this example an electricity consumption of 7.5 kWh/m^3 has been assumed. Some RO plants are being run with lower energy consumption than this. 5 kWh/m^3 is the lowest figure quoted (Glueckstern. P, 1994). This would reduce the energy figure to $1.75/m^3 which can be taken as a base figure. Obviously for installations with less solar energy or where higher discount factors prevail a higher energy cost would have to be used.

Extrapolating the above chart (Figure 3.3), a 5% discount factor and a mean annual wind speed of around 6.5 m/s will give a cost of electricity of about 8 cents/kWh. A 15% discount factor would require an average wind speed of 9 m/s to achieve a the same cost. The mean annual wind speed in Gaza is 4m/s which is clearly far too low to make wind energy a viable proposition. The Greek islands are known to have good wind regimes, mean annual speeds vary from 5.5 - 9.0 m/s but they are exceptional. Wind farms in the UK have to have a mean annual wind speed of around 9 m/s or higher to justify commercial development.

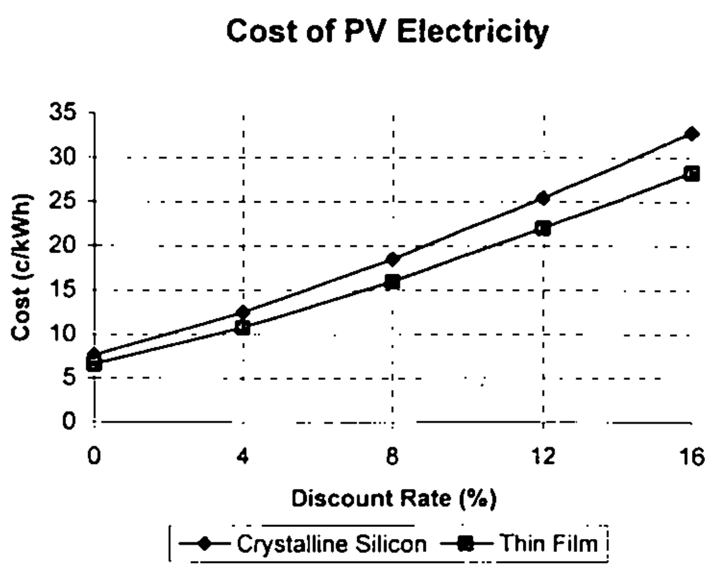
Figure 3.1 Economics of Desalination - Seawater



McBride, Morris & Hanbury

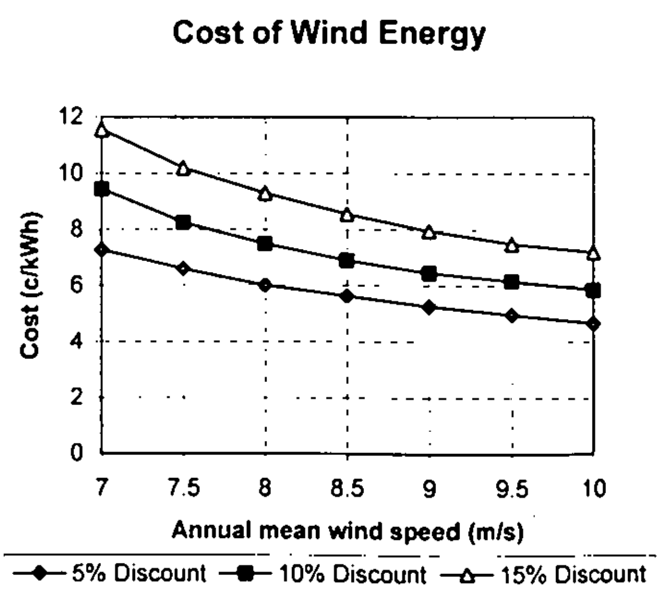
Item	Cents/m3
Chemicals	0.08
Capital	0.86
Staff	0.16
Membrane replacement	0.17
Power (8 cents/kWh)	0.6
Spares	0.08
Total	1.95

Figure 3.2 Cost of PV Electricity



Renewable Energy. T Johansson

Figure 3.3 Wind Energy Prices



BWEA 1966

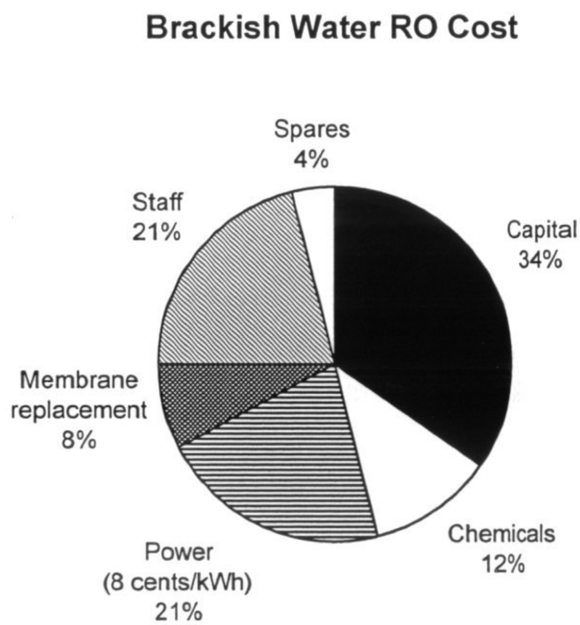
3.2 Desalination of Brackish Water

In remote communities at the end of long transmission lines or areas served by diesel generators electricity prices can be greater than 8 cents/kWh.

Operating Costs

Figure 3.4 shows a typical split.

Figure 3.4 Economics of Desalination - Brackish Water



Hanbury, Hodgkies & Morris. Desalination Technology 1993

Item	Cents/m3
Capital	0.18
Chemicals	0.06
Power (8 cents/kWh)	0.11
Membrane replacement	0.04
Staff	0.11
Spares	0.02
Total	0.52

The following data in Table 3.1 refers to the brackish water desalination plant constructed at Dir Al-Ballah in the Gaza Strip in 1993. The plant had an output of 45 m^3/hr.

Table 3.1 Brackish Water Desalination plant.

Item	Operating Cost
Staff costs	$2083/month
Chemicals	$458/month
Maintenance	$670/month
Electrical Power	$2183/month(based on 7 cents/kWh)
Total	$5394/month
Cost/m^3	$0.18/$m^3$ assuming 100% output over the period
The cost of the unit is made up as follows:	Capital Cost
Equipment cost	$400,000 including membranes
Membrane replacement cost	$70,000
Well pump & electricals	$100,000
Civil costs (Water tower, foundations etc.)	$150,000
Total project capital cost	$650,000

These costs need some qualification. The electrical costs included the supply of a stand-by generator which should not be necessary in future installations. Similarly the civil costs were increased significantly because of the security situation. A fair estimate for a future plant of this size would be $500,000 and this is the figure used in the following economic appraisal (Table 3.2).

The following assumptions have been included.

Membrane life	5 years
Plant life	20 years
Interest rate	8%
Power cost	7 cents/kWh
Plant availability	95%

Table 3.2 Water Production cost from Brackish Water.

Depreciation on Plant	21500	$/yr.
Depreciation on membranes	14000	$/yr.
Total depreciation cost	35500	$/yr.
Depreciation cost	**0.09**	**$/$m^3$**
Interest cost on plant	34400	$/yr.
Interest cost on membranes	5600	$/yr.
Total interest cost	40000	$/yr.
Interest cost	**0.11**	**$/$m^3$**
Operating cost	**0.18**	**$/$m^3$**
Total water cost	**0.38**	**$/$m^3$**

Based on this information the water cost would be $0.38/$m^3$. This is a production cost not a distributed cost.

As this plant was producing water with a better quality than was required, it was possible to dilute the product water with raw water and increase the plant output to 60 m^3/hr. This had the effect of reducing the cost of the water proportionately, i.e. $0.28/$m^3$.

These difference in cost in Table 3.2 and Figure 3.4 are mainly due to a difference in salinity, even though both are classified as brackish water. The salinity in Gaza (Table 3.1) is approximately 3,000 ppm, where as figure 3.4 assumes as salinity of between 6,000 - 8,000 ppm. Seawater has a salinity of approximately 35,000 ppm.

3.3 Seawater Greenhouse System

The Seawater Greenhouse represents a new approach to providing fresh water for growing crops in arid coastal regions. It is based on a Greenhouse, which provides a controlled environment where sea water is used to cool and humidify air, so that fresh water can be condensed from the humid air using heat exchangers. The fresh water is used to irrigate the ground both within the Greenhouse and in a shaded tent area behind the Greenhouse. The principles have been demonstrated at a small-scale over two years, which has enabled the performance of the Seawater Greenhouse to be modelled on a computer.

The likely capital and operating costs of a full sized Reference Scheme (a 1 ha Greenhouse with 16 ha of shaded tent, located in Oman) have been estimated using the predictions from this model and costs based on estimates made in conjunction with experts which have worked extensively in the region. Assuming replication of this scheme, (i.e. a low cost of capital and economies of scale), the fully developed scheme should be moderately profitable (6% annual rate of return over 20 years). However, the profitability depends greatly on the local geography, sea bed topography and the productivity of the scheme and so reasonably conservative assumptions have been used in the analysis presented below.

The Reference Scheme's applicability is limited by the need to draw sea water from a depth of about 1 km. An alternative concept has been developed: the "Low Costs Solution", which avoids the need for a deep sea water pipe. This uses a deeper Greenhouse (100 m front to back), in which the cooling is provided by recirculating sea water, which would make it suitable for locations such as Gaza. The amount of excess water produced per hectare is lower than in the Reference Scheme and so a smaller shaded tent area is adopted. This scheme has not yet been tested at a demonstration scale and so the results from the computer modelling should be treated with caution. However, if it achieves the predicted performance levels, the rate of return on the scheme should be significantly improved (e.g. 23% per annum).

The most important variable in both schemes is the value of the crops produced. The reference values were also chosen in discussion with experts who have worked in the region. However, by locating the Greenhouse in an area which minimises competition and by choosing to grow very high value produce, the Reference Scheme could be capable of producing far higher rates of return (~53% per annum). Confirmation of these higher rates of return would require a detailed regional evaluation of the demand and supply situation for horticultural products.

A more detailed analysis of the Seawater Greenhouse can be found in Annex A of this report.

3.4 PV Reverse Osmosis Plant

Dulas Ltd. has proposed a reverse osmosis (RO) system, which utilises well proven RO technology but with a photovoltaics energy supply and an enhancement to improve the overall efficiency of the scheme by recovering energy from the RO process.

In Annex B of this report, the economics of this approach have been evaluated for two sizes of scheme (producing 5 and 32 m^3 of fresh water daily) for both the prototype and mass produced systems. The costs used in the analysis were obtained primarily from direct quotations from manufacturers, whilst the efficiencies of various aspects of the scheme were based on previous experience of similar technologies.

The resulting costs of the various schemes have been listed below. The most important external variable effecting the production costs is the rate of finance, which was taken to be 20 % for the prototype schemes and 10% for the replicated schemes.

These costs are high compared to the cost of production from existing RO plant. This is attributable primarily to the small-scale of the scheme (which could not benefit from economies of size) and the use of PV cells for energy generation, which have a high capital cost. Further cost reductions might be achieved by going to a larger scale plant but this could present problems in finding sufficient area for the PV cells in some locations.

Table 3.3 Costs of Fresh Water from the Various RO/P.V Schemes

Scheme	Daily Output (m^3)	Rate of Finance (%)	Cost of Fresh Water (£/m^3)
Prototype	5	20	9.7
Prototype	32	20	6.9
Replicated	32	10	3.3

4. APPROPRIATE LOCATIONS AND CIRCUMSTANCES

Desalination schemes provide a means of using water that would otherwise be unsuitable for human use in coastal areas where other sources are limited. However, because of their cost and the conditions required for their introduction, the potential for desalination needs to be considered within the framework of an overall water resources management plan. This chapter outlines some of the background requirements for undertaking a water management review and establishing where small-scale desalination plants would be appropriate.

4.1 Key Requirements for Successful Water Management Options

Communities within semi-arid coastal regions have a wide variety of water needs and thus scales of demand. They also have varying levels of water resources availability, development and water management, as well as a range of supply options or access to alternative sources. The cost of water supply varies between communities according to these factors. Many coastal communities depend on a combination of runoff from inland upland areas and groundwater from coastal aquifers, which are often at risk from saline intrusion and contamination.

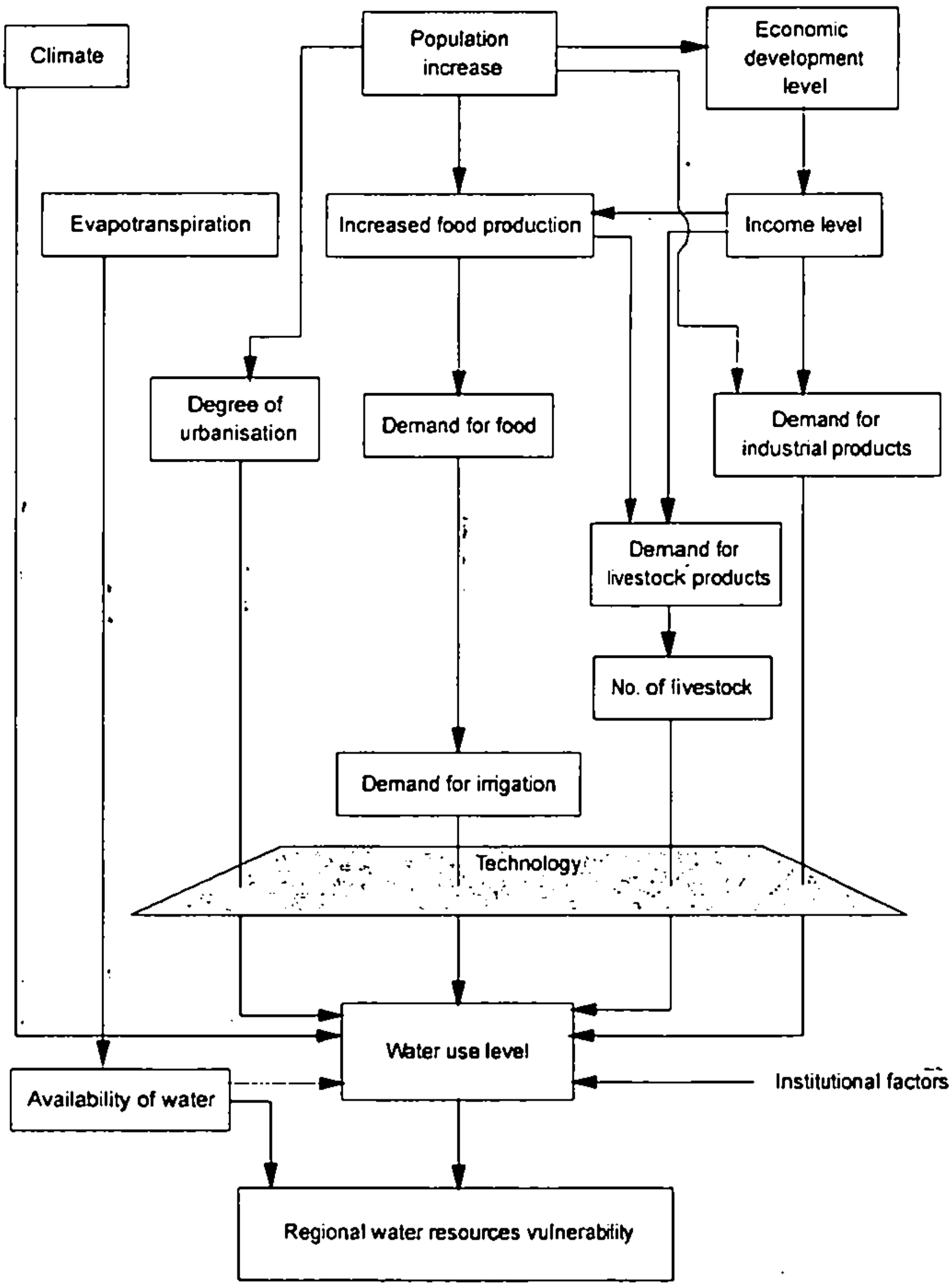
For example, in Malta saline intrusion has already affected the quality of potable supplies. Pumping rates would need to be reduced by at least 10% to avoid further deterioration and would need to be reduced by 45% to gain any improvement. Inefficient water use was encouraged by low water tariffs, which were only 10% of the true cost. Malta loses 30% of its water through leaks and a further 30% by illegal connections. Most of Malta's water supply now comes from desalination, in particular to meet summer tourist demands when the population increases threefold and demand can exceed 200,000 m^3/d. There are five desalination plants (with plans for a sixth) which consume 15% of the electricity supply. The costs of the desalinated water, however, are three times those of groundwater (Pearce, 1993).

The vulnerability of a region to water resources scarcity depends on the inter-relationship of a variety of factors, as illustrated in Figure 4.1 (FAO, 1995). Semi-arid and arid regions with low incomes and a high rate of population growth are especially vulnerable. A 'water exploitation index' can be used to indicate water resources vulnerability. This is a measure of the amount of water a country (or locality) uses as a percentage of the renewable water resources available: a high vulnerability to water shortages would be indicated if this exceeds 50%.

In the past, water resources management has tended to focus only on the supply-side. An appropriate water management strategy that also addresses the demand-side is essential. Supporting hydrological and other relevant information, such as present and predicted water demands are required for planning purposes over selected planning horizons (typically 10, 25 and 50 years).

Despite water shortages, the misuse of water is common and, all too often, water management measures are not applied until water shortages result in adverse socio-economic or environmental consequences. This may reflect:

Figure 4.1 Factors influencing water resources vulnerability



Source: after FAO,1995

Note: excludes water quality

- a weak institutional framework
- government policies
- the lack of an appropriate or enforceable water legislation and water tariff structure
- competition between different water sectors
- and a supply or project-orientated approach to development.

Before water management measures can be selected it may be necessary to undertake a review of the existing water sector policy to (FAO, 1995):

- show the importance of water in national, social and economic life
- identify problems and critical issues
- quantify and prioritise pressures on water resources
- and to identify options for mitigating these pressures.

An assessment of critical issues would normally require an assessment of the following (for a more complete checklist see FAO, 1995):

- supply-demand balance and trends by sector due to growth in population, increase per capita demand, over exploitation of groundwater, climate change, etc;
- level and quality of service due to shortage of investment, rapid growth of peri-urban settlements, etc;
- economic and financial importance of the water sector;
- water quality due to polluting industries, weak legislation, poor irrigation practices, etc;
- future water supply options and costs, such as the lack of alternative supply options, insufficient demand management, poor cost recovery, etc;
- efficiency of present water use, such as pipe leakage or poor irrigation practices;
- any conflicts in water use, such as competition between agricultural and urban users and the lack of a legal framework to settle disputes;
- environmental impacts, such as loss of wetland habitats;
- structural and institutional arrangements;
- any international sensitivity and commitments;
- data availability, such as population statistics and resource evaluations;
- and monitoring requirements, including water use and hydrological data.

Different emphasis would be placed on each issue depending on the importance that each government places on the respective issues and in relation to other government policies (e.g. self-sufficiency in food production). The review should formulate a water strategy and define an action programme and management monitoring plan.

The selection of water resources management measures should be guided by certain criteria, with the underlying basis that water should be considered as an economic resource. These include (after FAO, 1995):

- effectiveness and efficiency
- equity and distribution
- public health benefits and risks (including nutrition)
- environmental impact
- fiscal impact
- political and public acceptability (e.g. willingness to pay or water quality acceptability)

- sustainability
- security of supply
- investment and operating costs
- and administrative feasibility.

A balance should be sought between economic incentives (e.g. taxes) and control measures (e.g. regulations). For example, measures to reduce groundwater abstraction could include prices and charges (e.g. metering, taxes), controls on the quantity abstracted (e.g. permits, pumping quotas), or the transfer of entitlements (e.g. water markets in Spain, water 'banking' in California).

A realistic water pricing structure can promote a more efficient and equitable use of water as well as generating revenues for infrastructure, training, monitoring and other costs of supply. However, the most appropriate tariff structure may be difficult to identify. In countries where pumped groundwater forms an important source of supply, adjustments to the cost of energy and the formation of local water-user groups may be a more practical way of controlling water use. Government support for water saving technologies and publicity campaigns can result in benefits throughout the water sector.

The agricultural sector is often the main consumer of water supplies, yet it is also a relatively low value, low-efficiency and highly subsidised (both directly and indirectly) water user. Changes in policy, institutional reforms and improved agricultural techniques may be needed to reduce water demands in the agricultural sector whilst enhancing the economic benefits using an approach based on crop yield per unit of water rather than per unit of land.

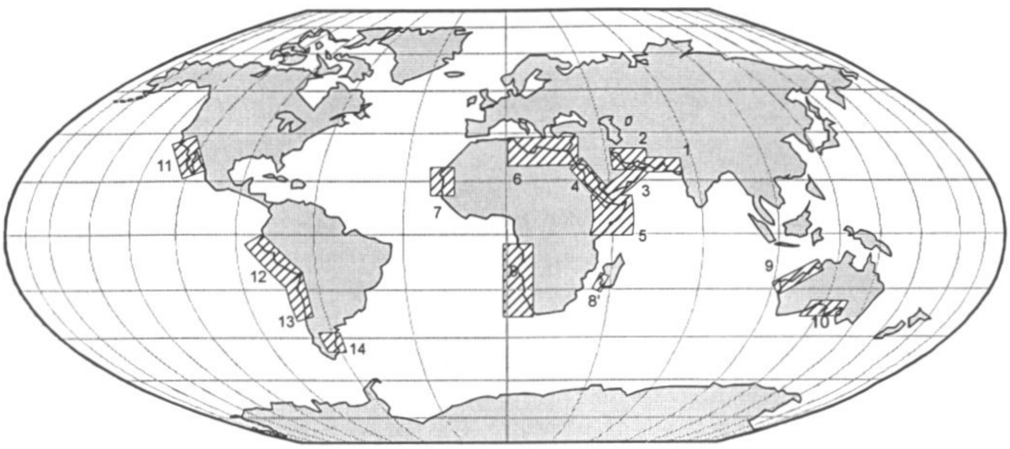
Significant savings in water demands are usually also possible in the industrial sector where a water tariff is not already imposed. Often, however, there is a lack of reliable information on industrial water use. Measures to encourage water recycling and low water use industries combined with a scaled water tariff structure can achieve significant water reductions in water demands and reduce potential pollution risks. For example water savings of 40 to 60% were achieved over two years in three industries in Sao Paulo, Brazil, by the introduction of pollution charges related to the volume and quantity of effluent produced. In Taijin, China, prescriptive norms based on reasonable usage are set for industrial users which are reinforced by higher water charges if these are exceeded (Israel has adopted a similar approach to curb agricultural use).

4.2 Key Requirements for Successful Technical Options for Desalination

4.2.1 General

The world-wide distribution of coastal areas (excluding islands) having less than 200 mm/y of rainfall (arid and hyperarid) is indicated in Figure 4.2. The length of coastline in each country within these zones is given in Table 4.1 and totals nearly 35000 km (UNDCTCD, 1985 after Bradonovic, 1982).

Figure 4.2 Arid and hyperarid coastal areas of the world



Source: UNDTCD, 1985

Table 4.1 Countries with significant lengths of arid (A) and very arid (HA) coastline

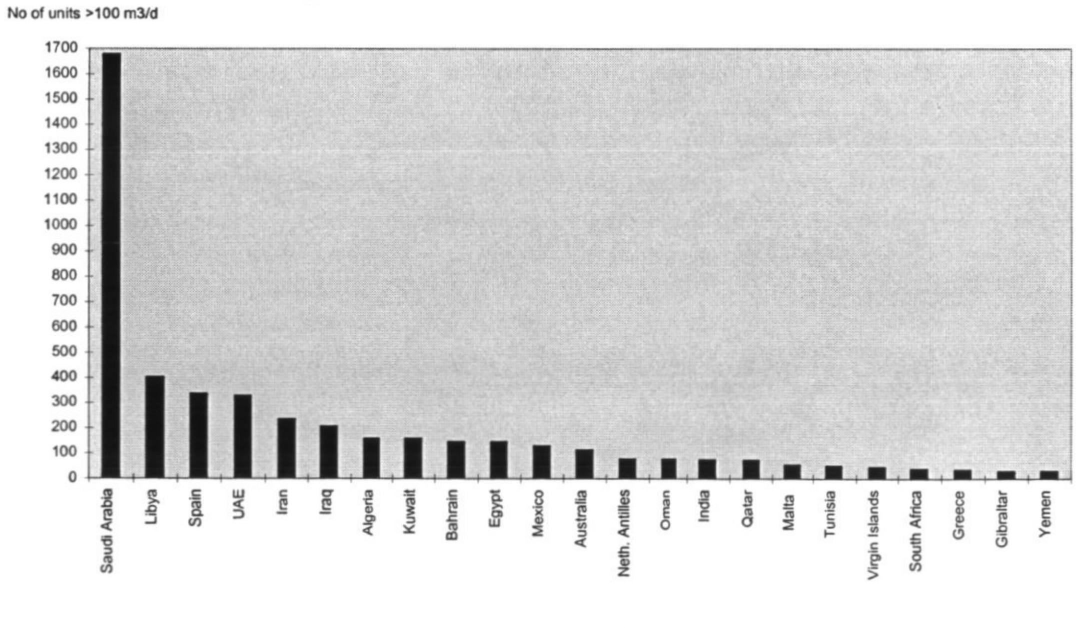
		Location (see Fig. 4.2)		Estimated length of arid coastline (km)
Africa:	Afars and Issas	4	A	244
	Egypt	4, 6	A - HA	2420
	Ethiopia	4	A	1010
	Libya	6	A	1685
	Mauritania	7	A	666
	Morocco	7	A	452
	Namibia	8	HA	1385
	Somalia	5	A	2955
	Sudan	4	A	716
	Tunisia	6	A	500
	Western Sahara	7	A	907
	Subtotal			12940
Australia:		9, 10	A	4700
Asia:	India	1	A	1105
	Iran, Islamic Republic	1, 2	A	1834
	of	1	A	753
	Pakistan	2, 4	A	2437
	Saudi Arabia	3	A - HA	1666
	Subtotal			7791
Central and South America:	Argentina	14	A	1700
	Chile	13	A - HA	1574
	Mexico	11	A	3800
	Peru	12	A - HA	2329
	Subtotal			9403
	TOTAL			34834

Source: UNDTCD, 1985 after Bradanovic, 1982

Communities within arid to semi-arid coastal regions are often situated on extensive coastal plains (e.g. Hodeida on the Tihama Plain of Yemen) or along the coasts of islands. Initially, these communities relied on shallow groundwater supplies or, more directly, on seasonal or perennial rivers draining the interior. Coastal alluvial plain aquifers may contain brackish groundwater at depth inland and saline groundwater intrusion at the coast. Unconsolidated aquifers bordering islands tend to be limited in extent and thickness, but may have saline groundwater at the coast in the underlying formations and access to deep water within a relatively short distance offshore.

Over 7500 desalination plants now operate world-wide with a total production of 4.8 billion m^3/y. The number of land-based desalination plants producing more than 100 m^3/day in selected countries with low rainfall is shown in Figure 4.3 (after Wangnick, 1994). Operational difficulties, such as corrosion or lack of technical personnel, have been a common problem with desalination plants in many countries. However, the greater reliability of modern systems has been an important factor in their growing use in developing countries as this has reduced maintenance costs and the need for skilled personnel. The cost of solar power units has also reduced considerably in recent years and increased the potential for small-scale plants serving local communities, hotels etc.

Figure 4.3 Number of desalination units in selected countries



The locations of the energy source, the water source, the desalination plant and the disposal of concentrated salt water after desalination need to be identified at an early stage. The factors influencing the site of the desalination plant may differ from those affecting the selection of a renewable energy site.

Whilst most major schemes, such as those in the Middle East, rely on seawater supplies, the opportunities for exploiting the considerable reserves of (usually non-renewable) brackish groundwater (e.g. Middle East) have yet to be fully exploited, in part because of the water composition. The desalination of brackish water is a rapidly growing area as costs can be less than half those of seawater desalination. For example, there are now more than 100 small RO plants using brackish groundwater operating in Florida. The various sources of poor quality water influence the choice of desalination technology. RO and ED (physical) methods are more suited to brackish water whilst RO and distillation (boiling and condensation) methods are more commonly used for seawater desalination.

In general small-scale desalination schemes are most appropriate for:

- providing supplies at locations where no other sources are available
- special supplies, such as where high quality water is required (e.g. hospitals)
- supplementing other sources of potable water supply to meet peak demands
- conjunctive use with existing conventional sources, especially in areas suffering from actual or potential water shortages and to sustain or promote socio-economic development.

However, because present desalination methods can involve a substantial investment and high operating costs, they are likely to be suitable only at particular locations and under certain circumstances. Whilst economic considerations and reliability are usually the most important factors governing the use of desalination schemes and type of method, other conditions that need to be taken into account in assessing the introduction of small-scale desalination schemes include:

- opportunities for and costs of further development of conventional sources, recycling and for implementing other water resource management options
- purpose, water demands (daily, seasonal, future) and present unit water costs
- availability of suitable physical locations
- source of supply (marine, brackish or combinations)
- energy source (non-renewable, renewable or combinations)
- environmental (disposal of salt and other products)
- technical support, maintenance, protection and security of supply
- and other factors, such as public perception of water costs, scope for private investment or side benefits (e.g. opportunities for greenhouse or hydroponic cultivation).

4.2.2 Water Resources and Demands

Current and future water demands should be assessed to identify where water savings can be achieved and the potential for water re-use, as outlined in Chapter 1 and Section 4.1 above. This may identify cheaper options than desalination or allow investment in desalination schemes to be postponed.

4.2.3 Energy Sources

Individual components of renewable energy or continuously powered desalination systems can be considered as mature technology. However, the combination of energy source and desalination process is still novel and most of the renewable energy sources are variable in power output and availability. This has required the processes to cater for short-term and long-term energy storage systems or frequent shutdowns. For the thermal processes this can be overcome as thermal energy in the form of hot liquids can be stored easily in insulated vessels. However, for the electrically-based systems this has been more difficult. Electricity is expensive to store in batteries and hence this approach has only been used for small systems to even out transient variations and to keep the plant running for short periods. Flywheels have also been used but again only on small systems. A more novel approach to store electrical power has been to use pumped storage hydropower, although this is very site specific, expensive and inefficient. Where it is paramount to keep the system operational overnight or for long periods, diesel powered back-up has been used, which effectively makes the desalination plant equivalent to being grid-connected, although a diesel supply does not offer the same security as a grid system and this combination requires a load management interface to control diesel power input to the system.

An audit of potential sources of renewable energy should be undertaken. These include wind, solar, wave, geothermal, hydropower, biomass and waste incineration. The appropriateness of the renewable energy source will depend on the climate, geography and topography of the location. Some renewable sources, such as wind power, are rather site specific but combinations, such as solar-power by day and wind power by night, may be possible. In many areas site-specific climatic data are often lacking. Where this is the case, data collection should commence as soon as possible by installing measuring equipment. General data may be available from global databases, such as the Global Ecosystems Database (Kinman and Ohrenschall, 1992), although this may be on a rather coarse grid (e.g. 0.5 degree).

Semi-arid and arid regions are normally characterised by high solar radiation intensity, particularly in coastal desert areas and the Middle East. However, seasonal variations can be as high as 50% and increase with latitude. Average levels of solar intensity are given in Table 4.2 for selected locations (Lawand, 1985).

Table 4.2 Average annual solar radiation in selected countries

Country	Solar radiation (watt hours/m^2/day)
Yemen (Aden)	6006
Australia (Sydney)	4446
Chile (Atacama Desert)	7159
Egypt (Giza)	5622
Mauritania (Nouackchott)	6507
Phillipines (Quezon)	4516
Trinidad (Port of Spain)	5634
Tunisia (Tunis)	5121
Wake Island	6495

Coastal locations are often suitable for wind energy. Wind speeds exceeding 4 m/s are normally required. The power available in the wind can be estimated from the following:-

$$P = \frac{1}{2}\rho U_\infty^3 A_D$$

Where:-

P	= power available in the wind	[W]
ρ	= density of the air	[kg/m^3]
U_∞^3	= Free stream velocity of the air	[m/s]
A_D	= Swept area of the rotor	[m^2]

However different turbines exhibit different power curves and local topography and other factors can effect wind capture, so the actual power derived is some proportion of this. The energy extracted from the wind by a wind turbine depends mostly on the following factors:

- Swept area of the rotor
- Cube of the free-stream wind velocity (which also increases with height above the ground)
- The rating of the turbine: design wind speed and design power
- Losses associated with turbulent wind
- Losses from interactions between turbines (e.g. wake interactions)
- Electrical and mechanical losses
- Downtime: maintenance and breakdown
- Distribution of wind speeds at the site

Choosing a wind turbine is a complicated process, the larger the machine the more energy extracted for a given wind speed. Larger turbines are mounted higher from the ground where the wind speed is higher also. Choosing a turbine with a design wind speed that is too low will mean that much of the wind will be wasted (passed through the turbine without producing power). Whereas choosing one with a design wind speed that is too high will mean that there will be too many times when the turbine is not running at all because there is insufficient wind.

Different areas have different ranges and distributions of wind speeds and in each instance the choice of turbine varies. Matching the distribution of wind speeds to the power curves of the turbine is important. The size of a wind turbine is usually denoted by its rated power (kW) which determines the length of the blades and the hub height. Modern wind turbines are typically horizontal axis designs.

Biomass production is normally low in semi-arid and arid areas. However, household waste may provide an alternative source of energy (with other environmental benefits) in more populated areas. For example, Gibraltar used to regularly import water by tanker but in 1992 a new 'waste-to-water' plant was opened which incinerates household waste to power the desalination plant. The plant now produces 1800 m^3/d, or about two-thirds of Gibraltar's water requirement.

Having undertaken an audit of various potential sources of energy (or combinations of energy), it should be possible to identify the size of plant required. For example, a very small plant would indicate a membrane desalination process. The availability of a grid supply would also possibly eliminate the need for a diesel back up or the use of a renewable energy source.

4.2.4 Sources of Water

Where seawater is used as the source of water supply, a protected flat area of land as near as possible to the sea with good access and large enough to accommodate any future expansion should be selected. The quality of the seawater is important and the intake should be situated so that the intake water is not disturbed by sand, turbid water or seaweed.

Where subsurface conditions are suitable, saline water abstracted from boreholes at the coast should be considered: many successful RO plants have adopted this approach as pre-treatment costs are reduced and membrane life increased. Distillation plants are less sensitive and mostly use open intakes or submerged intakes taken out to deep, quiet water.

The size of plant could be reduced if the output can be mixed with other conventional sources to provide an acceptable water quality. For example, a desalination plant at Deir Al-Balah (Gaza) has the capacity to produce 45 m^3/h of water with a salinity of 50 mg/l from a borehole with a salinity 1050 mg/l. The desalinated water is then blended with the borehole water before being pumped into the distribution system.

Some form of reservoir will be required for the product water. This can be sited at the plant or nearer the point of consumption. It should be sized conservatively to ensure that a supply can be maintained when supplies are interrupted, for example during adverse weather conditions or for maintenance. It may be possible to store the excess water within an underlying aquifer during times of low demand, although this should be given careful consideration since it is not always possible to fully recover the amount stored in this way and there may be risks of groundwater contamination.

4.2.5 Environmental

The concentrated salt water produced as a waste stream from a desalination plant can be environmentally damaging if not disposed of appropriately. This can be expensive if it has to be pumped long distances. There is also a risk of contaminating brackish water or seawater with the concentrate if disposal is not carefully planned. The concentrate could be disposed of in deep wells where subsurface conditions allow or it could be used for salt production.

4.2.6 Technical Support

All desalination plants require some level of technical support covering instrumentation, electronics, mechanical engineering, welding and machining. Sources of chemicals and parts, their supply and costs need to be taken into account. Costs of any pretreatment and supervision can be high and the more local and comprehensive this support can be, the better. For remote locations, plants using proven equipment, minimum chemicals etc. should be preferred.

5. BRIEF CASE STUDY OF THE GAZA AREA

5.1 Introduction

This Chapter seeks to explore the potential of new desalination technologies to contribute to the development of water resources in the Gaza Strip, an area faced with considerable challenges, both in adapting administratively to the development of self governance under the peace process, and in managing scarce natural resources under extreme population pressures.

The Gaza Strip faces many serious economic and environmental problems. Within an extremely limited land area of 365 km^2 there is an average population density of over 2,000 persons/km^2, reaching around 100,000 persons/km in Beach (refugee) Camp outside Gaza City. The population of the Gaza Strip has increased approximately twenty-fold since 1920 and, although current levels are uncertain, most estimates suggest a figure of around 850,000 (PEPA, 1994a). Migration has been a major contributory factor, with large influxes in the years around 1948 and 1967. The natural rate of population growth is around 4.8%/year, one of the highest figures in the world. Over 80% of the population of the Strip has been designated as urban (FAFO, 1993), with approximately 60% of the population living in over-crowded refugee camps. The economic fabric of the Gaza Strip has been considerably distorted by the legacy of its occupation by the Israelis, and by continuing restrictions, arising from Israeli security fears, on the movement of goods, services and labour between Gaza and Israel. As a result, the economy is dominated by a relatively unproductive agricultural sector, there has been little industrial development, and incomes are heavily dependent on wage labour in Israel (and therefore subject to the politics of Israeli border control practices).

Under Israeli occupation government attention to water resource issues was focused on agriculture, and there was a water department within the Gaza Agriculture Department. Strict water licensing and quota policies were enforced for agriculture with all abstraction metered, at least until the beginning of the Intifada when administration of the system became extremely difficult. Public water supply was generally administered by municipal or private utilities, although the United Nations Relief and Works Authority (UNRWA) plays an important role within the refugee camps. With self governing status the Palestinian authorities have formed the Palestinian Water Authority (PWA) which is responsible for planning and regulation within the sector. Pending the further development of a Palestinian bulk water undertaking and greater municipal involvement in water supply and waste water treatment, the PWA also manage and operate water supply institutions left behind by the Israelis.

Despite the environmental problems water and electrical grids are well developed within the strip. Most urban areas, even within small communities have access to the infrastructure, even if quality and reliability of supply are suspect. Major investment in power generating capacity is likely in the near future. At present there are no power plant in Gaza, all electricity is supplied to the grid from power plant in Israel.

The climate of the Gaza Strip is arid, and there are no significant surface water resources. As a result, supply is almost exclusively drawn from groundwater resources, with limited and localised rainwater harvesting and water import. There is also a small desalination plant near Gaza City, but operation is infrequent. Groundwater resources have been heavily over-exploited over the last 50 years or so, with the result that significant water quality deterioration has occurred through saline intrusion. Agricultural intensification and inadequate provision for wastewater disposal have also led to increased contaminant loading on the aquifer. As demographic and economic growth increase the pressure on scarce groundwater resources, the need to identify new water resources for the Strip and manage remaining resources more effectively has never been greater. It is, however, unlikely that water resource development will be in any way sufficient to meet demands, or to halt aquifer degradation. Demand management, including both conservation of water within sectors and reallocation of water from lower to higher value uses, would therefore seem essential component of any comprehensive water resources development and management strategy.

Novel desalination technologies can be regarded as having two roles within Gaza, subject to the limitations outlined below. The first would be to make an important, if limited, contribution to water supply in some communities. In areas where the aquifer has been degraded and brackish water is present, desalination may provide water for blending water extracted as part of a salinity management strategy. The second role would see the technology acting as a focus for public education with respect to the extent of the Strip's water resource problems and the various solutions that may be adopted to manage resources.

There are three main factors that will tend to limit the use of desalination technologies in the Gaza strip;

- The high population density means that while there are small communities within the Strip, any community will be within 5-10 km of one or more major population centres. Against this background, it is unlikely that self sufficiency in water abstraction and treatment within a small community can compete with the economies of scale inherent in water supply to the larger communities, especially as most households are already served by mains supply. In addition, the marginal cost of supplying very limited volumes of water to such communities from larger scale supply augmentation proposals designed to meet the needs of much larger numbers of people in the cities is likely to be extremely small.
- There may well be political resistance to the introduction of high technology solutions. There is a worry that these may prejudice the Palestinian negotiating position in the final settlement talks.
- High land costs in Gaza, especially along the seashore, may make desalination options requiring large land areas (e.g. PV RO desalination) uneconomic. However, it should be noted that the greenhouses required for greenhouse desalination could, in theory, be located a little distance away from the coast if pipelines could be constructed at reasonable cost.

5.2 Background

5.2.1 Climatic conditions in Gaza

Meteorological data in the Gaza Strip is available from a single comprehensive climate station operated by the Ministry of Transport. This is located very close to the shoreline, and data may not be representative for some purposes. For assessing desalination technologies, however, especially the solar greenhouse option, proximity to the sea may be an advantage.

The climate of Gaza is of middle latitude arid type, with a hot dry summer and only moderate rainfall during the winter months. The average total annual rainfall is 312 mm, but there are considerable inter-annual fluctuations. Evaporation is very high, reaching 1900 mm/year (see Figure 5.1).

Figure 5.1 Gaza climate data

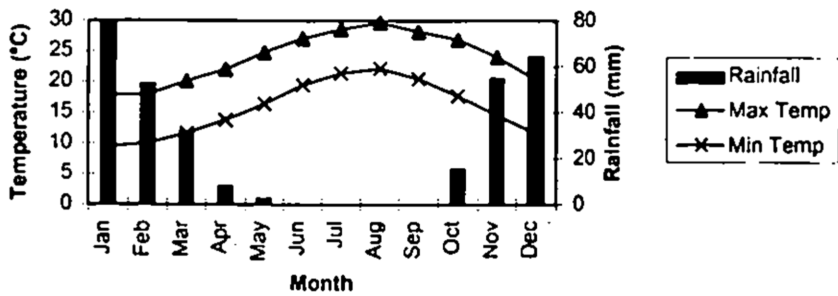
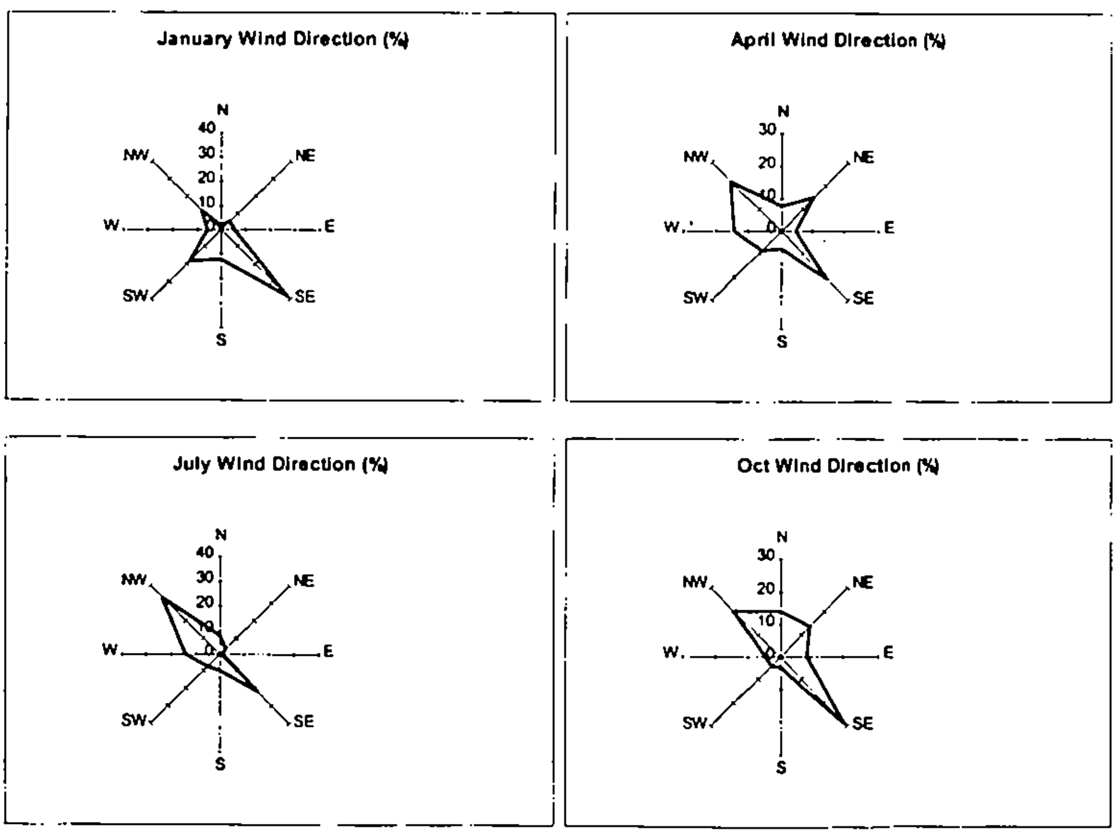


Figure 5.2 Gaza Wind Directions



While on shore winds predominate, during the dry season a significant diurnal variation is apparent, with onshore breezes during the day and offshore breezes at night. Mean annual wind speed is 4m/sec. Figure 5.2 illustrates variations in wind direction during the year.

5.2.2 Existing Water Resources and Demands

a) Water resources

The climate and topography of the Gaza Strip limit the potential water resources available within its borders. High agricultural groundwater abstraction and increasing municipal demand have therefore resulted in growing water scarcity.

Surface water resources

Surface water resources are very limited. There is one non-perennial surface water course - Wadi Gaza - that flows into the Strip, but flows are rare and upstream exploitation means that it can not be considered as a water supply source. It may be exploited as an element of an artificial groundwater recharge programme.

Groundwater resources

The Gaza Strip is underlain by a thick sequence of Quaternary, Neogene and Paleogene sediments, but at present only the Quaternary sands and poorly consolidated shelly sandstones are used for water supply. The base of the Quaternary aquifer consists of impermeable Pliocene marls. These in turn are underlain at depth by Eocene limestones but their water quality is uniformly poor and unsuitable for supply purposes. Figure 5.3 shows the general configuration of the Gaza aquifer.

Estimates of available groundwater resources are sensitive to many factors that are difficult to precisely quantify. Recharge to the aquifer from rainfall has been estimated at between 40 and 65 million cubic metres per annum (mcm/year). In addition, 10 - 20 mcm/year may flow from Israel and a further 20 mcm/year infiltrates from leaking domestic pipes, irrigation returns and waste water recharge. This implies that, ignoring water quality issues, between 70 and 105 mcm/year might be available for extraction without depletion of the aquifer (see Table 5.1).

In practice the primary constraint on groundwater exploitation in the Gaza Strip is not the absolute quantity of water available, but rather its quality. Much of the water in the Quaternary aquifer has already been degraded, either through intrusion of saline groundwater or through the poor quality of recharged irrigation returns and waste water. In addition, recharge estimates from rainfall do not take into consideration the quality or spatial distribution of recharging water. Although rainfall is of good quality, only a small proportion of it will fall on the sections of aquifer containing potable water. Some will recharge areas with very saline water and, as a consequence, its quality and value will be lost.

Saline intrusion occurs in freshwater aquifers where water levels in the aquifer are reduced by pumping to such an extent that saline water either flows horizontally in to an aquifer in contact with the sea, or flows upwards from deep saline waters. Saline intrusion of both kinds is already widespread in the Gaza Strip, and all evidence suggests that intrusion will continue until robust management measures are implemented, alternative supplies are provided or the quality deteriorates to such a level that the aquifer is unusable. In 1994 it was estimated that, by land area, 16% of the Strip was underlain by good quality water, 34% by water of moderate quality and 50% by water with more than 750 mgl^{-1} of Chloride, which is too saline for either domestic or agricultural usage (Calow et al, 1996).

Figure 5.3 Land Area Underlain By Saline Groundwater - Gaza 1974 to 1994

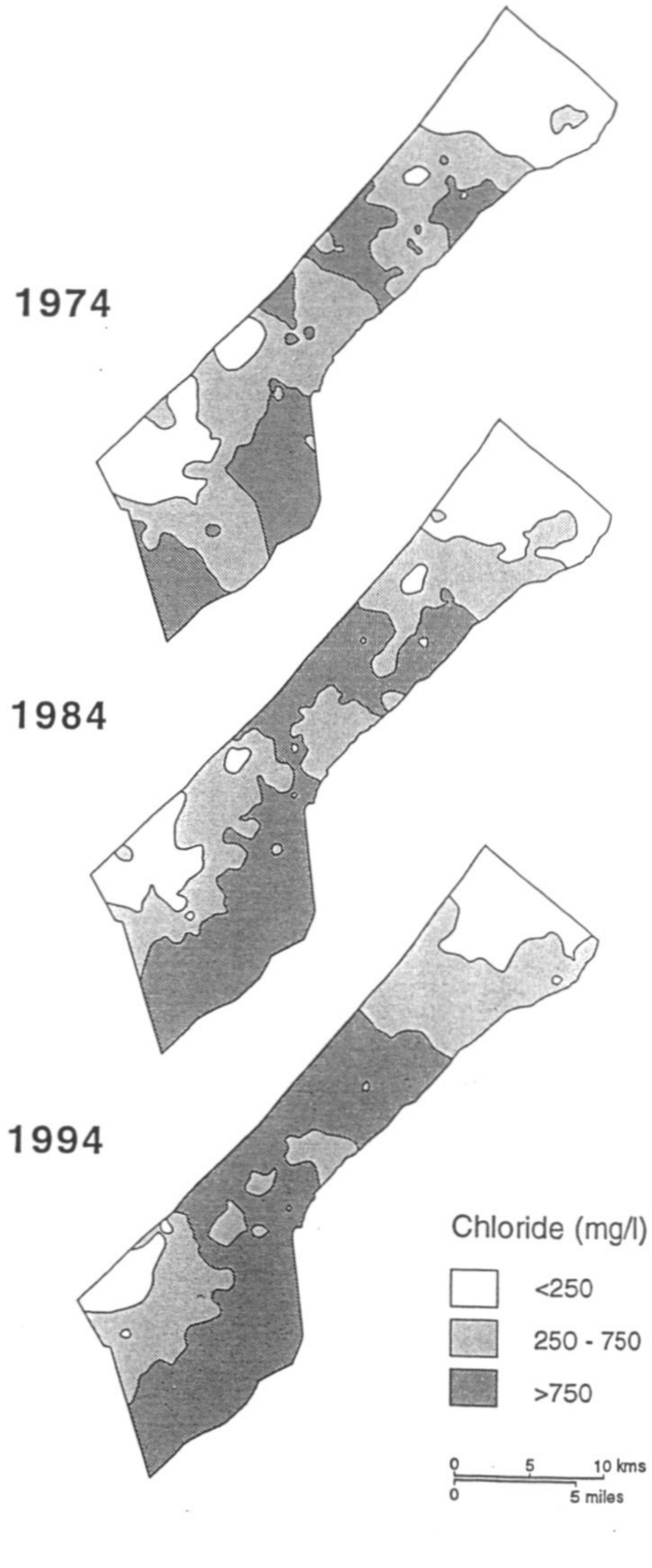
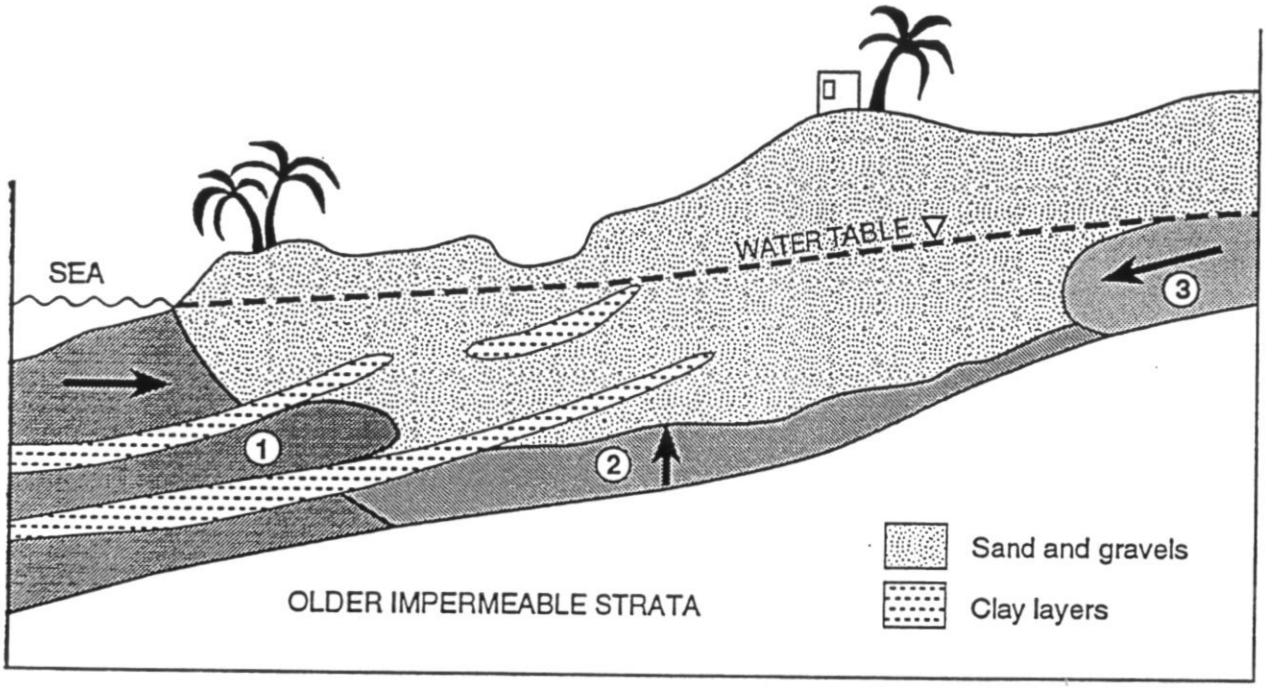


Figure 5.4 Lenses of Fresh Water in Gaza



Key:

Section showing the general configuration of aquifers in Gaza. The numbers refer to routes of saline intrusion.

1 - Flow from sea

2 - Flow from deeper saline aquifers

3 - Flow from saline aquifers

Figure 5.3 shows the increase in the land area underlain by saline groundwater from 1974 to 1994. The land area underlain by fresh water has been declining at approximately 1%/year in recent decades, and Figure 5.4 illustrates how only two lenses of freshwater remain: one on the north, and one in the south west. Farmers are already abandoning irrigation in areas of increased salinity, with citrus cultivation suffering most.

The spatial distribution of fresh water within the aquifer is constrained mainly by variations in the soil type and in the thickness of the unsaturated zone, either allowing rapid recharge of rainfall or limiting the recharge potential. The freshest water, in areas where recharge is most rapid, is also often the most vulnerable to contamination. Seventy seven per cent of urban boreholes in the Strip had Nitrate concentrations above World Health Organisation recommended limits of 50 mgl^{-1}, and 44% were above 100 mgl^{-1} (Shawwa, 1994).

Other water resources

While groundwater plays a dominant role, other sources of water used in Gaza include:

- 5 mcm/year imported water derived from the Israeli national carrier, and supplied by the Israeli national water undertaking, Mekerot, to 3 refugee camps and 6 towns and villages;
- A pilot scale RO brackish water desalination plant, that while often non-operational, has a capacity of 0.5 mcm/year;
- Limited rainwater harvesting programmes in some villages.

b) Water demands

There are over 2,000 wells pumping groundwater in the Gaza Strip. Figures for total abstraction cited in the literature vary greatly, with estimates ranging between 80-130 mcm/year (Grey, 1994). This reflects uncertainties over the number of unlicensed wells drilled in recent years, trends in agricultural abstraction since Israeli withdrawal, and levels of abstraction within the Israeli settlements. Whatever the exact figures, however, several consistent messages emerge:

- Total abstraction significantly exceeds recharge, with irrigated agriculture the major consumer;
- Municipal demands are increasing rapidly with population growth. In 1970, domestic and industrial demand was estimated at 10 mcm/year. By 1991/92, the figure had risen to 30 mcm/year (SAAR, 1992) and it may now be around 35 mcm/year. For a population of 850,000, this gives a per capita municipal consumption level, including unaccounted for losses and leakage, of just over 100 litres per capita per day (lcd), compared to around 300 lcd in Israel, or roughly 60 lcd assuming 40% distribution losses (see Section 5.3). Because of the small size of the industrial sector, most municipal water use (perhaps 32 mcm/year) is for domestic purposes.

Table 5.1 below illustrates a simple water balance derived for the Gaza Strip based on recharge and consumption estimates made by WRAP in 1994.

Table 5.1 Simple water balance for the Gaza Strip.

Recharge	
Net precipitation	50 mcm/year
Irrigation return flow	20 mcm/year
Total	*70 mcm/year*
Consumption	
Municipal	30 mcm/year
Agricultural	80 mcm/year
Israeli settlements	5 mcm/year
Total	*115 mcm/year*
Groundwater balance	*- 45 mcm/year*

Note: the balance ignores the quality and spatial distribution of groundwater recharge.

Even under the most optimistic recharge scenarios (assuming recharge of 105 mcm/year that is both recoverable and of adequate quality), there is an annual deficit of 10 mcm/year. In practice it is estimated that abstraction from the aquifer would need to be reduced to 50% of current levels for sustainable management.

Demand projections are difficult to make in view of uncertainties over current consumption levels and projected trends in economic activity, demographic change and institutional arrangements shaping patterns of water use. Nevertheless, it is clear that demand will increase significantly in future, even if the increases in per capita consumption required for development in a modern state are discounted. For example, an overall population growth rate of 4%/year would result in domestic demand almost doubling by the year 2010.

5.3 Water Resource Management

5.3.1 Addressing water scarcity

Addressing the problem of growing water scarcity within the Strip necessitates measures to manage demand as well as supplement existing supplies. A prerequisite is strong institutions and the political will to address conflicts of interest between different users and uses.

In many ways the political difficulties of pursuing a supply-led agenda are considerably less than those involved in demand management: managing demand through the promotion of conservation and reallocation inevitably requires that some users lose out at the expense of others, and there are powerful vested interests at work. This is particularly so for irrigated agriculture, the sector that stands to lose most. Nevertheless, augmenting existing supplies with costly alternatives, without consideration of short to medium term demand management options, would seem both short-sighted and economically wasteful.

In light of the above, management strategies can be broadly classified as follows:

- Identification of new resources within or outside the territory.

- Improved management and conservation of existing resources, including reallocation of water within and between uses and users. A prerequisite for this is the creation of an enabling institutional and economic environment.

In the following sections these broad strategies, and the different policy options associated with them, are considered in more detail.

a) Identifying new resources

Several studies have been carried out within Gaza to identify potential new water resources. Each option needs to be placed in the context not only of its technical and financial viability, but also its political and institutional feasibility. In particular several commentators on the Peace negotiations have noted the implicit linkages between Palestinian rights to waters from the West Bank mountain aquifers and water supply to the Gaza Strip. Any technological option that leaves Gaza beholden to an outside party, especially Israel, will be viewed as a risk to the security of the Palestinian administration. It will also be viewed as potentially damaging to the Palestinian negotiating position in discussions of equitable access to the region's water resources.

Possible new resources include:

1. ***Rainwater Harvesting.***- Rainwater is currently used by several communities, but its utility is limited by the low rainfall and high rates of evaporation.

2. ***Surface Water.*** - No exploitable surface water resources are available within the Gaza Strip.

3. ***Ground Water.*** - Existing over exploitation negates any possibility of increasing abstraction rates.

4. ***Waste water reuse.***- Waste water in Gaza is currently under used and inappropriately managed. Its use in the past has been limited by the lack of infrastructure for sewage treatment, and by consumer resistance. These factors are changing and it is likely that treated waste water use will increase markedly

5. ***Desalination.*** - With its coastal location, and with access to a productive brackish water aquifer the potential for desalination is limited only by its cost and by the need for energy to be imported in any large scale scheme. This option is dealt with in greater detail in Section 5.3.2 below. Desalination based on the treatment of brackish water from the Gaza aquifer would need to be planned carefully to ensure that pumping did not accelerate degradation of the aquifer.

6. ***Import by tanker.***- Several schemes have been suggested involving import of water by sea, generally from sources in Turkey. The economics of these schemes are usually linked to the scale of the programme. Supply of the relatively small quantities required for public supply would involve very high costs per m^3. Larger schemes with more realistic unit costs of US$ 0.17/m^3 - US$0.23/$m^3$ for 200 mcm/year would involve the use of water in the agricultural sector (Assaf, 1993). However, it is unlikely that such costs could be borne by farmers given current groundwater pumping costs of only around US$ 0.13/m^3 - US$0.15/$m^3$, and water values in agriculture as low as US$ 0.2/m^3 (Calow et al, 1996; 1995 prices).

7. ***Import by pipeline.*** - Water could be imported by pipeline from several sources. The economics of such schemes are similar to those of import by sea, and any pipeline scheme would depend on regional cooperation for success. A frequently neglected option is purchase of additional water from the Israelis via the national water carrier. This strategy is probably the simplest in terms of engineering, but the most dependent on political relationships between the interested parties. Water currently bought from Mekerot varies in price according to location and the margin taken by the municipal or village council that purchases and distributes the water. In March 1995, prices of up to NIS 1.8/m^3 were reported (approximately US$ 0.6/m^3 at the March 1995 exchange rate)

b) Improved management of existing supplies

Improved management and conservation of existing resources is an essential priority within the Gaza Strip, although it is unrealistic to suppose that existing sources will meet anything other than a proportion of future needs. Management and conservation should focus on the aquifer, on distribution systems and on end users.

The degradation of the aquifer is exacerbated by a proliferation of unlicensed and unregulated boreholes, ineffective waste water management in municipal areas and unmanaged and unregulated use of fertilisers, pesticides and herbicides in agricultural areas. Unmanaged abstraction increases drawdown and hastens the intrusion of saline water into the aquifer, whilst the majority of waste water is allowed to infiltrate without treatment into some of the more productive parts of the aquifer, polluting an already limited resource. In addition, the substitution of less intensive agricultural systems for highly intensive, horticultural ones on some of the most vulnerable areas of the aquifer has introduced greater contaminant loading. This is a relatively recent phenomenon.

Management options can be grouped by sector and within sectors can be divided into technical measures and their supporting policies. Technical measures are concerned with altering or reducing water use and contaminant loading. Supporting policies - including economic incentives and mandatory controls - serve as inducements to conserve water and reduce load by encouraging the adoption of the technical measures. In view of the nature of this report, an attempt is only made to provide an overview of the options available. More detailed discussion can be found elsewhere (e.g. Calow et al, 1996).

All options will require an enabling institutional environment, with effective and efficient organisations both to manage water resources and to deliver water to consumers and agricultural users. This is an area being addressed both by the Palestinian authorities and by donors, through the creation of the Palestinian Water Authority and strengthening of municipal capabilities.

1. Reducing agricultural water use and contaminant loading.

Although the economic returns of using water in irrigated agriculture are typically lower than in other uses, and within the sector there are wide disparities in water values for different crops (WRAP, 1994; Calow et al 1996), the agricultural sector is by far the largest user of groundwater in the Strip. In addition, agriculture *consumes* more groundwater than other sectors due to evaporation and transpiration losses, although a sizeable proportion is recharged to groundwater as (poor quality) irrigation returns. This indicates that even modest reductions in agricultural water use could potentially liberate relatively large percentage increases for other uses, assuming that the quality of conserved water was suitable for its intended use and that quality could be maintained (see Section 5.4 below).

Agricultural intensification, in particular the rapid growth of horticulture, has raised concerns about the impact of emerging forms of agriculture on groundwater resources. High background levels of Nitrate across the Strip (in some cases over 10 times WHO limits) indicate diffuse pollution from excess application of fertilisers, and similar concerns have been expressed about high pesticide levels. While comprehensive testing for these pollutants does not yet take place, the amounts reportedly used and the inherent vulnerability of the aquifer suggest that contamination is likely to be a growing problem.

Current groundwater usage by all sectors, but especially the agricultural, benefits from an implicit subsidy. Farmers do not pay the full economic cost of groundwater use, which would include the opportunity cost of water in non-agricultural uses, and no users are currently confronted with the 'user cost' which will be imposed on future generations denied use of the aquifer. In circumstances such as these, and in the absence of any form of cooperative (groundwater user) management and regulation, the case for government intervention in the public interest is a strong one. Measures that address the issue of efficient use of water in the agricultural sector, without complementary regulation, may just serve to increase demands as farmers seek to expand production to finance for the new technology needed.

a) Technical options

Measures for reducing agricultural water use and contaminant loading are closely related, and include the following:

- ***Reducing the irrigated area***: There are approximately 184,000 dunums of cultivated land within the Strip, of which roughly 114,000 dunums (62%) are irrigated. Although the proportion of irrigated land has increased considerably this century, present trends are difficult to gauge. In some areas, typically those affected by deteriorating water quality, the trend is being reversed and traditional rainfed systems are reappearing. In others, particularly in the dune areas along the coast, irrigated greenhouse systems are developing in hitherto undeveloped areas. Nevertheless, as competition for scarce land increases, it would seem that agriculture is the likely loser.

- ***Changing the crop mix to favour less water and agrochemical-consuming crops***: This option is closely related to the previous one. In the Gaza Strip, the growth in the importance of citrus has been a main driver of increased agricultural abstraction. Citrus is a very water demanding crop, and with traditional open furrow irrigation systems, water use can approach 1,000 m^3/dunum/year. The importance of citrus is now declining as horticulture has become more profitable. However, even though horticulture generally requires more controlled water applications by means of sprinkler and drip irrigation, water use can still be very high. For example, flowers may require up to 3,000 m^3/dunum/year, and horticulture is associated with much higher rates of agrochemical use. This illustrates how the economic environment within the sector does not, at present, provide the incentives necessary for water conservation. It also illustrates how the use of modern irrigation methods are not *necessarily* associated with reductions in water use if cropping patterns change.

- ***Increasing water use efficiency in irrigation***: All other things being equal, increasing irrigation efficiency reduces the amount of water applied through substitution of capital and/or labour for water. As noted above, the use of modem methods does not automatically bring reductions in use if a change in cropping patterns and agricultural systems serves to increase water demands. Nevertheless, substantial water savings within existing cropping patterns could undoubtedly be made. For example, roughly 13,000 dunums of citrus may still be irrigated using traditional, open furrow methods (SAAR, 1992). In view of the fact that fully irrigated citrus groves under drip or sprinkler systems consume around 30% less water than similar groves under furrow, water savings of almost 4 mcm/year could theoretically be realised through a change in technology alone. Going considerably further, substituting all remaining citrus groves with rainfed systems would yield around 30 mcm/year. Given the fact that citrus is demanding in terms of both water quality and quantity, the water made available would be of a high value. However, it should be borne in mind that the principal source of agricultural load is likely to be horticultural.

- ***Substituting saline water for freshwater in irrigation***: The benefits of using saline water for irrigation are clear as, in theory, each m^3 of saline water used will liberate the same volume of freshwater for other purposes. In addition, agrochemicals applied would not contaminate higher quality sources, assuming that sensitive recharge areas for the freshwater lenses remaining could be protected. Other countries in the Middle East already have experience with the use of salt tolerant cultivars.

- ***Substituting wastewater for freshwater.*** As with the use of saline rather than freshwater for irrigation, the use of waste water could potentially release fresh water for other (higher value) uses. The Gaza North area alone produces over 10 mcm/year of waste water that could be substituted for groundwater of roughly the same quantity currently used for irrigation in Beit Hanoun and Beit Lahia (Grey, 1994). PWA estimate that 50% of agricultural demands could, in theory, be met by the reuse of waste water by the year 2010 (Myers, 1996). In addition to the cultural and educational barriers to adoption noted earlier, however, farmers are also likely to be concerned about relinquishing long established groundwater rights.

- ***Reallocating water from irrigation to municipal uses and users***: Limited reallocation of groundwater within the agricultural sector already occurs in Gaza by means of local, informal, water markets. In this way, water is already being allowed to gravitate towards higher value uses. However, reallocation between sectors, from agricultural to municipal users, does not appear to be occurring. Reasons could include lack of the necessary physical 'plumbing', in terms of pipelines and distribution systems, needed to link regions and sectors, and administrative barriers which might effectively preclude competition between municipal utilities and private pumpers. Alternatively agricultural users could, in theory, sell their water *rights* to municipalities. However, there are significant political and institutional barriers to such trade, including ambiguities over the legalities and traditions of water rights, and difficulties in determining compensation arrangements for the water 'losers' (e.g. level of direct cash payment; provision of indirect compensation via alternative employment). The issue of groundwater rights and legality is a politically sensitive one, as many Palestinians (particularly those who have sunk 'unlicensed and illegal' wells since Israeli withdrawal) would question the validity of legal rights introduced by an occupying power.

Reallocation does not necessarily imply reduced abstraction. Without restrictions on abstraction, agricultural users maintaining title to water might simply decide to increase the rate of pumping in line with the demands of an increasing number of uses, and water intensive (and chemical intensive) agriculture could continue to flourish.

The discussion above raises complex issues for groundwater management as it is clear that, under present institutional and economic arrangements, some of the options described above do not by themselves guarantee reduced water use and reduced pollutant loading. This indicates a need for the creation of an enabling economic and institutional environment in which groundwater conservation, reallocation and protection can take place.

b) Supporting policies

- ***Economic inducements***: At present agricultural water is effectively free to pumpers, as farmers wishing to sink a well must only pay for the capital costs of well construction and the operation and maintenance costs of pumping. In March 1995, pumping costs were reported at around NIS 0.4/m^3 - NIS 0.45m^3 (US$0.13/m^3-US$0.15/m^3 at the March 1995 exchange rate), roughly the same as those quoted by Awartani (1994) for 1990, suggesting that energy prices have remained more or less the same. Israeli settlers in the Strip reportedly benefit from investment and operating subsidies and may therefore pay considerably less for groundwater (PEPA, 1994a), even though agricultural water charges in Israel itself are considerably higher at around US$0.20/m^3.

  While charging users the full economic cost of groundwater (including the opportunity cost of water in alternative (non-agricultural) uses, and 'user cost' imposed on future generations denied use of the aquifer) might be the economist's preferred solution, administering such a system and the setting of an appropriate tariff would seem problematic at best. In all probability; it would also lead to the complete elimination of irrigated agriculture in the Strip. Alternatives, apart from mandatory controls, could include direct economic interventions through, for example, the provision of grants for those making the transition from irrigated to rainfed agriculture, and extension advice on marketing and husbandry. Disincentives could also be used to dissuade farmers from growing 'new' water intensive crops such as flowers. For example, subsidies could be removed for those wanting to grow flowers. In short, moves to grow less water intensive (and agrochemical intensive) crops need encouragement. At present, some farmers are abandoning citrus in favour of water and chemical intensive horticulture.

- ***Regulatory framework***: The new administration is currently grappling with the sensitive issue of borehole licensing, and most commentators are agreed that the existing 'open access' situation has to end if the remaining lenses of freshwater are to be preserved. A water quota system was last applied under Israeli occupation and such a system, if enforced and given the legitimacy of Palestinian authority, would represent perhaps the simplest method of restricting abstraction, at least within those areas deemed sensitive and requiring careful management. Restrictions (and education) are also required to manage agrochemical use within the horticultural sector. Measures may include limits on land use and restrictions placed on applications within sensitive recharge areas, as well as absolute restrictions on the use of certain chemicals, such as soil fumigants.

- ***Education***: public education and the raising of awareness on the importance of groundwater conservation and protection already form an important component of PWA policy. To what extent agricultural users are targeted is not clear, but there is an obvious need to improve the quality of agricultural extension in terms of both advice on fertiliser and pesticide use, and in terms of irrigation management and water conservation.

2. Reducing municipal water use and contaminant loading

Municipal water use accounts for a relatively small proportion of groundwater use in the Strip, but can be considered as the most important and valuable use of water. Domestic water used for drinking and washing must be of high quality and is therefore the most expensive water to supply. For these reasons, losses and waste in the municipal sector are very costly to society. Most households in the Strip are connected to a mains system. Kahan (1987) reports that piped supplies have been made available to 90% of the population living in cities, and about 60% of the population living in small towns and villages.

The majority of households in the Gaza Strip are not served by a sewerage system, but rely on unsealed brick-lined vaults to dispose of waste from latrines. Solid waste is removed periodically by vacuum tankers, but liquid waste can seep through the vaults and reach the aquifer below. Only three communities have reticulated sewerage systems: Gaza City, Jabalia-Nazla village, and Jabalia refugee camp. These are generally in a poor state of repair, and none of the three waste water treatment plants in the Gaza Strip are functioning properly. Instead, they act more as collection stations, discharging waste onto adjacent land where it collects in large pools and infiltrates the aquifer.

a) Technical options

- ***Reducing leakage***: Unaccounted for losses - including leakage and illegal connections - are estimated at around 40% in Gaza City, and similar losses could be expected to occur throughout the Strip. City authorities recognise the problem, but are unable to do much about it with limited human and financial resources. Lack of long term investment in water distribution systems have led to high leakage rates from mains networks. The effect of leakage has been, to an extent, mitigated by consequent recharge to the aquifer. Leakage will, however, limit the economic viability of any new water resource pumped through old pipes, and it is possible that an entirely new distribution network would need to be built to convey new sources of high cost, high value water. Studies carried out in Israel and California indicate that the costs of water saved through leakage control vary significantly, from US\$0.15/m^3 - US\$0.35/m^3 (Arlosoroff, 1995).

- ***Installation of water efficient devices***: A large number of water saving devices have been developed around the world, including low-flush toilets and low volume shower heads. The appropriate question for Gaza is 'which of these devices makes sense in the local context?' The exact types of fixtures to be installed would depend on their relative cost and the water savings of each type. Experience from other countries such as Israel and the US indicate that significant water savings can be made at relatively low cost. For example, retrofitting buildings with water conservation kits (including toilet flush reduction, two-volume flushing, regulated shower heads, and flow regulators in kitchen and bathroom sink taps) has achieved demand reductions of 10-20% at an approximate cost of US\$0.10/m^3 - US\$0.15/m^3 (Arlosoroff, 1995).

- ***Managing wastewater***: this would involve either the repair or replacement of existing systems, and/or the extension of systems into areas currently unserved. Efforts are currently being made to improve the efficiency of the over-loaded waste water treatment plants, and the PWA have plans to build a further three plants with tertiary treatment.

b) Supporting policies

- ***Economic***: Per capita domestic water consumption in Gaza is already low at around 60 lcd, and it is unlikely that price rises which reflected the real cost of water provision and kept pace with inflation would have much effect on demand. However, it seems clear that municipal authorities are currently trapped in a spiral of low prices, poor cost recovery, and consequent failure of operation and maintenance. Consumers in the Gaza Strip pay different tariffs according to the supplier (UNWRA, Mekerot, or municipal water department), but most tariff structures include a fixed charge for the first 10, 20 or 30 m^3, with a progressive increase in rates for every $10m^3$ there after. Reports suggest that households in the Gaza Strip generally pay considerably less for water that those in the West Bank, with prices constrained by concerns over consumer ability and willingness to pay.

  While significant price increases may be politically unacceptable, more effective cost recovery would undoubtedly help provide funds for much needed leakage reduction programmes and new infrastructure. Nevertheless, massive investment over and above what could be collected from users would seem essential. It is also worth noting that water conservation is associated with reductions in wastewater production.

- ***Regulatory framework***: The judicious use of building codes and regulations could be used to ensure that new buildings are equipped with water efficient devices.

- ***Consumer education***.- Consumer education to reduce domestic demand and encourage water conservation will be important, but given the extremely low per capita rates of water supply and existing scarcity it is unrealistic to expect significant reductions in demand through educational programmes alone. However, such campaigns have an important auxiliary role to play in mobilising public support for difficult reforms, such as pricing. There may be more scope for environmental education to reduce pollution.

c) Other measures

In addition to the sector specific policies discussed above there is some scope for generalised measures, addressing the management of the aquifer itself.

- ***Artificial recharge***: The Gaza aquifer is suitable for artificial recharge, and a project to utilise the occasional flash floods of the Wadi Gaza for recharge is under consideration. Large scale artificial recharge schemes would require a source of water for recharge, and other commentators have suggested that excess seasonal waters from the Israeli national water carrier could be stored in the Gaza aquifer for later release. Such schemes have an obvious attraction in areas of high evaporation and land scarcity.

- ***Salinity control measures***: Several engineering options to control and limit saline intrusion might be considered. These include: artificial recharge to generally raise water levels; the establishment of a line of boreholes to create an injection barrier; an extraction barrier that would pump brackish water from near the coast and discharge it to the sea; physical grout curtains; and scavenger wells that would skim fresh water from the aquifer before it discharges to the sea. Such options are likely to be ineffective unless current pumping rates can be reduced.

5.3.2 Desalination's role in Gaza

If a decision is reached to build a large scale power plant involving steam generation, then MSF or MEB may be the preferred option. If diesel generation is involved the low temperature MEB process may be advantageous.

Desalination technology can play a useful role in helping produce potable water from contaminated aquifers, seawater or waste water.

a) Desalination of brackish water

A small RO plant with a capacity of 45 m^3/hr at a cost of $1.15 million was installed in 1994 in the town of Dir-El-Ballah to improve the quality of the drinking water being extracted from the aquifer. In recent years the salinity has increased to 2500 ppm TDS which is substantially higher than the WHO recommendation of 500 ppm TDS max. The plant improves water quality very successfully but has only operated intermittently mainly because of problems with the supply of chemicals necessary for its operation. These problems are not fundamental and there is no doubt that water quality in Gaza could be improved using this technology. The cost of treating the water in this way added 35c/ m^3 to the cost of the water. This very minor treatment was therefore quite expensive. However if this solution were adopted more widely it would lead to more rapid depletion of the aquifer. To produce a litre of potable water requires the extraction of 1.33 litres of raw water. This is therefore only a short term fix. A more fundamental solution is needed involving many of the management options outlined in this report.

b) Waste water recovery

Desalination technology can be used to recover potable water from sewage waste water. This is done in a number of areas. In Israel around 66% of the waste water from Tel Aviv is recovered and taken to potable standards. It is not in fact used for drinking, but technically it could be. The water is piped to Beer-sheba and used for agricultural irrigation. In Orange County in California, Water Factory 21 recovers water to potable standards and re-injects it into the aquifer as a barrier to sea water ingress. The Californian project uses membrane processes to treat the water, UK technology is well suited to do this. This would be a good solution for Gaza either to re-inject the water into the aquifer or to use the water for irrigation. It would be more environmentally friendly than building a sewage outfall into the sea.

Gaza City currently has a sewage system which covers 65% of the city, with refugee camps only partly sewered. Elsewhere vaults or septic tanks are used which have to be emptied by tanker. This is expensive and is done on an irregular basis which results in sewage overflows. The sewage plants that exist were seldom in operation due to breakdowns and lack of trained operators and were, therefore, by-passed with raw sewage going directly into the sea.

The development of the peace process has focused attention on this problem and efforts are being made to bring the existing plants back into operation. Ambitious plans for new sewers and new sewage treatment plants are underway. Various options for dealing with the sludge are under consideration including using it to enhance the soil either directly or as part of a composting project. Various options for recovering and treating the waste water for use in irrigation schemes are being considered. Such projects will be funded by donor countries or the international aid agencies.

c) Desalination of seawater

As a part of the Middle East Peace Process, there are plans to build a gas pipeline from Egypt to Israel with a spur into Gaza. This will give Gaza access to relatively cheap energy. There are also plans to complete the electrical grid round the Mediterranean including a line from Gaza into Egypt. At the moment Gaza is about to sign a contract for the construction of a 170 MW gas turbine power station. Present plans are that this will be a single purpose station on a simple cycle. Consideration is being given to converting this at a later stage to a combined cycle operation. Coupling this to a thermal desalination process is clearly an option but as far as is known no decision has been taken on this at present. Such plants may be able to produce water at a cost of \$1.00/m^3 depending on how the charges are split between electricity and water.

Water quality problems can be solved by desalination technology but only at a price which the people of Gaza may not be able to afford.

5.4 Comparing the options

Against a background of finite resources and growing and competing demands for water, the Palestinian authorities and donor agencies working in the Strip face a considerable challenge in planning water resource development and management. The task of comparing and contrasting options, and of assessing the viability of particular strategies is complicated by the political and economic constraints imposed by the dynamic nature of the peace process. In particular, the resources available to reconstruct the region's economies, especially Palestine's, make ambitious capital schemes attractive because of the potential 'peace dividend'. At the same time pragmatic solutions such as import of water from the Israeli bulk carrier may be politically unacceptable.

5.4.1 Conventional approaches

As discussed above, water scarcity in Gaza is such a serious problem that its resolution will require a comprehensive package of supply side *and* demand side measures.

With all demand management options, it is important to compare the quality as well as the quantity of water saved or made available. In addition, it is important to compare the likely locations of liberated water in relation to intended (alternative) uses, the value of water in its intended use in relation to the costs of conserving the water, and the opportunity cost of the measure. From the above discussion, several important points emerge:

- The quality of water that could potentially be saved in the agricultural sector is likely to be variable, and therefore not all of the same value. In the Gaza Strip two lenses of freshwater remain. There is a pressing need to protect these lenses from further degradation and ensure that this high quality, high value water is conserved for municipal rather than agricultural use. This implies a need for aquifer protection policies focusing on land use, agrochemical use and water use in these two zones.

- In comparing options, economic rather than financial cost-benefit analysis needs to be undertaken. The difference can be illustrated with reference to municipal and agricultural water conservation decisions. From the perspective of the individual living in an urban area, investments in water saving would only be worthwhile if the cost of water saved is less than the cost of water supply. If prices are very low, then investments may not make financial sense. From the perspective of society, however, improving water use efficiency is economic if the cost of conserved water is less than the cost of new supplies (including the opportunity cost of water in an alternative use). When comparing against supply alternatives, it therefore makes *economic* sense to implement all conservation measures whose cost of conserved water is less than the marginal cost of new supplies. Similarly in the agricultural sector, while it may not make financial sense for the individual farmer to invest in modern irrigation systems to conserve water, if a wider perspective is taken and the scarcity value of water to society is considered, the decision may well make economic sense. This is an argument for government intervention in the water sector to ensure that decisions are made according to economic (societal) criteria rather than just the 'private' costs and benefits facing individuals.

- When a number of different options for new supplies or conservation schemes are to be evaluated, a tabulation of the cost of water and its characteristics can be used to rank alternatives. Table 5.2 lists some of the supply augmentation alternatives for the Gaza Strip, whilst Table 5.3 illustrates one way in which different demand management options can begin to be compared. Accurate quantification of the costs is impossible without a detailed case by case examination of each option and site specific factors such as labour, material and land costs. Nevertheless some attempt is made to indicate the likely relative costs of different demand and supply options using 1995 figures from different published and unpublished sources.

Table 5.2 Supply Augmentation Options for the Gaza Strip

OPTION	APPLICABILITY	COST US$/m³	NOTES
Import by tanker	Only practical as part of a large scale project aimed at total substitution of groundwater for all sectors	0.17 - 0.23	Would require an investment of US$300 million, probably impractical
Import of water from Mekerot	This is already the practice in several communities.	0.14 - 0.60	Limited by political and security implications
Desalination, conventional distillation	Practical for medium scale projects.	1.25 - 1.7	May be an option if a major power station is constructed
Desalination, conventional RO	Practical for small communities, but potentially expensive to operate if seawater is used.	1.1 - 1.7	Desalinating brackish water cheaper, but may lead to aquifer degradation.
Greenhouse desalination	Proposed schemes produce small quantities of water for agricultural use only.	1.7 - 2.8	Economic viability depends on agricultural markets
Desalination PV RO	Only suitable for small communities	5.1 - 7	Availability of grid electricity in Gaza reduces incentive for use of PV.

Table 5.3 Demand Management Options for the Gaza Strip

	CHARACTERISTICS OF WATER SAVED Quantity	Quality	Cost/m³(US$)	ENABLING CONDITIONS	COMMENTS
AGRICULTURE					
Reduce irrigated area	Variable	Variable	NA	Economic inducements; mandatory controls	Occurring already, but in areas already affected by declining water quality; freshwater lenses need protecting
Change crop mix	Abandoning citrus yields 30 mcm/yr	Potable in citrus areas	NA	As above, plus agricultural extension advice	Occurring already, but new crops sometimes water intensive; need to encourage rainfed systems
Increase water efficiency	Drip for furrow on citrus yields > 4mcm/yr	As above	<0.2	Economic inducements, plus agricultural extension advice	Will not necessarily reduce water use if incentives favour change to more water demanding crops
Use of saline water	Poor	Variable	NA	As above	Maintains agricultural productivity in areas affected by declining water quality
Use of wastewater	10mcm/yr in North City Region	Potable in some areas of north	<0.15 - 0.40	As above	Farmer and (food) consumer reluctance needs to be overcome
Reallocation to municipal users	Variable	Trade unlikely for poor quality water	≥opportunity cost of water in agriculture	For trade in rights, need well defined and transferable title to water; direct and/or indirect compensation for 'losers' (farmers)	Water transfers require physical and institutional 'plumbing'
MUNICIPAL					
Reduce leakage	10% reduction in municipal use yields 3.5 mcm/yr	Potable	0.15-0.35*	Financial autonomy for supply utility; direct government spending	Raising municipal tariffs to pay for programmes difficult
Install water saving devices	10% reduction in municipal use yields 3.5 mcm/yr	Potable	0.10-0.15*	Building regulations	Codes require strict monitoring and enforcement

Note: figures denoted by * quoted by Arlosoroff (1995) based in projects undertaken in other countries.

5.4.2 Technical Options

All decisions have to be taken against a background of a developed distribution system for water and a grid system for electricity. There are no areas of Gaza that either do not have these facilities or could not be readily coupled to them. This makes the case for renewable energy very difficult.

Energy

The best renewable energy source for Gaza is undoubtedly solar energy. This is already widely used in Gaza for heating domestic water. As a point of interest, it is against the law in Israel to construct a house in Israel without a solar water heater. In Gaza land is in very short supply and therefore is commanding premier prices. It is therefore unlikely that there will be great enthusiasm for a renewable energy process which, if it is going to make a significant impact, will utilise a considerable area of land. This applies both to solar ponds and photovoltaics. Were this analysis being carried out in northern Sinai, the answer might be very different due to the vast areas of land available.

Disposal of municipal and agricultural waste is currently a problem. This is being addressed by a number of studies. One of the options which looks promising is composting. This could be done for municipal solid waste, sewage sludge and agricultural waste. The composting option is viewed favourably and is seen as being sustainable. It is successfully carried out in Egypt and in Israel. An incinerator for the municipal waste could be coupled to a thermal desalination process as is done in Gibraltar.

The mean annual wind speeds in Gaza is 4m/sec, which is too low to be a viable option.

Desalination

All of the processes described in the study (Chapter 2) are viable options. The thermal processes may be more attractive if coupled to a power plant. If fossil fuel sources are available at reasonable prices then a fully integrated power and water complex is undoubtedly the cheapest option for the desalination of seawater in Gaza.

Specific options

PV RO Desalination in Gaza

Whilst PV powered desalination in Gaza is perfectly feasible technically as mentioned above, it is unlikely to be attractive in economic terms. As is stated in 5.3.2 currently there are plans being finalised to build a gas turbine power station in Gaza. There are also plans to couple this to a pipeline supplying gas from Egypt to Israel with a spur into Gaza. This will enable the Palestinian National Authority (PNA) to generate power at competitive rates and certainly well below the rates PV can generate not taking into account the high price of land. Given the high density of population land is at a premium in Gaza. For these reasons PV driven desalination is not seen as a viable option for Gaza.

The Seawater Greenhouse

This process provides a moisture conserving horticultural environment with a water producing process. The water producing process of dehumidification of a saturated air stream has been looked at in the past but has not proved economical in itself. The concept of coupling this process to a horticultural project is novel and looks promising. The process has been demonstrated to work in the Canary islands at a small scale.

The adoption of the seawater greenhouse will not reduce demand within Gaza unless it substitutes for existing horticultural or agricultural water usage. The process as proposed produces water only for use within the greenhouse and attached shade netting.

Two concepts have been examined in Annex A of this report. The first concept is designed to exploit the temperature gradient in the sea and involves considerable investment in a pipe to extract the cold seawater. The second design does not require this pipe and is consequently cheaper, although it produces less water. This may be the more interesting of the two concepts in that it can be more widely applied and does not require a huge and potentially risky capital investment.

5.5 Conclusions and Recommendations for Gaza

5.5.1 Conclusions for Gaza

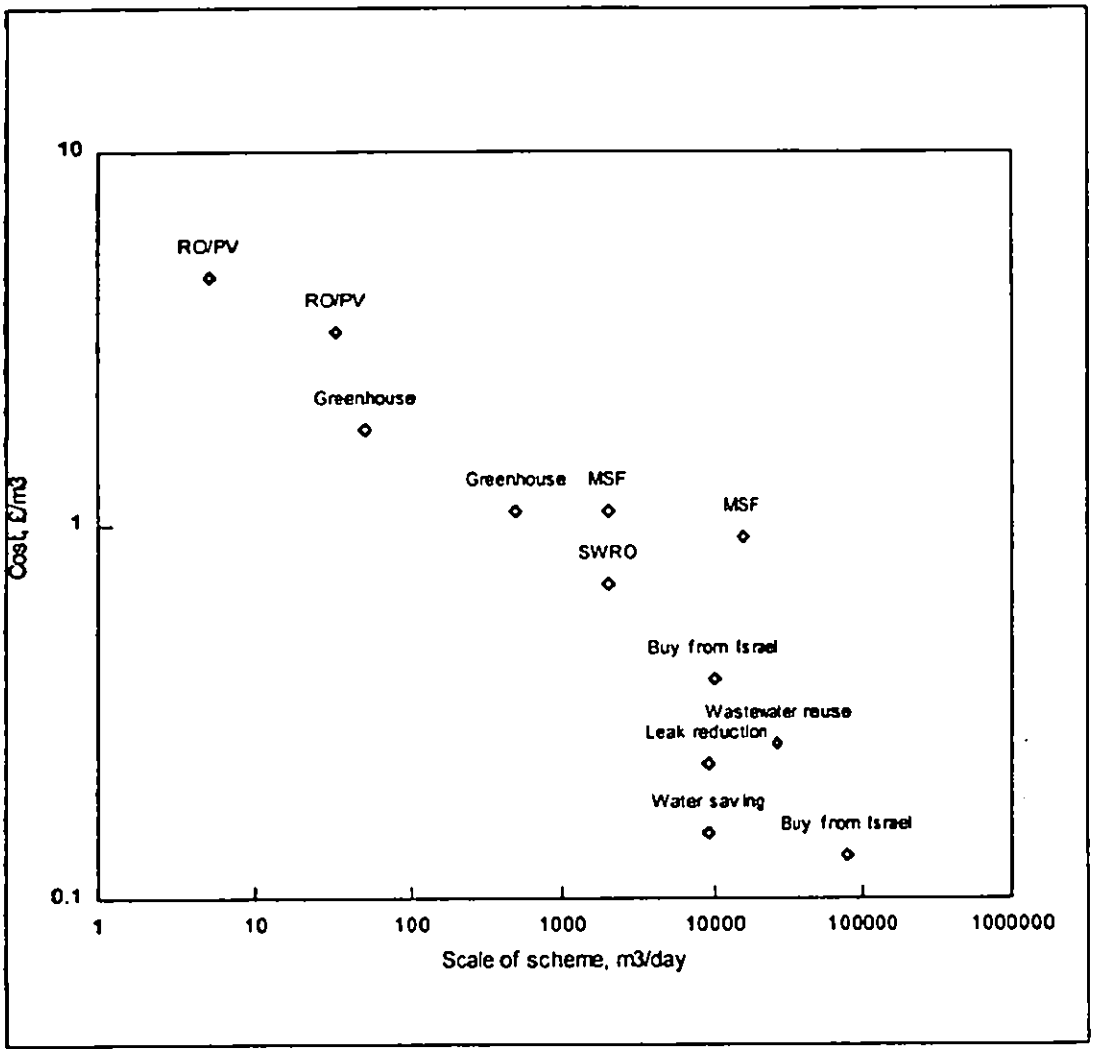
The combination of climate, topography, population pressure and politics give Gaza unique water scarcity problems. Existing water resources are already overexploited, leading to quantifiable degradation of the aquifer. Demands from all sectors are increasing. The legacy of occupation has been a laissez-faire institutional environment without incentives for conservation or effective management of water resources.

Given the scale of Gaza's problems any solution will need to be based on both supply management and demand management measures. The supply management options are limited to the import of water from outside Gaza, the exploitation of wastewater or the desalination of water within Gaza. While there is some scope for managing domestic and industrial demand through programmes of leak reduction and the installation of water efficient appliances, the bulk of demand is generated by the agricultural sector. The replacement of inefficient irrigation practices by modern methods and crop substitution could reduce demand, but in practice farmers will often seek to recoup investment in efficient irrigation technology by increasing the area irrigated, and high value crops use large quantities of potentially polluting agrochemicals.

Significant resolution of water scarcity in Gaza will require the reallocation of water, allowing transfers of water from low return agriculture to high return domestic and industrial use, coupled with integrated resource management to protect the aquifer from further deterioration. This will require institutional and legal developments that can only be addressed by the Palestinian authorities.

Figure 5.3 shows various demand side and supply side options for Gaza, relating the scale of the project to its cost.

Figure 5.3 Water Management Options - Gaza



Desalination is one technology that is under active consideration within Gaza to augment supplies. Desalination of seawater would provide a genuinely new source of water. Desalination of brackish water, while cheaper than desalination of seawater, needs to be managed carefully if it is not to precipitate further aquifer degradation.

Given the current and foreseeable price of renewable energy, it is unlikely that PV RO or other renewable energy based RO options have a role of any significance within Gaza. The factors mitigating against this are:

- high cost of land for solar collection
- low wind speeds
- developed grid for both electricity and water
- plans for power generation using gas from Egypt

The Greenhouse option is possibly feasible for Gaza, although its viability depends to a large extent on prices in a highly volatile agricultural market. The low cost option, which does not rely on a long pipeline to extract cold seawater, would be most appropriate, but would produce a relatively small amount of fresh water purely for agricultural use, while demanding significant areas of expensive land.

5.5.2 Recommendations for Gaza

* The ODA should discuss with the Palestine Water Authority potential water projects within Gaza with a view to selecting projects that are consistent with the authorities' development of an integrated water resource management plan.

• If the effectiveness of investment in the water sector in an area of great scarcity is measured by the production of water at low cost, then the development of leak reduction programmes, the installation of water saving devices and the treatment of wastewater are the most attractive options for investment.

• Present local conditions mitigate against PV desalination as an option. It should not be pursued until costs come down sufficiently to make it a competitive option.

• Disposal of solid waste in Gaza is a problem. Solid waste combustion with associated power generation and desalination should be investigated in greater detail.

* The greenhouse option may be viable, but within an agricultural context rather than as a substantive water supply project. A more detailed study should be carried out for constructing a commercial sized plant in Gaza, addressing issues of land cost and real agricultural returns.

* Investigate options for combining the planned gas fired power station in Gaza with a desalination plant.

The recommendations marked with an asterisk should be given priority.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 General Conclusions and Recommendations

6.1.1 General Conclusions

Water scarcity in semi-arid areas may often reflect poor water management and economic constraints rather than a shortage of water resources. An integrated water resources management strategy appropriate to local circumstances can often reduce demands by making more effective use of existing sources of supply. Although a wide range of measures are available, implementing such a strategy may depend on institutional, legal or other reforms which may require a decade or more before significant improvements can be made.

In the past, increased water demands were usually met by developing new surface water and groundwater supplies. However, this has often had adverse impacts on the environment and sustainability. Due to the rapid increase in population, rising living standards, industrialisation and the degradation of existing sources, water resources management must also consider the role of less conventional sources of supply, such as desalination, or importing supplies from elsewhere. Valid cost comparisons between conventional and non-conventional sources should take account of the water resources available to future generations.

There are a variety of technologies available for the desalination of seawater or brackish water using renewable energy sources. Numerous research and demonstration plants have been built, covering most of the possible combinations of the two processes, with a view to overcoming the problems of matching a discontinuous energy source to a desalination process that is best suited for continuous operation. However, there is still much to be done before such plants can be classed as being commercial.

Seawater is much more expensive to desalinate than brackish water. The cost of water produced by desalination technology using conventional fossil fuels is usually much higher than most economies can afford and much higher than naturally occurring water. Hence the only countries that have invested seriously in desalination are the oil rich Gulf countries. The cost of water produced by desalination using a renewable energy source is normally more expensive than using a conventional fossil fuel. The price of the water has to reflect the high capital investment in the desalination plant and the energy technology. Renewable energy driven desalination can be competitive in remote areas where there is no developed electrical grid or where fossil fuel prices are high. Desalination using renewable energy is not competitive in areas with access to fossil fuels at current market prices and where there is a developed electrical distribution system.

The costs associated with desalination are falling, and are expected to continue to fall. This is especially the case with PV where technology development will have a significant impact on economics. Wind energy prices have already fallen to close to commercial levels and will continue to drop. Lower technology costs will also increase the feasibility of desalination technology in the future.

In the absence of grid electricity or waste heat, the most likely renewable energy sources to be coupled to desalination plants using current technology are wind, solar energy and combustion of municipal solid waste or agricultural waste (biomass). Solar energy plants tend to cover large areas which can be a problem on small islands or in areas where land prices are high. The availability of biomass is questionable if there is a lack of water for agriculture, as given the cost of the water produced by desalination systems it is unlikely that it can be used for agriculture. But, there can be a good market for small desalination plants using renewable energy sources in specific remote locations. In remote coastal communities, without access to alternative water supplies and without access to grid electricity, the PV/wind RO and the Seawater Greenhouse concepts developed for desalination using alternative energy may prove cost effective. Longer term. VC processes could be developed with lower energy consumption than RO. The viability of the Seawater Greenhouse will depend on the specific topography of the coast, its climate and local demand for, and pricing of, horticultural produce. Oceanic islands with seasonal demand from tourism will probably be currently the most appropriate targets for the technology. As the technology is developed they may have wider application.

6.1.2 General Recommendations

Whether water scarcity is already existing, occurring occasionally due to drought or due to foreseeable rising demands, it is recommended that:

* an integrated water resources management strategy should be developed for areas subject to water scarcity in order to reduce demands. An integrated strategy makes more efficient use of existing water resources, and considers the potential contribution from less conventional and external sources of supply. The integrated planning and management strategy should cover the following areas: fiscal policy, legal matters, institutional structure, infrastructural needs, environmental management, water demand and supply issues and availability and costs of energy for water pumping and treatment.

* the strategy should identify any constraints on its implementation, a timescale for its introduction and take account of cost-benefits, the equitable distribution of supplies and intergenerational transfer of resources.

* whilst a range of demand reduction and water supply management measures are available, further work is needed to identify the cost-benefits and water savings for individual measures as well as combinations of measures. A water management planning manual containing information on these aspects, on the factors to be considered, and the planning steps to be taken would aid those responsible for water management in developing countries. It would also be useful to include contact details for organisations and institutions able to provide further advice and information on water management strategies.

* a selection of in-depth case studies should be carried out on existing schemes to identify the critical success factors for water management strategies in developing countries. This would help planners to assess their specific situation and learn from the experience of others.

* The case study on Gaza included in this report would be complemented by similar case studies for representative oceanic islands which may be more appropriate locations for deploying renewable energy desalination systems.

* R&D is needed to overcome the problems with desalination technologies associated with intermittent running of plant.

- R&D is needed for combining renewable energy technology with desalination plants such that there is suitable energy back up and switching technology for a steady power supply.
- * R&D is needed to optimise energy efficiency (use of energy) in small to medium sized RO plants using RES.
- R&D is needed on PV as a power source combined with VC desalination technology (including developments in VC energy efficiency).
- * A survey of the potential market for renewable energy powered desalination plants needs to be undertaken in order to give commercial companies the confidence to invest in product development.

The recommendations marked with an asterisk should be given priority.

6.2 Conclusions and Recommendations for Gaza

6.2.1 Conclusions for Gaza

The combination of climate, topography, population pressure and politics give Gaza unique water scarcity problems. Existing water resources are already overexploited, leading to quantifiable degradation of the aquifer. Demands from all sectors are increasing. The legacy of occupation has been a laissez-faire institutional environment without incentives for conservation or effective management of water resources.

Given the scale of Gaza's problems any solution will need to be based on both supply management and demand management measures. The supply management options are limited to the import of water from outside Gaza, the exploitation of wastewater or the desalination of water within Gaza. While there is some scope for managing domestic and industrial demand through programmes of leak reduction and the installation of water efficient appliances, the bulk of demand is generated by the agricultural sector. The replacement of inefficient irrigation practices by modern methods and crop substitution could reduce demand, but in practice farmers will often seek to recoup investment in efficient irrigation technology by increasing the area irrigated, and high value crops use large quantities of potentially polluting agrochemicals.

Significant resolution of water scarcity in Gaza will require the reallocation of water, allowing transfers of water from low return agriculture to high return domestic and industrial use, coupled with integrated resource management to protect the aquifer from further deterioration. This will require institutional and legal developments that can only be addressed by the Palestinian authorities.

Desalination is one technology that is under active consideration within Gaza to augment supplies. Desalination of seawater would provide a genuinely new source of water. Desalination of brackish water, while cheaper than desalination of seawater, needs to be managed carefully if it is not to precipitate further aquifer degradation. There are no power generation plants in Gaza at present, the electricity grid is powered from generation plant in Israel, so combining desalination plant with existing power plant in Gaza is not an option.

Given the current and foreseeable price of renewable energy, it is unlikely that PV RO or other renewable energy based RO options will have a role of any significance within Gaza in the short to medium term. The factors mitigating against this are:

- low wind speeds
- high cost of land for solar collection
- developed grid for both electricity and water
- plans for power generation using gas from Egypt

The Seawater Greenhouse is possibly a feasible option for Gaza, although its viability depends to a large extent on prices in a highly volatile agricultural market. The low cost option, which does not rely on a long pipeline to extract cold seawater, would be most appropriate, but would produce a relatively small amount of fresh water purely for agricultural use, while demanding significant areas of expensive land.

6.2.2 Recommendations for Gaza

* The ODA should discuss with the Palestine Water Authority potential water projects within Gaza with a view to selecting projects that are consistent with the authorities' development of an integrated water resource management plan.

- If the effectiveness of investment in the water sector in an area of great scarcity is measured by the production of water at low cost, then the development of leak reduction programmes, the installation of water saving devices and the treatment of wastewater are the most attractive options for investment.

- Present local conditions mitigate against PV desalination as an option. It should not be pursued until costs come down sufficiently to make it a competitive option.

- Disposal of solid waste in Gaza is a problem. Solid waste combustion with associated power generation and desalination should be investigated in greater detail.

* The greenhouse option may be viable, but within an agricultural context rather than as a substantive water supply project. A more detailed study should be carried out for constructing a commercial sized plant in Gaza, addressing issues of land cost and real agricultural returns.

* Investigate options for combining the planned gas fired power station in Gaza with a desalination plant.

The recommendations marked with an asterisk should be given priority.

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ANNEX A

ECONOMIC ASSESSMENT OF THE LIGHT WORKS SEAWATER GREENHOUSE

Executive Summary

The Seawater Greenhouse represents a new approach to providing fresh water for growing crops in arid coastal regions. It is based on a Greenhouse, which provides a controlled environment where sea water is used to cool and humidify air, so that fresh water can be condensed from the humid air using heat exchangers. The fresh water is used to irrigate the ground both within the Greenhouse and in a shaded tent area behind the Greenhouse. The principles have been demonstrated at a small-scale over two years, which has enabled the performance of the Seawater Greenhouse to be modelled on a computer.

The likely capital and operating costs of a full sized Reference Scheme (a 1 ha Greenhouse with 16 ha of shaded tent, located in Oman) have been estimated using the predictions from this model and costs based on estimates made in conjunction with experts which have worked extensively in the region. Assuming replication of this scheme, (i.e. a low cost of capital and economies of scale), the fully developed scheme should be moderately profitable (6% annual rate of return over 20 years). However, the profitability depends greatly on the local geography, sea bed topography and the productivity of the scheme and, as such, reasonably conservative assumptions have been used in this analysis.

The Reference Scheme's applicability is limited by the need to draw sea water from a depth of about 1 km. An alternative concept has been developed: the "Low Costs Solution", which avoids the need for a deep sea water pipe. This uses a deeper Greenhouse (100 m front to back), in which the cooling is provided by recirculating sea water, which would make it suitable for locations such as Gaza. The amount of excess water produced per hectare is lower than in the Reference Scheme and so a smaller shaded tent area is adopted. This scheme has not yet been tested at a demonstration scale and so the results from the computer modelling should be treated with caution. However, if it achieves the predicted performance levels, the rate of return on the scheme should be significantly improved (e.g. 23% per annum).

The most important variable in both schemes is the value of the crops produced. The reference values were also chosen in discussion with experts who have worked in the region. However, by locating the Greenhouse in an area which minimises competition and by choosing to grow very high value produce, the Reference Scheme could be capable of producing far higher rates of return (~53% per annum). Confirmation of these higher rates of return would require a detailed regional evaluation of the demand and supply situation for horticultural products.

Contents

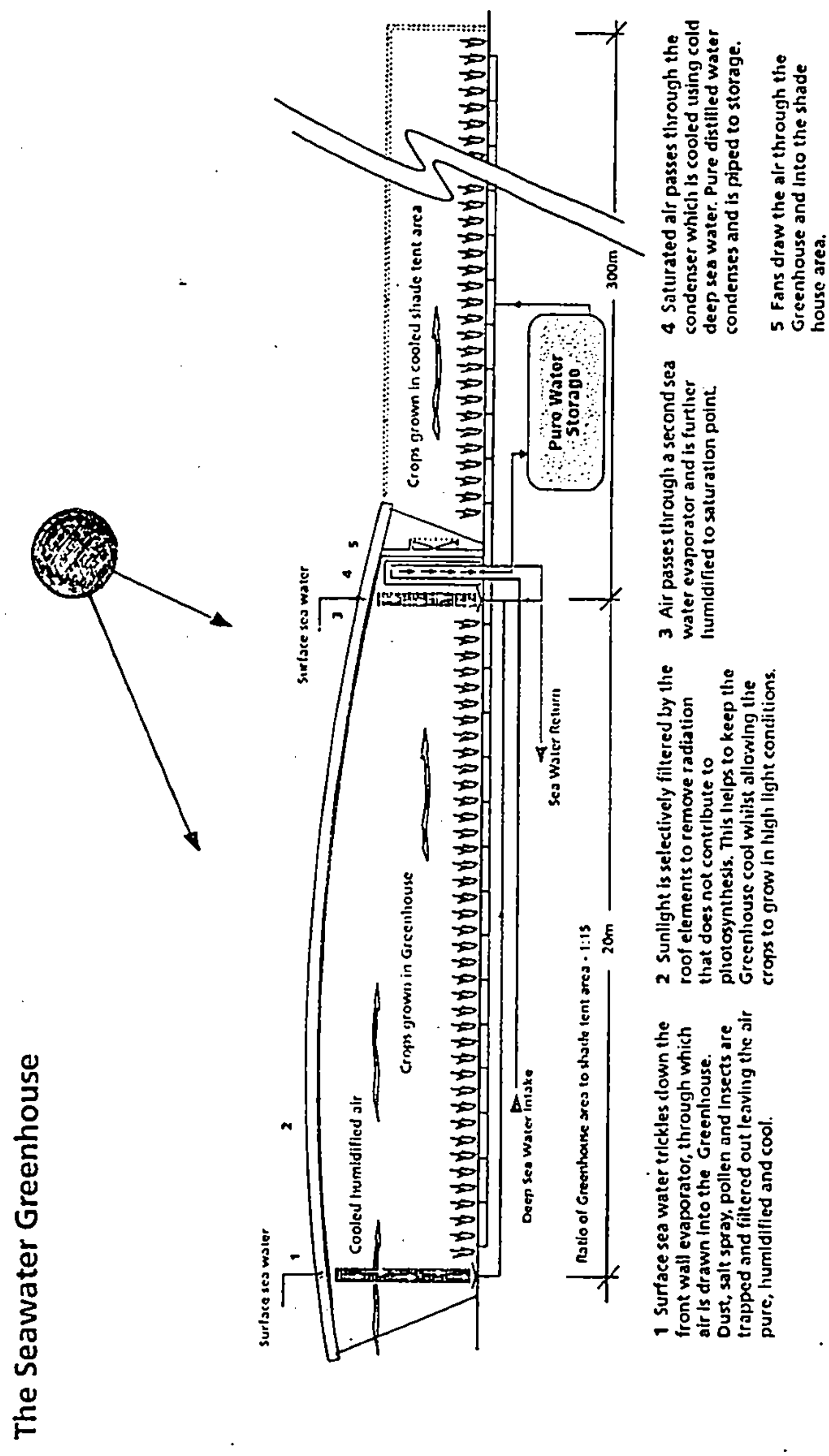
A1. Introduction

The world is facing increasing shortages of fresh water, leading to problems that will effect health, agriculture and industry (Serageldin, 1995). Light Works limited has developed and demonstrated a new horticultural system (Figure A1) that will allow crops to be grown in hot, arid coastal regions (Light Works, 1995). This is based on a Greenhouse, which provides a controlled environment where sea water is used to cool and humidify air, so that fresh water can be condensed from the humid air using heat exchangers. The fresh water is used for growing crops both inside the Greenhouse and in a shaded tent area behind the Greenhouse, as well as for local consumption.

Section A2 of this paper presents a brief outline of this novel scheme, covering its main features. Section A3 presents and evaluation of the likely economics of the Reference Scheme (a greenhouse covering one hectare, with 16 hectares of shaded tent using sea water supplied from off the coast of Oman) and a sensitivity study of the main factors influencing the economics. Section A4 consists of an economic evaluation of an alternative "Low Cost Solution", which would be the preferred scheme for deployment in areas without easy access to deep sea water, such as Gaza. Section A5 addresses the most important factor for the economics of the Seawater Greenhouse concept, the value of the produce grown in the scheme. Section A6 concludes by providing a summary of the main findings of the paper.

It is important to note that, whilst this system has been demonstrated, there is still significant scope for further development. In addition, the system has to be tailored to local climatic and geographical conditions, so there will be considerable variation of the systems performance with location. An attempt has been made to incorporate both of these factors in the economic analysis.

Figure A1 Outline of the Seawater Greenhouse



A2. Outline of the scheme

A2.1 BACKGROUND

Traditional European Greenhouses are designed to provide improved growing conditions, usually by protecting their crops from extreme weather and by providing higher temperatures, especially in winter. In nearly all cases, there is an adequate supply of water for irrigation purposes. The Seawater Greenhouse represents a radical departure from this traditional concept, because it is intended for use in coastal areas with inadequate water supply. Its main purpose is to supply fresh water in sufficient quantities for use in growing crops. This takes place in a controlled humid environment within the Greenhouse, where water loss is minimised, thereby providing excess fresh water for further agriculture in a shaded tent area behind the Greenhouse or for local consumption. The production of high value crops in the Greenhouse and associated workings is essential to offset the high capital costs of the scheme.

A small pilot plant has been built on the ITER Wind Park in Tenerife. Despite this being one of the windiest and most arid parts of Europe, the Seawater Greenhouse has demonstrated its capability for producing fresh water and growing cash crops throughout the two years that it has been in operation.

Operational experience has provided improved understanding of the complex behaviour of this system. This has enabled the designers:

- to model the behaviour of the Greenhouse on a computer;
- to identify the most cost-effective size of scheme for different applications
- to improve the concept for application in different areas.

A2.2 OPERATING PRINCIPLES

The Seawater Greenhouse scheme comprises a special designed Greenhouse (Figure A1) that is approximately 20 m deep (i.e. front to back) and as wide as is required (the initial ideas for a demonstration scheme covers one hectare. Behind the Greenhouse is a much larger area for growing more crops under shaded conditions provided by tenting or other cheap coverings. The scheme works by mimicking the natural hydrological cycle as follows (see Figure A1).

- Warm air enters the mouth of the Greenhouse (either driven by wind or assisted by fans);
- It is cooled and humidified by evaporative pads, that are wetted by sea water;
- The cool, humid air encourages growth of plants in the Greenhouse with minimum water loss by decreasing plant transpiration;
- The growing conditions within the Greenhouse are improved further by using roofing materials that filter the solar radiation, allowing only those wavelengths supportive of photosynthesis to pass through to the crops. This maintains sufficient radiation for growth but reduces solar heating of the Greenhouse;
- After passing over the crops, the warmer air is passed over a second humidifier, where it becomes saturated;
- The saturated air then passes through a condenser, through which is cooled by cold sea water.
- The fresh water from the condensers is stored and used for both crop irrigation and local consumption;

- The cooler air coming out of the Greenhouse can be passed over an area of shade tent to promote further crop production outside the Greenhouse itself.

The cold sea water for this scheme is obtained by pumping sea water from sufficiently deep offshore water depths, to ensure the water has not been heated by the sun. Depending on the seabed topography, this can require a substantial pipeline, which can add significantly to costs.

Depending on the local conditions and design of the Greenhouse, this system can provide 20-60 litres of water per day for each square metre of Greenhouse. Because of the improved environmental conditions inside the Greenhouse (i.e. lower transpiration rates entailing lower irrigation requirements), more water is produced than is required for irrigation of the crops in the Greenhouse. This excess water can be used to irrigate a greater area of crops under the shade tents or it can be used for other purposes.

The economics of this design require an extensive area of cultivation behind the Greenhouse and the production of high value products both inside and outside the Greenhouse.

A3. Economics of the reference scheme

A3.1 MODELLING OF THE SEAWATER GREENHOUSE

As noted in Section A2, the only scheme built to date is a demonstration plant. This plant is too small to prove economically viable and so can not be used as the basis for an economic analysis. However, the plant has been useful in providing a test bed for modelling of the complex systems operating within the Seawater Greenhouse. A software package has been developed for predicting the performance of a Greenhouse system, which can be used to tailor the system to local climatic and geographical constraints (Light Works, 1995). This software package has not been independently evaluated as part of this project but it has successfully predicted the performance of the demonstration plant across a wide variety of conditions, which indicates that some confidence can be placed in its results. Nevertheless, the package needs to be tested against another scheme before complete confidence can be gained.

A3.2 CHOICE OF REFERENCE SCHEME - OMAN

The computer model was used to predict the performance of a 1 ha Greenhouse, situated on the coast of Oman. The optimum depth of the Greenhouse is taken to be 20m, whilst the width of 500m is achieved by using by multi-linking single units together (an operation which is part of conventional Greenhouse practice). A Greenhouse this size would require a flow of cool sea water at almost 0.5 m^3/s. To achieve this the pipeline would have to be approximately 0.7 m in diameter. The favourable sea bed topography of the coast of Oman enables a relatively short length of pipeline to be used (4 km).

Modelling this scheme indicates that it would produce fresh water at an average of 50 $l/day/m^2$ of Greenhouse. Of this, approximately 1 l/day is required for irrigation of each square metre within the Greenhouse and 3 l/day are required for irrigation of each square metre of the shaded tent area behind the Greenhouse (Paton, 1996).

A3.3 CAPITAL COSTS OF REFERENCE SCHEME

For the purposes of this study, the capital costs of the major items (the Greenhouse structure, pipeline, heat exchangers, condensers) were estimated by obtaining quotations from suppliers. Usually, these quotations were for delivery in the UK and so they could be expected to underestimate costs for delivery to other countries. However, these were quotes for one-off systems, deliveries for multiple schemes would be expected to result in a decrease in costs sufficient to offset transportation charges. Also there are probably suppliers for much of this equipment located closer to the country, which would reduce the need to include an extra cost for delivery.

The cost of the pipeline was based on an independent study carried out as part of the demonstration scheme (Quest, 1995).

The main costs for the scheme under study are given in Table A1, together with the background assumptions used to derive the costs.

- The cost of the Greenhouse structure (plus internal irrigation) is approximately £67/m^2, which is similar to the cost estimated by Light Works.
- The dominant cost is that of the pipeline. This will vary from location to location, with the sea water temperature profile and the sea bed topography. However, most of the costs are associated with surveying and installing the pipeline through the splash zone (i.e. the first 30 m of water depth), so the variability of this cost should be small.
- It should be noted that the area of the shade tent is calculated on the excess water production (i.e. that not used in the Greenhouse) and the water production/irrigation rates cited in Section A3.2. The value used in this analysis (16 ha) assumes all excess fresh water is used for irrigating this area.

Table A1 Summary of Main Capital Costs for the Seawater Greenhouse

GREENHOUSE	COSTS	BACKGROUND DATA
Area of Greenhouse		20 m deep x 500 m wide
Cost of Structure	£200,000	£20 per m^2
Front Evaporator	£12,500	£250 per m^3
Back Evaporator	£12,500	£250 per m^3
Condenser	£250,000	£25 per m^2
Fans	£54,200	£542 per 5 m
Piping	£100,000	£200 per m width
INSTALLATION	£42,920	10% of equipment costs
SHADE TENT		
Area of Tent		326.7 m deep x 500 m wide
Cost of Tent	£816,667	£5 per m^2
PIPELINE		
Size of Pipe		710 mm x 4 km
Cost	£1,000,000	

A3.4 OPERATING AND MAINTENANCE COSTS OF REFERENCE SCHEME

The operating and maintenance costs for this scheme comprise several different aspects, as summarised in Table A2. In each case, a conservative estimate has been made to anticipate future economies of scale arising from significant deployment of this scheme.

- It has been assumed that labour costs need to include a proportion of skilled staff for operating the equipment and overseeing the intensive horticulture. The labour costs assumed might therefor be high for some developing countries.
- Maintenance costs of the shade tent and the Greenhouse covers annual replacement of parts and is estimated as 5% of the capital costs.
- Power costs are based on pumping sea water from a depth of 1 km around the Greenhouse and shaded tent area, assuming a cost of 10 p/kWh.

- Operating costs for the mechanical and electrical (M&E) plant cover the maintenance of the pumping plant, condensers, etc. and is estimated to be 2% of the capital cost per annum.

Table A2 Annual Operating and Maintenance Costs for the Scheme

Item	Annual Cost
Electricity Costs	£1,790
GREENHOUSE COSTS	
Maintenance	£31,460
Manure, Sprays, etc.	£13,125
Labour	£26,087
SHADE TENT COSTS	
Maintenance	£40,833
Manure, Sprays, etc.	£3,728
Labour	£27,163
M&E COSTS	£28,584
TOTAL	£172,771

A3.5 ECONOMICS OF THE REFERENCE SCHEME

The above Tables were entered in a spreadsheet based on EXCEL V5. They were used as an input to a calculation of the economics of the scheme. An example of the output of this is shown in Table A3.

- The first rows calculate the size of shaded area from both the amount of excess water left after the Greenhouse and the irrigation rate for the shaded tent area. If some of the water is to be diverted for human consumption, then the 'Fraction of Excess Water for Shade Irrigation' should be set to less than 100%. In practice, the water produced by this method is potable and, as such, almost too good to waste on agriculture. If some of the water from this system were used to satisfy the demands of the operators of the scheme, their waste water could be added to the remaining excess water and used for irrigation. Hence, it is appropriate to say that all the excess water could be used for irrigation.
- The second set of rows under 'Annual Costs' calculate the annual O&M costs and amortised costs; the latter assume a 20 year lifetime and a 5 % discount rate.
- The third set of rows under 'Annual Sales' assumes that the Greenhouse has a horticulture productivity of £225,000/ha/year, and the shaded tent area of £12,500/ha/year. This is approximately 25% greater than a UK-based facility but very much less than some crops in the prototype scheme in the Canaries which had productivities of nearly an order of magnitude greater than this (Thompson, 1995). This is a key factor in determining the economics of this approach and is discussed further in Section A5.
- The more customary rate of return calculation is carried out in the final rows, assuming a cost of finance of 5% (Nix, 1994).

Table A3 An Example Calculation of the Economics of the Seawater Greenhouse Reference Scheme for Oman

ITEM	Value	COMMENT
OUTPUT		
Fresh Water (l/day)	500,000	50 l/m²/day
Rate of Greenhouse Irrigation (l/day)	10,000	1 l/m²/day
Rate of Shade Tent Irrigation (l/day)		3 l/m²/day
Fraction of Excess Water for Shade Tent Irrigation		100%
Area of Shade Tent (ha)	16	
Volume of Fresh Water Left Over (l/day)	0	
ANNUAL COSTS		
Discount Rate		10%
Lifetime (years)		20
Total Capital Costs	£2,488,787	
Amortised Costs (per year)	£292,332	
O&M Costs (per year)	£172,771	
Total Annual Cost	£465,103	
ANNUAL SALES		
Net Sales from Greenhouse	£225,000	£225,000 per ha/year
Net Sales from Shaded Tent	£204,167	£12,500 per ha/year
Total Annual Sales	£429,167	
COST OF SUPPLY OF EXCESS WATER	N/A	
RATE OF RETURN CALCULATION		
Finance Rate	5%	
Finance Costs	£124,439	
Annual Margin	£138,135	
Rate of Return	5.3%	

These figures indicate that the scheme should be moderately profitable (a rate of return of 5.3% per annum), in addition to supplying work, sustenance and water for the indigenous population. However, it should be emphasised that these figures anticipate significant deployment (and hence economies of scale) and are sensitive to the local climate and geography.

A3.6 SENSITIVITY STUDY ON THE REFERENCE SCHEME

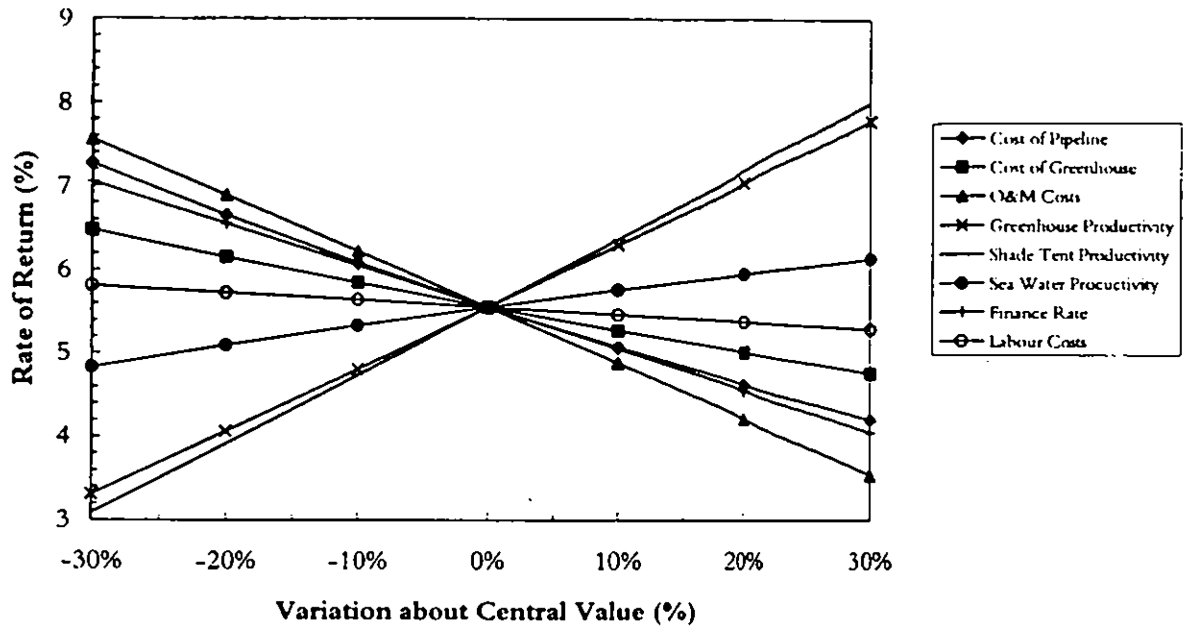
In order to assess the robustness of this analysis, a sensitivity study was carried out to determine the effect of the main parameters on the calculated rate of return. The values ascribed to the most important aspects of the scheme were varied by up to ± 30% about the central value assumed above.

The resulting plot (Figure A2) shows that the most important factors are the income from the produce grown in the Greenhouse and shaded tent area. There is considerable uncertainty about this value and, as explained in Section A3.5, the assumptions behind it are likely to be conservative. Light Works envisages that several pilot schemes might be established to serve as training centres for use of this technology. This should enable the establishment and spread of best practice, which will probably result in higher productivity for both the Greenhouse and shaded tent areas. This point is discussed further in Section A5.

The influence of the other factors are discussed below in order of their importance.

- The central rate of finance charges (5%) assumes a proven technology with productivity rates, costs, etc. supported by figures from extensive deployment experience. Normally, agricultural schemes involving this level of uncertainty would attract a higher rate of financing (e.g. 20%).
- The central value for operation and maintenance costs (including labour) is 7% of the capital cost. This is likely to be a conservative figure but one which should be achievable with a fully developed scheme.
- The cost of the pipeline is unlikely to vary significantly (see Section A3.3), providing cold water is available not too far below the surface of the sea.
- The cost of the Greenhouse structure might be reduced slightly if a local manufacturer could be found. A large proportion of the overall capital cost of the Greenhouse is associated with the condensers, which are typically an expensive construction (e.g. welded cupronickel). Light Works have identified an alternative approach that uses cheaper materials and simpler construction methods, which they anticipate bringing about up to a 75% reduction in the costs of the condensers. If this could be achieved, it would increase the rate of return by approximately 1.5% (assuming central values for other variables).
- Within the range looked at in this report, the productivity rate of fresh water has only a small influence on the rate of return. Light Works have identified several ways of potentially increasing the amount of fresh water produced for a given size of Greenhouse (e.g. applying feedback control to air and water flow rates). These might improve productivity by up to 80%, which would result in a increase in the rate of return of approximately 1.4% (assuming central values for other variables).
- Labour costs (for which there are limited available data) have only a minimal effect on the rate of return. Indeed, if all labour were free, there would be only a 2% increase in the rate of return (assuming central values for other variables).

Figure A2 Sensitivity Study of the Seawater Greenhouse Reference Scheme



A4 Reference to Gaza - the low cost solution

The scheme assessed in Section A3 is of limited applicability to Gaza, because the relatively gentle slope of the sea bed in the Mediterranean would probably require a long pipe to reach the required depth.

As an alternative approach to deploying this technology in such areas, Light Works have been developing other ways of achieving the required thermal differentials within the greenhouse. One of these, "The Low Cost Solution" uses a redesigned system (Davies, 1996) incorporating:

- sea water for cooling the condensers being provided by the front evaporative pads;
- a longer length of Greenhouse (100 m) to increase the temperature differential between front and back;
- no deep sea pipe or solar panels;
- a net to divide the roof space from the planting area
- a reduced area of shaded tent.

The above analysis was repeated using these changes and the results from a "more accurate model" of heat loss and transpiration using environmental data for Oman (Davies, 1996). The preliminary results indicate that the rate of excess water production decreased (and hence a much smaller area of shaded tent is used) but this was more than offset by the large reduction in costs associated with avoiding the deep sea pipe.

Using the same approach as developed for the reference Oman scheme (Section A3), the anticipated rate of return increased from 6% to nearly 23% as shown in Table A4. Therefore, if the practical performance of this new concept matches that predicted theoretically, the scheme should be economically viable in Gaza. In addition, the smaller capital costs associated with this new configuration and the higher rates of return would make this the favoured option for all locations. However, this would require confirmation of the predicted performance by a demonstration or pilot scheme.

Table A4 An Example Calculation of the Economics of the Seawater Greenhouse Low Cost Solution

ITEM	Value	COMMENT	
OUTPUT			
Fresh Water (l/day)	50,000	5	$l/m^2/day$
Rate of Greenhouse Irrigation (l/day)	28,400	2.84	$l/m^2/day$
Rate of Shade Tent Irrigation (l/day)		3	$l/m^2/day$
Fraction of Excess Water for Shade Tent Irrigation		100%	
Area of Shade Tent (ha)	1		
Volume of Fresh Water Left Over (l/day)	0		
ANNUAL COSTS			
Discount Rate		10%	
Lifetime (years)		20	
Total Capital Costs	£560,424		
Amortised Costs (per year)	£65,827		
O&M Costs (per year)	£77,525		
Total Annual Cost	£143,352		
ANNUAL SALES			
Net Sales from Greenhouse	£225,000	£225,000	per ha/year
Net Sales from Shaded Tent	£9,000	£12,500	per ha/year
Total Annual Sales	£234,000		
COST OF SUPPLY OF EXCESS WATER	N/A		
RATE OF RETURN CALCULATION			
Finance Rate	5%		
Finance Costs	£28,021		
Annual Margin	£128,454		
Rate of Return	23%		

A5 The high productivity scheme

The most important factor influencing the economics of the Seawater Greenhouse concept is the annual revenue earned from sale of crops (see Section A3.5). For the above schemes, this was based on a productivity of £225,000 per hectare in the Greenhouse and £12,500 per hectare in the shaded tent area. However, it is the intention of the designer that the Greenhouse should improve on this by growing high value produce in niche markets. This would require:

- siting of the Greenhouse in areas that minimise competition; the ability of the Seawater Greenhouse to provide water for irrigation in otherwise arid areas greatly contributes to this;
- selection of high value crops (e.g. cut flowers inside the Greenhouse and asparagus or ornamental palms in the shaded tent area);
- production of crops "out of season" when they would command the greatest added value.

Within the length of time available for this project, it has not been possible to carry out a full evaluation of these factors. However, discussions with experts in high value horticulture (Phillips, 1996) suggest that these would increase the revenue from the whole scheme to annual sales of between £2 million and £6 million, (primarily from increased value of crops grown in the shaded tent area). An annual sales value of about £2¼ million (i.e. near the minimum of this range) was incorporated in the spreadsheet used to assess the economics of this scheme. Changes were made to the costs of labour, fertilisers, etc. required by this increased productivity. In addition, a finance rate of 20% was assumed, reflecting the greater risks associated with guaranteeing all the key factors outlined above.

The resulting analyses of the Reference Scheme and the Low Cost Solution are shown in Tables A5 and A6 respectively. The greater value of the produce in the High Productivity Reference Scheme increased the rate of return from 6% to 53%, despite the higher costs of capital. However, the higher value of the produce in the High Productivity - Low Cost Solution scheme was offset by the higher cost of capital, so that the rate of return remained relatively constant at 20%. Therefore, if such sales could be achieved, solutions based on the design incorporated in Reference Scheme (i.e. deep sea pipe and extended shade tent area) would become the preferred solution in all locations with easy access to deep sea water (e.g. Oman).

It should be emphasised that these results are very sensitive to the value of the crops grown, as shown in Figure A2 for the High Productivity, Reference Scheme. In order to quantify reliably the likely rates of return for high productivity schemes, a detailed evaluation of the regional demand and supply of horticultural produce would be required for the area selected for deployment.

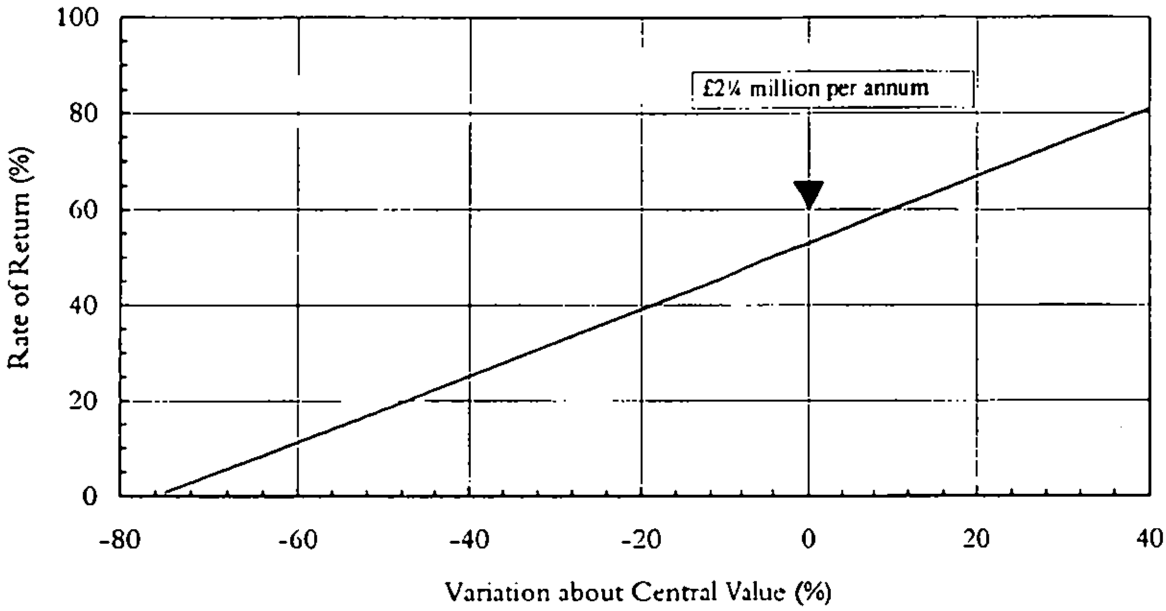
Table A5 A Calculation of the Economics of the Seawater Greenhouse: Reference Scheme with High Productivity

ITEM	Value	COMMENT
OUTPUT		
Fresh Water (l/day)	500,000	50 l/m^2/day
Rate of Greenhouse Irrigation (l/day)	10,000	1 l/m^2/day
Rate of Shade Tent Irrigation (l/day)		3 l/m^2/day
Fraction of Excess Water for Shade Tent Irrigation		100%
Area of Shade Tent (ha)	16	
Volume of Fresh Water Left Over (l/day)	0	
ANNUAL COSTS		
Discount Rate		10%
Lifetime (years)		20
Total Capital Costs	£2,488,787	
Amortised Costs (per year)	£292,332	
O&M Costs (per year)	£450,793	
Total Annual Cost	£743,125	
ANNUAL SALES		
Net Sales from Greenhouse	£225,000	£225,000 per ha/year
Net Sales from Shaded Tent	£2,041,667	£125,000 per ha/year
Total Annual Sales	£2,266,667	
COST OF SUPPLY OF EXCESS WATER	N/A	
RATE OF RETURN CALCULATION		
Finance Rate	20%	
Finance Costs	£497,757	
Annual Margin	£1,318,117	
Rate of Return	53%	

Table A6 An Example of the Economics of the Seawater Greenhouse: Low Cost Solution - High Productivity Scheme

ITEM	Value	COMMENT
OUTPUT		
Fresh Water (l/day)	50,000	5 l/m^2/day
Rate of Greenhouse Irrigation (l/day)	28,400	2.84 l/m^2/day
Rate of Shade Tent Irrigation (l/day)		3 l/m^2/day
Fraction of Excess Water for Shade Tent Irrigation		100%
Area of Shade Tent (ha)	1	
Volume of Fresh Water Left Over (l/day)	0	
ANNUAL COSTS		
Discount Rate		10%
Lifetime (years)		20
Total Capital Costs	£560,424	
Amortised Costs (per year)	£65,827	
O&M Costs (per year)	£89,781	
Total Annual Cost	£155,608	
ANNUAL SALES		
Net Sales from Greenhouse	£225,000	£225,000 per ha/year
Net Sales from Shaded Tent	£90,000	£12,500 per ha/year
Total Annual Sales	£315,000	
COST OF SUPPLY OF EXCESS WATER	N/A	
RATE OF RETURN CALCULATION		
Finance Rate	20%	
Finance Costs	£112,085	
Annual Margin	£113,134	
Rate of Return	20%	

Figure A2 Influence on the variation of sales of produce on the annual rate of return for the High Productivity Reference Scheme.



A6. Summary

The Seawater Greenhouse represents a new approach to providing fresh water for growing crops in arid coastal regions. It is based on a Greenhouse, which provides a controlled environment where sea water is used to cool and humidify air, so that fresh water can be condensed from the humid air using heat exchangers. The fresh water is used to irrigate the ground both within the Greenhouse and in a shaded tent area behind the Greenhouse. The principles have been demonstrated at a small-scale over two years, which has enabled the performance of the Seawater Greenhouse to be modelled on a computer.

The likely capital and operating costs of a full sized Reference Scheme (a 1 ha Greenhouse with 16 ha of shaded tent, located in Oman) have been estimated using the predictions from this model and costs based on estimates made in conjunction with experts which have worked extensively in the region. Assuming replication of this scheme, (i.e. a low cost of capital and economies of scale), the fully developed scheme should be moderately profitable (6% annual rate of return over 20 years). However, the profitability depends greatly on the local geography, sea bed topography and the productivity of the scheme and, as such, reasonably conservative assumptions have been used in this analysis.

The Reference Scheme's applicability is limited by the need to draw sea water from a depth of about 1 km. An alternative concept has been developed: the "Low Costs Solution", which avoids the need for a deep sea water pipe. This uses a deeper Greenhouse (100 m front to back), in which the cooling is provided by recirculating sea water, which would make it suitable for locations such as Gaza. The amount of excess water produced per hectare is lower than in the Reference Scheme and so a smaller shaded tent area is adopted. This scheme has not yet been tested at a demonstration scale and so the results from the computer modelling should be treated with caution. However, if it achieves the predicted performance levels, the rate of return on the scheme should be significantly improved (e.g. 23% per annum).

The most important variable in both schemes is the value of the crops produced. The reference values were also chosen in discussion with experts who have worked in the region. However, by locating the Greenhouse in an area which minimises competition and by choosing to grow very high value produce, the Reference Scheme could be capable of producing far higher rates of return (~53% per annum). Confirmation of these higher rates of return would require a detailed regional evaluation of the demand and supply situation for horticultural products.

A7. References

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ANNEX B

ECONOMIC ASSESSMENT THE DULAS PV POWERED REVERSE OSMOSIS DESALINATION PLANT

Executive Summary

Dulas Ltd. has proposed a reverse osmosis (RO) system, which utilises well proven RO technology but with a photovoltaics energy supply and an enhancement to improve the overall efficiency of the scheme by recovering energy from the RO process.

The economics of this approach were evaluated for two sizes of scheme (producing 5 and 32 m^3 of fresh water daily) for both the prototype and mass produced systems. The costs used in the analysis were obtained primarily from direct quotations from manufacturers, whilst the efficiencies of various aspects of the scheme were based on previous experience of similar technologies.

The resulting costs of the various schemes have been listed below. The most important external variable effecting the production costs is the rate of finance, which was taken to be 20 % for the prototype schemes and 10% for the replicated schemes.

These costs are high compared to the cost of production from existing RO plant. This is attributable primarily to the small-scale of the scheme (which could not benefit from economies of size) and the use of PV cells for energy generation, which have a high capital cost. Further cost reductions might be achieved by going to a larger scale plant but this could present problems in finding sufficient area for the PV cells in some locations.

Costs of Fresh Water from the Various Schemes

Scheme	Daily Output (m^3)	Rate of Finance (%)	Cost of Fresh Water (£/m^3)
Prototype	5	20	9.7
Prototype	32	20	6.9
Replicated	32	10	3.3

Contents

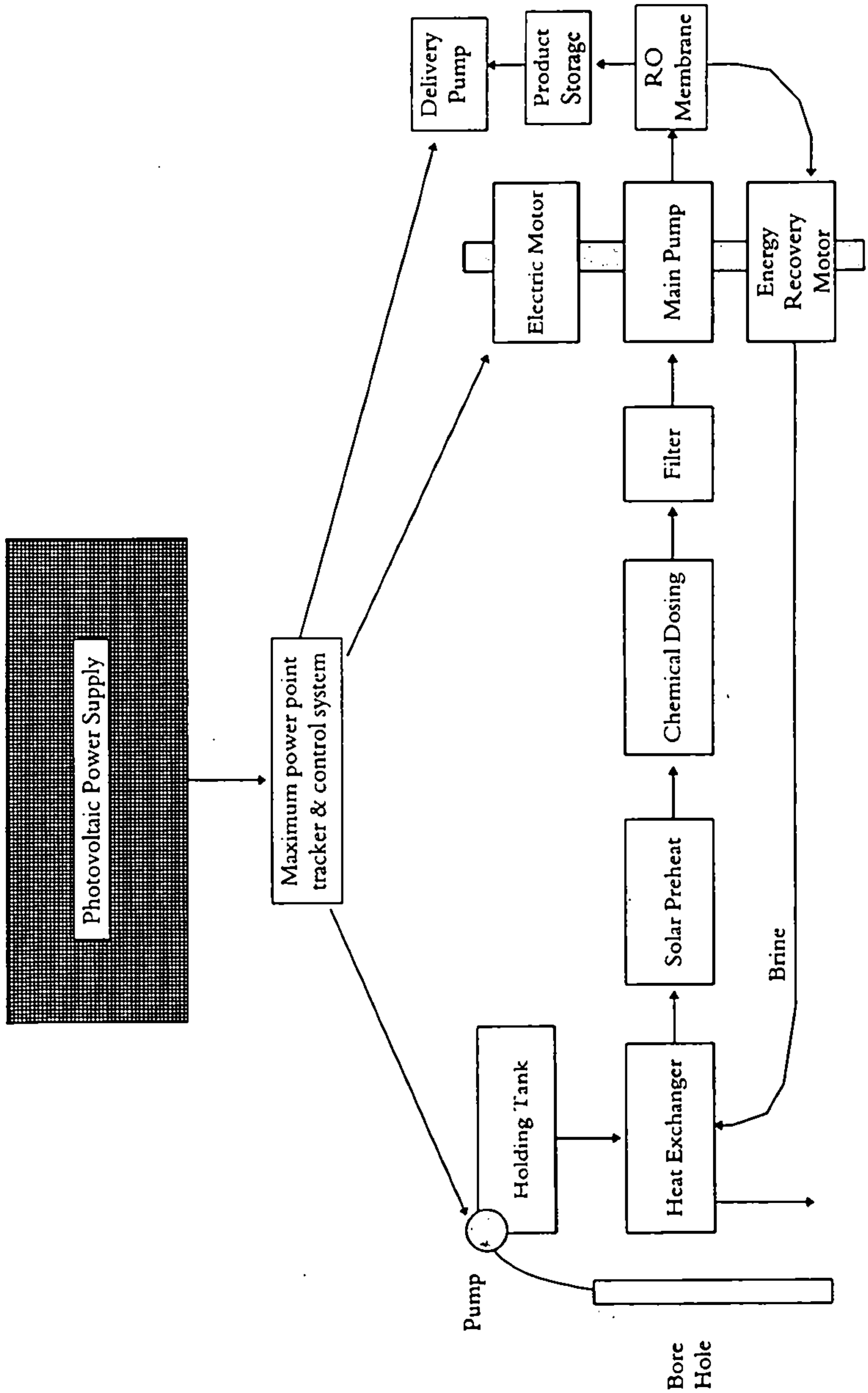
B1. Introduction

The world is facing increasing shortages of fresh water, leading to problems that will effect health, agriculture and industry. In many regions, fresh water is already being provided by desalination of sea water or brackish waters. Numerous methods have been developed for achieving this, including reverse osmosis (RO) powered by grid or diesel generated electricity.

Dulas Ltd. has proposed a new RO system (Figure B1). This utilises well proven RO technology but with a photovoltaics energy supply and energy recovery.

This paper reviews the system (Section B2) before going on to calculate the likely cost of fresh water from a small-scale prototype, large-scale prototype and large-scale mass produced schemes in Sections B3, B4 and B5 respectively.

Figure B1 Photovoltaic Powered, Reverse Osmosis System

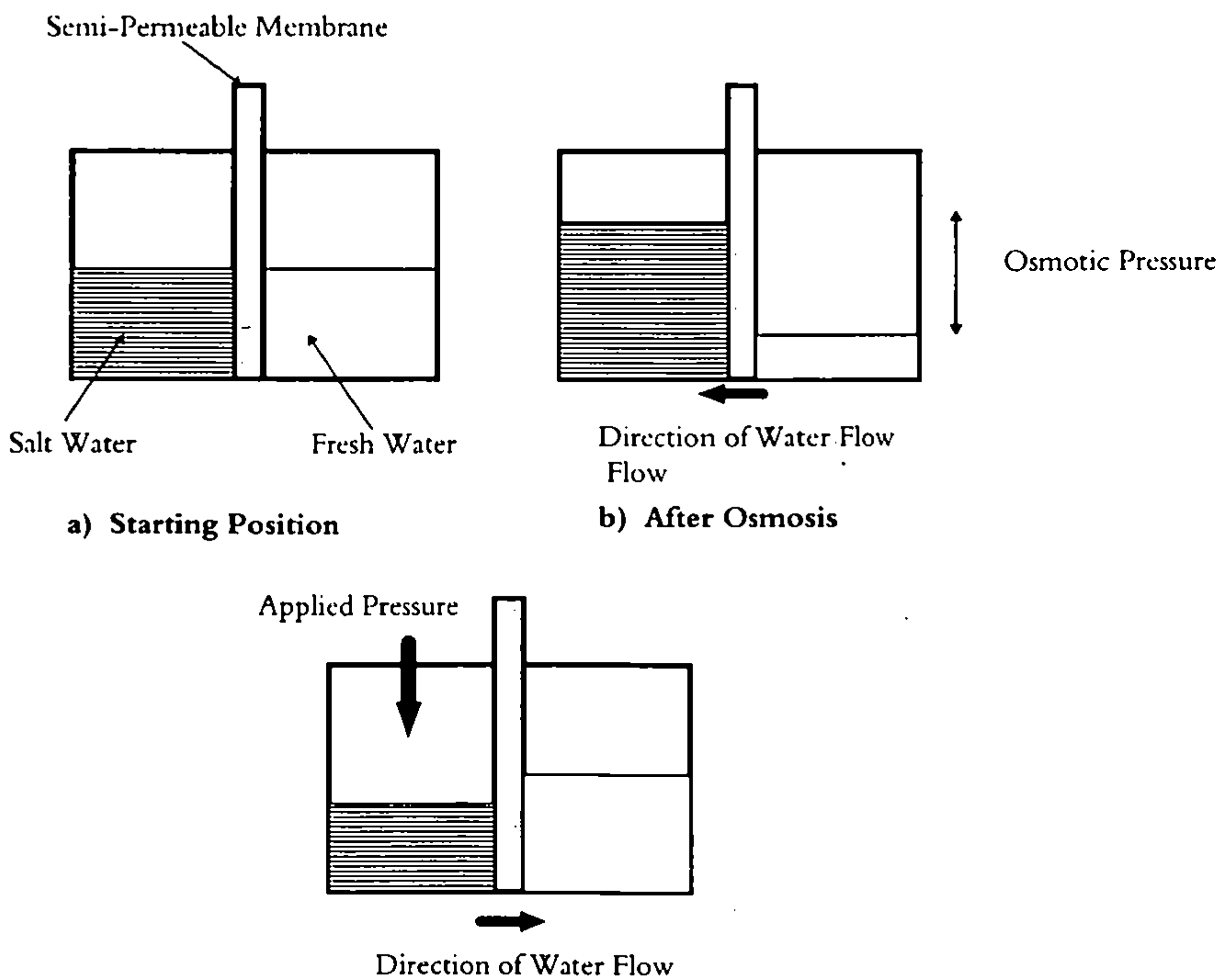


B2. Outline of the scheme

B2.1 OPERATING PRINCIPLES

If a saline solution is separated from fresh water by a semi-permeable membrane (a. in Figure B2), the fresh water will gradually pass through the membrane into the saline solution in an attempt to equalise the concentration of salt on both sides of the membrane. When this occurs with water inside a container (b. in Figure B2), the increase in volume of the saline side of the membrane will result in the water level rising above that on the fresh water side, this difference in height being a measure of the osmotic pressure. Conversely, if an external pressure (greater than the osmotic pressure) is applied to the saline solution side, then the water flow will reverse direction, from the concentrated solution to the fresh water side. The application of pressure to achieve this reverse osmosis requires energy and results in an increase in the volume of available fresh water (c. in Figure B2) at the expense of a reduced volume of more concentrated saline solution.

Figure B2 Operating Principles of Reverse Osmosis



a) Starting Position

b) After Osmosis

c) With Reverse Osmosis

B2.2 OUTLINE OF SCHEME

A diagrammatic outline of the scheme is shown in Figure B1. Solar powered photovoltaic cells are used to drive the processes directly (i.e. no condition monitoring, storage, etc.). This approach is claimed to have several features:

- It allows the plant to operate away from an electricity grid (the cheaper electricity available off a grid, would make this scheme uneconomic if used near a grid);
- It will limit the operating time of the plant to day light hours and hence lower maintenance costs. However, the diurnal stop-start and pressure fluctuations might increase the need for maintenance;
- it will require a larger RO plant than would otherwise be required because of the intermittent nature of its operation;
- it will require variable speed pumps to match the available solar power;
- it will avoid losses associated with batteries.

The PV cells will be mounted on a sun tracking system, which will increase the output by about 40%. They will operate at 120 V DC. However, the operation of this and some other aspects of the scheme will require some diurnal energy storage, which is not present in the current outline of the scheme.

The PV output is used to pump saline water from a bore hole using a standard centrifugal pump. This will probably occur at the start and end of the day, when the light levels are too low to operate the rest of the RO plant. When the available solar energy is sufficient, this water is stored in a holding tank, before being passed through a heat exchanger and solar preheater to raise its temperature to 35 °C, which is close to the optimum operating temperature for the RO plant. The saline water is then dosed with chemicals and filtered to remove particles in order to prolong the life of the RO membranes.

The PV system powers the main motor (permanent magnet DC type) which is connected to both the high pressure pump (which feeds the saline solution to the semi-permeable membrane) and the energy recovery motor. This pump provides a pressure of 60 bar, to feed a RO plant and is of conventional specification. The RO plant produces both "fresh" water (the permeate), which is stored for use, and a more concentrated brine solution, which is still at a high pressure. By passing it through an energy recovery motor (a pressure exchange device), most of this energy can be recovered, thereby increasing the overall efficiency of the scheme and reducing its costs. A commercially available design has been adopted for this motor. The low pressure concentrated brine is fed to the heat exchanger to warm up the incoming brine before being discharged.

Overall, the scheme aims to avoid the need for grid or diesel generated electricity by making the system sufficiently efficient that it can be operated commercially by PV cells. Without these increases in efficiency, more PV cells would be required, entailing a prohibitively high capital cost.

Two sizes of scheme have been assessed, with outputs of 5 m^3 per day (for small-scale use) and 32 m^3 per day (for use by a whole village). In order to differentiate between prototype schemes and mass production, both a one-off scheme and a multi-replicated scheme have been considered.

B3. Economics of the prototype small-scale scheme

B3.1 OUTPUT FROM THE SCHEME

Dulas Ltd had modelled the system on a computer. The model calculated the output of the scheme using one hourly steps throughout a representative day. It used solar irradiation characteristics representative of the Middle East (Figure B3) and typical efficiencies for the various parts of the scheme (Figure B4). The model was used to size the scheme for production of 5 and 32 m^3 per day.

This model was evaluated briefly and no errors were found. Its output was checked against another model produced previously for similar calculations for other regions and no significant discrepancies were found.

In their model, Dulas have assumed a 100% availability. This has not been achieved by any RO plant. Given the variable power input, an overall availability of 90% has been adopted. This is slightly lower than for large-scale plants, allowing for its operation in remote areas.

Figure B3 Solar Irradiation Characteristics Used in Modelling

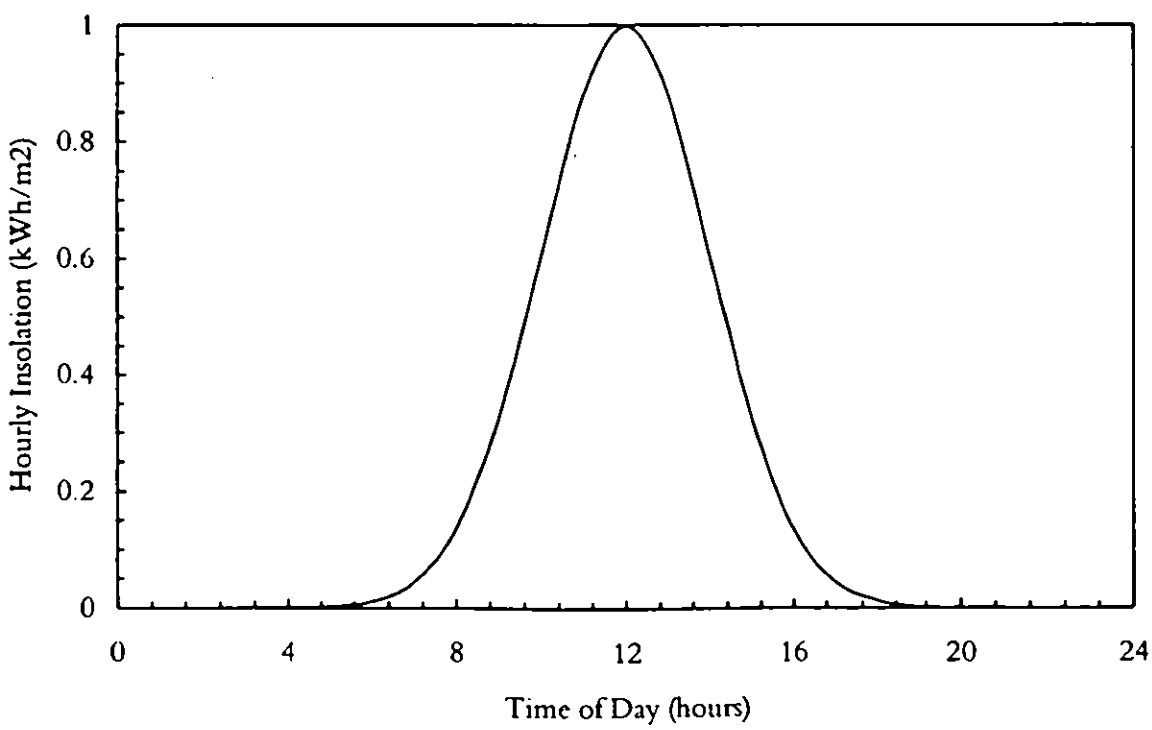
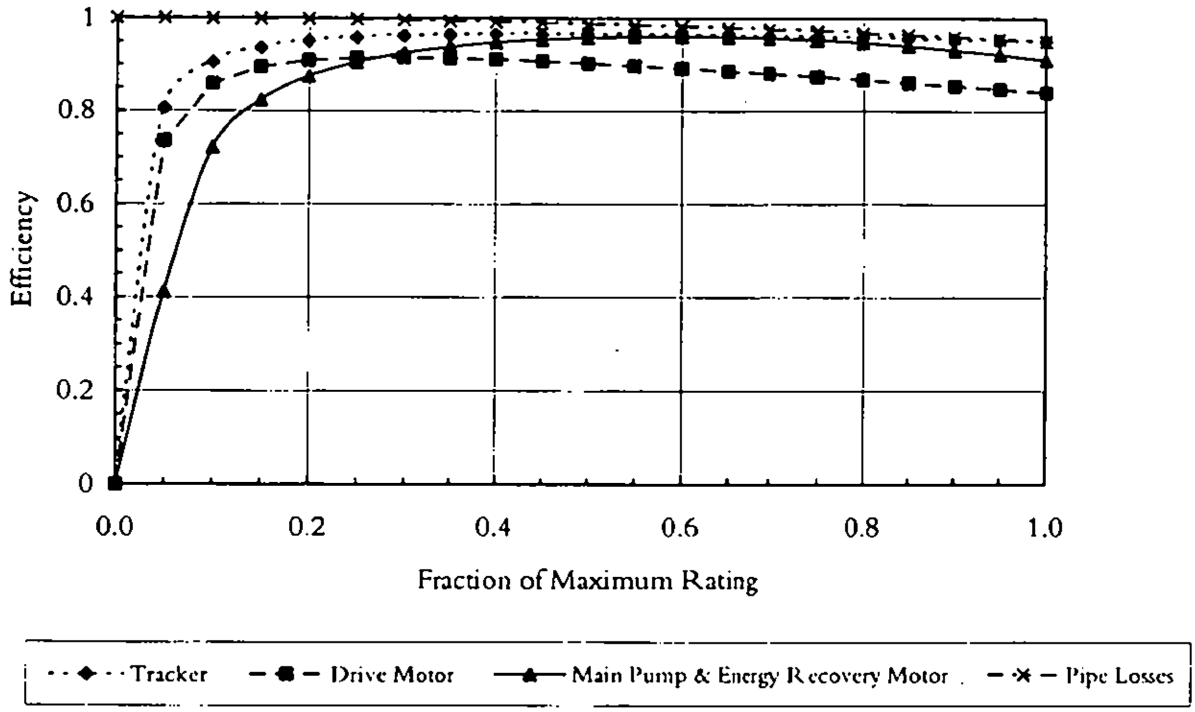


Figure B4 Efficiencies of the Main Components in the System



B3.2 CAPITAL COSTS

A single, small-scale scheme has been broken down into its main capital cost centres, as shown in Table B1. The costs of the main items were obtained from written quotations from suitable suppliers or manufacturers. In all cases, the quotations were for standard, "off the shelf" equipment; no novel technology (with its associated cost uncertainties) was involved. In addition, care was taken wherever possible to ensure complete compatibility between the designated items and their service requirements.

The costs of the incidental items were derived from either quotations or from comparison with other applications. Design, delivery, assembly and installation is estimated at 15% of the capital costs (£8,061), whilst project management and system optimisation is estimated at a further 10% of the scheme (£6,180). These ratios are taken from a range of engineering schemes.

Therefore, the complete capital cost of the whole scheme is £67,980.

B3.2 OPERATING AND MAINTENANCE COSTS

Once operating, the main operation and maintenance (O&M) is associated with repair of the high pressure pumps, adjustment the chemistry of the saline solution for the RO process and the periodic replacement of the semi-permeable membranes. The capital cost of these items were based on quotations for standard operating practice. The cost of labour was based on using skilled labour at appropriate day rates (£ 250 per diem). The total, annual O&M cost (allowing 10% for spare parts for the pumps) is estimated as £2,261 as shown in Table B2.

Table B1 Summary of Capital Costs for Small-Scale Prototype Scheme

Item	Cost
PV Plant	£10,355
PV Tracking	£1,900
Auxiliary System	£1,512
RO Plant	£30,000
Control System	£2,000
Maximum Power Point Tracker	£960
Holding Tank	£375
Feed Water Pre Heater	£2,380
Energy Recovery Motor	£698
Pump & Controls	£1,000
Ancillary (piping, etc.)	£2,559
TOTAL	£53,739

Table B2 Annual O&M Costs for the Small-Scale Prototype Scheme

Item	Cost
Replacement Membranes	£250
Consumables	£1,085
Local Labour	£720
Management, advice, etc.	£206
TOTAL	£2,261

B3.3 COSTS OF FRESH WATER FOR THE PROTOTYPE SYSTEM

Using the information derived above for the prototype system, the cost of producing 5 m^3 of fresh water per day can be estimated for a given finance rate on capital as shown in Table B3. A value of £9.65/m^3 is taken as representative of this prototype scheme.

In order to assess the robustness of this analysis, a sensitivity study was carried out to determine the effect of the main parameters on the calculated rate of return. The values ascribed to the most important aspects of the scheme were varied by up to $\pm$ 30% about the central value assumed above.

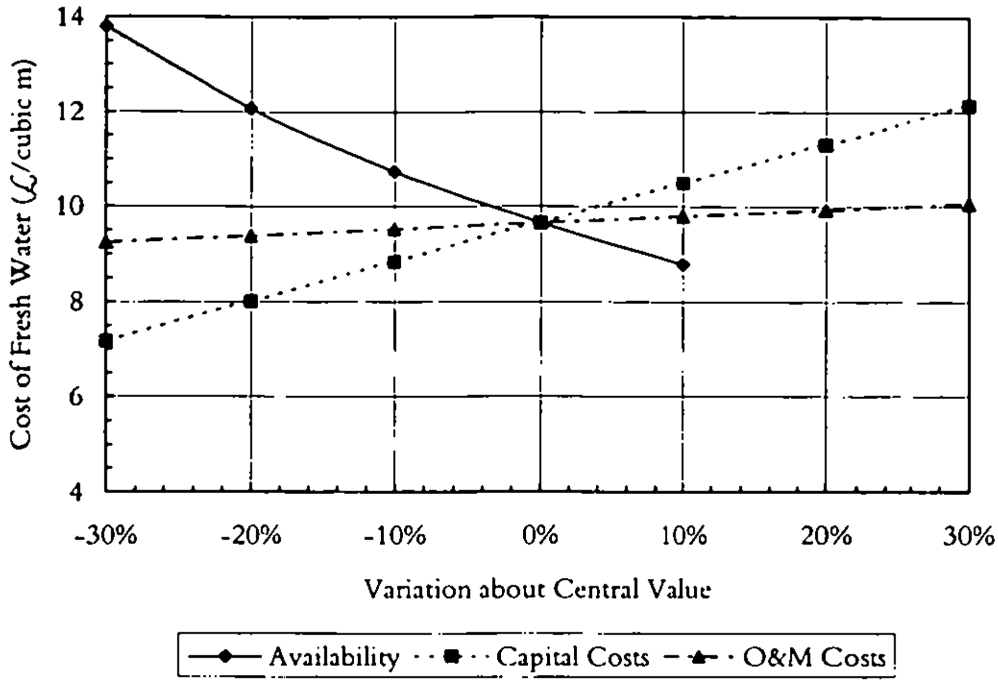
Table B3 Economics of the Small-Scale Prototype Scheme

Item	Central Value
Availability	90%
Output of Fresh Water	4.5 m^3/day
Capital Costs	£67,980
Finance Rate	20%
Annual Capital Cost	£13,596
O&M Costs	£2,261
Total Annual Costs	£15,857
Costs of Fresh Water	9.65 £/m^3

The resulting plot (Figure B5) shows the effect of the most important factors: the availability, the capital cost of the scheme, the rate of finance and the O&M costs.

- An availability of 90% has been assumed as a central value. Increasing this to a maximum would lower the cost by nearly £1 to £8.7 /m^3.
- Nearly 90% of the direct capital costs of the scheme have been obtained from quotations. Therefore, the main uncertainty here is that associated with design, delivery, assembly and installation of the system (£8,061) and overall project management/system optimisation (£6,180). As stated above, these values were obtained from comparison with engineering project of a similar nature and together they account for just over 20% of the total costs of the scheme. Therefore, any uncertainty associated with these costs are likely to be accommodated within the variation shown in Figure B5.
- Since this is taken to be a prototype scheme, a high rate of finance is deemed appropriate (20%). The effect of lower rates of finance is addressed in the Section B5.
- O&M costs have a negligible effect on the overall economics of the scheme.

Figure B5 Sensitivity Analysis of the Small-Scale Prototype Scheme



B4 Economics of the prototype large-scale scheme

An analysis similar to that undertaken in Section B3 was carried out for the prototype, large-scale scheme, which is capable of delivering 32 m^3 of fresh water daily. The capital and O&M were derived in a similar way to those for the small-scale scheme (Tables B4 and B5 respectively). The only difference was in the energy recovery motor, because, at present, there is no commercially available motor of sufficient size. Therefore, the cost of this was estimated by scaling the cost of the small-scale motor to the required power levels. This is a relatively small capital item and so any uncertainties will have little effect on the final results

The same rates were used for the additional costs associated with design, delivery, assembly and installation of the system (15%)) and overall project management/system optimisation (10%).

Table B4 Summary of Capital Costs for Large-Scale Prototype Scheme

Item	Cost
PV Plant	£61,382
PV Tracking	£11,726
Auxiliary System	£2,500
RO Plant	£130,000
Control System	£2,000
Maximum Power Point Tracker	£5,100
Holding Tank	£990
Feed Water Pre Heater	£12,068
Energy Recovery Motor	£3,491
Pump & Controls	£5,000
Ancillary (piping, etc.)	£11,713
TOTAL	£245,970

Table B5 Annual O&M Costs for the Large-Scale Prototype Scheme

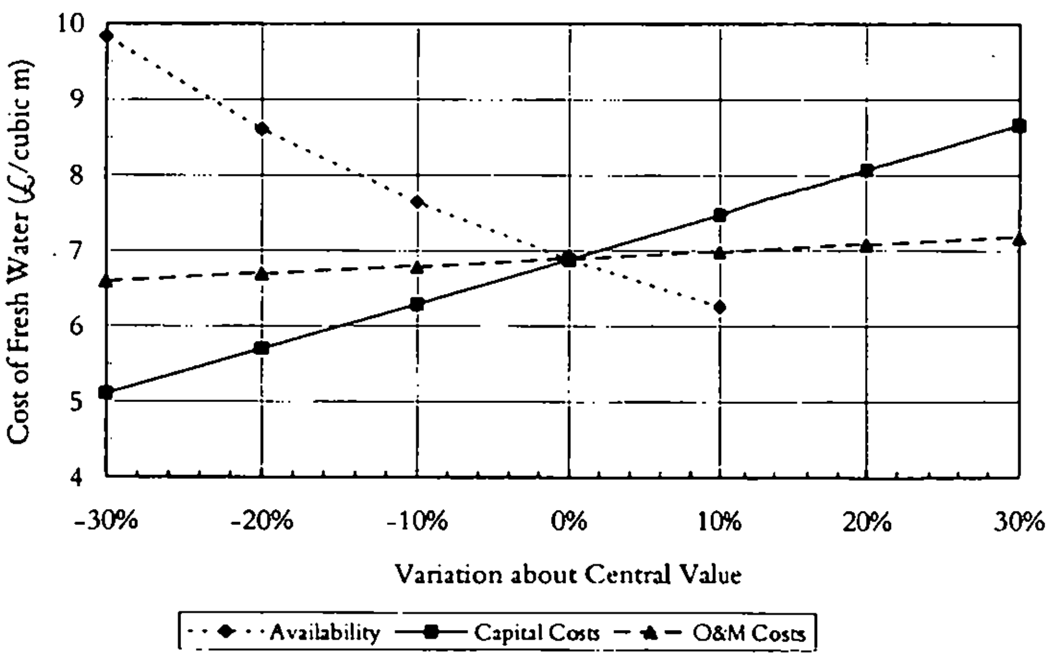
Item	Cost
Replacement Membranes	£800
Consumables	£6,969
Local Labour	£1,440
Management, advice, etc.	£921
TOTAL	£10,130

The overall cost of fresh water production was considerably lower than that estimated for the small-scale scheme (£6.9 /m^3 v £8.7 /m^3), as shown in Table B6. This indicates that there will probably considerable potential economies of scale on moving to larger schemes. The variation of the water production costs with availability, O&M costs, capital costs and rate of finance is shown in Figure B6.

Table B6 Economics of the Large-Scale Prototype Scheme

Item	Central Value
Availability	90%
Output of Fresh Water	29 m^3/day
Capital Costs	£311,152
Finance Rate	20%
Annual Capital Cost	£62,230
O&M Costs	£10,130
Total Annual Costs	£72,360
Costs of Fresh Water	6.88 £/m^3

Figure B6 Sensitivity Analysis of the Large-Scale Prototype Scheme



B5 Economics of the replicated large-scale scheme

Where possible, information was supplied by the manufacturers on the likely discounts obtainable for bulk purchase (i.e. for 1,000 of the large-scale scheme). This resulted in moderate discounts as shown in Table B7, the largest being for the RO plant (25%). A lower rate for design, delivery, assembly and installation of the system was adopted (10%).

No economies of scale were assumed in the O&M of the replicated scheme compared to the prototype scheme.

Table B7 Comparison of Capital Costs of the Replicated and Prototype Large-Scale Schemes

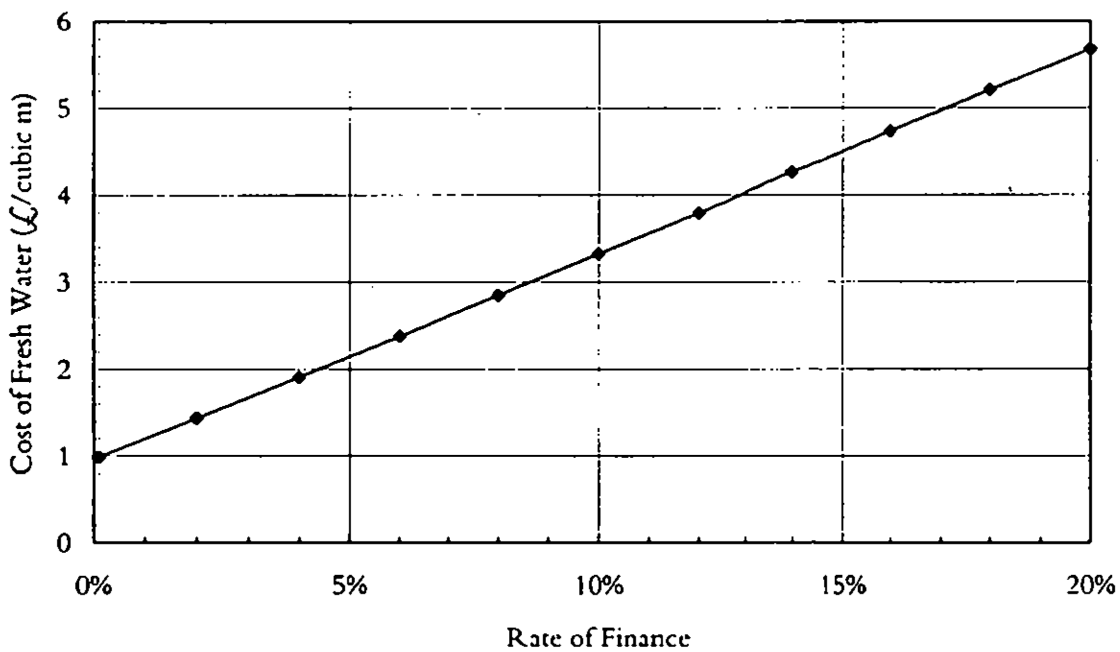
Item	Cost for Prototype	Cost for Replicated Scheme
PV Plant	£61,382	£57,699
PV Tracking	£11,726	£11,726
Auxiliary System	£2,500	£2,125
RO Plant	£130,000	£97,500
Control System	£2,000	£1,700
Maximum Power Point Tracker	£5,100	£4,355
Holding Tank	£990	£990
Feed Water Pre Heater	£12,068	£10,861
Energy Recovery Motor	£3,491	£3,491
Pump & Controls	£5,000	£4,500
Ancillary (piping, etc.)	£11,708	£9,746
TOTAL	£245,875	£204,673

In considering the likely financing of the scheme, it was assumed that a lower rate of finance (10 %) would be applicable, reflecting the greater confidence in the technology following proving by the prototype scheme. The resulting cost of fresh water production is less than 50% of that produced by the prototype scheme, as shown in Table B8 and in Figure B7.

Table B8 Economics of the Large-Scale Replicated Scheme

Item	Value
Availability	90%
Output of Fresh Water	29 m^3/day
Capital Costs	£247,655
Finance Rate	10%
Annual Capital Cost	£24,765
O&M Costs	£10,130
Total Annual Costs	£34,895
Costs of Fresh Water	3.32 £/m^3

Figure B7 Cost of Fresh Water Production for the Large-Scale Replicated Scheme



B6 Discussion and summary

The PV powered RO system proposed by Dulas Ltd is considered capable of supplying fresh water in remote areas far from accessible grid connection. The scheme as proposed is relatively small-scale, in accordance with its application at a village level.

The relative costs of fresh water supplied by this scheme is high compared to large-scale plant. This is attributable to two main reasons:

- The use of PV as the power supply is a capital intensive solution. However, it might be the more economic solution in remote locations away from easy grid connection or supply of fuel for diesel generation.
- The small size of these schemes means that they do not achieve the economies of size of conventional, large-scale RO systems; the capital cost per cubic metre of water per day is approximately an order of magnitude greater than large-scale schemes.

Therefore, the application of this PV RO system should not be compared directly to large-scale systems.

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