Water Supply for Majuro, Republic of Marshall Islands

A Technical Appraisal for Feasible Options

SOPAC/ Water Resource Unit
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SOPAC Technical Report 258

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1. Introduction

Majuro is currently facing a severe drought in the wake of the current ENSO (El Niño Southern Oscillation) event. The Government of the Republic of the Marshall Islands (RMI) through its Fiji Embassy requested SOPAC's Water Resource Unit on 27 February 1998 to undertake, as soon as possible, an appraisal of feasible options to alleviate drought impacts in the short and longer term for the Majuro area.

This appraisal is not a pre-feasibility study. It should be seen as an extension to SOPAC Technical Report No. 236, Water & Sanitation Sector Strategy and Action Plan, Action Plan. That report had been forwarded to the relevant water managers and decision makers in November 1996. It should be acknowledged that those recommended strategies and actions, if implemented, would have meant a significant alleviation to the current water crisis.

2. Overview and Current Water Problems

The primary source for freshwater is rain. Rainwater collection systems widely used in most water- short countries are not very well developed although existing legislation requires new buildings to be provided with rainwater collection and storage facilities. In some favourable locations some of the rainwater may accumulate in a freshwater lens which can be accessed through wells.

On Majuro Atoll the average daily quantity available for distribution to the community is about 3,700 m^3 produced both and from rainwater harvested from part of the paved area of the international airport and the Laura groundwater lens

The basic information for the Majuro water supply system has been summarised in Table 1.

		Unit	Comments
Population			
RMI total	65460	[c]	Based on extrapolation of 1988 census data
Majuro total:	29460	[c]	Based on extrapolation of 1988 census data
Water Supply Majuro:			
Actual Supply:	3700	[m^3/d]	
Provided through:			
Community System	2727	[m^3/d]	Rainwater harvested on the international airport Groundwater Lens
Rainwater Catchments	999	[m^3/d]	Roof catchments, storage supplemented with community water
Groundwater Wells	74	[m^3/d]	Isolated wells
Average Daily Per Capita Consumption:	126	[l/c/d]	Freshwater; toilets are served by a separate seawater system

Table 1: Basic Data for the Majuro Water Supply

Current water problems on Majuro Atoll are mainly the result off the ENSO (El Niño) effect combined with a slightly exaggerated average demand for drinking water[1]. The El Niño effect can be roughly characterised by the absence of the normally prevailing easterly tradewinds, which allow warm water from the West Pacific to flow deep into the East Pacific (see Figure 1). As a rule of thumb this leads to dryer periods in the West Pacific and more Cyclones and floods in the East Pacific though significant local differences may occur.

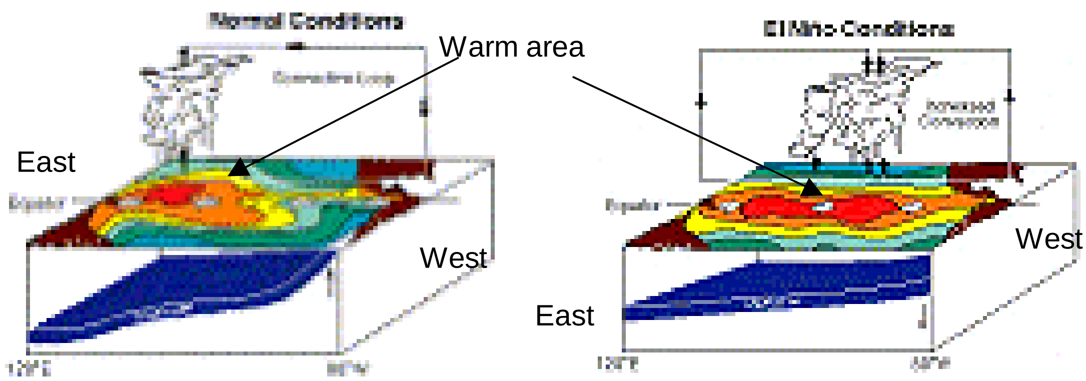
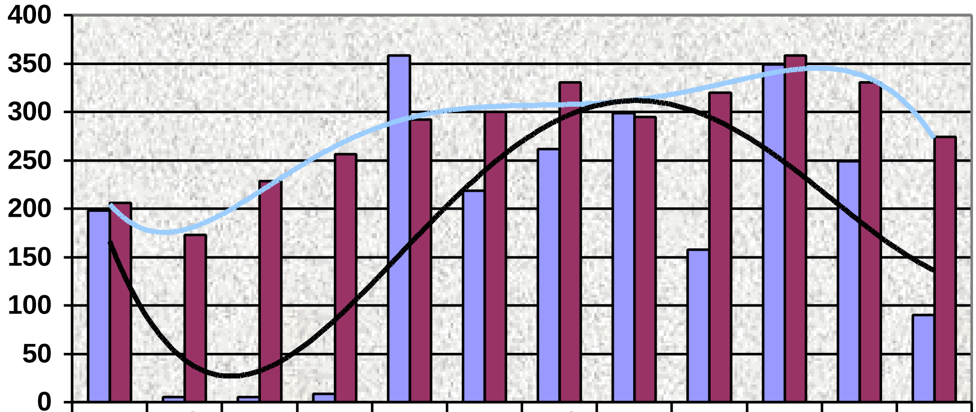


Figure 1: Normal weather condition and El Niño Condition in the Pacific.

[1] Note that the given figure of 125 l/c/d refers only to drinking water.

The Majuro Atoll receives usually about 3300 mm of rain per year. Rainfall is generally highest in October and lower in February. Extended droughts throughout the period from February to April are well known on Majuro and recently occurred in 1970, 1982 and 1992. Figure 2 shows rainfall data for an average year and a typical drought year with their respective trendlines.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Typical Drought Year	198.12	5.08	5.08	8.89	358.14	218.44	261.62	298.45	157.48	349.25	248.92	90.17
Average Rainfall	205.74	172.72	228.6	256.54	292.1	299.72	330.2	294.64	320.04	358.14	330.2	274.32

Figure 2: Average Rainfall compared with Typical Drought Year Rainfall in Millimetre for Majuro Atoll

3. Possible Water Supply Options

3.1 Low-technology options: Rainwater Harvesting and Runoff collection

The Marshall Islands Government requested an appraisal for possible water supply technologies with special emphasis on desalination technology. This prioritisation does not necessarily reflect that those technologies represent the most appropriate or most economic solution. Therefore Appendix 1 gives a concise overview about alternatives which in part are already applied for the water supply in the RMI and for which local experience is readily available. Options discussed there include:

- Rainwater Harvesting from Rooftop Catchments
- Rainwater harvesting in Situ
- Runoff collection from Paved and Unpaved Roads.

3.2 Medium Technology Option: Wastewater Reuse

3.2.1 Wastewater Reuse

Once freshwater has been used for an economic or beneficial purpose, it is generally discarded as waste. In many countries, these wastewater are discharged, either as untreated waste or as treated effluent, into natural watercourses, from which they are abstracted for further use after undergoing "self-purification" within the stream. Through this system of indirect reuse, wastewater may be reused up to a dozen times or more before being discharged to the sea. Such indirect reuse is common in the larger river systems of Latin America. However, more direct reuse is also possible: the technology to reclaim wastewater as potable or process waters is a technically feasible option for agricultural and some industrial purposes (such as for cooling water or sanitary flushing), and a largely experimental option for the supply of domestic water. Wastewater reuse for drinking raises public health, and possibly religious, cultural or aesthetic concerns among consumers. The adoption of wastewater treatment and subsequent reuse as a means of supplying freshwater is also determined by economic factors.

In many countries, water quality standards have been developed governing the discharge of wastewater into the environment. Wastewater, in this context, includes sewage effluent, stormwater runoff, and industrial discharges. The necessity to protect the natural environment from wastewater-related pollution has led to much improved treatment techniques. Extending these technologies to the treatment of wastewater to potable standards was a logical extension of this protection and augmentation process.

Technical Description

One of the most critical steps in any reuse program is to protect the public health, especially that of workers and consumers. To this end, it is most important to neutralise or eliminate any infectious agents or pathogenic organisms that may be present in the wastewater. For some reuse applications, such as irrigation of non-food crop plants, secondary treatment may be acceptable. For other applications, further disinfection, by such methods as chlorination or ozonation, may be necessary. Table 2 presents a range of typical survival times for potential pathogens in water and other media.

Pathogen	Freshwater and sewage	Crops	Soil
Viruses	< 120 but usually < 50	< 60 but usually < 15	< 100 but usually < 20
Bacteria	< 60 but usually < 30	< 30 but usually < 15	< 70 but usually < 20
Protozoa	< 30 but usually < 15	< 10 but usually < 2	< 70 but usually < 20

Source: U.S. Environmental Protection Agency, Process Design Manual: Guidelines for Water Reuse. Cincinnati, Ohio, 1992 (Report No. EPA-625/R-92-004).

Table 2: Typical Pathogen Survival Times at 20 - 30° C (in days)

A typical example of wastewater reuse is the system at the Sam Lords Castle Hotel in Barbados. Effluent consisting of kitchen, laundry, and domestic sewage ("grey-water") is collected in a sump, from which it is pumped, through a comminutor, to an aeration chamber. No primary sedimentation is provided in this system, although it is often desirable to do so. The aerated mixed liquor flows out of the aeration chamber to a clarifier for gravity separation. The effluent from the clarifier is then passed through a 16-foot-deep chlorine disinfection chamber before it is pumped to an automatic sprinkler irrigation system. The irrigated areas are divided into sixteen zones; each zone has twelve sprinklers. Some areas are also provided with a drip irrigation system. Sludge from the clarifier is pumped, without thickening, as a slurry to suckwells, where it is disposed of. Previously the sludge was pumped out and sent to the Bridgetown Sewage Treatment Plant for further treatment and additional desludging.

Wastewater Reuse is not very well known throughout the Pacific. Mana Island, a Resort Island in the Fiji Group uses a Sequence Batch Reactor (SBR) to treat and recycle wastewater for toilets and gardens.

- **Operation and Maintenance**

The operation and maintenance required in the implementation of this technology is related to the previously discussed operation and maintenance of the wastewater treatment processes, and to the chlorination and disinfection technologies used to ensure that pathogenic organisms will not present a health hazard to humans. Additional maintenance includes the periodic cleaning of the water distribution system conveying the effluent from the treatment plant to the area of reuse; periodic cleaning of pipes, pumps, and filters to avoid the deposition of solids that can reduce the distribution efficiency; and inspection of pipes to avoid clogging throughout the collection, treatment, and distribution system, which can be a potential problem. Further, it must be emphasised that, in order for a water reuse program to be successful, stringent regulations, monitoring, and control of water quality must be exercised in order to protect both workers and the consumers.

- **Costs**

Cost data for this technology are very limited. Most of the data relate to the cost of treating the wastewater prior to reuse. Additional costs are associated with the construction of a dual or parallel distribution system. In many cases, these costs can be recovered out of the savings derived from the reduced use of potable freshwater (i.e., from not having to treat raw water to potable standards when the intended use does not require such extensive treatment). The feasibility of wastewater reuse ultimately depends on the cost of recycled or reclaimed water relative to alternative supplies of potable water, and on public acceptance of the reclaimed water. Costs of effluent treatment vary widely according to location and level of treatment (see the previous section on wastewater treatment technologies). The degree of public acceptance also varies widely depending on water availability, religious and cultural beliefs, and previous experience with the reuse of wastewater.

See Appendix 2 for more information on wastewater reuse.

3.2.2 Possible Application for Wastewater Reuse on Majuro/RMI

In the urban area of Majuro seawater is being used in the sewerage system to flush toilets. The reuse of this seawater with the associated costs doesn't make economical sense. Taking further into consideration that the freshwater used for drinking, cooking etc. is discharged into the main sewage system the reuse of this greywater would require a separate sewage system.

Furthermore wastewater reuse doesn't create or develop new water resources but conserves them. Although this is an important feature for the water supply in general the specific conditions given above don't deem it an advisable option to supplement the water supply in Majuro.

3.3 High Technology Options: Desalination Technologies

Desalination is a separation process used to reduce the dissolved salt content of saline water to a usable level. All desalination processes involve three liquid streams: the saline feedwater (brackish water or seawater), low-salinity product water, and very saline concentrate (brine or reject water). The saline feedwater is drawn from oceanic or underground sources. The desalination process separates it into the two output streams: the low-salinity product water and very saline concentrate streams. The use of desalination overcomes the paradox faced by many coastal communities, that of having access to a practically inexhaustible supply of saline water but having no way to use it. Although some substances dissolved in water, such as calcium carbonate, can be removed by chemical treatment, other common constituents, like sodium chloride, require more technically sophisticated methods, collectively known as desalination

The product water of the desalination process is generally water with less than 500 mg/l total dissolved solids (TDS), which is suitable for most domestic, industrial, and agricultural uses. A by-product of desalination is brine. Brine is a concentrated salt solution (with more than 35 000 mg/l dissolved solids) that must be disposed of, generally by discharge into deep saline aquifers, surface waters with a higher salt content or back into the sea. Brine can also be diluted with treated effluent and disposed of by spraying on golf courses and/or other open space areas.

3.3.1 Desalination by Reverse Osmosis

- **Technical Description**

There are two types of membrane process used for desalination: reverse osmosis (RO) and electrodialysis (ED). In the RO process, water from a saline solution is separated from the dissolved salts by flowing through a water-permeable membrane. The permeate (the liquid flowing through the membrane) is encouraged to flow through the membrane by the pressure differential created between the pressurised feedwater and the product water, which is at near-atmospheric pressure. The remaining feedwater continues through the pressurised side of the reactor as brine. No heating or phase change takes place. The major energy requirement is for the initial pressurisation of the feedwater. For brackish water desalination the operating pressures range from 250 to 400 psi, and for seawater desalination from 800 to 1 000 psi.

In practice, the feedwater is pumped into a closed container, against the membrane, to pressurise it. As the product water passes through the membrane, the remaining feedwater and brine solution becomes more and more concentrated. To reduce the concentration of dissolved salts remaining, a portion of this concentrated feedwater-brine solution is withdrawn from the container. Without this discharge, the concentration of dissolved salts in the feedwater would continue to increase, requiring ever-increasing energy inputs to overcome the naturally increased osmotic pressure. A reverse osmosis system consists of four major components/processes:

- pre-treatment
- pressurisation,
- membrane separation,
- and (4) post-treatment stabilisation.

- ***Pre-treatment***:

The incoming feedwater is pre-treated to be compatible with the membranes by removing suspended solids, adjusting the pH, and adding a threshold inhibitor to control scaling caused by constituents such as calcium sulphate.

- ***Pressurisation***:

The pump raises the pressure of the pre-treated feedwater to an operating pressure appropriate for the membrane and the salinity of the feedwater.

- ***Separation***:

The permeable membranes inhibit the passage of dissolved salts while permitting the desalinated product water to pass through. Applying feedwater to the membrane assembly results in a freshwater product stream and a concentrated brine reject stream. Because no membrane is perfect in its rejection of dissolved salts, a small percentage of salt passes through the membrane and remains in the product water. Reverse osmosis membranes come in a variety of configurations. Two of the most popular are spiral wound and hollow fine fiber membranes. They are generally made of cellulose acetate, aromatic polyamides, or, nowadays, thin film polymer composites. Both types are used for brackish water and seawater desalination, although the specific membrane and the construction of the pressure vessel vary according to the different operating pressures used for the two types of feedwater.

- ***Stabilisation***:

The product water from the membrane assembly usually requires pH adjustment and degasification before being transferred to the distribution system for use as drinking water. The product passes through an aeration column in which the pH is elevated from a value of approximately 5 to a value close to 7. In many cases, this water is discharged to a storage cistern for later use.

- **Operation and Maintenance**

Operating experience with reverse osmosis technology has improved over the past 15 years. Fewer plants have had long-term operational problems. Assuming that a properly designed and constructed unit is installed, the major operational elements associated with the use of RO technology will be the day-to-day monitoring of the system and a systematic program of preventive maintenance. Preventive maintenance includes instrument calibration, pump adjustment, chemical feed inspection and adjustment, leak detection and repair, and structural repair of the system on a planned schedule.

The main operational concern related to the use of reverse osmosis units is fouling. The purification of water by any process will lead to a concentration of any material present in the feed water and may cause fouling of the desalination system. These materials may consist of a wide range of chemicals and particulate matter.

In membrane processes the foulant can physically block the membrane surface thereby preventing water flow through the membrane. It limits the amount of water that can be treated before cleaning is required. Membrane fouling can be corrected by backwashing or cleaning (about every 4 months), and by replacement of the cartridge filter elements (about every 8 weeks). The lifetime of a membrane in Argentina has been reported to be 2 to 3 years, although, in the literature, higher lifespans have been reported.. Prevention of fouling is essential in all water purification systems to maximise the efficiency of the system. Correct pre-treatment of the feed water will minimise the fouling of the system and the use of polymeric additives to control scale formation is now well established. Plants may well be designed to operate with such additives, which are capable of preventing system fouling when added in very small quantities.

Operation, maintenance, and monitoring of RO plants require trained engineering staff. Staffing levels are approximately one person for a 200 m^3/day plant, increasing to three persons for a 4000 m^3/day plant. In the pacific two RO plants that were installed on Tuvalu but found to be too expensive to operate and were finally shut down.

3.3.2 Desalination by Nanofiltration

Nanofiltration, also referred to as membrane softening, is very similar to reverse osmosis. The major difference is in the permeability of the membrane. This process will remove larger ions and dissolved matter, leaving the smaller ions in the water. This method is well suited for waters which have a low salinity but which are contaminated by organic matter that produces undesirable colours and/or taste to the water.
The other advantage of nanofiltration is that it operates at a much lower pressure than reverse osmosis, which gives much lower operating costs. This process is used in the Florida region to improve local brackish waters to a potable level.

3.3.3 Desalination by Distillation

Distillation is the oldest and most commonly used method of desalination. The world's first land-based desalination plant, a multiple-effect distillation (MED) process plant that had a capacity of 60 m^3/day, was installed on Curaçao, Netherlands Antilles, in 1928. Further commercial development of land-based seawater distillation units took place in the late 1950s, and initially relied on the technology developed for industrial evaporators (such as sugar concentrators) and for the shipboard distillation plants which were built during World War II. The multistage-flash (MSF), Multiple Effect (MED), and vapour-compression (VC) processes have led to the widespread use of distillation to desalinate seawater.

- **Technical Description**

Distillation is a phase separation method whereby saline water is heated to produce water vapour, which is then condensed to produce freshwater. The various distillation processes used to produce potable water, including Multistage Flash (MSF), Multiple Effect (MED), Vapour Compression (VC), and waste-heat evaporators, all generally operate on the principle of reducing the vapour pressure of water within the unit to permit boiling to occur at lower temperatures, without the use of additional heat. Distillation units routinely use designs that conserve as much thermal energy as possible by interchanging the heat of condensation and heat of vaporisation within the units. The major energy requirement in the distillation process thus becomes providing the heat for vaporisation to the feedwater.

3.3.3.1 Multistage Flash (MSF)

The incoming seawater passes through the heating stage(s) and is heated further in the heat recovery sections of each subsequent stage. After passing through the last heat recovery section, and before entering the first stage where flash-boiling (or flashing) occurs, the feedwater is further heated in the brine heater using externally supplied steam. This raises the feedwater to its highest temperature, after which it is passed through the various stages where flashing takes place. The vapor pressure in each of these stages is controlled so that the heated brine enters each chamber at the proper temperature and pressure (each lower than the preceding stage) to cause instantaneous and violent boiling/evaporation.

The freshwater is formed by condensation of the water vapour, which is collected at each stage and passed on from stage to stage in parallel with the brine. At each stage, the product water is also flash-boiled so that it can be cooled and the surplus heat recovered for preheating the feedwater.

Because of the large amount of flashing brine required in an MSF plant, a portion (50% to 75%) of the brine from the last stage is often mixed with the incoming feedwater, recirculated through the heat recovery sections of the brine heater, and flashed again through all of the subsequent stages. A facility of this type is often referred to as a "brine recycle" plant. This mode of operation reduces the amount of water-conditioning chemicals that must be added, and can significantly reduce operating costs. On the other hand, it increases the salinity of the brine at the product end of the plant, raises the boiling point, and increases the danger of corrosion and scaling in the plant. In order to maintain a proper brine density in the system, a portion of the concentrated brine from the last stage is discharged to the ocean. The discharge flow rate is controlled by the brine concentration at the last stage.

3.3.3.2 Multiple Effect (MED)

In multiple-effect units steam is condensed on one side of a tube wall while saline water is evaporated on the other side. The energy used for evaporation is the heat of condensation of the steam. Usually there is a series of condensation-evaporation processes taking place (each being an "effect"). The saline water is usually applied to the tubes in the form of a thin film so that it will evaporate easily. Although this is an older technology than the MSF process described above, it has not been extensively utilised for water production. However, a new type of low-temperature, horizontal-tube MED process has been successfully developed and used in the Caribbean. These plants appear to be very rugged, easy to operate, and economical, since they can be made of aluminium or other low-cost materials.

3.3.3.3Vapour Compression (VC)

The vapour-compression process uses mechanical energy rather than direct heat as a source of thermal energy. Water vapour is drawn from the evaporation chamber by a compressor and except in the first stage is condensed on the outsides of tubes in the same. The heat of condensation is used to evaporate a film of saline water applied to the insides of the tubes within the evaporation chambers. These units are usually built with capacities of less than 100 m^3/day and are often used at resorts and industrial sites.

3.3.3 4 Membrane Distillation

Membrane distillation is a relatively new process, having been introduced commercially only in the last few years. The process works by using a specialised membrane, which will pass water vapour but not liquid water. This membrane is placed over a moving stream of warm water, and as the water vapour passes through the membrane it is condensed on a second surface which is at a lower temperature than that of the feedwater.

3.3.3.5 Dual Purpose

Most of the large distillation units in the world are dual-purpose facilities. Specifically, they derive their source of thermal energy from steam that has been used for other purposes, usually for power generation. Thus, the feedwater is heated in a boiler to a high energy level and passed through a steam turbine before the steam is extracted for use at a lower temperature to provide the heat required in the distillation plants. At this point, the desalination then conforms to the processes described above.

- **Operation and Maintenance**

Most plants are installed in isolated locations where construction is troublesome and where the availability of fuel, chemicals, and spare parts is limited. In these places, there is usually also a scarcity of qualified personnel; therefore, people are often selected from the local communities and trained to operate the plants. The operation of distillation plants requires careful planning, well-trained operators, and adequate operation and maintenance budgets to guarantee the supply of good quality water. Except for an annual shut-down of 6 to 8 weeks for general inspection and maintenance, the operation of desalination plants is usually continuous. Maintenance and preventive maintenance work, for a MSF plant, consists of:

- Repairing damage (cracks) to the stainless steel liners in the stages.
- Removing scale and marine growths in the tubes in all stages using high pressure "hydrolaser" sprayers.
- Removing the vacuum system ejectors for cleaning, inspection, and replacement as necessary; most parts have a lifetime of 3 to 4 years.
- Inspecting all pumps and motors, replacing bearings and bushings, and renewing protective coatings on exposed parts (e.g., pumps must be primed and painted before being installed).

3.3.4 Energy Use of Desalination Plants

The energy used in the desalination process is primarily electricity and heat. Energy requirements for desalination plants depend on the salinity and temperature of the feedwater, the quality of the water produced, and the desalting technology used. Estimates for electricity use requirements for various technologies for seawater desalination are:

Technology	KWh/Acre Feet	KWh/m^3
Multistage Flash (MSF)	3,500 – 7,000	2.83 – 5.67
Multiple Effect Distillation (MED)	2,500 – 5,000	2.02 – 4.04
Vapour Compression (VC)	10,000 – 15,000	8.08 – 12.12
Reverse Osmosis (RO) – single pass	5,800 – 11,000	4.7 – 8.92
Reverse Osmosis (RO) – double pass	6,500 – 12,000	5.27 – 9.73

Table 3: Energy Consumption for different Distillation Technologies

In addition to electricity requirements, MSF, MED, and some VC plants also use thermal energy to heat feedwater. (Because of the inefficiency of converting thermal energy to electricity, there is a high energy "penalty" if electricity is used to heat feedwater.) For example, in addition to the 2.83 to 5.7 kWh/m^3 of energy required for electricity, the thermal energy needs for a MSF distillation plant is estimated at 219,000 Btu/m^3 (about 21.1 kWh/m3). For MED plants, the estimated additional thermal energy requirements are 186,500 Btu/m^3 (about 17.84 kWh/m^3)[2]. Consequently, the total energy needs for distillation technologies are higher than for RO technologies.

Both RO and distillation plants can benefit from cogeneration plants to reduce energy use. Since increased energy use may cause adverse environmental impacts, the individual and cumulative impacts of energy use and production at a proposed desalination plant will require case-by-case analysis.

3.3.5 Economics of Desalination

Cost figures for desalination have been difficult to obtain and in the literature desalinated water costs using conventional energy sources ranges from US$0.80 - US$8.00 per cubic meter (or even higher). The following chapter gives an overview.

[2] British thermal unit (Btu) values are multiplied by 0.33 to compute a kWh-equivalent because the efficiency of conversion from thermal energy to electricity is about 33%.

3.3.5.1 Costs of RO Processes

The most significant costs associated with reverse osmosis plants, aside from the capital cost, are the costs of electricity, membrane replacement, and labour. All desalination techniques are energy-intensive relative to conventional technologies. Table 4 presents generalised capital and operation and maintenance costs for a 19,000 m^3 per day reverse osmosis desalination in the United States. Reported cost estimates for RO installations in Latin American and the Caribbean are shown in Table 5. The variation in these costs reflects site-specific factors such as plant capacity and the salt content of the feedwater. Other sources give costs of about US$1.40/m3 for large plants (> 15,000 m^3 per day).

Feedwater Type	Capital Cost per Unit of Daily Capacity (US$/$m^3$/day)	Operation & Maintenance per Unit of Production (US$/$m^3$)
Brackish water	380 - 562	0.28 - 0.41
Seawater	1 341 - 2 379	1.02 - 1.54

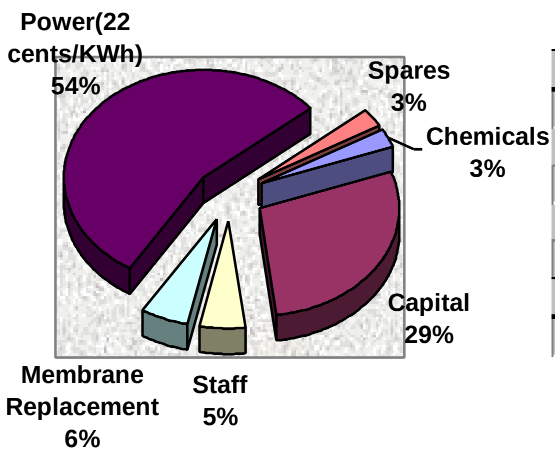
Table 4: U.S. Army Corps of Engineers Cost Estimates for RO Desalination Plants in Florida

Country	Capital Cost ($/$m^3$/day)	Operation and Maintenance (US$/$m^3$)	Production Cost (US$/$m^3$)[a]
Antigua	264 - 528	0.79 - 1.59	
Argentina		3.25	
Bahamas			4.60 - 5.10
Brazil	1,454 – 4,483		0.12 - 0.37
British Virgin Islands	1,190 – 2,642		[b/]3.40 - 4.30
Chile	1,300		1.00

[a] Includes amortization of capital, operation and maintenance, and membrane replacement.
[b] Values of US$2.30 - US$3.60 were reported in February 1994.

Table 5: Comparative Costs of RO Desalination for Several Latin American and Caribbean Developing Countries

To show on example Figure 3 states the production cost for a RO-plant fed with seawater and using renewable energy sources. Using brackish water instead of seawater would reduce costs dramatically (down to five times) depending on the salinity of the brackish water.



Item	US$/m3
Chemicals	0.08
Capital	0.86
Staff	0.16
Membrane Replacement	0.17
Power(22 cents/KWh)	1.65
Spares	0.08
Total	**3.1**

Figure 3: Production Cost per Cubic Meter for 450 m3 per day output RO plant

3.3.5.2 Costs of Distillation Processes

The production cost of water is a function of the type of distillation process used the plant capacity, the salinity in the feedwater (seawater or brackish water), and the level of familiarity with the distillation process that exists in the region. Table 6 shows a range of costs that have been reported by different countries using this technology. Production costs appear to increase in proportion to the capacity of the plant. In many applications, distillation provides the best means of achieving waters of high purity for industrial use: for volumes of less than 4 000 m^3/day, the VC process is likely to be most effective; above that range, the MSF process will probably be preferable.

Country	**Distillation Process**	**Production Cost (US$/$m^3$)**
Chile	VC	1.47
U.S. Virgin Is.	MED and VC	4.62
Curaçao	MSF	4.31

Table 6 Estimated Cost of Distillation Processes in Latin American Countries for plants

The overall costs of water production are about the same for RO and some forms of distillation plants.

Price estimates of water produced by desalination plants in California range from US$0.81 to US$3.24/m^3. The costs include capital and operating and maintenance costs. For long-term projects, capital costs would most likely be amortised over an assumed plant life of 20 to 30 years. Capital costs for RO plants tend to be lower than for distillation plants. Some of the proposals are for plants that would operate for only a few years. Operating a plant on a part-time, rather than full-time, basis may be more expensive in the long run because maintenance and capital costs must be paid while the plant is shut down. Other sources give costs of about US$1.44/$m^3$ for MSF-, US$1.31/$m^3$ for MED- Technology for large plants (> 15,000 m^3 per day).

3.3.6 Comparison of Distillation and Reverse Osmosis Technologies

One advantage of distillation plants is that there is a greater potential for economies of scale. Distillation plants also do not shut down a portion of their operations for cleaning or replacement of equipment as often as RO plants, although distillation plants can and have shut down for tube bundle replacement and cleaning. Pre-treatment requirements are greater for RO plants, because coagulants are needed to settle out particles before water passes through the membranes. Unlike RO plants, distillation plants do not generate waste from backwash of pre-treatment filters.

Advantages of RO plants over distillation include:

- RO plant feedwater generally does not require heating, so the thermal impacts of discharges are lower;
- RO plants have fewer problems with corrosion:
- RO plants usually have lower energy requirements; RO plants tend to have higher recovery rates-about 45% for seawater;
- the RO process can remove unwanted contaminants, such as trihalomethane-precursors, pesticides, and bacteria;
- and RO plants take up less surface area than distillation plants for the same amount of water production.

A more thorough comparison of both technologies including their specific advantages and disadvantages suitability, cultural impacts, the level of involvement and future developments is attached as Appendix 3,4 and 5.

4. Possible Application of Desalination Technologies in the RMI

As far as information was available to this desk study RMI currently has 4 desalination plants:

- one on the Ebeye, Kwajalein Atoll, with an rated output of 1,300 m3/day (distillation technology)
- one on Majuro for the Hospital with an rated output of 100 m3/day (RO technology),
- and two more plants for bottled drinking water producing company (RO technology)

The production cost per unit for the plant in Ebeye are US$2.10 – 2.65 per m^3 and for the Hospital plant on Majuro Atoll are Hospital: US$1.50 per m^3. Costs for the bottling plants were not made available. It remains unclear why unit the costs for the Hospital plant are less than for the Ebeye plant because usually economics of scale are applicable to desalination plants. Considering the fact that the RMI has already experience with desalination technology on the Kwajalein Atoll in Ebeye it seems advisable to use the same technology on Majuro Atoll.

Assuming that a per capita consumption of 40 litres per day and capita (which is three times less than the actual consumption of about 126l/c/d) would be reasonable the plant had to produce between 1200 m^3 of freshwater per day. For desalination plants of this size the unit cost can be estimated to about US$1.50 – US$2.50 per cubic meter[3].

Accepting the current consumption of about 126 l/c/d and day would require the daily production of 3,700 cubic meter of freshwater with unit costs ranging from US$ 1.30 – US$ 2.00. Table 7 shows the water costs for an average household of seven persons under the assumption that all related costs such as depreciation costs, interest costs and operating costs are levied on the consumer.

	Unit		
Consumption	[l/c/d]	40	126
Plant Output per Day	[m^3]	1200	3700
Unit Cost	[US$/$m^3$]	1.50 – 2.50	1.30 – 2.00
Daily cost per household	[US$/d]	0.42 – 0.7	1.16 – 1.78
Monthly cost per household	[US$/m]	12.6 – 21	34.8 – 53.4
Yearly cost per household	[US$/yr]	151 - 252	417 - 641

Table 7: Comparison of average household water costs for different consumption rates for desalinated water (distillation process)

Although unit costs for the bigger plant are principally lower the higher consumption leads to a significant increased financial burden of the average household. Please note that only production costs are given. Actual distribution costs are even higher. Table 7 underlines therefore the importance for not only keeping unit costs low but also the consumption. Before making any decision on extending the Majuro water supply system the potential for saving water should be scrutinised. This could even lead to the result that no significant extension of the water supply system was necessary.

[3] But may vary even more according to the energy sources used for the process.

5. General Recommendations

This appraisal doesn't aim at recommending certain measures to resolve the water supply problems on Majuro Atoll. It has been prepared to brief the RMI Government on general feasible options for their water supply system with special focus on desalination technology. The application of wastewater reuse has been discussed and not found a viable option. Together with the information on low technology supply options given as Appendices to this appraisal the following options should be subject to further investigations depending on the preferences of the RMI Government:

1. The water supply system relies entirely on desalination technology.
2. The purchase of emergency desalination[4] plants as a supplement to the existing rainwater/ groundwater supply.
3. A combined strategy as recommended in the Action Plan for the Republic of the Marshall Islands (SOPAC,1996) with the following actions:
   - promote individual rain roof catchment and storage systems
   - apply demand management and conservation strategies (e.g. leak fixing, consumption reduction)
   - optimise groundwater abstraction at the Laura groundwater lens
   - further investigation of the suitability of desalination technology for the Marshall Islands

Option 2 and 3 seem to be the most promising options to cope with the increasing problems of the Majuro water supply system at this stage and are therefore recommended to the RMI Government for further consideration.

[4] Further emergency supply options are given in Appendix 6.

Desalination

A Technical Appraisal for its Application in Pacific Island Countries

Appendices

SOPAC/ Water Resource Unit
Edited and Compiled by Harald Schölzel

Appendix 1: Low Technology Options

Appendix 1: Low Technology Options

1.1 Rainwater Harvesting from Rooftop Catchments

The application of an appropriate rainwater harvesting technology can make possible the utilisation of rainwater as a valuable and, in many cases, necessary water resource. Rainwater harvesting has been practised for more than 4,000 years, and, in most developing countries, is becoming essential owing to the temporal and spatial variability of rainfall. Rainwater harvesting is necessary in areas having significant rainfall but lacking any kind of conventional, centralised government supply system, and also in areas where good quality fresh surface water or groundwater is lacking. Annual rainfall ranging from less than 500 to more than 1 500 mm can be found in most Pacific Island Countries (PIC). Very frequently most of the rain falls during a few months of the year, with little or no precipitation during the remaining months. There are countries in which the annual and regional distributions of rainfall also differ significantly.

- **Technical Description**

A rainwater harvesting system consists of three basic elements: a collection area, a conveyance system, and storage facilities. The collection area in most cases is the roof of a house or a building. The effective roof area and the material used in constructing the roof influence the efficiency of collection and the water quality.

A conveyance system usually consists of gutters or pipes that deliver rainwater falling on the rooftop to cisterns or other storage vessels. Both drainpipes and roof surfaces should be constructed of chemically inert materials such as wood, plastic, aluminum, or fiberglass, in order to avoid adverse effects on water quality. The water ultimately is stored in a storage tank or cistern, which should also be constructed of an inert material. Reinforced concrete, fiberglass, or stainless steel are suitable materials. Storage tanks may be constructed as part of the building, or may be built as a separate unit located some distance away from the building. All rainwater tank designs should include as a minimum requirement:

- A solid secure cover
- A coarse inlet filter
- An overflow pipe
- A manhole, sump, and drain to facilitate cleaning
- An extraction system that does not contaminate the water; e.g., a tap or pump
- A soakaway to prevent spilled water from forming puddles near the tank

Additional features might include:

- A device to indicate the amount of water in the tank
- A sediment trap, tipping bucket, or other "foul flush" mechanism
- A lock on the tap
- A second sub-surface tank to provide water for livestock, etc.

The following questions need to be considered in areas where a rainwater cistern system project is being considered, to establish whether or not rainwater catchment warrants further investigation:

- Is there a real need for an improved water supply?
- Are present water supplies either distant or contaminated, or both?
- Do suitable roofs and/or other catchment surfaces exist in the community?
- Does rainfall exceed 400 mm per year?
- Does an improved water supply figure prominently in the community's list of development priorities?

If the answer to these five questions is yes, it is a clear indication that rainwater collection might be a feasible water supply option. Further questions, however, also need to be considered:

- What alternative water sources are available in the community and how do these compare with the rooftop catchment system?
- What are the economic, social, and environmental implications of the various water supply alternatives (e.g., how able is the community to pay for water obtained from other sources; what is the potential within the community for income generating activities that can be used to develop alternative water sources; does the project threaten the livelihood of any community members, such as water vendors?)
- What efforts either the community or an outside agency has made,, to implement an improved water supply system in the past? (Lessons may be learned from the experiences of the previous projects.)

All catchment surfaces must be made of nontoxic material. Painted surfaces should be avoided if possible, or, if the use of paint is unavoidable, only nontoxic paint should be used (e.g., no lead-chromium-, or zinc-based paints). Overhanging vegetation should also be avoided.

- **Operation and Maintenance**

Rainwater harvesting systems require few skills and little supervision to operate. Major concerns are the prevention of contamination of the tank during construction and while it is being replenished during a rainfall. Contamination of the water supply as a result of contact with certain materials can be avoided by the use of proper materials during construction of the system. The main sources of external contamination are pollution from the air, bird and animal droppings, and insects. Bacterial contamination may be minimised by keeping roof surfaces and drains clean but cannot be completely eliminated. If the water is to be used for drinking purposes, filtration and chlorination or disinfection by other means (e.g., boiling) is necessary. The following maintenance guidelines should be considered in the operation of rainwater harvesting systems:

A procedure for eliminating the "foul flush" after a long dry spell deserves particular attention. The first part of each rainfall should be diverted from the storage tank since this is most likely to contain undesirable materials, which have accumulated on the roof and other surfaces between rainfalls. Generally, water captured during the first 10 minutes of rainfall during an event of average intensity is unfit for drinking purposes. The quantity of water lost by diverting this runoff is usually about 14 l/m of catchment area.

The storage tank should be checked and cleaned periodically. All tanks need cleaning; their designs should allow for this. Cleaning procedures consist of thorough scrubbing of the inner walls and floors. Use of a chlorine solution is recommended for cleaning, followed by thorough rinsing.
Care should be taken to keep rainfall collection surfaces covered, to reduce the likelihood of frogs, lizards, mosquitoes, and other pests using the cistern as a breeding ground. Residents may prefer to take care to prevent such problems rather than have to take corrective actions, such as treating or removing water, at a later time. Chlorination of the cisterns or storage tanks is necessary if the water is to be used for drinking and domestic uses.

Gutters and downpipes need to be periodically inspected and cleaned carefully. Periodic maintenance must also be carried out on any pumps used to lift water to selected areas in the house or building. More often than not, maintenance is done only when equipment breaks down.
Community systems require the creation of a community organisation to maintain them effectively. Similarly, households must establish a maintenance routine that will be carried out by family members.

As has been noted, in some cases the rainwater is treated with chlorine tablets. However, in most places it is used without treatment. In such cases, residents are advised to boil the water before drinking. Where cistern users do not treat their water, the quality of the water may be assured through the installation of commercially available in-line charcoal filters or other water treatment devices. Community catchments require additional protections, including:

- Fencing of the paved catchment to prevent the entry of animals, primarily livestock such as goats, cows, donkeys, and pigs, that can affect water quality.
- Cleaning the paved catchment of leaves and other vegetative matter.
- Repairing large cracks in the paved catchment as a result of soil movement, earthquakes, or exposure to the elements.
- Maintaining water quality at a level where health risks are minimized. In many systems, this involves chlorination of the supplies at frequent intervals.
-

Problems usually encountered in maintaining the system at an efficient level include the lack of availability of chemicals required for appropriate treatment and the lack of adequate funding.

- **Effectiveness of theTechnology**

Rainfall harvesting technology has proved to be very effective throughout several Latin American countries and most of the Caribbean islands, where cisterns are the principal source of water for residences. Cisterns are capable of providing a sufficient supply for most domestic applications. The use of rainwater is very effective in lessening the demand on the public water supply system in the British Virgin Islands. It also provides a convenient buffer in times of emergency or shortfall in the public water supply. Also, because of the hilly or mountainous nature of the terrain in the majority of the British Virgin Islands, combined with dispersed housing patterns, rainfall harvesting appears to be the most practical way of providing a water supply to some residents. In many countries it is very costly, and in some cases not economically feasible, to extend the public water supply to all areas, where houses are isolated from one another or in mountainous areas.
Steep galvanised iron roofs have been found to be relatively efficient rainwater collectors, while flat concrete roofs, though highly valued as protection from hurricanes, are very inefficient. Rooftop catchment efficiencies range from 70% to 90%. It has been estimated that 1 cm of rain on 100 m^2 of roof yields 10 000 l. More commonly, rooftop catchment yield is estimated to be 75% of actual rainfall on the catchment area, after accounting for losses due to evaporation during periods when short, light showers are interspersed with periods of prolonged sunshine. Likewise, at the other extreme, the roof gutters and downpipes generally cannot cope with rainfalls of high intensity, and excess water runs off the roof to waste during these periods.

- **Suitability**

This technology is suitable for use in all areas as a means of augmenting the amount of water available. It is most useful in arid and semi-arid areas where other sources of water are scarce.

- **Advantages**

Rainwater harvesting provides a source of water at the point where it is needed. It is owner operated and managed.
It provides an essential reserve in times of emergency and/or breakdown of public water supply systems, particularly during natural disasters.
The construction of a rooftop rainwater catchment system is simple, and local people can easily be trained to build one, minimising its cost.
The technology is flexible. The systems can be built to meet almost any requirements. Poor households can start with a single small tank and add more when they can afford them.

It can improve the engineering of building foundations when cisterns are built as part of the substructure of the buildings, as in the case of mandatory cisterns.
The physical and chemical properties of rainwater may be superior to those of groundwater or surface waters that may have been subjected to pollution, sometimes from unknown sources.
Running costs are low.
Construction, operation, and maintenance are not labor-intensive.

- **Disadvantages**

The success of rainfall harvesting depends upon the frequency and amount of rainfall; therefore, it is not a dependable water source in times of dry weather or prolonged drought.
Low storage capacities will limit rainwater harvesting so that the system may not be able to provide water in a low rainfall period. Increased storage capacities add to construction and operating costs and may make the technology economically unfeasible, unless it is subsidized by government.
Leakage from cisterns can cause the deterioration of load bearing slopes.
Cisterns and storage tanks can be unsafe for small children if proper access protection is not provided.
Possible contamination of water may result from animal wastes and vegetable matter.
Where treatment of the water prior to potable use is infrequent, due to a lack of adequate resources or knowledge, health risks may result; further, cisterns can be a breeding ground for mosquitoes.
Rainfall harvesting systems increase construction costs and may have an adverse effect on home ownership. Systems may add 30% to 40% to the cost of a building.
Rainfall harvesting systems may reduce revenues to public utilities.

Cultural Acceptability

In Pacific Island Countries, it has been found that projects that involved the local community from the outset in the planning, implementation, and maintenance have the best chance of enduring and expanding. Those projects which have been predominantly run by local people have had a much higher rate of success than those operated by people foreign to an area, and those to which the community has contributed ideas, funds, and labour have had a greater rate of success than those externally planned, funded, and built. Successful rainwater harvesting projects are generally associated with communities that consider water supply a priority.

In the Caribbean, attitudes toward the use of rainwater for domestic consumption differ. Some people, who depend on rainwater as their only source of supply, use it for all household purposes, from drinking and cooking to washing and other domestic uses. Other people, who have access to both rainwater and a public water supply, use rainwater selectively, for drinking or gardening or flushing toilets, and use the public water supply for other purposes. These varying attitudes are related to the level of education of the users as well as to their traditional preferences. Different sectors of the society need to be informed about the advantages of harvesting rainwater and the related safety aspects of its use, including the threat of mosquito problems and other public health concerns.

Further Development of the Technology

There is a need for the water quality aspects of rainwater harvesting to be better addressed. This might come about through:

- Development of first-flush bypass devices that are more effective and easier to maintain and operate than those currently available.
- Greater involvement of the public health department in the monitoring of water quality.
- Monitoring the quality of construction at the time of building.
- Other development needs include:
- Provision of assistance from governmental sources to ensure that the appropriate-sized cisterns are built.

- Promotion of rainwater harvesting as an alternative to both government- and private-sector-supplied water, with emphasis on the savings to be achieved on water bills.
- Provision of assistance to the public in sizing, locating, and selecting materials and constructing cisterns and storage tanks, and development of a standardised plumbing and monitoring code.
- Development of new materials to lower the cost of storage.
- Preparation of guidance materials (including sizing requirements) for inclusion of rainwater harvesting in a multi-sourced water resources management environment.

1.2 Rainwater Harvesting In Situ

In arid and semi-arid regions, where precipitation is low or infrequent during the dry season, it is necessary to store the maximum amount of rainwater during the wet season for use at a later time, especially for agricultural and domestic water supply. One of the methods frequently used in rainwater harvesting is the storage of rainwater *in situ*. Topographically low areas are ideal sites for *in situ* harvesting of rainfall. This technique has been used in several Pacific Island countries including the republic of the Marshall Islands. The *in situ* technology consists of making storage available in areas where the water is going to be utilised.

- **Technical Description**

All rainfall harvesting systems have three components: a collection area, a conveyance system, and a storage area. In this application, collection and storage is provided within the landscape. Topographic depressions represent ideal collection and storage areas. In many situations, such areas are impermeable, being underlain by clay soils that minimise infiltration. Methods of rainwater harvesting *in situ*, including site preparation of agricultural areas in Brazil, are described below.

- Use of Topographic Depressions as Rainfall Harvesting Areas

In Paraguay, areas of low topography used for rainwater storage are known as *tajamares*. *Tajamares* are constructed in areas with clay soils at least 3 m deep. The *tajamares* are served by distribution canals that convey water from the storage area to the areas of use. The collection and storage areas need to be fenced to avoid contamination by animals. This technology is usually combined with storage tanks built of clay. The water is delivered from the *in situ* rainfall collection area to the storage tank by means of a pump, usually driven by a windmill.

- Use of Furrows as Rainwater Storage Areas

Furrows may be used as an *in situ* means of storing harvested rainwater. They are built prior to or after planting to store water for future use by the plants. A variation on the use of topographic depressions to store rainfall, this method uses flattened trenches between the rows of crops to store water (Figures 4a-4c). Furrows may have mud dams or barriers every 2 m to 3 m along the row in order to retain water for longer periods of time and avoid excessive surface runoff and erosion (Figure 4d). Raised beds may also be used to trap the water in the furrows, or uncultivated areas may be left between rows, spaced at 1 m apart, to assist in capturing rainwater falling on the land surface between furrows (Figures 4e and 4f).

- The *Guimares Duque*

The *Guimares Duque* method was developed in Brazil during the 1950s, and uses furrows and raised planting beds, on which cross cuts to retain water are made using a reversible disk plow with at least three disks. The furrows are usually placed at the edge of the cultivation zone.

- **Operation and Maintenance**

This technology requires very little maintenance once the site is chosen and prepared. Maintenance is done primarily during the course of normal, day-to-day agricultural activities, and consists primarily of keeping the collection area free of debris and unwanted vegetation. Where only parts of the rows are cultivated, rotating the areas that are plowed will enable more efficient maintenance of the available storage area.

- **Effectiveness of the Technology**

This technology increases water supply for irrigation purposes in arid and semi-arid regions. It promotes improved management practices in the cultivation of corn, cotton, sorghum, and many other crops. It also provides additional water supply for livestock watering and domestic consumption.

- **Suitability**

This technology is applicable to low topographic areas in arid or semi-arid climates.

- **Advantages**

This technology requires minimal additional labour.
It offers flexibility of implementation; furrows can be constructed before or after planting.
Rainwater harvesting allows better utilisation of rainwater for irrigation purposes, particularly in the case of inclined raised beds.
Rainwater harvesting is compatible with agricultural best management practices, including crop rotation.
It provides additional flexibility in soil utilization.
Permeable *in situ* rainwater harvesting areas can be used as a method of artificially recharging groundwater aquifers.

- **Disadvantages**

In situ rainwater harvesting cannot be implemented where the slope of the land is greater than 5%.
It is difficult to implement in rocky soils.
Areas covered with stones and/or trees need to be cleared before implementation.
The additional costs incurred in implementing this technology could be a factor for some farmers.
It requires impermeable soils and low topographic relief in order to be effective.
The effectiveness of the storage area can be limited by evaporation that tends to occur between rains.

- **Cultural Acceptability**

In situ rainfall harvesting has been practiced for many years by the agricultural communities of northeastern Brazil, Paraguay, and Argentina. Agricultural communities in other arid and semi-arid regions can readily improve their level of irrigation and increase their production yield using this technique.

- **Further Development of the Technology**

The equipment used in the construction of the furrows and storage areas must be improved. Relatively inexpensive plows and tractors can reduce the cost of implementation and contribute to the more widespread use of this technology by small farmers. New methods of soil conservation should be explored.

1.3 Runoff Collection from Paved and Unpaved Roads

In countries like Brazil and Argentina, with semi-arid climates in which the amount and frequency of precipitation are small and variable, it is important to capture and store as much rainwater runoff as possible for later use. In Brazil, runoff from paved and unpaved roads is captured by street gutters and stored in subsurface galleries or dams strategically distributed along the roadsides. Since 1935, underground barriers have been built in Brazil to capture runoff. In 1965, an underground barrier was built along the bed of the Trici River with the objective of storing runoff water to provide water for domestic use in the municipality of Taua. In Argentina and Venezuela, this technology has been used to provide water for trees along the roadsides and for water-supply augmentation.

- **Technical Description**

Paved and unpaved roads tend to shed water to their outside edges because they are "crowned" or cambered. The runoff can be captured in drainage ditches or underground galleries. A number of methods have been used for this purpose. In most of these systems, the components include a collection area, drainage system, storage area, and distribution system.

When formalised, most gutters are of trapezoidal shape with a length of 40 m, a width of 1 m, and an average depth of 1 m, as shown in Figure 9. They are either parallel or perpendicular to the roads. The roadside ditches store water temporarily, dissipate hydrologic energy through the use of stones or other structures designed to slow the velocity at which the water runs off the road surface, and convey the runoff to storage areas. Storage areas may be constructed perpendicular to the drainage ditches, and take the form of other conduits or underground galleries. These are generally about 15 m in length and 1.3 m in depth and width. A stone masonry wall is placed at the inlet of the gallery. This wall is solid to a depth of approximately 0.8 m, below which the wall is perforated to allow the water to enter the gallery while screening out large particulates, animals, or debris. The base is a stone bed, approximately 0.4 m thick.

- **Operation and Maintenance**

The ditches and swales must be cleaned periodically by removing branches, leaves, litter, and sediments. Ant infestation is a problem that needs to be controlled in some areas. Whenever the roads are repaved or rebuilt, the gutters, ditches, and/or swales should also be rebuilt or repaired. The storage facilities, if used, should be inspected on a regular basis, and cracks or other problems corrected. Litter and debris should be removed from the gallery entrance.

- **Level of Involvement**

Government involvement is necessary since the water collected with this technology is normally used to aid in the reforestation of public areas and lands. Generally, construction and maintenance is managed by the roads department, which is also responsible for road construction and maintenance. In cases where the impounded water is used by the community, private participation in constructing the water distribution system is desirable.

- **Effectiveness of the Technology**

The application of this technology as a means of supplying moisture for plantings along roadsides in the Province of Mendoza, Argentina, was very successful. During the period from 1985 through 1995, carob trees grew an average of 30.7 cm/year and pepper trees an average of 35 cm/year during the same period.

- **Suitability**

The technique is suitable for use in arid and semi-arid rural areas where runoff from paved and unpaved roads can be collected and stored.

- **Advantages**
- Runoff collection and storage enhance the flora and fauna of a region.
- Runoff collection can enable cultivation in arid and semi-arid regions.
- The technology has a low operating cost; the capital cost can be subsumed in the cost of constructing the road.
- It is easy to operate and maintain.
- It reduces erosion and controls sedimentation.

- **Disadvantages**
- Plants may require supplemental irrigation during dry periods.
- Animals must be kept away from the plantings to avoid plant damage.
- It requires appropriate soil conditions.
- Water collected from roadways may be contaminated by litter and debris and in the urbanised areas by chemical pollutants from vehicles.

- **Cultural Acceptability**

This technology is well accepted by public works departments in arid and semi-arid areas. Communities in those areas also support the technology.

- **Further Development of the Technology**

This technology should be combined with some of the *in situ* or regional impoundment techniques to improve the efficiency and utilisation of runoff capture and storage. Since it is a simple and low-cost technology, its use should be encouraged.

Appendix 2: Medium Technology Options

Appendix 2: Medium Technology Option

Extent of Use
For health and aesthetic reasons, reuse of treated sewage effluent is presently limited to non-potable applications such as irrigation of non-food crops and provision of industrial cooling water. There are no known direct reuse schemes using treated wastewater from sewerage systems for drinking. Indeed, the only known systems of this type are experimental in nature, although in some cases treated wastewater is reused indirectly, as a source of aquifer recharge. Table 8 presents some guidelines for the utilisation of wastewater, indicating the type of treatment required, resultant water quality specifications, and appropriate setback distances. In general, wastewater reuse is a technology that has had limited use, primarily in small-scale projects in the region, owing to concerns about potential public health hazards.

Wastewater reuse in the Pacific is primarily in the form of irrigation water. In Fiji, some hotels have used wastewater treatment effluent for golf course irrigation, while the major industrial water users, the bauxite/alumina companies, engage in extensive recycling of their process waters

Type of Reuse	Treatment Required	Reclaimed Water Quality	Recommended Monitoring	Setback Distances
AGRICULTURAL **Food crops commercially processed** **Orchards and Vineyards**	Secondary Disinfection	pH = 6-9 BOD $\leq$ 30 mg/l SS = 30 mg/l FC $\leq$ 200/100 ml Cl_2 residual = 1 mg/l min.	pH weekly BOD weekly SS daily FC daily Cl_2 residual continuous	100 m from potable water supply wells 30 m from areas accessible to public
PASTURAGE **Pasture for milking animals** **Pasture for livestock**	Secondary Disinfection	pH = 6-9 BOD $\leq$ 30 mg/l SS $\leq$ 30 mg/l FC$\leq$ 200/100ml Cl_2 residual = 1 mg/l min.	pH weekly BOD weekly SS daily FC daily Cl_2 residual continuous	100 m from potable water supply wells 30 m from areas accessible to public
FORESTATION	Secondary Disinfection	pH = 6-9 BOD $\leq$ 30 mg/l SS $\leq$ 30 mg/l FC $\leq$ 200/100 ml Cl_2 residual = 1 mg/l min.	pH weekly BOD weekly SS daily FC daily Cl_2 residual continuous	100 m from potable water supply wells 30 m from areas accessible to the public
AGRICULTURAL **Food crops not commercially processed**	Secondary Filtration Disinfection	pH = 6-9 BOD $\leq$ 30 mg/l Turbidity $\leq$ 1 NTU FC = 0/100ml Cl_2 residual = 1 mg/l min.	pH weekly BOD weekly Turbidity daily FC daily Cl_2 residual continuous	15 m from potable water supply wells
GROUNDWATER RECHARGE	Site-specific and use-dependent	Site-specific and use-dependent	Depends on treatment and use	Site-specific
Source: USEPA, Process Design Manual: Guidelines for Water Reuse, Cincinnati, Ohio, 1992, (Report No. EPA-625/R-92-004).				

Table 8: Guidelines for Water Reuse

Hotels, for lawn irrigation use treated wastewater in small-scale agricultural projects and, particularly. In Chile, up to 220 l/s of wastewater is used for irrigation purposes in the desert region of Antofagasta. In Brazil, wastewater has been extensively reused for agriculture. Treated wastewater have also been used for human consumption after proper disinfection, for industrial processes as a source of cooling water, and for aquaculture. Wastewater reuse for aquacultural and agricultural irrigation purposes is also practiced in Lima, Peru. In

Argentina, natural systems are used for wastewater treatment. In such cases, there is an economic incentive for reusing wastewater for reforestation, agricultural, pasturage, and water conservation purposes, where sufficient land is available to do so. Perhaps the most extensive reuse of wastewater occurs in Mexico, where there is large-scale use of raw sewage for the irrigation of parks and the creation of recreational lakes.

International water quality guidelines for wastewater reuse have been issued by the World Health Organization (WHO). Guidelines should also be established at national level and at the local/project level, taking into account the international guidelines. Some national standards that have been developed are more stringent than the WHO guidelines. In general, however, wastewater reuse regulations should be strict enough to permit irrigation use without undue health risks, but not so strict as to prevent its use. When using treated wastewater for irrigation, for example, regulations should be written so that attention is paid to the interaction between the effluent, the soil, and the topography of the receiving area, particularly if there are aquifers nearby.

Level of Involvement
The private sector, particularly the hotel industry and the agricultural sector are becoming involved in wastewater treatment and reuse. However, to ensure the public health and protect the environment, governments need to exercise oversight of projects in order to minimise the deleterious impacts of wastewater discharges. One element of this oversight should include the sharing of information on the effectiveness of wastewater reuse. Government oversight also includes licensing and monitoring the performance of the wastewater treatment plants to ensure that the effluent does not create environmental or health problems.

Effectiveness of the Technology
The effectiveness of the technology, while difficult to quantify, is seen in terms of the diminished demand for potable-quality freshwater and, in the Caribbean islands, in the diminished degree of degradation of water quality in the near-shore coastal marine environment, the area where untreated and unreclaimed wastewater were previously disposed. The analysis of beach waters in Jamaica indicates that the water quality is better near the hotels with wastewater reuse projects than in beach areas where reuse is not practised.

Suitability
This technology has generally been applied to small-scale projects, primarily in areas where there is a shortage of water for supply purposes. However, this technology can be applied to larger-scale projects. In many developing countries, especially where there is a water deficit for several months of the year, implementation of wastewater recycling or reuse by industries can reduce demands for water of potable quality, and also reduce impacts on the environment.

Large-scale wastewater reuse can only be contemplated in areas where there are reticulated sewerage and/or stormwater systems. (Micro-scale wastewater reuse at the household or farmstead level is a traditional practice in many agricultural communities that use night soils and manures as fertilizers.) Urban areas generally have sewerage systems, and, while not all have stormwater systems, those that do are ideal localities for wastewater reuse schemes. Wastewater for reuse must be adequately treated, biologically and chemically, to ensure the public health and environmental safety. The primary concerns associated with the use of sewage effluents in reuse schemes are the presence of pathogenic bacteria and viruses, parasite eggs, and worms (all biological concerns) and of nitrates, phosphates, salts, and toxic chemicals, including heavy metals (all chemical concerns) in the water destined for reuse.

Advantages

- This technology reduces the demands on potable sources of freshwater.
- It may reduce the need for large wastewater treatment systems, if significant portions of the waste stream are reused or recycled.
- The technology may diminish the volume of wastewater discharged, resulting in a beneficial impact on the aquatic environment.
- Capital costs are low to medium, for most systems, and are recoverable in a very short time; this excludes systems designed for direct reuse of sewage water.
- Operation and maintenance are relatively simple except in direct reuse systems, where more extensive technology and quality control are required.
- Provision of nutrient-rich wastewater can increase agricultural production in water-poor areas.
- Pollution of seawater, rivers, and groundwater may be reduced.
- Lawn maintenance and golf course irrigation is facilitated in resort areas.
- In most cases, the quality of the wastewater, as an irrigation water supply, is superior to that of well water.

Disadvantages

- If implemented on a large scale, revenues to water supply and wastewater utilities may fall as the demand for potable water for non-potable uses and the discharge of wastewater is reduced.
- Reuse of wastewater may be seasonal in nature, resulting in the overloading of treatment and disposal facilities during the rainy season; if the wet season is of long duration and/or high intensity, the seasonal discharge of raw wastewater may occur.
- Health problems, such as water-borne diseases and skin irritations, may occur in people coming into direct contact with reused wastewater.
- Gases, such as sulfuric acid, produced during the treatment process can result in chronic health problems.
- In some cases, reuse of wastewater is not economically feasible because of the requirement for an additional distribution system.
- Application of untreated wastewater as irrigation water or as injected recharge water may result in groundwater contamination.

Cultural Acceptability

A large percentage of domestic water users are afraid to use this technology to supply of potable water (direct reuse) because of the potential presence of pathogenic organisms. However, most people are willing to accept reused wastewater for golf course and lawn irrigation and for cooling purposes in industrial processes. On the household scale, reuse of wastewater and manures as fertilizer is a traditional technology.

Further Development of the Technology

Expansion of this technology to large-scale applications should be encouraged. Cities and towns that now use mechanical treatment plants that are difficult to operate, expensive to maintain, and require a high skill level can replace these plants with the simpler systems; treated wastewater can be reused to irrigate crops, pastures, and lawns. In new buildings, plumbing fixtures can be designed to reuse wastewater, as in the case of using gray water from washing machines and kitchen sinks to flush toilets and irrigate lawns. Improved public education to ensure awareness of the technology and its benefits, both environmental and economic, is recommended.

Appendix 3: High Technology Options: Advantages and Disadvantages of Different Desalination Technologies

Appendix 3: High Technology Option: Advantages and Disadvantages of Different desalination Options

	• **Desalination by Reverse Osmosis**	• **Desalination by Distillation**
Suitability	• This technology is suitable for use in regions where seawater or brackish groundwater is readily available.	• MSF plants have been extensively used in the Middle East, North Africa, and the Caribbean. Although MED is an older technology than the MSF process, having been used in sugar refineries, it has not been extensively utilised for water production. However, the new low-temperature horizontal-tube MED process has been successfully used in the Caribbean, usually in units with capacities of less than 100 m^3/d (25,000 gpd) installed at resorts and industrial sites.
Advantages	• The processing system is simple; the only complicating factor is finding or producing a clean supply of feedwater to minimise the need for frequent cleaning of the membrane. • Systems may be assembled from prepackaged modules to produce a supply of product water ranging from a few litres per day to 750 000 l/day for brackish water, and to 400 000 l/day for seawater; the modular system allows for high mobility, making RO plants ideal for emergency water supply use. • Installation costs are low. • RO plants have a very high space/production capacity ratio, ranging from 25 000 to 60 000 l/day/m^2. • Low maintenance, non-metallic materials are used in construction. • Energy use to process brackish water ranges from 1 to 3 kWh per 1 000 l of product water. • RO technologies can make use of use an almost unlimited and reliable water source, the sea. • RO technologies can be used to remove organic and inorganic contaminants. • Aside from the need to dispose of the brine, RO has a negligible environmental impact. • The technology makes minimal use of chemicals.	• Distillation offers significant savings in operational and maintenance costs compared with other desalination technologies. • In most cases, distillation does not require the addition of chemicals or water softening agents to pretreat feedwater. • Low temperature distillation plants are energy-efficient and cost-effective to operate. • Many plants are fully automated and require a limited number of personnel to operate. • Distillation has minimal environmental impacts, although brine disposal must be considered in the plant design. • The technology produces high-quality water, in some cases having less than 10 mg/l of total dissolved solids. • Distillation can be combined with other processes, such as using heat energy from an electric-power generation plant.

	• **Desalination by Reverse Osmosis**	• **Desalination by Distillation**
Disadvantages	• The membranes are sensitive to abuse. • The feedwater usually needs to be pretreated to remove particulates (in order to prolong membrane life). • There may be interruptions of service during stormy weather (which may increase particulate resuspension and the amount of suspended solids in the feedwater) for plants that use seawater. • Operation of a RO plant requires a high quality standard for materials and equipment. • There is often a need for foreign assistance to design, construct, and operate plants. • An extensive spare parts inventory must be maintained, especially if the plants are of foreign manufacture. • Brine must be carefully disposed of to avoid deleterious environmental impacts. • There is a risk of bacterial contamination of the membranes; while bacteria are retained in the brine stream, bacterial growth on the membrane itself can introduce tastes and odours into the product water. • RO technologies require a reliable energy source. Desalination technologies have a high cost when compared to other methods, such as groundwater extraction or rainwater harvesting.	• Some distillation processes are energy-intensive, particularly the large-capacity plants. • Disposal of the brine is a problem in many regions. • The distillation process, particularly MSF distillation, is very costly. • Distillation requires a high level of technical knowledge to design and operate. • The technology requires the use of chemical products, such as acids, that need special handling.
Level of Involvement	The cost and scale of RO plants are so large that only public water supply companies with a large number of consumers, and industries or resort hotels, have considered this technology as an option. Small RO plants have been built in rural areas where there is no other water supply option. In some cases, such as the British Virgin Islands, the government provides the land and tax and customs exemptions, pays for the bulk water received, and monitors the product quality. The government also distributes the water and in some cases provides assistance for the operation of the plants. •	The manufacturing capacity to produce MSF evaporators is available in those places where power plant equipment is fabricated. Thus, many countries in Latin America have the potential to manufacture locally the equipment needed to develop desalination plants. Further, some local manufacturers have signed licensing agreements with major foreign desalination manufacturing firms as a result of governmental policies of import substitution, in order to offer desalination equipment, particularly MSF plants, to the electric-generating industry in the region. In the Caribbean, desalination by distillation is being used primarily in the private sector, especially in the tourist industry. Some industrial concerns and power companies have incorporated distillation into their operations as part of a dual process approach. Government participation has been very limited. Future developments of this technology, which are expected to reduce the cost of desalination plants, will be likely to encourage greater government participation in the use of distillation in the development of public water supply systems.

	• **Desalination by Reverse Osmosis**	• **Desalination by Distillation**
Effectiveness of the Technology	Twenty-five years ago, researchers were struggling to separate product waters from 90% of the salt in feedwater at total dissolved solids (TDS) levels of 1 500 mg/l, using pressures of 600 psi and a flux through the membrane of 18 $l/m^2/day$. Today, typical brackish installations can separate 98% of the salt from feedwater at TDS levels of 2 500 to 3 000 mg/l, using pressures of 13.6 to 17 atm and a flux of 24 $l/m^2/day$ --and guaranteeing to do it for 5 years without having to replace the membrane. Today's state-of-the-art technology uses thin film composite membranes in place of the older cellulose acetate and polyamide membranes. The composite membranes work over a wider range of pH, at higher temperatures, and within broader chemical limits, enabling them to withstand more operational abuse and conditions more commonly found in most industrial applications. In general, the recovery efficiency of RO desalination plants increases with time as long as there is no fouling of the membrane.	Desalination through distillation of seawater is a relatively expensive method of obtaining freshwater. The MSF system has proved to be a very efficient system, when properly maintained. It produces high quality product water (between 2 and 150 mg/l of total dissolved solids at the plant in Curaçao); TDS contents of less than 10 mg/l have been reported from the VC plant in Chile. Because the water is boiled, the risk of bacterial or pathogenic virus contamination of the product water is minimal.
Cultural Acceptability	RO technologies are perceived to be expensive and complex, a perception that restricts them to high-value coastal areas and limited use in areas with saline groundwater that lack access to more conventional technologies. At this time, use of RO technologies is not widespread.	Despite significant progress toward becoming more energy-efficient and cost-effective, the level of community acceptance of distillation technologies is still limited. Their use is mainly restricted to resort hotels and high-value-added industries, and to the Caribbean islands.

Appendix 4: High Technology Options: Use of Desalination Technologies

Appendix 4: Use of Desalination Technologies

1.1 Desalination by Reverse Osmosis

Extent of Use
The capacity of reverse osmosis desalination plants sold or installed during the 20-year period between 1960 and 1980 was 1 050 600 m^3/day. During the last 15 years, this capacity has continued to increase as a result of cost reductions and technological advances. RO-desalinated water has been used as potable water and for industrial and agricultural purposes.

Water Use:
RO technology is currently being used in the RMI, Fiji and Tuvalu to desalinate groundwater. New membranes are being designed to operate at higher pressures (7 to 8.5 atm) and with greater efficiencies (removing 60% to 75% of the salt plus nearly all organics, viruses, bacteria, and other chemical pollutants). In Tuvalu the technology has been found too expensive and the plants were abandoned.

Industrial Use:
Industrial applications that require pure water, such as the manufacture of electronic parts, speciality foods, and pharmaceuticals, use reverse osmosis as an element of the production process, where the concentration and/or fractionating of a wet process stream is needed.

Agricultural Use:
Greenhouse and hydroponic farmers are beginning to use reverse osmosis to desalinate and purify irrigation water for greenhouse use (the RO product water tends to be lower in bacteria and nematodes, which also helps to control plant diseases). In some Caribbean islands like Antigua, the Bahamas, and the British Virgin Islands reverse osmosis technology has been used to provide public water supplies with moderate success.

In Antigua, there are five reverse osmosis units which provide water to the Antigua Public Utilities Authority, Water Division. Each RO unit has a capacity of 750 000 l/d. During the eighteen-month period between January 1994 and June 1995, the Antigua plant produced between 6.1 million l/d and 9.7 million l/d. In addition, the major resort hotels and a bottling company have desalination plants.

In the British Virgin Islands, all water used on the island of Tortola, and approximately 90% of the water used on the island of Virgin Gorda, is supplied by desalination. On Tortola, there are about 4 000 water connections serving a population of 13 500 year-round residents and approximately 256 000 visitors annually. In 1994, the government water utility bought 950 million litres of desalinated water for distribution on Tortola. On Virgin Gorda, there are two seawater desalination plants. Both have open seawater intakes extending about 450 m offshore. These plants serve a population of 2 500 year-round residents and a visitor population of 49 000, annually. There are 675 connections to the public water system on Virgin Gorda. In 1994, the government water utility purchased 80 million litres of water for distribution on Virgin Gorda.

1.2 Desalination by Distillation

Extent of Use
Since 1971, about 65 single-purpose service or experimental plants have been installed in Latin America and the Caribbean, with capacities ranging from 15 to 1 000 m^3/day. In Mexico

they supply freshwater to fishing villages and/or tourist resorts in Baja California and in the north-central and southeastern parts of the country. Distillation technology is currently used in the RMI. They also provide freshwater to agricultural communities.
Desalination for municipal freshwater supply purposes started in Mexico in the late 1960s, when the Federal Electricity Commission installed two 14 000 m^3/day MSF distillation units in its Rosarito Power Plant in the city of Tijuana in Northwest Mexico. At that time, those units were among the largest in the world. The Federal Electricity Commission currently operates about 31 desalination plants to produce high-quality boiler make-up water, and maintains the two dual-purpose units in Tijuana. The Mexican Navy also installed some smaller solar distillation plants to provide a supply of freshwater to some islands in the Pacific Ocean. PEMEX, the national oil company of Mexico, operates about 62 small seawater desalination plants for human freshwater consumption on off-shore oil platforms or ships. These distillation units are mainly VC, waste heat, submerged-tube evaporators, and RO plants.

The island of Curaçao, in the Netherlands Antilles, currently has two distillation plants. One is for public water supply and the other is used by the oil refinery, PEDEVESA. Both use the MSF process. The public supply plant has a maximum design capacity of 47 000 m^3/day (although the average daily production is currently 41 000 m^3/day), which is higher than the estimated domestic water consumption of 35 000 m^3/day.

Appendix 5: High Technology Options: Further Development of Desalination Technologies

Appendix 5: Further Development of the Technology

Reverse Osmosis

The seawater and brackish water reverse osmosis process would be further improved with the following advances:

- Development of membranes that are less prone to fouling, operate at lower pressures, and require less pretreatment of the feedwater.
- Development of more energy-efficient technologies that are simpler to operate than the existing technology; alternatively, development of energy recovery methodologies that will make better use of the energy inputs to the systems.
- Commercialization of the prototype centrifugal reverse osmosis desalination plant developed by the Canadian Department of National Defence; this process appears to be more reliable and efficient than existing technologies and to be economically attractive.

Distillation

Research into the falling (or spray) film MED thermal desalination process suggests that further development of distillation technologies can produce product waters that are comparable in quality to those produced with current MSF technologies and also offer additional advantages, including lower pumping requirements, higher heat transfer rates, and greatly reduced pressure differentials across the heat transfer surfaces. These favourable comparisons also apply to a falling (or spray) film VC design. Some additional considerations include:

- Lower operating temperatures (150 to 180^{o} F)(66 to 82^{o} C) and vapor velocities, reducing system losses.
- Higher thermal efficiencies to reduce fuel and energy costs.
- Improved materials for evaporator heat transfer surfaces (aluminum has two major benefits over other materials: a lower cost than copper-nickel, with nearly triple the thermal conductivity and higher operating temperatures, with an upper limit of 150^{o} F (65^{o} C) for aluminum alloys containing approximately 2% magnesium).
- Improved coatings for use in shell construction (with aluminum evaporator heat transfer surfaces, it is essential to prevent corrosion caused by the proximity of other metal ions; the carbon steel shell must be appropriately coated, and provision made for all supporting structures to be protected).
- Improved piping material for use with low temperature distillation techniques; piping should be of PVC, fiberglass, or other suitable non-metallic material.

A further alternative and promising new concept for a dual purpose plant has been the development of an evaporative condenser which is equipped with dimpled flat plate elements that could greatly increase the efficiency of this type of plant.

Appendix 6: Emergency Water Supply Options

Appendix 6:emergency Water supply Options

1.1 Emergency Water Supply through Desalination

The technology used for emergency water supply by desalination plants is the same as described in the main section. It is therefore not necessary to mention them again.

1.2 Water Conveyance by Marine Vessels

In extreme cases where water is completely lacking or inadequate and no other conventional supplies are available, it may be necessary to transport water by tanker from another source far removed from the point of use. When such water transfers require shipment across the sea, motorized water tanker vessels or barges are commonly used. Islands which suffer regular droughts should consider providing permanent barge off-loading facilities, including storage, as a component of their water distribution systems.

Technical Description

Barging of water involves the physical transportation of water from one location to another by sea, using a barge or similar tank vessel. Barges should contain storage tanks of adequate size to maximize the value of the volume of water transported relative to the cost of transportation. The storage tanks must be suitably constructed and cleaned to prevent contamination of the water; generally, they should be single-purpose vessels and not used for the transportation of other liquids. Barges may be self-propelled, but are generally towed by another vessel such as a tugboat. Once the barge arrives at a suitable port, it is secured and the water transferred by pumps to storage tanks or vehicles on land. The water is then either pumped directly into the water distribution system from the storage tanks, or distributed to consumers using tanker trucks. Protecting the purity of transported drinking water is essential, and the quality of the water should be monitored.

Extent of Use

Lots of Fiji's outer islands had been provided with water during the last droughts. Marine vessels were used in Antigua during the drought of 1982-1983. More than 20 million gallons of water were barged during that emergency. Currently the Morton Salt Company in Inagua, Bahamas, and the Bahamas Water and Sewerage Corporation in New Providence use vessels to transport water. The Water and Sewerage Corporation has chartered a 5 000 deadweight ton (dwt) water tanker and a 14 000 dwt motorized barge/water tanker on time charter, to operate continuously between Andros and New Providence. In New Providence, 54% of all water consumed comes from the island of Andros.

Operation and Maintenance

The main operational problem experienced in the use of marine vessels is weather delays. Based on the experience in the Bahamas, barges are unable to operate on an average of approximately 25 days per year. The second most frequent problem experienced is mechanical breakdown of the vessels, which can halt water transportation for a period of 1 to 7 days per incident. Approximately 15 days per year are lost due to mechanical problems. The Water and Sewerage Corporation on Andros employs one person, periodically assisted by a second, to manage the charter operation. The need of the Corporation for spare parts is minimal (repairs are undertaken by the charter operator) and the skill level required to fill and empty the barge is very basic. Of greatest concern to the Corporation is assuring the purity of the transported water. The Corporation maintains its own laboratory to test the water, and treatment facilities are available to provide any necessary treatment before the water is introduced into the supply system.

Level of Involvement
The level of government participation in the conveyance of water using marine vessels is usually very high. The scale of this type of operation is so large that only organizations involved in public water supply or large resort operators could consider it as an option.

Cost
Transporting water by marine vessels is generally more costly than other alternatives. However, this form of waterborne transport does have merit during emergencies.
Water catering in Fiji summed up to several millions of dollars over the last years. The cost of barging water from the island of Dominica to the island of Antigua is US$20/1 000 gal landed in Antigua; to transport the 1 000 gal by truck from the port of St. John costs between $25 and $50.

The key to low-cost water transportation by barge or tanker is transporting large quantities using large tankers continuously over the long term. Economies of scale significantly reduce the unit cost of water transported in this manner. However, for this type of transportation to be effective, there must be very efficient loading and unloading facilities. If these do not already exist, they can be very expensive to construct. The shipment cost of water transported in the Bahamas between Andros Island and New Providence is about $3.41/1 000 gal, including fuel costs. Factoring in the cost of the shore facilities (the Water and Sewerage Corporation owns both the production facility on Andros and the receiving facility in New Providence), the total cost of the water is approximately $5.84/1 000 gallons shipped.

Effectiveness of the Technology
The transport of water from Andros to New Providence started in 1976 after the failure of the reverse osmosis and distillation plants on New Providence, which had produced up to 2 mgd each. The production and cargo landing sites and vessels (tugs and barges) were placed in operation within a year, and began transporting 1.8 mgd. This was planned as a temporary solution to the problem, but since it remains the least costly option for providing New Providence with good quality water, the practice continues. Andros now produces 5 mgd of freshwater for New Providence. (While groundwater extraction on New Providence has a lower unit cost than water shipped from Andros, the volume of groundwater available has remained constant for the past 20 years mainly because additional land for well-field expansion cannot be acquired; thus, increased water demands in the future will have to continue to be met by the shipment of water from external sources.)

This technology also was effective in augmenting the water supply in Antigua during the severe drought of 1982-83. However, it was determined that it could not supply the needs of the island on a continuing basis because of the prohibitive transportation costs. For this reason, a desalination plant was constructed in 1987 to provide an assured water supply.

Suitability
This method of transporting water is suitable for most coastal areas where there are suitable berthing facilities for barges and the infrastructure is in place to store or distribute the water after it is unloaded.

Advantages
- The technology does not require highly skilled personnel to operate it.
- It may be cost-effective, depending on the costs of the available alternatives.

Disadvantages
- There is a lag period before the technology can be implemented; start-up times to charter a ship are generally about 3 to 6 months.
- Operations are affected by the weather; shipping may be halted when winds are greater than 27 knots and the seas higher than 11 ft.
- The cost of transportation is high and in some cases may be prohibitive.

- Transportation times are relatively slow.
- The quality of the water at the point of use may be difficult to assure, owing to possible contamination by seawater and/or other contaminants during transportation.
- Water must be distributed from the barge to the consumers.

Cultural Acceptability
The use of this technology is well accepted in the Caribbean islands and on the Fiji Islands where the water borne transportation of water is feasible.

Further Development of the Technology
In order to make water conveyance by marine vessels more efficient, infrastructure must be put in place to allow for the immediate distribution of barged water to consumers once the barge arrives in a port. This requires that pumps, treatment or disinfection facilities, and transmission lines be in place at the port. Considering that in many cases this infrastructure might only be used every 5 to 7 years, during drought periods, it becomes difficult to justify such an investment. Thus, inexpensive portable off-loading facilities that can be used in times of emergency would be a desirable future development.

1.3 Water Conveyance by Pipelines, Aqueducts, and Water Tankers
In some countries, water is routinely transported from regions where it is plentiful to regions where it is scarce. Several water conveyance and distribution techniques are available, and are actively used in many countries of the Pacific, Latin America and the Caribbean.

Technical Description
Among the most common water conveyance methods are tanker trucks, rural aqueducts, and pipelines. In some cases, this involves the transfer of water from one portion of a river basin to another, or between river basins. Each of these methods is described below.

- Tanker Trucks

Tanker trucks are fitted with a cistern or storage tank to transport and distribute water from a point of supply to the point of use, particularly to suburban and rural areas not served by a piped supply. If water is not supplied from a central treatment facility, it is usually extracted from the closest natural source (rivers, canals, reservoirs, or groundwater sources) and transported by the trucks to the point of use. Water thus transported may be pumped into a storage cistern, dispensed directly into household or other containers, or discharged into a small-scale treatment facility for centralized distribution. The tanks on the trucks are usually manufactured locally, and some trucks are equipped to carry portable pumps to extract the water from its source.

- Pipelines

Water may conveyed through pipelines by gravity flow or by pumping. The latter system will be significantly more expensive to construct, operate and maintain than similar gravity-flow systems. Large-diameter pipelines can be used to convey water over large distances, while smaller-diameter pipelines can be used to provide bulk or individual supplies at the point of use.

- Aqueducts

Aqueducts are canals used to bring water from a river or reservoir to a water distribution center. The main factors to be considered in the design of an aqueduct are the demand to be met, the source of the water, the topography in the area in which the aqueduct is to be built, the size and nature of the storage facilities, and the size and location of the distribution network. Aqueducts are best suited to meeting large-scale demands in areas with a fairly flat or gently sloping landscape suitable for conveying water to the point of use by gravity.

Extent of Use
Tanker trucks are used in most rural and urban areas of Latin American countries and in some Caribbean islands. Most trucks are privately owned; in some cases government sells the water to truck owners who then resell it to users.

Rural aqueducts have been built throughout the region and have been used to supply water for agriculture and domestic use in rural areas. Interbasin transfers using pipelines are common throughout the Latin American region.

Operation and Maintenance
Pipelines and aqueducts, whether operated by gravity or by a pumping system, need regular maintenance and repair of the pumps, pipes, and canals, and periodic upgrading of the facilities. Problems with water leaks, pumps, and storage facilities require immediate attention in order to avoid interruption of services.
Maintenance of the distribution system includes servicing the pumps and other treatment plant components, inspecting the diversion systems and pipelines, repairing leaks, and replacing electrical motors and other moving parts. A number of problems were encountered in the operation and maintenance of a distribution system in Jamaica. The level of skill needed to operate these systems is medium to high, and involves some technical training of the operators.

Level of Involvement
In Jamaica, water distribution projects using pipelines have had a high level of government participation. The projects were conceived and designed by the government, funded by an international agency, and constructed by a group of engineering consultants, with overall project coordination provided by government. Easements to permit the pipelines to traverse private property were purchased by the government.

Costs
The costs of these conveyance systems vary depending on their capacity and complexity, as a function of the terrain, the availability of labor, and the demand to be met. For example, in Panama, a small aqueduct system designed to serve a few families cost $500.

Operation and maintenance costs are a function of the specific problems that can affect each project, such as clogging of intake pipes, or high turbidity and/or high values of coliform bacterial in the source water that requires treatment prior to use.

Effectiveness of the Technology
This group of technologies spans a number of scales of application. Tanker trucks are an extremely effective means of distributing potable water to urban and rural populations, especially as an emergency measure. Their use on a day-to-day basis is more costly in the long term than providing a piped supply, but, again, the method provides an effective short-term solution to a water supply problem. On a larger scale, use of aqueducts and pipelines can provide bulk water to users at a competitive cost. While these latter technologies are limited by the cost of operation to less-steep terrain, they are widespread throughout, the Pacific, Latin America and the Caribbean. By varying the diameter of the pipes (and, to a lesser extent, the geometry of the channels), these technologies can span the range of requirements from large-scale source-to-treatment-works applications to individual user delivery applications.

Suitability
This technology is suitable for use in areas where piped water service is not available or has been interrupted. The use of aqueducts is well-suited to transporting large volumes of water over great distances. They are usually associated with impoundments, and are most often used in arid and semi-arid areas.

Advantages
Tanker trucks:
- Transporting water obviates the need for more complex water supply projects.
- The technology can efficiently provide water in small quantities to less accessible areas.

Pipeline and aqueduct systems:

- Large quantities of water can be transported without degradation in quality or evaporative losses.
- Electricity can be generated along the pipeline route if there is significant head and flow.
- Industrial and agro-industrial enterprises can be situated where water is otherwise unavailable if economic factors are favourable.
- The technology has a low operation and maintenance cost.
- Agricultural production can be improved and increased by transporting water to irrigate crops.
- Compared to open channel methods, transportation of water by pipeline reduces water loss from evaporation, seepage, and theft.

Disadvantages

Tanker trucks:

- Water prices are increased because of the expense of transporting relatively small quantities by road.
- There is a lack of quality control.
- Water distribution is costly and slow.
- Adequate roads are required to transport water from one region to another.

Pipeline and aqueduct systems:

- The capital cost is high; it usually requires borrowing, thus adding to the country's national debt.
- The skilled personnel needed to operate and maintain the project are not always locally available.
- If the water transported is of poor quality, it will contaminate the water resources of another basin where the necessary treatment to rectify the problem may not be available or affordable.
- River diversion projects can create environmental problems downstream for aquatic life and water users, and can result in the transfer of nuisance species from one basin to another, exacerbating water quality problems throughout a country.
- Transporting large quantities of water can deplete the resources available within the supplying basin.
- Vandalism of the pipeline and appurtenances can occur unless the communities through which the pipeline passes are served by the water supply.
- Environmental impacts, such as threats to endangered species, must be carefully considered and actions taken to minimise negative impacts.

Cultural Acceptability

Tanker vehicles, pipelines, and aqueducts are centuries-old technologies for transporting water and are well accepted by all communities.

Further Development of the Technology

Development of improved, more durable, and less costly piping materials will improve community access to this technology, and increase the use of this method of water conveyance. Training and development of skills among local users is needed to facilitate the construction, operation, and maintenance of future projects. Better methods for water quality control need to be implemented in all water conveyance systems.