# 2.1 Desalination by reverse osmosis

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. It is separated by the desalination process 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. In the past, the difficulty and expense of removing various dissolved salts from water made saline waters an impractical source of potable water. However, starting in the 1950s, desalination began to appear to be economically practical for ordinary use, under certain circumstances.

The product water of the desalination process is generally water with less than 500 mg/1 dissolved solids, 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/1 dissolved solids) that must be disposed of, generally by discharge into deep saline aquifers or surface waters with a higher salt content. Brine can also be diluted with treated effluent and disposed of by spraying on golf courses and/or other open space areas.

## Technical Description

There are two types of membrane process used for desalination: reverse osmosis (RO) and electrodialysis (ED). The latter is not generally used in Latin America and the Caribbean. In the RO process, water from a pressurized 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 pressurized feedwater and the product water, which is at near-atmospheric pressure. The remaining feedwater continues through the pressurized side of the reactor as brine. No heating or phase change takes place.

The major energy requirement is for the initial pressurization 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 pressurize 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: (1) pretreatment, (2) pressurization, (3) membrane separation, and (4) post-treatment stabilization. Figure 16 illustrates the basic components of a reverse osmosis system.

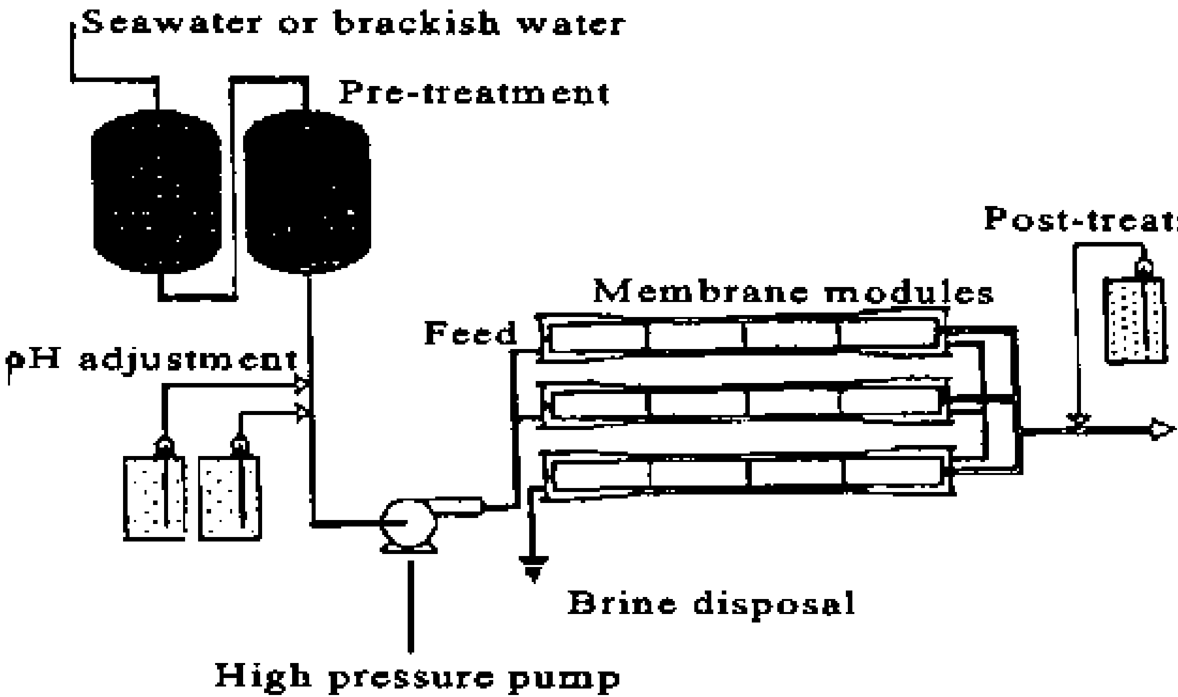
***Pretreatment:*** The incoming feedwater is pretreated to be compatible with the membranes by removing suspended solids, adjusting the pH, and adding a threshold inhibitor to control scaling caused by constituents such as calcium sulphate.

***Pressurization:*** The pump raises the pressure of the pretreated 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 (see Figure 17). 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.

***Stabilization:*** 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.

# Figure 16: Elements of the Reverse Osmosis Desalination Process.



Source: O.K. Buros, et. Al., *The USAID Desalination Manual,* Englewood, N.J., U.S.A., IDEA Publications.

## 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.

***Potable Water Use****:* RO technology is currently being used in Argentina and the northeast region of Brazil 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).

***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). Reverse osmosis technology has been used for this type of application by a farmer in the State of Florida, U.S.A., whose production of European cucumbers in a 22 ac. greenhouse increased from about 4 000 dozen cucumbers/day to 7 000 dozen when the farmer changed the irrigation water supply from a contaminated surface water canal source to an RO-desalinated brackish groundwater source. A 300 l/d reverse osmosis system, producing water with less than 15 mg/1 of sodium, was used.

In some Caribbean islands like Antigua, the Bahamas, and the British Virgin Islands (see case study in Part C, Chapter 5), 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 liters 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 liters of water for distribution on Virgin Gorda.

In South America, particularly in the rural areas of Argentina, Brazil, and northern Chile, reverse osmosis desalination has been used on a smaller scale.

**Figure 17: Two Types of Reverse Osmosis Membranes.**

Source: O.K. Buros, et. al.. *The USAID Desalination Manual,* Englewood, N.J., U.S.A., IDEA Publications

## 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. Fouling is caused when membrane pores are clogged by salts or obstructed by suspended particulates. 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.

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 4 000 $m^3$/day plant.

**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.

## Costs

The most significant costs associated with reverse osmosis plants, aside from the capital cost, are the costs of electricity, membrane replacement, and labor. All desalination techniques are energy-intensive relative to conventional technologies. Table 5 presents generalized capital and operation and maintenance costs for a 5 mgd reverse osmosis desalination in the United States. Reported cost estimates for RO installations in Latin American and the Caribbean are shown in Table 6. The variation in these costs reflects site-specific factors such as plant capacity and the salt content of the feedwater.

The International Desalination Association (IDA) has designed a Seawater Desalting Costs Software Program to provide the mathematical tools necessary to estimate comparative capital and total costs for each of the seawater desalination processes.

**Table 5 U.S. Army Corps of Engineers Cost Estimates for RO Desalination Plants in Florida**

| Feedwater Type | Capital Cost per Unit of Daily Capacity ($/m$^3$/day) | Operation & Maintenance per Unit of Production ($/m$^3$) |
|---|---|---|
| Brackish | 380 - 562 | 0.28 - 0.41 |

| | | |
|---|---|---|
| Brackish water | 380 - 562 | 0.28 - 0.41 |
| Seawater | 1341 - 2379 | 1.02 - 1.54 |

## Table 6 Comparative Costs of RO Desalination for Several Latin American and Caribbean Developing Countries

| Country | Capital Cost ($/m$^3$/day) | Operation and Maintenance ($/m$^3$) | Production Cost* ($/m$^3$)[a] |
|---|---|---|---|
| Antigua | 264 - 528 | 0.79 - 1.59 | |
| Argentina | | 3.25 | |
| Bahamas | | | 4.60 - 5.10 |
| Brazil | 1454 - 4483 | | 0.12 - 0.37 |
| British Virgin | 1190 - 2642 | | [b]3.40 - 4.30 |

| | | | |
|---|---|---|---|
| Islands | | | [illegible] |
| Chile | 1300 | | 1.00 |

[a] Includes amortization of capital, operation and maintenance, and membrane replacement.

[b] Values of $2.30 - $3.60 were reported in February 1994.

## 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/1, 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/1, 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.

## Suitability

This technology is suitable for use in regions where seawater or brackish groundwater is readily available.

## Advantages

- The processing system is simple; the only complicating factor is finding or producing a clean supply of feedwater to minimize 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 liters 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, nonmetallic materials are used in construction.

- Energy use to process brackish water ranges from 1 to 3 kWh per 1 0001 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.

**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 odors 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.

**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.

## Further Development of the Technology

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 Defense; this process appears to be more reliable and efficient than existing technologies and to be economically attractive.

## Information Sources

## Contacts

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## 2.2 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 n. The multistage-flash (MSF), MED, and vapor-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 vapor, which is then condensed to produce freshwater. The various distillation processes used to produce potable water, including MSF, MED, VC, and waste-heat evaporators, all generally operate on the principle of reducing the vapor 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 vaporization within the units. The major energy requirement in the distillation process thus becomes providing the heat for vaporization to the feedwater.

- Multistage Flash (MSF)

Figure 18 shows a simplified schematic of a multistage-flash unit. 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 vapor, 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 affect 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.

- 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 (in a manner similar to the VC process shown in Figure 19). 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 utilized 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 aluminum or other low-cost materials.

**Figure 18: Simplified Schematic of a Multistage Flash**

**(MSF) Distillation Plant.**

Source: O.K. Buros, et. al., *The USAID Desalination Manual.* Englewood, N.J., U.S.A., IDEA Publications, 1982.

- Vapor Compression (VC)

The vapor-compression process uses mechanical energy rather than direct heat as a source of thermal energy. Water vapor 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 chambers, as is shown in Figure 19. 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'/day and are often used at resorts and industrial sites.

**Figure 19: Simplified Schematic of a Vapor Compression Distillation Plant.**

Source: O.K. Buros, et al., *The USAID Desalination Manual.* Englewood, New Jersey, U.S.A., IDEA Publications, 1982.

- 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 specialized membrane which will pass water vapor but not liquid water. This membrane is placed over a moving stream of warm water, and as the water vapor passes through the membrane it is condensed on a second surface which is at a lower temperature than that of the feedwater.

- 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.

## 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. 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.

**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 shutdown 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).

**Level of Involvement**

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 die 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.

**Costs**

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 7 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'/day, the VC process is likely to be most effective; above that range, the MSF process will probably be preferable.

## Table 7 Estimated Cost of Distillation Processes in Latin American Countries

| Country | Distillation Process | Capital Cost ($) | Operation and Maintenance Cost ($/year) | Energy Cost ($/year) | Production Cost ($/m$^3$/year) |
|---|---|---|---|---|---|
| Aruba | MSF | 10000 | 1612 | 2860 | |
| Chile | VC | | | | 1.47 |
| U.S. Virgin Is. | MED and VC | | | | 4.62 |

| | | | | | |
|---|---|---|---|---|---|
| Curaçao | MSF | | | | 4.31 |

## Effectiveness of the Technology

Desalination 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/1 of total dissolved solids at the plant in Curaçao); TDS contents of less than 10 mg/1 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.

## Suitability

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 utilized 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'/d (25,000 gpd) installed at resorts and industrial sites.

**Advantages**

- 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/1 of total dissolved solids.

- Distillation can be combined with other processes, such as using heat energy from an electric-power generation plant.

**Disadvantages**

- 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.

**Cultural Acceptability**

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.

## Further Development of the Technology

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 favorable comparisons also apply to a falling (or spray) film VC design. Some additional considerations include:

- Lower operating temperatures (150 to 180° F)(66 to 82° 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° F (63" 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.

## Information Sources

### Contacts

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## 2.3 Clarification using plants and plant material

Native plants have traditionally been used to improve the quality of the water in a number of countries in Africa and Latin America. For example, the seeds of the *Moringa oleifera* are commonly used in Guatemala, and peach and bean seeds are used in Bolivia, as coagulant aids to clarify water. Dried beans *(vicia fava)* and peach seeds *(percica vulgaris)* also have been used in Bolivia and other countries for this purpose. An emergent aquatic plant used for water quality treatment in Bolivia and Peru is *Schoenoplectus tatora,* commonly known as *totora* in those countries. This plant, which is similar to the cattail, is used to remove phosphorus and nitrogen from effluents before they are discharged to natural drainage systems. The plant biomass is then used for a variety of handicraft purposes, including the weaving of baskets and the production of the well-known reed boats of Lake Titicaca.

In addition to providing the basis for clarification, aquatic plants are also used in aquaculture applications, the production of aquatic organisms (both floral and faunal, but generally including fish) under controlled conditions. Aquaculture has been practiced for centuries, primarily to grow food, fiber, and fertilizer.

The use of aquaculture as a means of treating wastewater involves both natural and artificial wetlands and the production of both algae and higher plants (submersed and emersed), invertebrates, and fish, to remove contaminants such as manganese, chromium, copper, zinc, and lead from the water. The water hyacinth *(Eichhornia crassipes)* appears to be one of the most promising aquatic plants for the treatment of wastewater and has received the most attention in this regard. Other plants are also being studied, among them duckweed, seaweed, and alligator weed.

An experimental technology that has been tested successfully on the Bogotá savannah in Colombia is a form of hydroponic cultivation of grasses using domestic wastewater. This procedure works through three mechanisms: physical, adsorption, and absorption. It not only removed more than 70% of the organic content and suspended solids but produced a large grass crop that could be used to pasture livestock. It might also be practicable for restoring eroded lands. Because of the space requirements, it is best suited to rural areas. Since it has been tried only under controlled conditions, its real cost and possible disadvantages need further assessment.

## Technical Description

- Native Plant Seeds

The seeds of many plants native to the South American continent contain essential oils and have other properties that have been exploited by traditional cultures for centuries. Among these is the ability of certain seed extracts to flocculate particulates in water. To prepare the seeds for use as a coagulant aid, the following procedure is commonly used:

  - Extract the seeds from the plant or fruit.
  - Dry the seeds for up to three days.
  - Grind die seeds to a fine powder.

- Prepare a mixture of water and ground seed material; the volume of water depends on the type of seed material used (in the case of *Moringa oleifera,* add 10 $cm^3$ of water for each seed; for peach or bean seeds, add 1 l of water to each 0.3 to 0.5 g of ground seed material).

- Mix this solution for 5 to 10 minutes; the faster it is stirred, the less time is required.

- Finally, after the sediments settle, decant the treated water. Testing it for pH, color, and turbidity is recommended.

- If the test results are acceptable, the treated water can be used for consumption and other domestic purposes.

- Aquatic Plants

Several aquatic plants have been used in water purification and wastewater treatment. Among die most widely used are cattails, *totora,* water hyacinth, and duckweed.

*Totora* and cattails grow in shallow lakes, rivers, and impoundments. The plants are rooted in the soil or bottom sediments of the body of water at depths of about 1 m and grow to between 2 m and 3 m above the water surface. These plants can absorb nitrate, phosphate, heavy metals such as manganese, and other chemical compounds. They are generally used to provide secondary treatment of effluents, in small lagoons filled with cattails or *totora.* Several physical and chemical processes take place in these lagoons:

- Sedimentation of suspended solids.
- Biological decomposition of organic compounds.

- Nitrogen removal through absorption by the plants and fixation by the plants and attached organisms, and denitrification by aerobic bacteria associated with the plants that convert organic forms of nitrogen into inorganic forms, including $N_2$ and $N_2O$ gases that escape into the atmosphere (at high pH, ammonium is converted into ammonia gas, which also escapes into the atmosphere).

- Phosphorus removal by absorption and fixation in the plant biomass and/or its adsorption onto suspended particulates which later settle to the bottom of the lagoon (the amount of phosphorus removal is a function of the plant density in the treatment area).

- Removal of manganese, copper, zinc, and lead.

- Reduction of pathogenic microorganisms due to the grazing by protozoans, adsorption onto clay particles, and exposure to environmental extremes such as pH variations within the lagoon.

Design criteria for a treatment system using cattails or *totora* include the flow rate of the water to be treated; the initial nitrogen and phosphorus concentrations; the initial concentrations of other water quality parameters, such as heavy metal concentrations and pH; the desired water quality of the effluent; and the potential uses of the treated water. In Peru, a small system capable of treating 5 l/s required 900 $m^2$ of *totora* lagoon, with a maximum water depth of 0.9 m. These techniques are especially useful in rural areas where advanced technology for water treatment is not available and where high turbidity and color are the primary water quality problems.

The water hyacinth, a native of South America, is found naturally in waterways, bayous, and other backwaters. It thrives in nitrogen-rich environments, and consequently does extremely well in raw and partially treated wastewaters. When it is used for effluent treatment, wastewater is passed through a water-hyacinth-covered basin, where the plants remove nutrients, suspended solids, heavy metals, and other contaminants. Batch treatment and flow-through systems, using single and multiple lagoons, are used. Because of its rapid growth rate and inherent resistance to insect predation and disease, water hyacinth plants must be harvested from these systems. While many uses of the plant material have been investigated, it is generally recommended as a source of methane when anaerobically digested. Its use as a fertilizer or soil conditioner (after composting), or as an animal feed, is often not recommended owing to its propensity to accumulate heavy metals. The plant also has a low organic content (it is primarily water) and, when composted, leaves behind little material with which to enrich the soil.

Design criteria for wastewater treatment using water hyacinth include the depth of the lagoons, which should be sufficient to maximize root growth and the absorption of nutrients and heavy metals; detention time; the flow rate and volume of effluent to be treated; and the desired water quality and potential uses of the treated water. Land requirements for pond construction are approximately 1 $m^2/m^3$/day of water to be treated. Phosphorus reductions obtained in such systems range between 10% and 75%, and nitrogen reductions between 40% and 75% of the influent concentration. Table 8 presents performance data from four different wastewater treatment systems using the water hyacinth.

**Table 8 Performance of Four Different Wastewater Effluent Treatment Systems Using Water Hyacinth**

| Source | BOD Reduction | COD Reduction | TSS Reduction | N Reduction | P Reduction |
|---|---|---|---|---|---|
| Secondary effluent | 35% | n/a | n/a | 44% | 74% |
| Secondary effluent | 83% | 61% | 83% | 72% | 31% |
| Raw wastewater | 97% | n/a | 75% | 92% | 60% |
| Secondary effluent | 60-79% | n/a | 71% | 47% | 11% |

Source: U.S. Environmental Protection Agency, *Innovative and Alternative Technology Assessment Manual,* Washington, D.C**.,** 1976, (Report No. EPA-430/9-78-009).

Wastewater treatment using natural and constructed wetland systems remains largely in the developmental stage, although several full-scale experimental demonstration systems are in operation, including one in Puno, Peru. Wetland treatment systems generally use spray or flood irrigation to distribute the wastewater into the wetland area. Alternatively, the wastewater may be passed through a system of shallow ponds, lagoons, channels, basins, or other constructed areas where emersed aquatic vegetation has been planted and is actively growing.

## Extent of Use

The use of plant materials is a traditional technology for clarifying potable water that is still in widespread use in rural areas of Latin America. The use of natural products has recently been rediscovered by water-supply technologists and is being further developed along more scientific lines.

Treatment of wastewaters using artificial wetlands is still experimental, but is receiving a moderate amount of use. It has been tested and is currently being used in Guatemala and to treat water from rivers near La Paz, Bolivia. *Totora* technology is also being used in Bolivia and in Puno, Peru, on the shores of Lake Titicaca, to treat small wastewater flows (of 5 to 6 l/s). However, higher flow rates (30 to 50 l/s) can be treated using larger aquatic plant pools. The *totora* treatment systems used in Bolivia involve transplanting natural plants into the treatment lagoons. Experimental results from Bolivia indicate that heavy metals are absorbed by *totora* rooted in a gravel bed. The use of aquatic plants appears to be effective only during the growing season, and is subject to temperature constraints. This technology should be very useful in developing countries with hot climates and low land costs.

Treatment systems using water-hyacinth-based technology are also still in the developmental stage, with a number of full-scale demonstration systems in operation. Some small water-hyacinth systems are in use in Mexico. This technology is useful for polishing treated effluents. It has potential as a low-cost, low-energy-consuming alternative, or addition, to conventional treatment systems, especially for small flows. It has been successfully used in combination with chemical treatment and overland flow land treatment systems. Wetland systems may also be suitable for seasonal use in treating wastewaters from recreational facilities, some agricultural operations, and/or other waste-producing activities where the necessary land is available. It also has potential application as a method for the pretreatment of surface waters for domestic supply and stormwater management.

**Operation and Maintenance**

Operation and maintenance of plant-based water clarifiers are very simple. For plant-seed solutions a household mixer or blender is the only equipment needed. The *totora* treatment systems are also simple, requiring no machinery or specialized labor. Maintenance involves periodic removal of non-biodegradable materials, and the harvesting and disposal of plant material. Disposal may either be in the form of composting, methane gas generation, or use for fiber-based handicrafts. Dredging of sediments may be required every 3 to 5 years.

Gravity flows are generally used in wastewater treatment systems using the water hyacinth. Energy to operate the water-hyacinth-based systems is provided by sunlight. However, the plants must be harvested regularly. Fifteen to 20 percent of the plants should be removed at each harvest. While the water hyacinth system can successfully cope with a variety of stresses, the health of the plants must be maintained for most effective treatment. Several precautionary steps have been identified. Studies have shown that the presence of high chlorine residuals inhibits plant growth. Therefore, chlorination of the effluent is best done after water hyacinth treatment. However, if local conditions dictate that pre-treatment chlorination is necessary, care should be taken to maintain chlorine residuals in the influent at less than 1 mg/l. The system should also be monitored for the presence of weevils and other insects that damage the plants. Diseased or damaged plants should also be removed.

In wetland treatment systems, a knowledge of the mosquito life cycle and habitat needs helps managers avoid mosquito breeding problems. Open water areas, which are subject to wind action and provide easy access to predators (such as fishes), will limit mosquito production. Maintaining good water circulation in vegetated areas also gives access to predators and lessens mosquito production. The vegetation resulting from wetland systems can be utilized as compost or as animal feed supplements, or digested to produce methane. Depending on the plant species involved and their fiber content, plant material can also be used for handicrafts and the manufacture of specialty papers. Skill requirements for the operation and maintenance of wetland treatment systems are low.

**Level of Involvement**

These forms of treatment have been practiced primarily by the private sector in rural areas, and by universities and government institutions for research and development purposes. The Government of Peru has contributed financial and technical resources to the construction of two experimental treatment facilities using *totora* in Puno, Perú. In Bolivia, experiments have been performed at the University of San Andrés (UMSA).

**Costs**

Very little information is available concerning the cost of plant-based technologies. This is especially true in the case of water clarification using *Moringa oleifera* and other seeds.

The main cost appears to be the labor in acquiring the plant seeds and producing the flocculent solution.

Cost estimates of wetland-based wastewater treatment systems are equally scarce. The cost of the *totora* treatment system in Peru is estimated at $65 000. Generalized construction, operation, and maintenance costs for wetland systems are shown in Figure 23. The costs shown in this figure were derived from wetland treatment systems at Vermontville and Houghton Lake in Michigan, U.S.A.

## Effectiveness of the Technology

In using ground seeds for water clarification, the size of the particles is an important factor: generally speaking, the smaller the particles, the more efficient the clarification process. This is particularly important in the removal of color using peach and bean seeds (Figure 20). The concentration of the resulting coagulant solution has also an effect on the reduction of turbidity in the product water (Figure 21). For most plant seeds, the lower the pH of the water, the more effective the treatment. Suspended materials coagulate better at lower pH values. Peach seeds are an exception to this rule of thumb. *Moringa oleifera* was found to be more efficient at reducing turbidity than aluminum sulfate (alum). In general, also, the higher the initial turbidity, the higher the removal rate.

**Figure 20: Percent Color Removal as a Function of Seed Particle Size.**

Source: Freddy Camacho Villegas, Institute of Hydraulics and Hydrology, UMSA, La Paz.

**Figure 21: Turbidity Reduction as a Function of Coagulant Concentration.**

Source: Freddy Camacho Villegas, Institute of Hydraulics and

Hydrology, UMSA, La Paz.

Wetland treatment systems using *totora* are quite efficient at removing nutrients and oxygen-demanding substances from effluents. Table 9 shows the percentage of removal of chemical compounds from wastewater by the system in Puno. Parasites were also removed from the inflow waters, and total and fecal coliforms were reduced in concentration by 80% and 99%, respectively. The experiments performed in Bolivia on the removal of heavy metals by *totora* show that lead, silver and copper can be removed from effluents in less than 2 days. Figure 22 shows the decline in concentration of several heavy metals in a typical effluent.

**Table 9 Removal of Chemicals by *Totora***

| Parameter | Inflows (g) | Outflows (g) | % Removed |
|---|---|---|---|
| Ammonium-N | 6.92 | 2.40 | 65.30 |
| Ammonia-N | 8.45 | 2.93 | 65.20 |

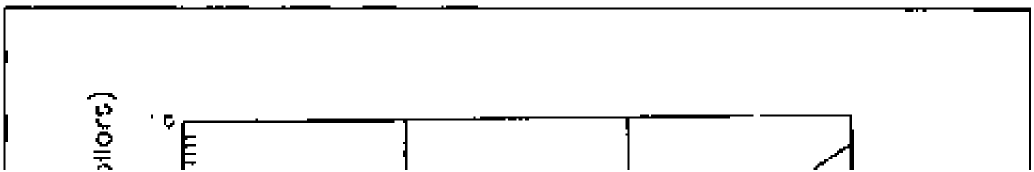
| | | | |
|---|---|---|---|
| Ammonia-N | 8.45 | 2.95 | 65.20 |
| Nitrate-N | 2.15 | 0.21 | 90.20 |
| BOD | 112.60 | 17.60 | 84.40 |

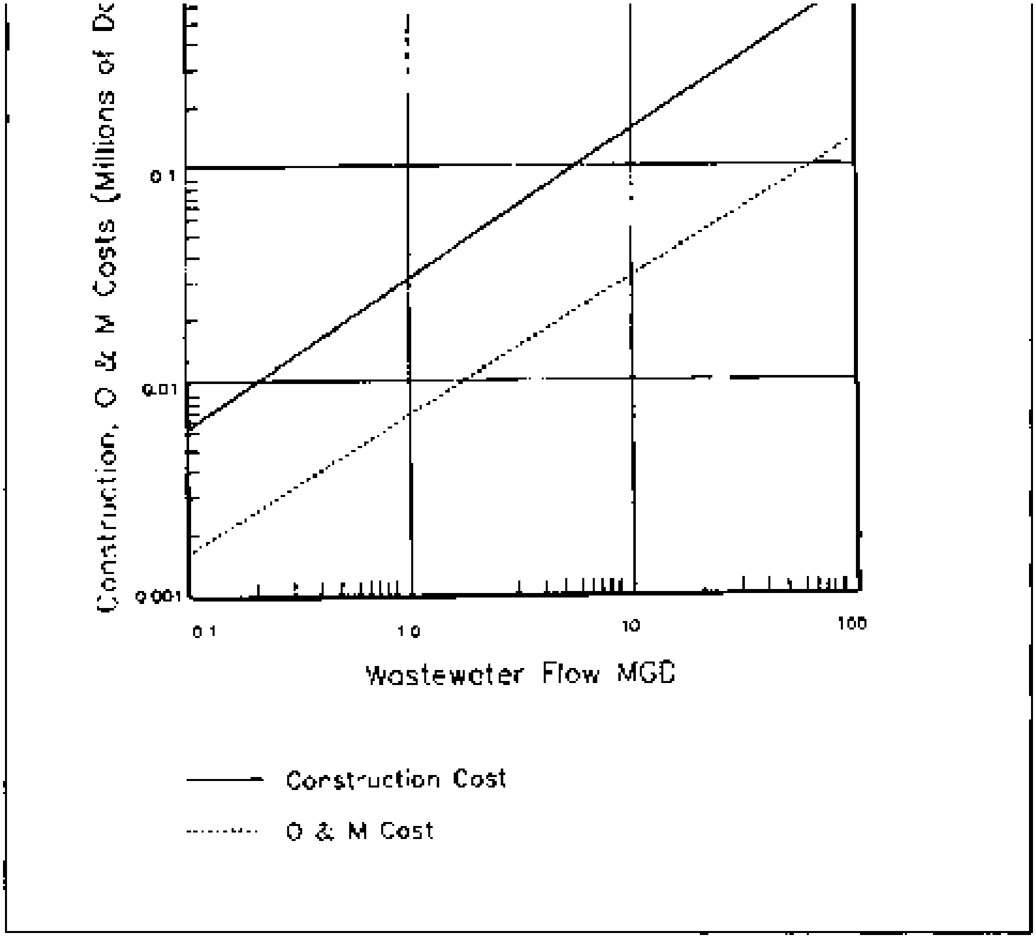
Source: Freddy Camacho Villegas, Institute of Hydraulics and Hidrology, UMSA, La Paz.

**Figure 22: Absorption of Heavy Metals by *Totora.***

Source: Freddy Camacho Villegas, Institute of Hydraulics and Hydrology, UMSA, La Paz.

**Figure 23: Generalized Construction and Operation and Maintenance Costs for Aquaculture and Wetland Systems.**




Construction, O & M Costs (Millions of Do
0.1
0.01
0.001
0.1
1.0
10
100
Wastewater Flow MGD
Construction Cost
O & M Cost

Source: Edward J. Martin. *Handbook for Appropriate Water and Wastewater Technology/or Latin America and the Caribbean* Washington, D.C., PAHO and IDB, 1988.

## Suitability

These technologies are useful in areas where suitable plants are readily available. In areas where they are not, any introduction of plants species must be undertaken with caution to minimize the possibility of creating nuisance growth conditions. Even introducing them into constructed enclosures should be done carefully, and with the foreknowledge that there is a strong likelihood that they will enter natural water systems (especially as they must be harvested from the treatment systems and disposed of).

## Advantages

- *Moringa oleifera* trees are hardy and drought-resistant, fast-growing, and a source of large numbers of seeds. They are nontoxic and effective coagulants useful for removing turbidity and bacteria from water.

- The cost of both seed treatment and wetlands is very low, in most cases negligible.

- These technologies are traditional, rudimentary, and easy to implement, ideal for rural areas.

- Wetland systems are easy to build, simple to operate, and require little or no maintenance.

- Most small-scale wetland treatment systems require relatively small land areas.

- Wetland technologies reduce nutrient

contamination of natural systems.

- Heavy metals absorbed by the plants in wetland treatment systems are not returned to the water.

- Water-hyacinth-based and other wetland systems produce plant biomass that can be used as a fertilizer, animal feed supplement, or source of methane.

**Disadvantages**

- In some places plant seeds may not be readily available.

- *Totora* treatment systems require an initial capital investment that may not always be easily accessible to potential users.

- The lifespan of *totora* as an efficient water quality treatment technology is still undetermined.

- Temperature (climate) is a major limitation, since effective treatment is linked to the active growth phase of the emersed (surface and above) vegetation.

- Herbicides and other materials toxic to the plants can affect their health and lead to a reduced level of treatment.

- Duckweed is prized as food by waterfowl and fish, and can be seriously depleted by these species.

- Winds may blow duckweed to the windward shore unless wind screens or deep trenches are employed.

- Plants die rapidly when the water temperature approaches the freezing point; therefore, greenhouse structures may be necessary in cooler climates.

- Water hyacinth is sensitive to high salinity, which restricts the removal of potassium and phosphorus to the active growth period of the plants.

- Metals such as arsenic, chromium, copper, mercury, lead, nickel and zinc can accumulate in water hyacinth plants and limit their suitability as fertilizer or feed materials.

- Water hyacinth plants may create small pools of stagnant surface water which can serve as mosquito breeding habitat; this problem can generally be avoided by maintaining mosquitofish or similar fishes in the system.

- The spread of water hyacinth must be closely controlled by barriers, since the plant can spread rapidly and clog previously unaffected waterways.

- Water hyacinth treatment may prove impractical for large-scale treatment plants because of the land area required.

- Evapotranspiration in wetland treatment systems can be 2 to 7 times greater than evaporation alone.

- Harvesting the water hyacinth or duckweed plants is essential to maintain high levels of system performance.

**Cultural Acceptability**

Seed treatment is not widely known in Latin America and the Caribbean, and its acceptability cannot be conjectured.

Use of aquatic plants as a wastewater treatment medium is well accepted in areas where it is a traditional technology. It is especially well accepted in the Andean areas, where the plants used in the treatment process have value for handicraft production, cattle feed, and other economic uses.

## Further Development of the Technology

Other native plants and plant materials should be investigated as coagulants for use in the removal of color and turbidity, and the control of pH. Additional studies will be needed to establish the appropriate dosages of flocculent solutions to be used in water quality treatment.

The use of *totora* or other aquatic plants can help to clean nutrient- and metal-laden water from agricultural and mining operations, both for water reuse and to eliminate downstream contamination. Future development should be focused on determining appropriate aquatic plant densities required to clean certain types of wastewaters and improving the efficiency of plant uptake after several water treatment cycles. Other uses of the harvested plants should be investigated to make this technology economically attractive.

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# 2.4 Disinfection by boiling and chlorination

Boiling and chlorination are the most common water and wastewater disinfection processes in use throughout the world. Boiling is primarily used in rural areas in developing countries to eliminate living organisms, especially bacteria, present in the water. It is also used in emergencies when other, more sophisticated methods of disinfection are not available. Prior to the development of chlorination, boiling was the principal method used to kill pathogenic organisms.

## Technical Description

- Boiling

Boiling is a very simple method of water disinfection. Heating water to a high temperature, 100°C, kills most of the pathogenic organisms, particularly viruses and bacteria causing waterborne diseases. In order for boiling to be most effective, the water must boil for at least 20 minutes. Since boiling requires a source of heat, rudimentary or non-conventional methods of heat generation may be needed in areas where electricity or fossil fuels are not available.

- Chlorination

Chlorination has become the most common type of wastewater and water disinfection. It should be noted that it is designed to kill harmful organisms, and generally does not result in sterile water (free of all microorganisms). Two types of processes are generally used: hypochlorination, employing a chemical feed pump to inject a calcium or sodium hypochlorite solution, and gas chlorination, using compressed chlorine gas.

***Hypochlorination.*** Calcium hypochlorite is available commercially in either a dry or wet form. High-test calcium hypochlorite (HTH), the form most frequently used, contains about 60% available chlorine. Because calcium hypochlorite granules or pellets are readily soluble in water and are relatively stable under proper storage conditions, they are often favored over other forms. Figure 24 shows a typical hypochlorite installation.

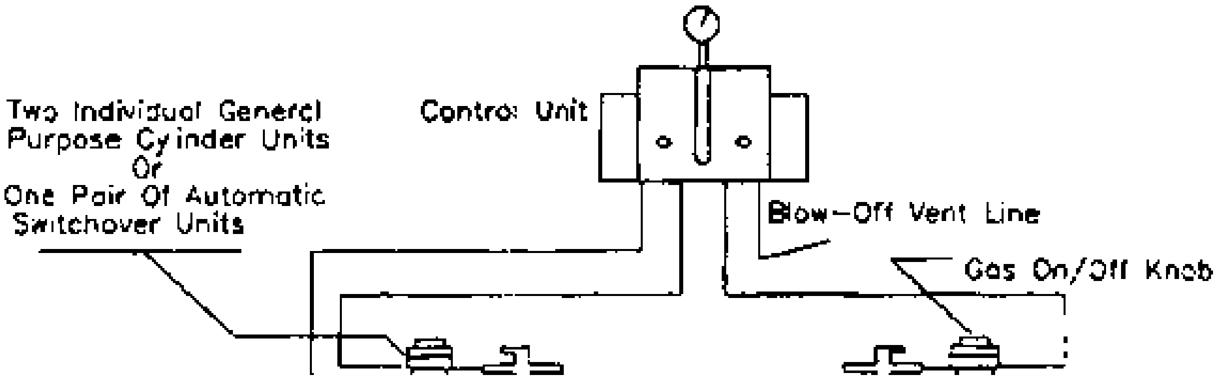
Sodium hypochlorite is available in strengths from 1.5% to 15%, with 3% available chlorine as the typical strength used in water treatment applications. The higher the strength of the chlorine solution, the more rapidly it decomposes and the more readily it is degraded by exposure to light and heat. It must therefore be stored in a cool location and in a corrosion-resistant tank. Typically, 30 minutes of chlorine contact time is required for optimal disinfection with good mixing. Water supply treatment dosages are established on the basis of maintaining a residual concentration of chlorine in the treated water.

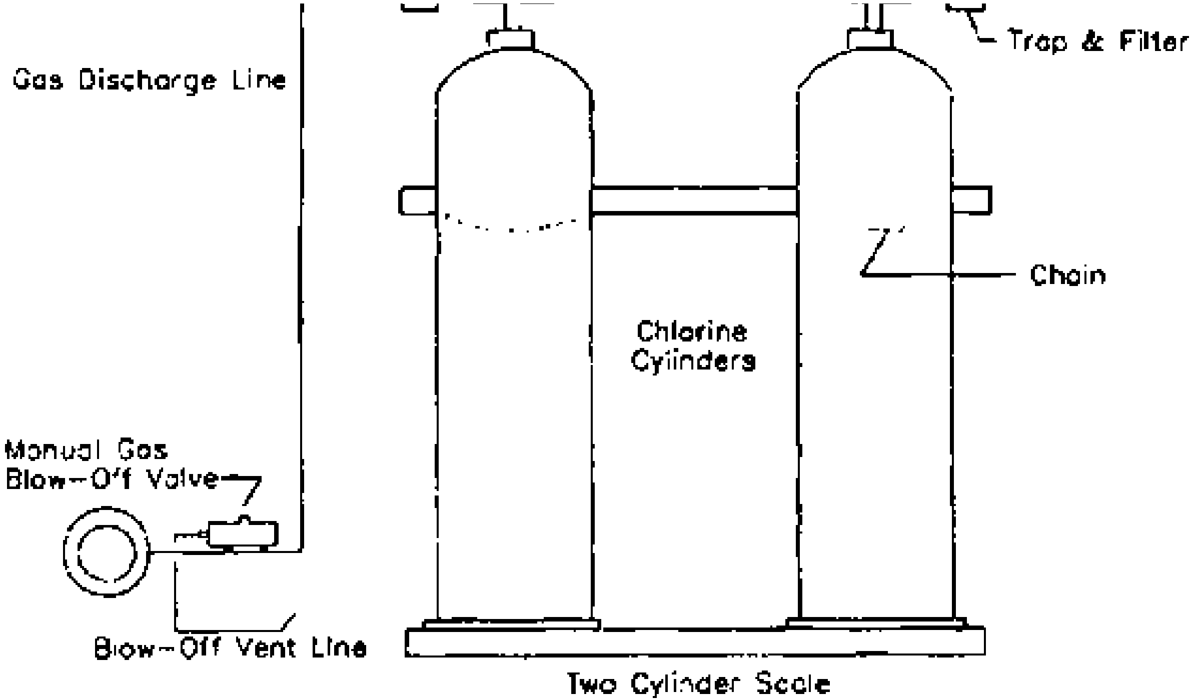
Water-based solutions of either the liquid or the dry form of hypochlorite are prepared in predetermined stock solution strengths. Solutions are injected into the water supply using special chemical metering pumps called hypochlorinators. Positive displacement types are the most accurate and reliable and are commonly preferred to hypochlorinators employing other feed principles (usually based on suction). Positive-displacement-type hypochlorinators are readily available at relatively modest costs. These small chemical-feed pumps are designed to pump (inject under pressure) an aqueous solution of chlorine into the water system. They are designed to operate against pressures as high as 100 psi, but may also be used to inject chlorine solutions under ambient (atmospheric) or negative head conditions. Hypochlorinators come in various capacities ranging from 3.8 to 227 l/day. Usually, the pumping rate is manually adjusted by varying the stroke of the pump's piston or diaphragm. Once the stroke is set, the hypochlorinator accurately feeds chlorine into the system at that rate, maintaining a constant dose. This works well if the water supply rate and the output of the pump are fairly constant.

**Figure 24: A Typical Hypochlorite Installation.**

Source: Liguori P. Small, *Water Systems Serving the Public,* Washington, D.C., U.S. Environmental Protection Agency, 1978.

**Figure 25: A Typical Chlorine Cylinder Setup for Gas Chlorination Treatment.**






Source: James M. Montgomery Consulting Engineers, *Water Treatment Principles and Design,* Walnut Grove, Cal., 1985.

Montserrat has been using floating chlorinators, but in response to concern expressed by the Director of Health Services that they leave chlorine residues in the water supply and that "the chlorine values are generally too low to guarantee safety," the Montserrat Water Authority looked into various other methods and decided on gaseous chlorine. It is now proceeding cautiously to replace floating chlorinators with gas chlorination as treatment plant operators are trained in the new system.

***Gas Chlorination.*** In gas chlorination systems, chlorine is supplied as a liquefied gas under high pressure from containers varying in size from 100 Ib to 1 ton or from tank cars for larger sizes. Cylinders in use should be set on platform scales flush with the floor; the loss of weight is used as measure of the dosage. The following precautions have to be taken when handling chlorine gas:

- Chlorine gas is both very poisonous and very corrosive; adequate exhaust ventilation at floor level must be provided since chlorine gas is heavier than air.

- Chlorine-containing liquids and gases can be handled in wrought-iron piping; however, chlorine solutions are highly corrosive and should be handled in rubber-lined or corrosion-resistant plastic piping with hard rubber fittings where necessary.

- Pressurized chlorine gas should never be piped in silver, glass, Teflon, or other piping material that cannot handle the pressure; exposure to concentrated chlorine gas can be fatal.

A gas chlorinator meters the gas flow and mixes the gas with water. The resulting chlorine solution is then injected into the product water. Small water supplies can be effectively served by a 100 or 150 lb container; larger containers are not recommended for small systems, as they require special hoists and cradles. (Chlorine gas is a highly toxic lung irritant compound and special facilities are required for storing and housing gas chlorinators.) The advantage of this method, however, is the convenience afforded by the relatively large quantity of chlorine gas available for continuous periods of operation lasting several days or weeks, without the need to mix chemicals.

Figure 25 shows a typical chlorine gas cylinder system for gas chlorination treatment.

## Extent of Use

Boiling is a primary technology used to control the spread of waterborne diseases. It is a traditional technology that was used prior to the advent of existing technologies. It is still used in areas where the energy supplies and modem facilities needed for other technologies are lacking, and in areas where the quality of the water supply is questionable.

The most common system of disinfection in Latin America and the Caribbean is chlorination. Chlorine tablets, liquid, powder, and gas are widely used. Chlorination of water supplies on an emergency basis was practiced in the region as early as about 1850. At present, chlorination of both water supplies and wastewater is widespread. Chlorination for disinfection is used to prevent the spread of waterborne diseases and to control algal growth and odors. Economics, ease of operation, and convenience are the main factors used to evaluate disinfection processes.

For safety, and to ensure a constant supply of chlorine, on-site generation is recommended. Most commercially available chlorine generation equipment will operate on waters ranging in salinity from freshwater to seawater, and also on brine solutions prepared for the purpose. Hypochlorite solutions prepared from seawater are usually limited to about 1 800 mg/l of available chlorine, and those produced from brine to about 8 000 mg/l. Heavy metal ions present in seawater interfere with the stability of hypochlorite solutions prepared using water from this source.

## Operation and Maintenance

***Gas Chlorinators.*** Gas chlorinators have an advantage in situations where water flow rates are variable, because the chlorine feed rates may be synchronized to inject variable quantities of chlorine into the product water. Capital costs of gas chlorination, however, are somewhat greater, but chemical costs may be less. Normal operation of a gas chlorinator requires routine observation and preventive maintenance. Daily duties of an operator should include the following tasks:

- Reading the chlorinator rotameter daily and recording the information.

- Reading the product water flow meters and recording the amount of water pumped.

- Checking the chlorine residual levels in the distribution system and, as necessary, adjusting the rotameter to increase the feed rate if they are too low and decrease it if they are too high.

- Calculating the chlorine usage, and ordering further chlorine stocks if necessary.

- Cleaning the equipment and the building weekly, cleaning the "Y" strainer three times a week, and replacing the gaskets periodically.

- Performing preventive maintenance on the equipment.

***Hypochlorinators.*** Because of its oxidizing potential, calcium hypochlorite should be stored in a cool, dry location, away from other chemicals, in corrosion-resistant containers. Operators should perform the following maintenance tasks:

- Reading and recording the level of the solution tank at the same time every day.

- Reading the product water flow meters and recording the amount of water pumped.

- Checking the chlorine residual levels in the system and adjusting the chlorine feed rate as necessary, in order to maintain a chlorine residual level of 0.2 mg/l at the most remote point in the distribution system (the suggested free chlorine residual for treated water or well water is 0.5 mg/l at the point of chlorine application, provided that the 0.2 mg/l concentration is maintained throughout the distribution system). The chlorine feed rate of a floating chlorinator must be adjusted daily to increase or decrease the dosage in conformity with the water output of the treatment plant.

- Checking and adjusting the chemical feed pump operation; most hypochlorinators have a dial indicating the chlorine feed rate, with a range from 0 to 10, the pointer of which should initially be set to approximately 6 or 7, when using a 2 % hypochlorite solution. The pump should be operated in the upper ranges of the dial to ensure that the strokes or pulses from the pump are frequent enough so that the chlorine will be fed continuously into the water being treated.

- Replacing the chemicals and washing the chemical storage tank as necessary so that a 15-to 30-day supply of chlorine is on hand to meet future needs; hypochlorite solutions, however, should be prepared only in quantities needed for two to three days of operation, in order to preserve their potency.

- Checking the operation of the check valve.

- Inspecting and cleaning the feeder valves.

Commercial sodium hypochlorite solutions (such as Clorox) contain an excess of caustic soda (sodium hydroxide, NaOH); when diluted with highly alkaline water, they produce a solution that is supersaturated with calcium carbonate, which tends to form a coating on the valves in the solution feeder. Similarly, in systems using calcium hypochlorite (HTH), when sodium fluoride is injected at the same point as the hypochlorite solution the calcium and fluoride ions combine and form a coating. The coated valves will not seat properly and the feeder will fail to chlorinate the product water properly. (Small hypochlorinators are sealed so that they cannot be repaired without replacing the entire unit. Otherwise, they require very little maintenance, mostly consisting of a periodic oil change and lubrication.)

Frequent visits are required to the chlorination points in the distribution system to make adjustments, to clear PVC tubing of sludge formation that stops tablets from dissolving, and to recharge tablets.

**Level of Involvement**

Boiling is exclusively the responsibility of individual users.

Chlorination is normally conducted by the private sector in small-scale hypochlorite treatment systems. Regional or large-scale systems require the involvement of a public utility or regional water supply authority, particularly if gas chlorination is used. For large systems, government involvement and financing are required.

**Costs**

The cost of boiling is related to the cost of the energy used in the process.

The cost of chlorination systems varies considerably depending on the geographic location and the type of chlorination system used. Table 10 shows a comparison of capital costs of two different chlorination systems.

**Table 10 Comparison of Capital Costs of Chlorination Systems ($)**

| Item | Gas Chlorination | Hypochlorite Tablets |
|---|---|---|
| Equipment | 10482 | 875 |
| Installation | 1516 | 150 |
| Building | 10000 | - |

| | | |
|---|---|---|
| [illegible] | [illegible] | |
| Total | 21999 | 1020 |

Source: Margaret Dyer-Howe, General Manager, Montserrat Water Authority, 1995.

## Effectiveness of the Technology

Boiling is a very effective disinfection technology, but it is recommended only as a backup to other technologies because of its volume limitations and energy requirements.

Chlorination is a very effective and well-known technology. Its effectiveness is a function of the quality of the water that is being chlorinated and the method of chlorination used. Normally gas chlorination is a more efficient method of disinfection, although a system based on the use of hypochlorite tablets is easier to operate and maintain and is preferred by individual users. Table 11 shows a comparison of the two methods as used on the Caribbean island of Montserrat.

**Table 11 Technological Efficiency of Chlorination Methods**

| Chlorination Method | Tablets/Granules | Chlorine Gas |
|---|---|---|
| Chlorine usage | 201 lb $Cl^2$ | 102 lb gas |
| Total Cl residue | 27.1 mg/l | 40.5 mg/l |
| Residue/$Cl_2$ ratio | 0.13mg/lb $Cl^2$ | 0.46 mg/lb of $Cl^2$ |
| % of available chlorine | 65% | 100% |
| Treatment cost | $1532 | $172 |

Source: Margaret Dyer-Howe. General Manager, Montserrat Water Authority, 1995.

## Suitability

Boiling is applicable everywhere, although it is now most often used in emergencies or in rural areas where chlorinated public water supplies are not available.

Chlorination can be used in most areas depending on the availability of chemicals. Gas Chlorination, however, is best used in controlled situations such as provided by a public water utility.

**Advantages**

As was noted above, boiling, while an effective technology, is generally considered to be a secondary or emergency means of disinfecting water supplies. For this reason, the following advantages refer to Chlorination systems:

- The systems are extremely reliable; the hypochlorite system is somewhat easier to operate than the gas system because the operators need not be as skilled or as cautious.

- Chlorination is less costly than other disinfection systems and is generally easier to implement; chlorine ($Cl_2$) can be made in the region and safety considerations for its production, transportation, and use are well known.

*Hypochlorinator system:*

- Hypochlorite compounds are non-flammable.

- Hypochlorite does not present the same hazards as gaseous chlorine and therefore is safer to handle; spills may be cleaned up with large volumes of water.

- Floating chlorinators can be adapted to small community systems or individual rainwater collector systems. They easy to construct and to transport. However, they cannot easily guarantee uniform residual chlorine concentrations.

*Gas feeder system:*

- Gas feeder systems are fitted with valves to automatically close the vacuum regulator in case of leaks or accidental breaks in the vacuum line, stopping gas flow at source.

- The systems have an automatic shut-off in case of interruption of feedwater supplies.

- The use of chlorine gas is cheaper and cleaner.

- Chlorine supplies last approximately three months.

- Dosage rates and the resulting chlorine residual can be accurately controlled.

## Disadvantages

- Boiling requires a reliable source of energy and is limited in terms of the volume able to be treated.

- The use of chlorine in gaseous form or in solution can cause safety hazards; all operating personnel should be made aware of these hazards and trained in their mitigation.

- Chlorine is reactive and interacts with certain chemicals present in the product water, depending on pH and water temperature; this results in the depletion of the chlorine concentration, leaving only residual amounts of chlorine for disinfection (over-chlorination may result in the formation of chlorinated hydrocarbons, such as trihalomethanes, which are known to be carcinogenic).

- Chlorine will also oxidize ammonia, hydrogen sulfide, and metals present in the product water to their reduced states.

- Chlorine gas is heavier than air, and is extremely toxic and corrosive in moist atmospheres. Dry chlorine can be safely handled in steel containers and piping, but where moisture is present (as it is in most treatment plants), corrosion-resistant materials such as silver, glass, Teflon, and certain other plastics must be used - though not, as was said above, for pressurized gas.

- Hypochlorite may cause damage to eyes and skin upon contact, and, because it is a powerful oxidant, may cause fires if it comes into contact with organic or other easily oxidizable substances.

## Cultural Acceptability

Boiling is a widely accepted practice. Chlorination is a common practice in water treatment plants in urban areas, but is rarely used in rural areas.

## Further Development of the Technology

Boiling and chlorination are very well known technologies used by most of the world's population for the routine and/or emergency disinfection of water supplies and wastewaters. Nevertheless, chlorination systems could be improved primarily in the area of safety both in the production of chlorine gas and the methods of handling and distributing the gas within the treatment plants. Development of corrosion-resistant materials that are not affected by chlorine could increase the frequency of utilization of gas chlorination, which is a more efficient method of disinfection than hypochlorite. Hypochlorite production methods, using seawater and brackish water as source waters for the production of chlorine solutions, could also be improved, to reduce the cost and to make use of the by-products of this process.

## Sources of Information

### Contacts

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## 2.5 Filtration systems

Filtration systems are primarily used to purify water for domestic consumption. Several types of filtration systems have been used extensively in developing countries throughout the world, particularly in Latin America and the Caribbean. These include residential filters, slow and rapid sand filters, and dual media filters. Vertical flow pre-filters with gravel media tested in Guatemala and up-flow solids contact filters used in Brazil have potential for future use.

The design and application of different types of filters depend on the volume, flow rate, and quality of the inflowing water; the desired degree of water purification; and the use of the filtered water. The availabilities of filtering materials and skilled personnel are also factors to be considered in the selection of an appropriate filtration system.

Normally, the quality of the product water can be improved by mechanical straining through a porous material, such as sand or gravel. Depending on the size of the pores and the nature of the filter material, straining, or filtering, may remove a significant portion of the undesirable contents of the feedwater: suspended and colloidal matter, bacteria and other microorganisms, and, sometimes, certain chemicals. The filter material may be any porous, chemically stable material, but sand (silica and garnet) is used most often. Sand is cheap, inert, durable, and widely available. It has been extensively tested and has been found to give excellent results. (Other materials have been used, some of which are described below; others, such as the reverse osmosis technologies described previously, are also a specialized form of filtration.)

## Technical Description

- Residential Filters

Residential filters are a common form of filtration. They can be either homemade or purchased commercially. The homemade filters usually consist of a sand- or gravel-filled pipe or tub, while the commercial systems usually have a stainless steel frame, with appropriate connections that make installation and operation relatively simple. Many commercial filters contain filtration media other than sand or gravel.

The basic form of residential filter, used in rural areas with no public water supply, is the tub filter. The tub filter consists of two tubs made of mud or clay, pottery or plastic, and joined together. The upper tub contains the filter medium (sand, gravel, coal, stone, etc.), into which the water to be treated is poured. It moves through the filter medium, through holes in the base of the upper tub, to the lower tub, where it is stored until used. A faucet is usually installed in the lower tub for convenient access. Homemade filters, such as the tub filter, are usually constructed of locally available materials. For example, in El Salvador, they are constructed of a concrete pipe, approximately 0.5 m in diameter and 1 m in length, fitted with a perforated pipe, which is placed at the bottom of the filter in a 10 cm layer of gravel and connected to a pipe with a 3/4-inch internal diameter from which the filtered water is extracted. The gravel is overlain by 60 cm of sand. Both the gravel and the sand are cleaned and dried in the sun, before use. In Mexico, residential filters are constructed of porous volcanic rock assembled in a wooden frame and protected by a screen. In the Dominican Republic, residential filters are installed at the point of discharge of storage cisterns, or at the point where water enters the houses. The frame of these filters is usually made of stainless steel, with layers of sand, quartzitic gravel, anthracite, and activated carbon as the filtration media.

- Slow Sand Filters

A slow sand filter consists of a watertight box, fitted with an underdrain, which supports the filtering material and distributes the flow evenly through the filter. Many different media have been used for the underdrain system. Bricks, stone, and even bamboo have been used for this purpose; bamboo, however, requires frequent replacement because it is organic and subject to decomposition. The effective size of the sand used in slow sand filters is about 0.2 mm, and may range between 0.15 mm and 0.35 mm, with a coefficient of uniformity of between 1.5 and 3.0. In a mature bed, a layer of algae, plankton, and bacteria forms on the surface of the sand. The walls of the filter can be made of concrete or stone. Sloping walls, dug into the earth and supported or protected by chicken wire reinforcement and a sand or sand-bitumen coating, could be a cost-effective alternative to concrete. Some Latin American countries, such as Ecuador and El Salvador, use concrete reinforced with a minimal amount of iron (ferrocement). Inlets and outlets should be provided with controllers to keep the raw water level and the filtration rate constant. Lateral pipes range from 2 to 8 in, while the bottom drains are normally between 10 and 30 in. Bottom drains consist of a system of manifold and lateral pipes. Figure 26 is a diagram of a typical slow sand filter.

The successful performance of a slow sand filter depends mainly on the retention of inorganic suspended matter by the straining action of the sand. Filtration rates usually employed in developing countries range between 2.5 and 6.0 $m^3/m^2$/day. Higher rates may be used after a series of tests demonstrates that the effluents are of good quality. The system should be designed for flexibility, and should consist of a number of separate units to enable maintenance to be performed without interruption of the water service. The suggested number of units for a given population size ranges from two units for a population of 2 000 up to six units for a population of 200 000.

- Rapid Sand Filters

Rapid sand filters differ from slow sand filters in the size of the media employed. Media in rapid sand filters may range in size from 0.35 to 1.0 mm, with a coefficient of uniformity of 1.2 to 1.7. A typical size might be 0.5 mm, with an effective size of 1.3 to 1.7 mm. This range of media size has demonstrated the ability to handle turbidities in the range of 5 to 10 NTU at rates of up to 4.88 $m^3/m^2/h$. Filtration rates for rapid filters may be as high as 100 to 300 $m^3/m^2$/day, or about 50 times the rate of a slow sand filter. The number of filters used for a specific plant ranges from 3 filters for a plant capacity of 50 l/s to 10 filters for a plant capacity of 1 500 l/s.

A typical rapid sand filter consists of an open watertight basin containing a layer of sand 60 to 80 cm thick, supported on a layer of gravel. The gravel, in turn, is supported by an underdrain system. In contrast to a slow sand filter, the sand is graded in a rapid rate filter configuration. The sand is regraded each time the filter is backwashed, with the finest sand at the top of the bed. The underdrain system, in addition to performing the same functions served in the slow rate filter, serves to distribute the backwash water uniformly to the bed. The underdrain system may be made of perforated pipes, a pipe and strainer, vitrified tile blocks with orifices, porous plates, etc. A clear well is usually located beneath the filters (or in a separate structure), to provide consistent output quantity. The minimum number of filter units in a system is two. The surface area of a unit is normally less than 150 $m^2$. The ratio of length to width is 1.25 to 1.35.

- Dual- or Multi-Media Filters

Dual-media filtration uses two layers, a top one of anthracite and a bottom one of sand, to remove the residual biological floe contained in settled, secondary-treated wastewater effluents and residual chemical-biological floe after alum, iron, or lime precipitation in potable water treatment plants. It is also used for tertiary or independent physical-chemical waste treatment in the United States and other countries. Gravity filters operate by using either the available head from the previous treatment unit or the head developed by pumping the feedwater to a flow cell above the filter cells. A filter unit consists of an open watertight basin; filter media; structures to support the media; distribution and collection devices for influent, effluent, and backwash water flows; supplemental cleaning devices; and the necessary controls to sequence water flows, levels, and backwashing.

**Figure 26: Slow Sand Filtration System.**

Source: Edward J. Martin, *Handbook for Appropriate Water and Wastewater Technology for Latin America and the Caribbean,* Washington, D.C., PAHO and IDB, 1988.

- Upflow Solids Contact Filter

These units eliminate the need for separate flocculators and settling tanks, since they perform liquid-solid separation, filtration, and sludge removal in a single unit process. Coagulation and flocculation are performed in a granular medium (such as a layer of gravel under a sand bed). The use of flocculent aids improves filtration results. This process should be restricted to raw waters of low turbidity (up to 50 JTU) and no more than 150 mg/l of suspended solids. It is widely used, especially in Brazil. These filters are designed for rates of filtration between 120 and 150 $m^3/m^2$/day.

**Extent of Use**

Both homemade and commercially purchased residential filters are commonly used in developing countries where the quality of water for domestic use is poor. El Salvador, Dominican Republic, and Mexico have promoted the use of these types of filters. In general, most Latin American countries use residential filters for water purification, particularly in rural areas.

Slow and rapid sand filters have been used in the rural community of La Pinera, El Salvador. In Ecuador, slow sand filters are used extensively for both surface and groundwaters. Filtration systems using vertical reactors with gravel beds have been tested as a means of pre-filtration in a water treatment plant in the municipalities of Cabañas and

Zacapa, Guatemala. Rapid sand filters are more complex to operate than then-slow sand filter counterparts, but they are widely used, especially in areas with high turbidity and where land requirements may be an important design consideration. Conventional rapid sand filtration plants are widely available and widely used in Latin America and other developing countries throughout the world.

Dual or multimedia filters are limited to developing countries that can inexpensively acquire anthracite. The higher skill level and energy requirements for the operation of these high rate systems may limit their application.

Upflow solids contact filters, because of their simplicity and low cost, could be an effective technology in many developing countries. Brazil has successfully used this type of filtration system.

## Operation and Maintenance

The filter media of homemade residential filters must be periodically changed to maintain the filter's effectiveness. Most of the residential filters acquired commercially can be purchased with a maintenance contract, which will prolong their operational life.

A number of factors affect the operation and maintenance of slow sand filters. The initial resistance (loss of head) of a clean filter bed is about 6 cm. During filtration, impurities are deposited in and on the surface layer of the sand bed, and the loss of head increases. At a predetermined limit (the head loss is usually not allowed to exceed the depth of water over the sand, or about 1 m to 1.5 m), the filter is taken out of service and cleaned. The period between cleaning is typically 20 to 60 days. The filter can be cleaned by either scraping off the surface layer of sand and replacing it with washed sand stored after previous cleanings (periodic re-sanding of the bed), or washing the sand in place with a washer that travels over the sand bed. If sand is readily available, the former method is favored; workers with wide, flat shovels do the scraping, removing 1 to 2 cm of the topmost material. The amount of time this takes depends on the area of the filter bed, but it can usually be completed in one or two days. After washing, the sand is stored and replaced on the bed when, after successive cleanings, the thickness of the sand bed has been reduced to about 50 to 80 cm. A sand and gravel filter needs to be replaced every two years or so. When using the method of washing in place, about 0.2% to 0.6% of the water filtered is required for washing purposes. The bacteriological layer, which is the most important layer in the filtration process, needs to be reactivated in the new filter. Reactivation usually lasts two months.

Rapid sand filtration plants are complicated to operate, requiring operator training in order for the plant to produce a product water of consistent quality and quantity. The filters require frequent backwashing to maintain satisfactory operating heads in the system (filter runs may vary from only a few hours to as many as 24 to 72 hours, depending on the suspended solids in the influent). Backwashing rates are typically 0.6 $m^3$/min or higher, for a period of several minutes. In addition, the initial production following backwashing is channeled to waste for several minutes. Thus, the water backwashing uses can be as much as 10% to 15% of the total plant output. On the other hand, rapid sand filtration plants (including chemical treatment) can effectively treat higher solids loadings and produce higher outputs than slow sand filters. The land area requirements are significantly lower.

Dual-media filters, like rapid sand filters, are cleaned by hydraulic backwashing (upflow) with potable water. Thorough cleaning of the bed makes it advisable in the case of single medium filters, and mandatory in the case of dual- or mixed-media filters, to use auxiliary scour or so-called surface wash devices before or during the backwash cycle. In dual-media and mixed-media beds, such additional effort is needed to remove accumulated floe, which is stored throughout the bed depth to within a few inches of the bottom of the fine media. Backwashing is generally carried out every 24 to 72 hours. The optimum rate of washwater application is a direct function of water temperature, as expansion of the bed varies inversely with the viscosity of the washwater. For example, a backwash rate of 18 gpm/ft$^2$ at 20°C equates to 15.7 gpm/ft$^2$ at 5°C, and to 20 gpm/ft$^2$ at 35°C. The time required for backwashing varies from 3 to 15 minutes. After the washing process, water should be discharged to waste until the turbidity drops to an acceptable value. Few data are available on the operation and maintenance of the vertical reactor pre-filters tested in Guatemala, which remain in the experimental stage.

Other operational considerations relating to the use of filtration technologies include the use of flocculent aids. Coagulants such as alum, ferrous sulfate, and lime may be added to aid in the flocculation and sedimentation of particulates. The coagulant dosage is generally determined from jar tests, and the chemicals are almost always added with rapid mix systems. In the case of water treatment plants, flocculation is usually performed ahead of the settling process to improve the effectiveness of this process.

Maintenance considerations include the resolution of a number of problems which can interfere with the consistent operation of sand filters. These problems often are due to poor design or operation of the filtration systems. The problems most often encountered and their possible solutions are as follows:

- Surface clogging and cracking: This problem, caused by an overload of solids at the thin filter layer in sand filters, can be alleviated by using dual or multiple media, which allows deeper penetration of solids into the bed, and, generally, longer run times.

- Gravel displacement or mounding: This problem can be alleviated by placing a 76 mm layer of coarse garnet between the gravel supporting the media and the fine bed material.

- "Mudball" formation: This problem can be reduced by increasing the backwash flow rate (e.g., up to 20 $gpm/ft^2$), and by providing for auxiliary water or air scouring of the washed surface.

- Sand leakage: This problem may be alleviated by adding the garnet layer.

- Accumulation of air bubbles in the bed: This problem, which causes a significantly increased resistance to flow through the filter, can be minimized by maintaining adequate water depths in the clear well and filters; frequent backwashing may help.

## Level of Involvement

In many developing countries, filtration methods are introduced and promoted by both governmental agencies and NGOs, with the full participation of the community. This is the case in El Salvador, where the Centro Salvadoreño de Tecnología Apropiada (CESTA) builds and installs residential filters for rural communities at a minimum cost. In Dominican Republic, the private sector, particularly the companies which manufacture filtration systems, promotes the technology. In Ecuador, NGOs like Plan Internacional and CARE actively participate in the implementation of these technologies in order to reduce the use of contaminated water. In Brazil, the government and the private sector are actively involved in the development and implementation of filtration systems.

## Costs

Homemade residential filters were constructed in El Salvador at a cost of $23. Operation and maintenance costs are about $6/year. The cost of residential filters manufactured and commercially distributed in Dominican Republic varies with the flow capacity of the filter. It ranges from $382 for 1 gpm to $588 for 6 gpm; this price includes installation and maintenance. Commercially manufactured tub filters are sold in Dominican Republic hardware stores at a price ranging from $26 to $45. The cost of quarry filters used in Mexico was $50, with little or no operation and maintenance cost. Figure 27 shows the construction cost of an upflow solids contact filter a function of the filtration area.

The unit filtering cost of slow and *rapid* sand filters in Ecuador ranges between $0.13/m$^3$ and $0.20/m$^3$. Slow sand filters were constructed in Ecuador at a cost of $132.30 with an estimated operation and maintenance cost of 25% of the construction cost. Table 12 shows estimated per capita costs of construction and of operation and maintenance for slow and rapid sand filters.

## Effectiveness of the Technology

Homemade residential filters can adequately reduce the level of contaminants in water, but, because quality control tests are usually not performed on the product water, there is a risk of some contamination remaining after filtration. For example, quarry filters used in Mexico reduce bacteriological contaminants by up to 90%. However, quarry filters must be covered and protected with a screen, and a faucet at the outlet is recommended. This filter needs to be cleaned every 3 to 4 months, depending on the quality of the water treated.

Commercially available residential filters are usually more effective at producing a good quality product water since quality control is performed during the manufacturing process and a level of efficiency is initially guaranteed. Quality product water can be further ensured through the regular inspections performed by technicians from the supplier in the case of systems sold with a service contract.

Slow sand filters are very effective in removing solids and turbidity when the raw water has low turbidity and color (turbidity up to 50 NTU and color up to 30 Pt units). Taste and odor are also improved. However, if the raw water quality is poor, filtration is often less effective. In such situations, roughing filters, or pre-filters, are often used before the feedwater enters the slow sand filters. The slow sand filters are very effective in removing bacteria; in general, their effectiveness in removing bacteriological contaminants ranges between 80% and 99%, depending on the initial level of contaminants and the number and design of the filtration units. In many regions of Ecuador, the effectiveness is close to 100%. In El Salvador, they are estimated to remove 84% and 99% of total and fecal coliform bacteria, respectively. Reductions in the levels of iron, manganese, and nitrate concentrations and turbidity are also observed. Chemicals are typically not used. The flow rates for slow sand filters are many times slower than for rapid sand and roughing filters, and the operating filter bed is not stratified.

Multimedia filters are usually more effective, since the filtration media combine the filtration properties of several materials. In the system of vertical flow pre-filters used in Guatemala, turbidity reduction ranged from 23% to 45%, and color reduction between 34% and 56%.

**Suitability**

Filtration technologies are suitable for use throughout the region. Homemade residential filters are better suited to rural areas where the equipment, skills, and infrastructure necessary to provide piped domestic water supplies are lacking. The other, more complex filtration systems are best used at water treatment plants and are generally located in urban areas.

**Advantages**

- Filtration systems have a low construction cost, especially when built using manual labor.

- These systems are simple to design, install, operate, and maintain, which makes them ideal for use in areas where skilled personnel are few.

- No chemicals are required, although flocculent aids are sometimes used in conjunction with large-scale filtration systems; supplies of sand can usually be found locally.

- Power is not required.

- Large quantities of washwater are not required.

- Use of filtration to pretreat water and wastewaters results in fewer sludge disposal problems because fewer contaminants are left to be removed during the treatment process.

- Residential filters provide adequate treatment of water for average-sized households, particularly in rural areas.

- Filters are environmentally friendly.

**Disadvantages**

- In some areas, there is a lack of locally available filtration media.

- There may be a lack of skilled personnel to operate the more sophisticated filtration systems, particularly in rural areas.

- Use of filtration alone is recommended only for source waters with low levels of contamination.

- Pretreatment may be required for many applications.

- Provision must be made for washing and storing used sand from sand filters, either permanently or temporarily, and for moving sand from the filters to the wash site and from the wash site to the storage site and back, as needed.

- If sand from slow sand filters is to be washed, a separate backwash facility and washwater supply may be required; treated water must often be used for washing, which could reduce the available supply of treated water, especially in water-poor areas.

- Precise operational control of the rate of head loss is required to prevent air bubbles from entering and binding the system; this type of interference is a potential problem in all types of filters.

- There may be a lack of quality control of the product water in rural areas.

- To obtain good results from slow sand filters, the raw feedwater must not generally have a suspended solids content of less than 50 mg/1.

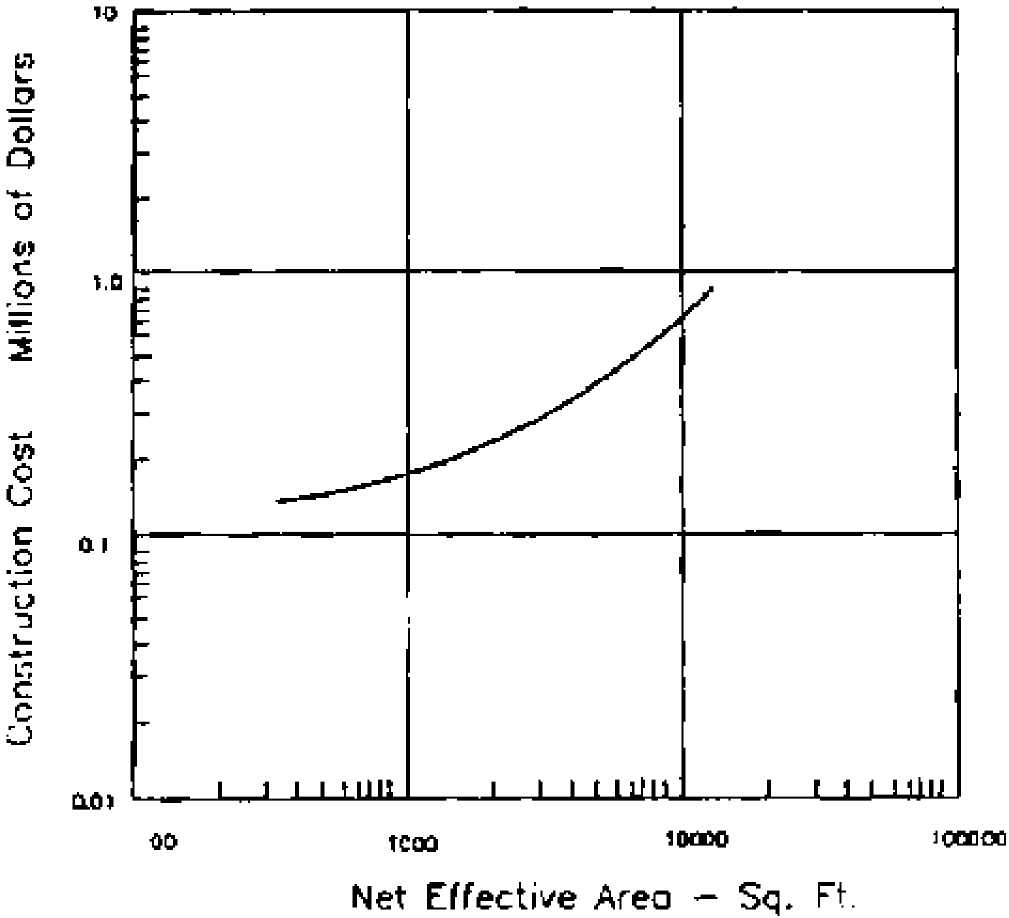
## Cultural Acceptability

Filtration is a well-accepted technology when applied in the treatment of industrial and public water supplies. It has limited acceptance in other applications, and at the household level in rural areas.

## Further Development of the Technology

Additional research is needed to develop more efficient filtration media that can remove both bacteriological and chemical contaminants. Education is needed, particularly in the rural areas, to encourage the use of homemade filtration systems and disinfection of household water supplies.

**Figure 27: Construction Cost ofUpflow Solids Contact Filter.**


10
1.0
0.1
0.01
Construction Cost Millions of Dollars
00
1000
10000
100000
Net Effective Area – Sq. Ft.

Source: Edward J. Martin. *Handbook for Appropriate Water and Wastewater Technology for Latin America and the Caribbean,* Washington, D.C., PAHO and IDB, 1988.

## Table 12 Per Capita Costs of Construction, and of Operation and Maintenance for Slow Sand Filters and Rapid Sand Filters (S)

| Population Scale | Item | Cost Range | |
|---|---|---|---|
| | | Slow Sand Filter | Rapid Sand Filter |
| 500 - 2499 | Construction | 17.08 - 27.00 | 12.84 - 15.12 |
| | Operation and Maintenance | 1.80 - 6.75 | 2.43 - 5.40 |
| 2500 - | Construction | 12.19 - | 10.08 - |

| | | | |
|---|---|---|---|
| 2500 - 14999 | | 19.28 | 11.88 |
| | Operation and Maintenance | 0.81 - 3.04 | 1.22 - 2.70 |
| 15000 - 49999 | Construction | 8.55 - 13.5 | 5.73 - 6.75 |
| | Operation and Maintenance | 0.45 - 1.69 | 5.72 - 2.36 |
| 50000 - 100000 | Construction | 5.33 - 8.44 | 3.04 - 3.58 |
| | Operation and Maintenance | 0.27 - 1.01 | 0.91 - 2.03 |

Source: *G.* Reid and K. Coffey. *Appropriate Methods of Treating Water and Wastewater in Developing Countries,* Stil-water, Oklahoma, University of Oklahoma, Bureau of Water and Environmental Resources Research, 1978.

## Information Sources

## Contacts

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## 3.1 Wastewater treatment technologies

Relatively simple wastewater treatment technologies can be designed to provide low cost sanitation and environmental protection while providing additional benefits from the reuse of water. These technologies use natural aquatic and terrestrial systems. They are in use in a number of locations throughout Latin America and the Caribbean.

These systems may be classified into three principal types, as shown in Figure 28. Mechanical treatment systems, which use natural processes within a constructed environment, tend to be used when suitable lands are unavailable for the implementation of natural system technologies. Aquatic systems are represented by lagoons; facultative, aerated, and hydrograph controlled release (HCR) lagoons are variations of this technology. Further, the lagoon-based treatment systems can be supplemented by additional pre- or post-treatments using constructed wetlands, aquacultural production systems, and/or sand filtration. They are used to treat a variety of wastewaters and function under a wide range of weather conditions. Terrestrial systems make use of the nutrients contained in wastewaters; plant growth and soil adsorption convert biologically available nutrients into less-available forms of biomass, which is then harvested for a variety of uses, including methane gas production, alcohol production, or cattle feed supplements.

**Figure 28: Summary of Wastewater Treatment Technologies.**

**Mechanical**

- Oxidation ditch
- Extended aeration
- Sequencing batch reactor
- Trickling filter - SCP

**Aquatic (Lagoons)**

- Facultative
  - Free water surface
  - Subsurface flow
- Aerated
  - *Aquaculture*
    - -Water Hyacints
    - -Duckweed
  - *Sand filters*
    - -Intermittent
    - -Recirculating
- HCR

**Terrestrial**

- Slow-rate
- Overland flow
- Rapid infiltration
- Subsurface Infiltration

Source: Ernesto Pérez, P.E., Technology Transfer Chief, Water Management Division, USEPA Region

IV, Atlanta, Georgia.

## Technical Description

- Mechanical Treatment Technologies

Mechanical systems utilize a combination of physical, biological, and chemical processes to achieve the treatment objectives. Using essentially natural processes within an artificial environment, mechanical treatment technologies use a series of tanks, along with pumps, blowers, screens, grinders, and other mechanical components, to treat wastewaters. Flow of wastewater in the system is controlled by various types of instrumentation. Sequencing batch reactors (SBR), oxidation ditches, and extended aeration systems are all variations of the activated-sludge process, which is a suspended-growth system. The trickling filter solids contact process (TF-SCP), in contrast, is an attached-growth system. These treatment systems are effective where land is at a premium.

- Aquatic Treatment Technologies

Facultative lagoons are the most common form of aquatic treatment-lagoon technology currently in use. The water layer near the surface is aerobic while the bottom layer, which includes sludge deposits, is anaerobic. The intermediate layer is aerobic near the top and anaerobic near the bottom, and constitutes the facultative zone. Aerated lagoons are smaller and deeper than facultative lagoons. These systems evolved from stabilization ponds when aeration devices were added to counteract odors arising from septic conditions. The aeration devices can be mechanical or diffused air systems. The chief disadvantage of lagoons is high effluent solids content, which can exceed 100 mg/l. To counteract this, hydrograph controlled release (HCR) lagoons are a recent innovation. In this system, wastewater is discharged only during periods when the stream flow is adequate to prevent water quality degradation. When stream conditions prohibit discharge, wastewater is accumulated in a storage lagoon. Typical design parameters are summarized in Table 13.

Constructed wetlands, aquacultural operations, and sand filters are generally the most successful methods of polishing the treated wastewater effluent from the lagoons. These systems have also been used with more traditional, engineered primary treatment technologies such as Imhoff tanks, septic tanks, and primary clarifiers. Their main advantage is to provide additional treatment beyond secondary treatment where required. In recent years, constructed wetlands have been utilized in two designs: systems using surface water flows and systems using subsurface flows. Both systems utilize the roots of plants to provide substrate for the growth of attached bacteria which utilize the nutrients present in the effluents and for the transfer of oxygen. Bacteria do the bulk of the work in these systems, although there is some nitrogen uptake by the plants. The surface water system most closely approximates a natural wetland. Typically, these systems are long, narrow basins, with depths of less than 2 feet, that are planted with aquatic vegetation such as bulrush *(Scirpus* spp.) or cattails *(Typha* spp.). The shallow groundwater systems use a gravel or sand medium, approximately eighteen inches deep, which provides a rooting medium for the aquatic plants and through which the wastewater flows.

**Table 13 Typical Design Features Aquatic Treatment Units**

| Technology | Treatment goal | Detention Time (days) | Depth (feet) | Organic Loading (lb/ac/day) |
|---|---|---|---|---|
| Oxidation pond | Secondary | 10-40 | 3-4.5 | 36-110 |
| Facultative | Secondary | 25-180 | 4.5- | 20-60 |

| | | | | |
|---|---|---|---|---|
| pond | | | 7.5 | |
| Aerated pond | Secondary, polishing | 7-20 | 6-18 | 45-180 |
| Storage pond, HCR pond | Secondary, storage, polishing | 100-200 | 9-15 | 20-60 |
| Root zone Treatment, Hyacinth pond | Secondary | 30-50 | <4.5 | <45 |

Source: S.C. Reed, et al., *Natural Systems for Waste Management and Treatment,* New York, McGraw-Hill, 1988.

Aquaculture systems are distinguished by the type of plants grown in the wastewater holding basins. These plants are commonly water hyacinth *(Eichhornia crassipes)* or duckweed *(Lemna* spp.). These systems are basically shallow ponds covered with floating plants that detain wastewater at least one week. The main purpose of the plants in these systems is to provide a suitable habitat for bacteria which remove the vast majority of dissolved nutrients. The design features of such systems are summarized in Table 14. (See also section 2.3, in Chapter 2, for a discussion of the role of the plants themselves.)

**Table 14 Typical Design Features for Constructed Wetlands**

| Design Factor | Surface water flow | Subsurface water flow |
|---|---|---|
| Minimum surface area | 23-115 ac/mgd | 2.3-46 ac/mgd |
| Maximum water depth | Relatively shallow | Water level below ground surface |
| Bed depth | Not applicable | 12.30m |

| | | |
|---|---|---|
| Minimum hydraulic residence time | 7 days | 7 days |
| Maximum hydraulic loading rate | 0.2-1.0 gpd/sq ft | 0.5-10 gpd/sq ft |
| Minimum pretreatment | Primary (secondary optional) | Primary |
| Range of organic loading as BOD | 9-18 lb/ac/d | 1.8-140 lb/ac/d |

Source: USEPA, *Wastewater Treatment/Disposal for Small Communities.* Cincinnati, Ohio, 1992. (EPA Report No. EPA-625/R-92-005)

Sand filters have been used for wastewater treatment purposes for at least a century in Latin America and the Caribbean. Two types of sand filters are commonly used: intermittent and recirculating. They differ mainly in the method of application of the wastewater. Intermittent filters are flooded with wastewater and then allowed to drain completely before the next application of wastewater. In contrast, recirculating filters use a pump to recirculate the effluent to the filter in a ratio of 3 to 5 parts filter effluent to 1 part raw wastewater. Both types of filters use a sand layer, 2 to 3 feet thick, underlain by a collection system of perforated or open joint pipes enclosed within graded gravel. Water is treated biologically by the epiphytic flora associated with the sand and gravel particles, although some physical filtration of suspended solids by the sand grains and some chemical adsorption onto the surface of the sand grains play a role in the treatment process. (See also section 2.5, in Chapter 2.)

- Terrestrial Treatment Technologies

Terrestrial treatment systems include slow-rate overland flow, slow-rate subsurface infiltration, and rapid infiltration methods. In addition to wastewater treatment and low maintenance costs, these systems may yield additional benefits by providing water for groundwater recharge, reforestation, agriculture, and/or livestock pasturage. They depend upon physical, chemical, and biological reactions on and within the soil. Slow-rate overland flow systems require vegetation, both to take up nutrients and other contaminants and to slow the passage of the effluent across the land surface to ensure maximum contact times between the effluents and the plants/soils. Slow-rate subsurface infiltration systems and rapid infiltration systems are "zero discharge" systems that rarely discharge effluents directly to streams or other surface waters. Each system has different constraints regarding soil permeability.

Although slow-rate overland flow systems are the most costly of the natural systems to implement, their advantage is their positive impact on sustainable development practices. In addition to treating wastewater, they provide an economic return from the reuse of water and nutrients to produce marketable crops or other agriculture products and/or water and fodder for livestock. The water may also be used to support reforestation projects in water-poor areas. In slow-rate systems, either primary or secondary wastewater is applied at a controlled rate, either by sprinklers or by flooding of furrows, to a vegetated land surface of moderate to low permeability. The wastewater is treated as it passes through the soil by filtration, adsorption, ion exchange, precipitation, microbial action, and plant uptake. Vegetation is a critical component of the process and serves to extract nutrients, reduce erosion, and maintain soil permeability.

Overland flow systems are a land application treatment method in which treated effluents are eventually discharged to surface water. The main benefits of these systems are their low maintenance and low technical manpower requirements. Wastewater is applied intermittently across the tops of terraces constructed on soils of very low permeability and allowed to sheet-flow across the vegetated surface to the runoff collection channel. Treatment, including nitrogen removal, is achieved primarily through sedimentation, filtration, and biochemical activity as the wastewater flows across the vegetated surface of the terraced slope. Loading rates and application cycles are designed to maintain active microorganism growth in the soil. The rate and length of application are controlled to minimize the occurrence of severe anaerobic conditions, and a rest period between applications is needed. The rest period should be long enough to prevent surface ponding, yet short enough to keep the microorganisms active. Site constraints relating to land application technologies are shown in Table 15.

**Table 15 Site Constraints for Land Application Technologies**

| Feature | Slow Rate | Rapid | Subsurface | Overland |
|---|---|---|---|---|

| | | Infiltration | Infiltration | Flow |
|---|---|---|---|---|
| Soil texture | Sandy loam to clay loam | Sand and sandy loam | Sand to clayey loam | Silty loam and clayey loam |
| Depth to groundwater | 3 ft | 3 ft | 3 ft | Not critical |
| Vegetation | Required | Optional | Not applicable | Required |
| Climatic restrictions | Growing season | None | None | Growing season |
| Slope | <20%, cultivated land<br>< 40%, uncultivated land | Not critical | Not applicable | 2%-8% finished slopes |

Source: USEPA, *Wastewater Treatment/Disposal for Small Communities.* Cincinnati, Ohio, 1992. (EPA Report No. EPA-625/R-92-005)

In rapid infiltration systems, most of the applied wastewater percolates through the soil, and the treated effluent drains naturally to surface waters or recharges the groundwater. Their cost and manpower requirements are low. Wastewater is applied to soils that are moderately or highly permeable by spreading in basins or by sprinkling. Vegetation is not necessary, but it does not cause a problem if present. The major treatment goal is to convert ammonia nitrogen in the water to nitrate nitrogen before discharging to the receiving water.

Subsurface infiltration systems are designed for municipalities of less than 2,500 people. They are usually designed for individual homes (septic tanks), but they can be designed for clusters of homes. Although they do require specific site conditions, they can be low-cost methods of wastewater disposal.

## Extent of Use

These treatment technologies are widely used in Latin America and the Caribbean. Combinations of some of them with wastewater reuse technologies have been tested in several countries. Colombia has extensively tested aerobic and anaerobic mechanical treatment systems. Chile, Colombia, and Barbados have used activated sludge plants, while Brazil has utilized vertical reactor plants. Argentina, Bolivia, Colombia, Guatemala, Brazil, Chile, Curaçao, Mexico, Jamaica, and Saint Lucia have successfully experimented with different kinds of terrestrial and aquatic treatment systems for the treatment of wastewaters. Curaçao, Mexico, and Jamaica have used stabilization or facultative lagoons and oxidation ponds; their experience has been that aquatic treatment technologies require extensive land areas and relatively long retention times, on the order of 7 to 10 days, to adequately treat wastewater. An emerging technology, being tested in a number of different countries, is a hybrid aquatic-terrestrial treatment system that uses wastewaters for hydroponic cultivation. However, most of the applications of this hybrid technology to date have been limited to the experimental treatment of small volumes of wastewater.

## Operation and Maintenance

Operation and maintenance requirements vary depending on the particular technology used. In mechanical activated-sludge plants, maintenance requirements consist of periodically activating the sludge pumps, inspecting the system to ensure that are no blockages or leakages in the system, and checking BOD and suspended solids concentrations in the plant effluent to ensure efficient operation.

In the case of aquatic treatment systems using anaerobic reactors and facultative lagoons for primary wastewater treatment, the following operational guidelines should be followed:

- Periodically clean the sand removal system (usually every 5 days in dry weather, and every 2 to 3 days in wet weather).

- Daily remove any oily material that accumulates in the anaerobic reactor.

- Daily remove accumulated algae in the facultative lagoons.

- Open the sludge valves to send the sludge to the drying beds.

- Establish an exotic aquatic plant removal program (aquatic plant growth can hamper the treatment capacity of the lagoons).

- Properly dispose of the materials removed, including dried sludge.

A preventive maintenance program should also be established to increase the efficiency of the treatment systems and prolong their lifespan.

When using terrestrial treatment systems or hybrid hydroponic cultivation systems for wastewater treatment, it is advisable to have two parallel systems, and to alternate applications of wastewater to these systems every 12 hours in order to facilitate aeration and to avoid damage to the system. Care is required to avoid hydraulic overload in these systems, as the irrigated plant communities could be damaged and the degree of treatment provided negated. Periodic removal of sediments accumulated in the soil is also required to improve the soil-plant interaction and to avoid soil compaction/subsidence.

**Figure 29: Comparative Operation and Maintenance Cost of Wastewater Treatment Technologies.**

Source: Ernesto Pérez, P.E., Technology Transfer Chief, Water Management Division, USEPA Region IV, Atlanta, Georgia.

**Figure 30: Comparative Capital Cost of Wastewater Treatment Technologies.**

Source: Ernesto Pérez, P.E., Technology Transfer Chief, Water Management Division, USEPA Region IV, Atlanta, Georgia.

**Level of Involvement**

Government involvement is essential in the implementation of most of the wastewater treatment technologies. The private sector, particularly the tourism industry, has successfully installed "packaged" or small-scale, self-contained sewage treatment plants at individual sites. In some cases, the installation of these plants has been combined with the reuse of the effluent for watering golf courses, lawns, and similar areas. The selection and construction of the appropriate wastewater treatment technology is generally initiated and financed, at least partially, by the government, with the subsequent operation and maintenance of the facility being a responsibility of the local community. Nevertheless, despite the large number of well-known and well-tested methods for wastewater treatment, there still exist a significant number of local communities in Latin America which discharge wastewater directly into lakes, rivers, estuaries, and oceans without treatment. As a result, surface water degradation, which also affects the availability of freshwater resources, is more widespread than is desirable within this region.

Costs

Construction costs and operation and maintenance costs for wastewater treatment systems with a capacity of 0.1 to 1 million gallons per day are summarized in Figures 29 and 30. Most of the cost data come from systems implemented in the United States. Similar systems in Latin America might be less expensive, in some cases, owing to lower labor costs and price differentials in construction materials. Nevertheless, the relative cost comparison among technologies is likely to be applicable to all countries.

Figure 29 compares the operating and maintenance costs (labor, energy, chemicals, and materials such as replacement equipment and parts) of the various systems of 0.1 to 1 mgd treatment capacity. All costs were obtained from the USEPA *Innovative and Alternative Technology Assessment Manual.*

They have been indexed to the USEPA Operation, Maintenance, and Repair Index of Direct Costs for the first quarter of 1993 (4.3). All costs are presented in dollars per million gallons of wastewater treated. The cost for mechanical systems is significantly larger than for any of the other systems, particularly at smaller flows. The cost of harvesting plants from aquaculture systems is not included; this could be a significant amount for some systems.

Figure 30 compares of the capital cost of the wastewater treatment processes. The cost data are also from the *Innovative and Alternative Technology Assessment Manual,* with the exception of wetland and aquaculture data, which were obtained from more recent sources. All natural systems are assumed to have a facultative lagoon as the primary treatment unit. The cost of chlorination/disinfection is included for all systems except the slow rate and rapid infiltration systems. The cost of land is excluded in all cases, as is the cost of liners for the aquatic treatment systems. The mechanical treatment plant cost was derived as the cost of an oxidation ditch treatment system, and includes the cost of a clarifier, oxidation ditch, pumps, building, laboratory, and sludge drying beds. These costs also include the cost of engineering and construction management, in addition to the costs for piping, electrical systems, instrumentation, and site preparation. All costs are in March 1993 dollars.

## Effectiveness of the Technology

Natural treatment systems are capable of producing an effluent quality equal to that of mechanical treatment systems. Figure 31 summarizes the treatment performance of each of the systems. All can meet the limits generally established for secondary treatment, defined as biological oxygen demand (BOD) and total suspended solids (TSS) concentrations of less than 30 mg/l. All except the lagoon systems can also produce effluents that meet the criteria generally categorized as advanced treatment, defined as

BOD and TSS concentrations of less than 20 mg/l. The results of a project conducted in Bogota, Colombia, to compare the performance of different sewage treatment processes are summarized in Table 16.

**Figure 31: Treatment Performance of Wastewater Treatment Technologies.**

* 2ND = secondary limits of treatment for BOD and suspended solids < 30 mg/l.
* ADV = advanced treatment limits for BOD and total suspended solids < 20 mg/l.
*$NH_3$ = 2 mg/l, TP < 2 mg/l, TN < 2 mg/l.

Source: Ernesto Pérez, P.E., Technology Transfer Chief, Water Management Division, USEPA Region IV, Atlanta, Georgia.

## Suitability

Mechanical systems are more suitable for places where land availability is a concern, such as hotels and residential areas. Mechanical plants are the least land intensive of the wastewater treatment methods based on natural processes.

Lagoon and oxidation pond technologies are suitable where there is plenty of land available. Slow-rate systems require as much as 760 acres. Hybrid hydroponic cultivation techniques, using aquatic and terrestrial plants for the treatment for wastewater, also require relatively large amounts of land, and are best suited to regions where suitable aquatic plants can grow naturally.

**Advantages**

Table 17 summarizes the advantages of the various wastewater treatment technologies. In general, the advantages of using natural biological processes relate to their "low-tech/no-tech" nature, which means that these systems are relatively easy to construct and operate, and to their low cost, which makes them attractive to communities with limited budgets. However, their simplicity and low cost may be deceptive in that the systems require frequent inspections and constant maintenance to ensure smooth operation. Concerns include hydraulic overloading, excessive plant growth, and loss of exotic plants to natural watercourses. For this reason, and also because of the land requirements for biologically based technologies, many communities prefer mechanically-based technologies, which tend to require less land and permit better control of the operation. However, these systems generally have a high cost and require more skilled personnel to operate them.

**Table 16 Comparative Performance of Sewage Treatment Systems**

| Process | Oxygen Supply | Reactor | Retention | Removal |
|---|---|---|---|---|

| | | Volume | Time | Efficiency |
|---|---|---|---|---|
| Activated sludge | Pressurized air | 10 $m^3$ | 4-6 hr | 90%-95% organic matter 90%-95% suspended solids |
| Biologic rotary discs | Air | 1 $m^3$ | 1-3 hr | 90%-95% organic matter |
| Ascendant flow | Anaerobic | 2 $m^3$ | 24 hr | 50%-60% organic matter 57% suspended solids |
| Anaerobic | Anaerobic | 2 $m^3$ | 36 hr | 40%-50% |

| | | | | |
|---|---|---|---|---|
| filtration | | $2 m^3$ | | organic matter 52% suspended solids |
| Septic tank | Anaerobic | $2 m^3$ | 36 hr | 25% organic matter |
| Hydroponic cultivation | Aerobic/anaerobic | $6 m^3$ | 12 hr | 65%-75% organic matter |

Source: Ernesto Pérez, P.E., Technology Transfer Chief, Water Management Division, USEPA Region IV, Atlanta, Georgia.

**Disadvantages**

Table 17 also summarizes the disadvantages of the various wastewater treatment technologies. These generally relate to the cost of construction and ease of operation. Mechanical systems can be costly to build and operate as they require specialized personnel. Nevertheless, they do offer a more controlled environment which produces a more consistent quality of effluent. Natural biological systems, on the other hand, are more land-intensive, require less-skilled operators, and can produce effluents of variable quality depending on time of year, type of plants, and volume of wastewater loading. Generally, the complexity and cost of wastewater treatment technologies increase with the quality of the effluent produced.

**Cultural Acceptability**

Governments and the private sector in many Latin American countries fail to fully recognize the necessity of wastewater treatment and the importance of water quality in improving the quality of life of existing and future generations. The contamination of natural resources is a major impediment to achieving the stated objective of Agenda 21 of environmentally sustainable economic growth and development.

## Further Development of the Technology

The cost-effectiveness of all wastewater treatment technologies needs to be improved. New designs of mechanical systems which address this concern are being introduced by the treatment plant manufacturing industry. The use of vertical reactors with an activated-sludge system, being tested in Brazil in order to acquire data for future improvement of this technology, is one example of the innovation going on in the industry. Similar product development is occurring in the use of aquatic and terrestrial plants and hybrid hydroponic systems, as a means of wastewater treatment; however, these technologies are still in an experimental phase and will require more testing and research prior to being accepted as standard treatment technologies. In addition, education to create an awareness of the need for wastewater treatment remains a critical need at all levels of government and

## Table 17 Advantages and Disadvantages of Conventional and Non-conventional Wastewater Treatment Technologies

| Treatment Type | Advantages | Disadvantages |
|---|---|---|
| *Aquatic Systems* | | |
| Stabilization lagoons | Low capital cost<br>Low operation and maintenance costs<br>Low technical manpower requirement | Requires a large area of land<br>May produce undesirable odors |

| | | |
|---|---|---|
| Aerated lagoons | Requires relatively little land area<br>Produces few undesirable odors | Requires mechanical devices to aerate the basins<br>Produces effluents with a high suspended solids concentration |
| *Terrestrial Systems* | | |
| Septic tanks | Can be used by individual households<br>Easy to operate and maintain<br>Can be built in rural areas | Provides a low treatment efficiency<br>Must be pumped occasionally<br>Requires a landfill for periodic disposal of sludge and septage |

| | | |
|---|---|---|
| Constructed wetlands | Removes up to 70% of solids and bacteria<br>Minimal capital cost<br>Low operation and maintenance requirements and costs | Remains largely experimental<br>Requires periodic removal of excess plant material<br>Best used in areas where suitable native plants are available |
| *Mechanical Systems* | | |
| Filtration systems | Minimal land requirements; can be used for household-scale treatment<br>Relatively low cost<br>Easy to operate | Requires mechanical devices |
| Vertical biological | Highly efficient treatment method | High cost<br>Complex |

| | | |
|---|---|---|
| reactors | Requires little land area<br>Applicable to small communities for local-scale treatment and to big cities for regional-scale treatment | technology<br>Requires technically skilled manpower for operation and maintenance<br>Needs spare-parts-availability<br>Has a high energy requirement |
| Activated sludge | Highly efficient treatment method<br>Requires little land area<br>Applicable to small communities for local-scale treatment and to big cities for regional-scale treatment | High cost<br>Requires sludge disposal area (sludge is usually land-spread)<br>Requires technically skilled manpower for operation and |

| | | |
|---|---|---|
| | | maintenance |

## Information Sources

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## 3.2 Wastewater reuse

Once freshwater has been used for an economic or beneficial purpose, it is generally discarded as waste. In many countries, these wastewaters 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 wastewaters 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, 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 wastewaters 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 neutralize 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 18 presents a range of typical survival times for potential pathogens in water and other media.

**Table 18 Typical Pathogen Survival Times at 20 - 30°C (in days)**

| Pathogen | Freshwater and sewage | Crops | Soil |
|---|---|---|---|
| Viruses | < 120 but usually <50 | <60 but usually < 15 | <100 but usually <20 |
| Bacteria | <60 but usually <30 | <3 0 but usually < 15 | <70 but usually <20 |
| Protozoa | <30 but usually <15 | <10 but usually <2 | <70 but usually <20 |
| Helminths | Many months | <60 but | Many months |

| | | | |
|---|---|---|---|
| | | usually <30 | |

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

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 ("gray 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.

**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 19 presents some guidelines for the utilization 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 Caribbean is primarily in the form of irrigation water. In Jamaica, 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 (see case study in Part C, Chapter 5). In Barbados, effluent from an extended aeration sewage treatment plant is used for lawn irrigation (see case study in Part C, Chapter 5). Similar use of wastewater occurs on Curaçao.

**Table 19 Guidelines for Water Reuse**

| | Treatment | Reclaimed | Recommended | Setback |
|---|---|---|---|---|

| Type of Reuse | Treatment Required | Water Quality | Recommended Monitoring | Setback Distances |
|---|---|---|---|---|
| AGRICULTURAL | Secondary Disinfection | pH = 6-9 | pH weekly | 300 ft from potable water supply wells |
| Food crops commercially processed | | BOD ≤ 30 mg/l | BOD weekly | |
| | | SS = 30 mg/l | SS daily | |
| Orchards and Vinerds | | FC ≤ 200/100 ml | FC daily | 100 ft from areas accessible to public |
| | | $Cl_2$ residual = 1 mg/l min. | $Cl_2$ residual continuous | |
| PASTURAGE | Secondary Disinfection | pH = 6-9 | pH weekly | 300 ft from potable |
| Pasture for milking animals | | BOD ≤ 30 mg/l | BOD weekly | |

| | | | | |
|---|---|---|---|---|
| | | SS ≤ 30 mg/l | SS daily | water supply wells |
| Pasture for livestock | | FC ≤ 200/100 ml | FC daily | 100 ft from areas accessible to public |
| | | $Cl_2$ residual = 1 mg/l min. | $Cl_2$ residual continuous | |
| FORESTATION | Secondary Disinfection | pH = 6-9 | pH weekly | 300 ft from potable water supply wells |
| | | BOD ≤ 30 mg/l | BOD weekly | |
| | | SS ≤ 30 mg/l | SS daily | |
| | | FC ≤ 200/100 | FC daily | 100 ft from |

| | | | | |
|---|---|---|---|---|
| | | ml | | areas accessible to the public |
| | | $Cl_2$ residual = 1 mg/l min. | $Cl_2$ residual continuous | |
| AGRICULTURAL | Secondary Filtration Disinfection | pH = 6-9 | pH weekly | 50 ft from potable water supply wells |
| Food crops not commercially processed | | BOD ≤ 30 mg/l | BOD weekly | |
| | | Turbidity ≤ 1 NTU | Turbidity daily | |
| | | FC = 0/100 ml | FC daily | |
| | | $Cl_2$ residual = 1 mg/l min. | $Cl_2$ residual continuous | |
| GROUNDWATER RECHARGE | Site-specific | Site-specific | Depends on treatment and | Site-specific |

| | | | | |
|---|---|---|---|---|
| | and use-dependent | and use-dependent | use | |

Source: USEPA*, Process Design Manual: Guidelines for Water Reuse,* Cincinnati, Ohio, 1992, (Report No. EPA-625/R-92-004).

In Latin America, treated wastewater is used in small-scale agricultural projects and, particularly by hotels, for lawn irrigation. 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 wastewaters 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.

In the United States, the use of reclaimed water for irrigation of food crops is prohibited in some states, while others allow it only if the crop is to be processed and not eaten raw. Some states may hold, for example, that if a food crop is irrigated in such a way that there is no contact between the edible portion and the reclaimed water, a disinfected, secondary-treated effluent is acceptable. For crops that are eaten raw and not commercially processed, wastewater reuse is more restricted and less economically attractive. Less stringent requirements are set for irrigation of non-food crops.

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.

**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 emphasized 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.

**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 minimize 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.

## 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 wastewaters.

## 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 wastewaters 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 practiced: Beach #1 in Table 20 is near a hotel with a wastewater reuse project, while Beach #2 is not. From an aesthetic point of view, also, the presence of lush vegetation in the areas where lawns and plants are irrigated with reclaimed wastewater is further evidence of the effectiveness of this technology.

**Table 20 Water Quality of Beach Water in Wastewater Reuse Project in Jamaica**

| Site | BOD | TC | FC | $NO_3$ |
|---|---|---|---|---|
| Beach # 1 | 0.30 | <2 | <2 | 0.01 |
| Beach # 2 | 1.10 | 2.400.00 | 280.00 | 0.01 |

Source: Basil P. Fernandez, Hydrogeologist and Managing Director, Water Resources Authority, Kingston, Jamaica.

## Suitability

This technology has generally been applied to a 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, worms, and helminths (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 wastewaters can increase agricultural production in water-poor areas.

- Pollution of seawater, rivers, and groundwaters 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 wastewaters 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 wastewaters 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 wastewaters 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.

## Information Sources

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## 4.1 Raised beds and waru waru cultivation

This technology is based on modification of the soil surface to facilitate water movement and storage, and to increase the organic content of the soil to increase its suitability for cultivation. This system of soil management for irrigation purposes was first developed in the year 300 B.C., before the rise of the Inca Empire. It was later abandoned as more technically advanced irrigation technologies were discovered. Nevertheless, in 1984, in Tiawanaco, Bolivia, and Puno, Peru, the system was re-established. It is known in the region as *Waru Warn,* which is the traditional Indian (Quechua) name for this technique.

## Technical Description

The technology is a combination of rehabilitation of marginal soils, drainage improvement, water storage, optimal utilization of available radiant energy, and attenuation of the effects of frost. The main feature of this system is the construction of a network of embankments and canals, as shown in Figure 32. The embankments serve as raised beds for cultivation of crops, while the canals are used for water storage and to irrigate the plants. The soils used for the embankments are compacted to facilitate water retention by reducing porosity, permeability, and infiltration. Infiltration in the clay soils of the region varies from 20% to 30% of the precipitation volume. Thus, clay soils are preferred for this purpose. Sandy soils have too great a porosity to retain the water within the beds.

The cultivation takes place in the "new" soils within the raised bed created by the construction of the embankment. Within the bed, the increased porosity of the new soils results in enhanced infiltration, often increasing infiltration by 80% to 100% of the original soil. This system permits the recycling of nutrients and and all the other chemical and biological processes necessary for crop production. Water uptake by the raised beds is through diffusion and capillary movements using water contained within the beds or supplied from the surrounding canals. The soils are kept at an adequate moisture level to facilitate the cultivation of plants such as potatoes and quinoa *(Chenopodium quinoa).* Thermal energy is captured and retained in the soil as a result of the enhanced moisture levels, which protect the soils of the bed from the effects of frost. The system acts as a thermoregulator of the microclimate within the bed.

There are three types of raised bed systems, characterized by the source of water:

- Rainwater systems, in which rainwater is the primary source of moisture. These systems require small lagoons for storage during dry periods and a system of canals to distribute the water to the beds. They are usually located at the base of a hill or a mountain, as shown in Figure 33.

- Fluvial systems, in which moisture is supplied by water from nearby rivers. These systems require a hydraulic infrastructure, such as canals and dikes, to transport the water, as shown in Figure 34.

- Phreatic systems, in which groundwater is the source of moisture in the beds. These systems are located in areas where the groundwater table is close to the surface of the soil and there is a mechanism for groundwater recharge, such as an infiltration lagoon, as shown in Figure 35.

The main design considerations for raised bed cultivation include the following:

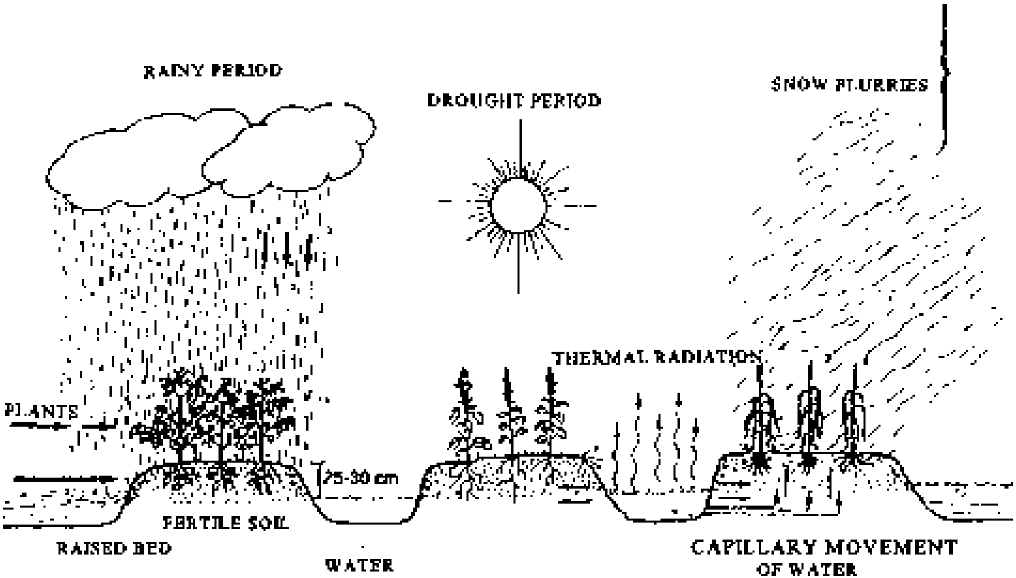
- Depth of the water table, since a high water table increases the height of the embankment required.

- Soil characteristics, which affect both the dimensions of the embankment and the nature of the cultivation zone.

- Climatic conditions, *which* include the volume and frequency of rainfall, temperature range, and frost frequency.

An example of a typical embankment and canal system is shown in Figure 36. Soft fill (e.g., compost or mulch) might be required within the embanked bed to maintain an adequate level of soil moisture.

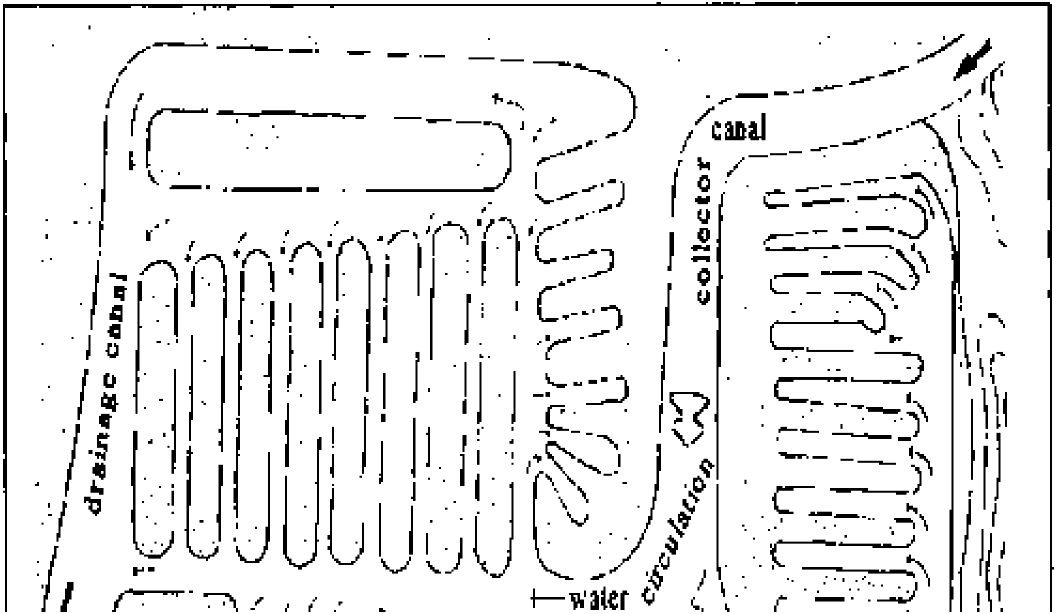
**Figure 32: Raised Bed Irrigation System in Puno, Peru.**

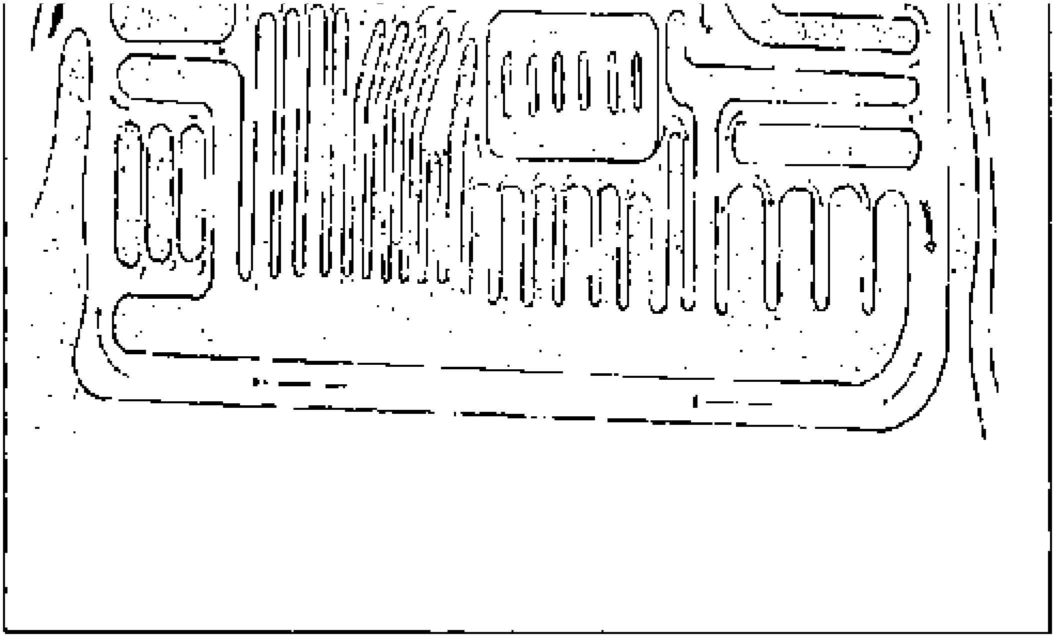



Source: Alipio C. Murilo and Ludgardo L. Mamani, *Manual Técnico de Waru Waru, Para la*

*Reconstrucción, Producción y Evaluación Económica,* Puno, Peru, Programa Interinstitucional de *Waru Waru,* Convenio PELT/INADE-IC/COTESU, 1992.

**Figure 33: Design of a Rainwater *Waru Waru* System.**

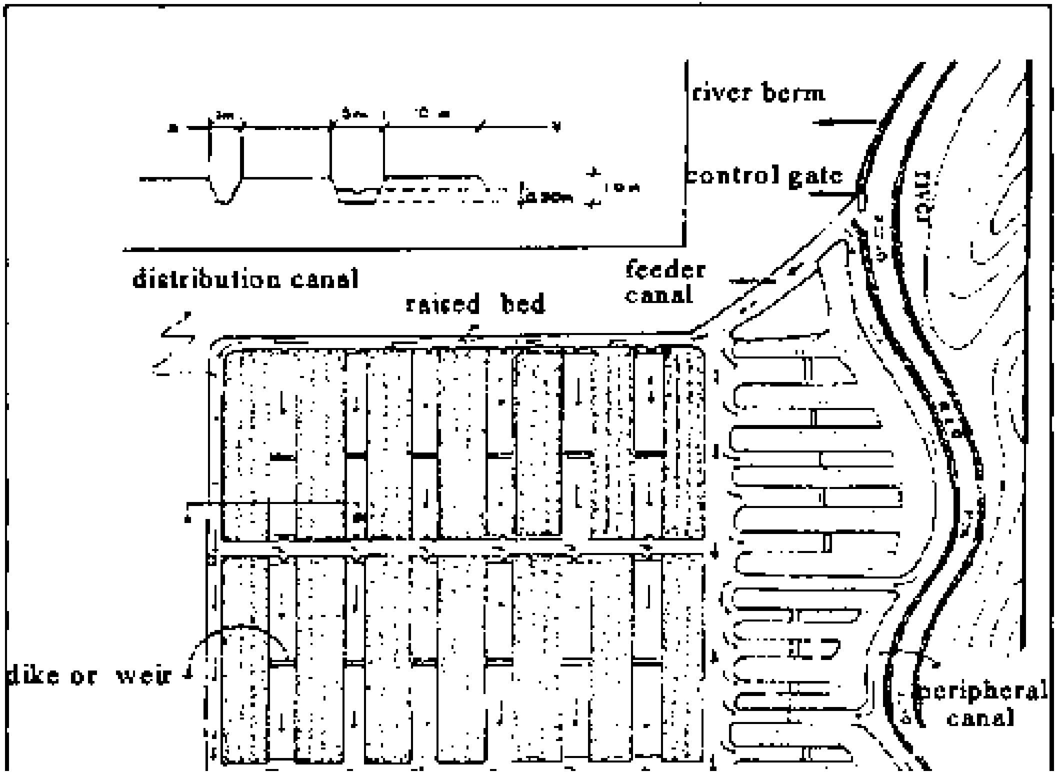


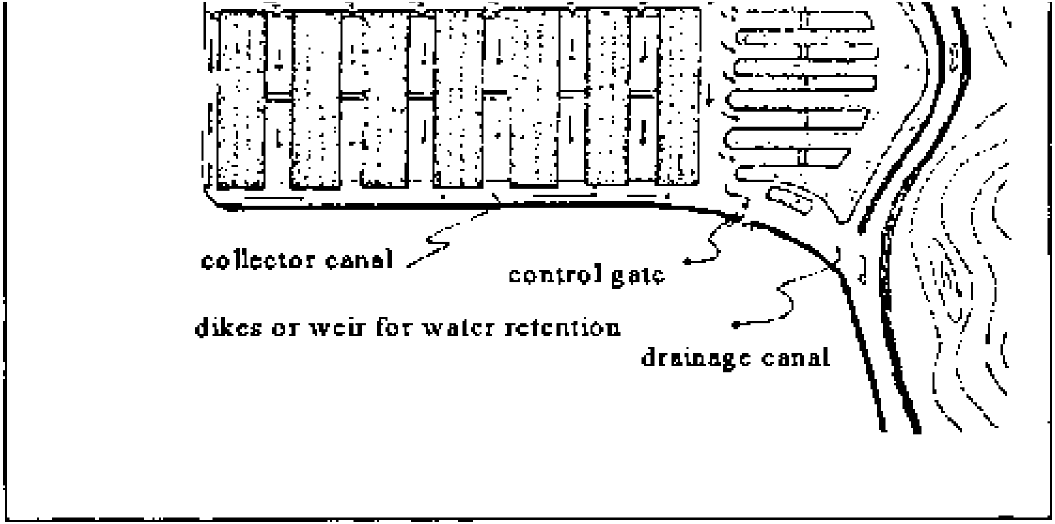


Source: Alipio C. Murilo and Ludgardo L. Mamani, *Manual Técnico de Waru Waru, Para la Reconstrucción, Producción y Evaluación Económica,* Puno, Peru, Programa Interinstitucional de *Waru Waru,* Convenio PELT/INADE-

IC/COTESU, 1992.

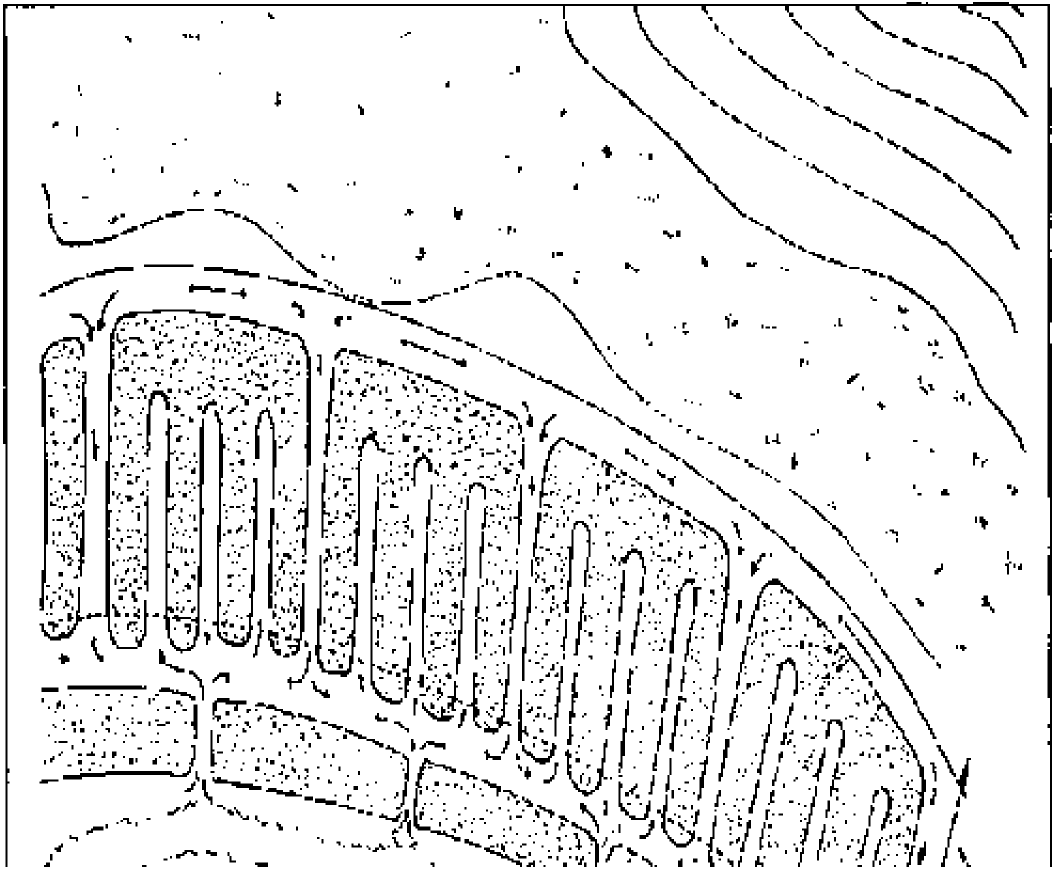
## Figure 34: Design of a Fluvial *Waru Waru* System.

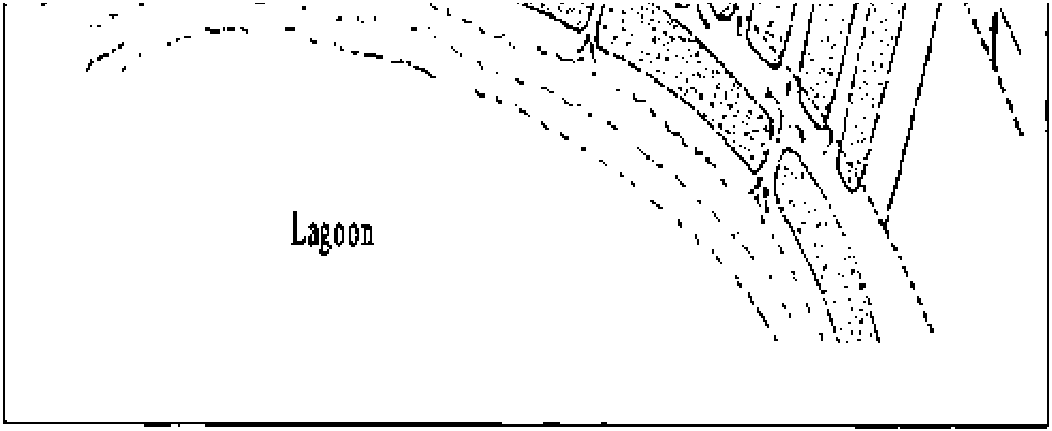





Source: Alipio C. Murilo and Ludgardo L. Mamani, *Manual Técnico de Waru Waru, Para la Reconstrucción, Producción y Evaluación Económica,* Puno, Peru, Programa Interinstitucional de *Waru Waru,* Convenio PELT/INADE-IC/COTESU, 1992.

# Figure 35: Design of a Phreatic *Warn Waru* System.






Source: Alipio C. Murilo and Ludgardo L. Mamani, *Manual Técnico de Waru Waru, Para la Reconstrucción, Producción y Evaluación Económica,* Puno, Peru, Programa Interinstitucional de *Waru Waru,* Convenio PELT/INADE-IC/COTESU, 1992.

**Figure 36: Cross-section of a Canal, Embankment and Raised Bed System.**

Source: Alipio C. Murilo and Ludgardo L. Mamani, *Manual Técnico de Waru Waru, Para la Reconstrucción, Producción y Evaluación Económica,* Puno, Peru, Programa Interinstitucional de *Waru Waru,* Convenio PELT/INADE-IC/COTESU, 1992.

## Extent of Use

This technology has been used primarily in the Lake Titicaca region at Puno, Peru, and in the Illpa River basin of Bolivia.

## Operation and Maintenance

Periodic reconstruction of the embankments or raised beds is necessary to repair damage caused by erosion and water piping. Reconstruction is usually done during the dry season (March to May, in Peru), although in some areas it is done immediately after harvesting because of a lack of available labor at other times of the year. Cultivation of pasture and other grasses of differing heights on the embankments will help to prevent or control erosion caused by torrential rains during the wet season. Cultivation practices can also damage the embankments. Raising animals such as hogs near the embankments should be avoided, since they can damage the cultivation areas in their search for food.

Periodic fertilization of the raised beds is recommended, and the use of insecticides and fungicides may be necessary to limit crop damage. Insecticides are particularly advisable in the cultivation of potatoes.

**Level of Involvement**

This technology has been promoted, and assistance to farmers provided, by several Peruvian governmental organizations, including the Institute Nacional de Investigación Agropecuaria y Agroindustrial (INIAA), the Centre de

Investigación Agropecuaria Salcedo (CIAS), the Centro de Proyectos Integrales Andinos (CEPIA), and by a number of NGOs. These organizations intend to reconstruct 500 ha of *Waru Waru* in 72 rural communities in the vicinity of Puno. Such an approach is considered to be representative of the involvement necessary to successfully implement a *Waru Waru* cultivation program in the region. Once established, the operation and maintenance of the systems, like the planting and harvesting of agricultural products, becomes the responsibility of the farmers who benefit from the use of this technology.

## Costs

Very little information is available on the costs of these systems. The technology is at present largely experimental and limited to portions of the Andean Altiplano in Peru and Bolivia. Nevertheless, the cost per hectare of a phreatic raised-bed system for the cultivation of potatoes is estimated at $1 460 on the basis of the system created in Chatuma, Peru. Of this, 70% is direct cost and 30% is indirect cost. The production cost for 11.2 kg of potatoes using this technology in Chatuma was estimated at $480. The technology produces economic benefits during the first 3 years following construction, but, shortly thereafter reconstruction becomes necessary to maintain the productivity of the system.

**Effectiveness of the Technology**

In the communities around Puno, during the seven-year period between 1982 and 1989, 229 ha were converted to this technology, with mixed results. Some areas experienced large increases in productivity, particularly in the cultivation of potatoes, while other areas did not. Climatic conditions, such as drought and extremely cold weather, are likely to have contributed to the decrease in productivity in some areas, while poor design and construction of embankments may have led to the decline in productivity recorded in others.

**Suitability**

This technology is suitable in areas with extreme climatic conditions, such as mountainous areas that experience heavy rainfalls and periodic droughts, and where temperature fluctuations range from intense heat to frost. It should be very useful in arid and semi-arid areas.

**Advantages**

- This technology can contribute to mitigating the effects of extreme climatic variations.
- The construction cost is relatively low.
- It can increase the production of certain agricultural crops.

**Disadvantages**

- The life span of the technology is relatively short; the systems require reconstruction after about 3 years of operation.

- Testing of soil texture and composition is necessary before implementation.

- *Waru Waru* systems require annual maintenance and periodic repair.

**Cultural Acceptability**

This is an ancient technology, well accepted in the agricultural communities of Peru and Bolivia.

**Further Development of the Technology**

Application of this technology in other areas with different soil and climatic conditions will be a measure of its potential utility outside of the areas where it is traditionally used. Improvements in the design of the raised bed cultivation system are necessary in order to extend the economic life of the technology and to minimize the need for regular reconstruction of the beds to maintain their productivity.

## Information Sources

### Contacts

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## 4.2 Small-scale clay pot and porous capsule irrigation

This technology consists of using clay pots and porous capsules to improve irrigation practices by increasing storage and improving the distribution of water in the soil. It is not new; it was used by the Romans for many centuries. This ancient irrigation system has been modernized and reapplied in water-scarce areas.

### Technical Description

This low-volume irrigation technology is based on storing and distributing water to the soil, using clay pots and porous capsules interconnected by plastic piping. A constant-level reservoir is used to maintain a steady hydrostatic pressure. Clay pots are open at the top and are usually fired in home furnaces after being fabricated from locally obtained clay or clay mixed with sand. The pots, usually conical in shape and of 10 to 121 capacity, are partially buried in the soil with only the top extending above ground. Distribution is by plastic (PVC) piping to ensure a fairly uniform permeability and porosity. Hydrostatic pressure is regulated by maintaining a constant level in the storage reservoir, as shown in Figure 37.

A similar system, tested in Mexico and Brazil, uses smaller, closed containers, or porous capsules, completely buried in the soil. These containers distribute the water either by suction and capillary action within the soil, or by external pressure provided by a constant-level reservoir (as in the previous system). Each capsule normally has two openings to permit connection of the plastic (PVC) piping which interconnects the capsules. The capacity of these capsules ranges between 7 and 15 1, and the storage tanks supplying the system are elevated 1 or 2 m above the soil surface. The capsules are buried in a line 2 meters apart, at least 10 cm under the top layer of the soil.

The number of pots or capsules used is a function of the area of cultivation, soil conditions, climate, and pot size. Up to 800 pots/ha were installed in Brazil; the system there is shown in Figure 38.

**Extent of Use**

This technology is being used for small-scale agricultural irrigation in the arid and semi-arid regions of Argentina, Brazil (see case study in Part C, Chapter 5), Ecuador, Bolivia, and Mexico. It has also been used in tropical countries such as Guatemala, Panama, and the Dominican Republic during drought periods.

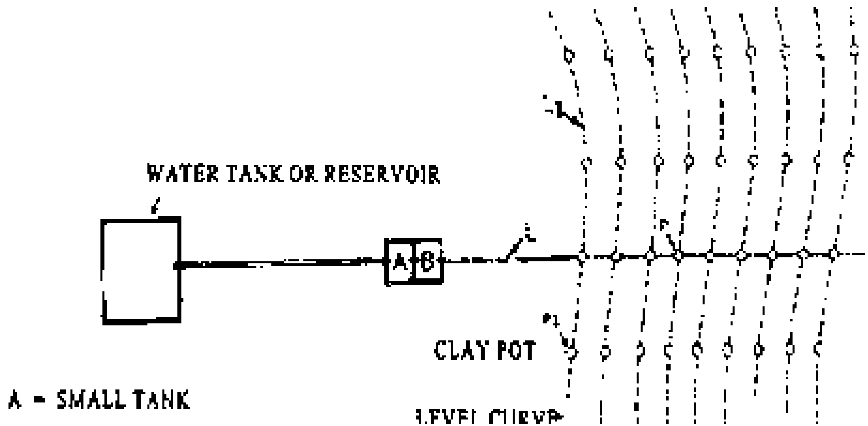
## Operation and Maintenance

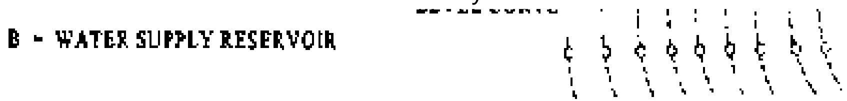
The operation is very simple, requiring only the opening of valves to replace the water used from the pots and capsules. However, the installation of the system does require a degree of care since the pots and capsules are made of clay and can be easily broken; also, the gradients must be correct if gravity flows are desired. It is also important to maintain the hydrostatic pressure. If this pressure cannot be maintained, the connections between pots must be checked for possible leaks and/or breakages. Replacement of the pots or capsules is necessary every 3 to 5 years. A soil investigation before the installation is advisable.

## Level of Involvement

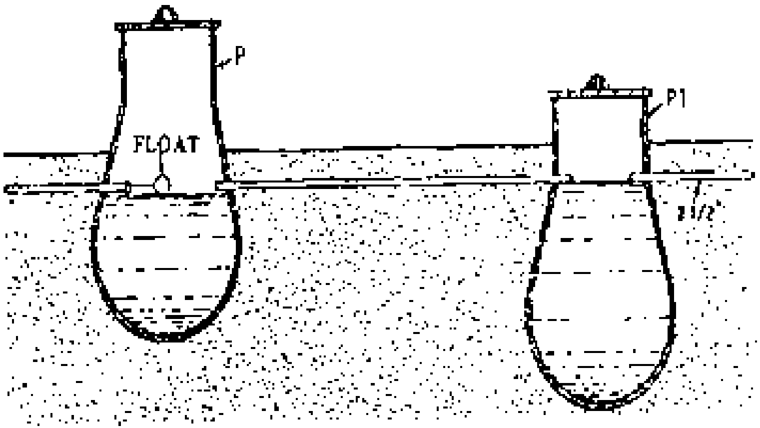
The participation of the community is essential in the implementation of this technology. Further, the support of the government and research institutions is also desirable. In Brazil, the government of the state of Pernambuco built a factory to manufacture porous capsules and developed small areas of bean cultivation for the application of the technology. In Ecuador and Bolivia, universities and government agricultural institutions are testing it.

**Figure 37: Schematic Representation of a Clay Pot Irrigation System.**





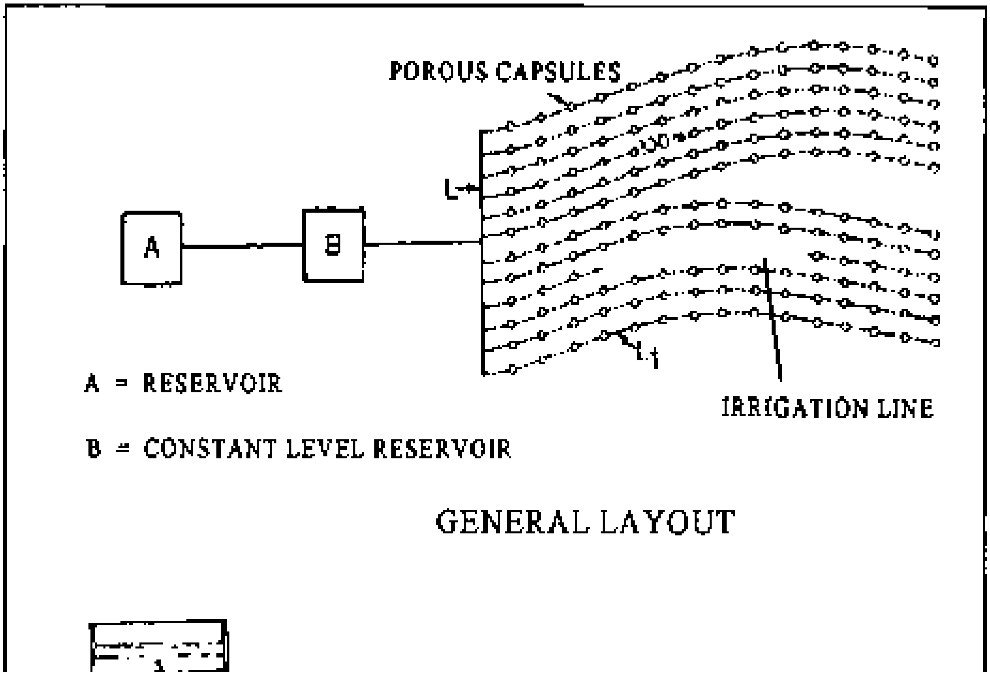

PLANT VIEW

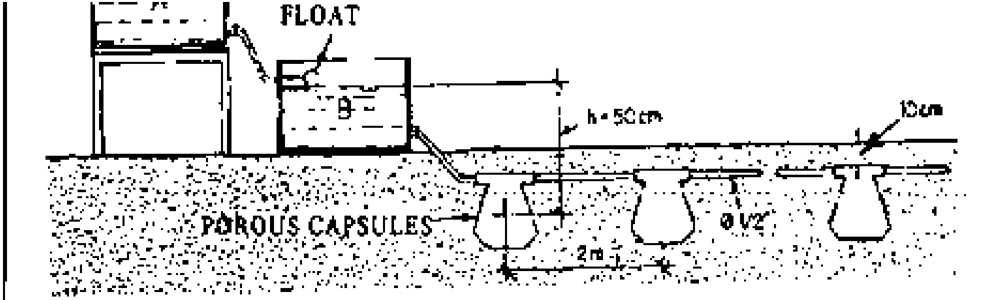



DETAIL OF PRINCIPAL AND SECONDARY POTS

Source: Aderaldo Silva De Souza, et al. *Irrigación par Potes de Barro: Descripción del Método y Pruebas Preliminares,* Petrolina, PE, Brasil, 1982, (EMBRAPA-CPATSA Boletín de Investigación No. 10).

**Figure 38: Schematic of a Porous Capsule Irrigation System.**






DETAILED SKETCH OF POROUS CAPSULES SYSTEM

Source: Aderaldo Silva De Souza, et al. *Irrigación par Potes de Barro: Descripción del Método y Pruebas Preliminares,* Petrolina, PE, Brasil, 1982, (EMBRAPA-CPATSA Boletín de Investigación No. 10).

## Costs

Costs vary according to the materials and the type of system used. In Brazil, the reported cost was $ 1 300/ha cultivated using clay pots, and $1 800/ha cultivated using porous capsules. A clay pot system in the Dominican Republic reported an annual cost of $ 1 280. Smaller experimental systems in Bolivia and Panama were built for less than $100.

**Effectiveness of the Technology**

The technology has been shown to improve the stability of the soils. It has allowed agricultural development in areas where climatic conditions and the quality of the soils have prevented the use of conventional irrigation methods. Tests performed in Panama, using fruit trees, show significant improvements in the size of the stem and the number of fruits per plant; a yield of six fruits per plant was achieved with this system versus two with conventional irrigation. In Bolivia, the use of this technology in the cultivation of potatoes resulted in a yield of 42 000 kg/ha versus 18 000 kg/ha using traditional irrigation methods.

## Suitability

This technology is suitable for arid and semi-arid regions, and for small-scale agricultural projects in areas affected by periodic drought. Countries like Bolivia, Brazil, Peru, Argentina, and Chile can definitely benefit from the use of this technology in rural areas.

## Advantages

- This is a low-cost technology.

- Agricultural production is higher with this technology than with other irrigation technologies.

- Agriculture can be undertaken at lower air temperatures.

- Infiltration losses are reduced.

- Weeds can be better controlled, by managing their access to water.

- This system does not cause environmental impacts.

- This technology is very useful in family gardens and in horticulture.

- Water management using this technology allows agricultural development in arid lands and salty soils.

- Vandalism is minimized since most of the equipment is under the soil surface.

- It is easy to operate and maintain.

- It can reduce fertilizer use, by allowing application to defined, cultivated areas.

- Use of this technology can minimize soil erosion.

**Disadvantages**

- The technology is difficult to use in rocky soils.

- Broken pots or capsules can disrupt the irrigation operation and reduce productivity. «Some plants with extended root systems are difficult to cultivate using this technology.

- In some areas, it may be difficult to purchase or manufacture the clay pots and/or capsules.

- It is only applicable to small-scale agriculture.

**Cultural Acceptability**

This technology is gaming acceptance among agricultural communities in arid areas. It is well developed as a technology for use in household gardening.

## Further Development of the Technology

Improvements in the construction of the porous capsules are desirable, perhaps using different materials which have acceptable levels of porosity but are more robust and can avoid breakages. It is also desirable to develop systems using porous capsules or clay pots, that can be used in large-scale or commercial agricultural operations. Educational and informational programming on the benefits of the technology, and training in the manufacture of porous capsules, and pots are required.

## Information Sources

## Contacts

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## 4.3 Automatic surge flow and gravitational tank irrigation systems

This technology was developed and applied in Mexico during the 1970s. It is essentially an intermittent gravity-flow irrigation system. It has been used almost exclusively for small-scale agriculture and domestic gardening.

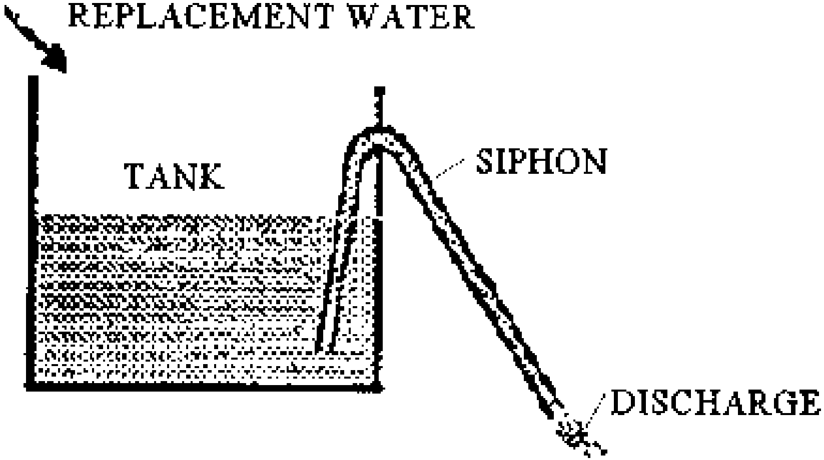
## Technical Description

Prior to the development of this technology, electronically controlled valves were used to produce intermittent water flows for irrigation. These valves are expensive and require some technical training to operate. The *diabeto* (from Greek *diabetes* or siphon) was developed for the purpose of replacing these valves with a device that would be more cost-effective and easier to operate and maintain with a minimum consumption of energy. The system consists of a storage tank equipped with one or more siphons, as shown in Figure 39. The storage tank must be designed to keep a predetermined head in the system to ensure that the water discharged during the siphoning process does not exceed the water flow into the storage tank, thereby draining the tank.

Another system that produces similar results is the use of a storage tank with a bottom discharge. This system as shown in Figure 40, is equipped with a floater, shown in Figure 41, which allows the cyclical opening and closing of a gate at the bottom of the tank. In effect, the operation of the floater is similar to the mechanism in the storage tank of a toilet flushing system.

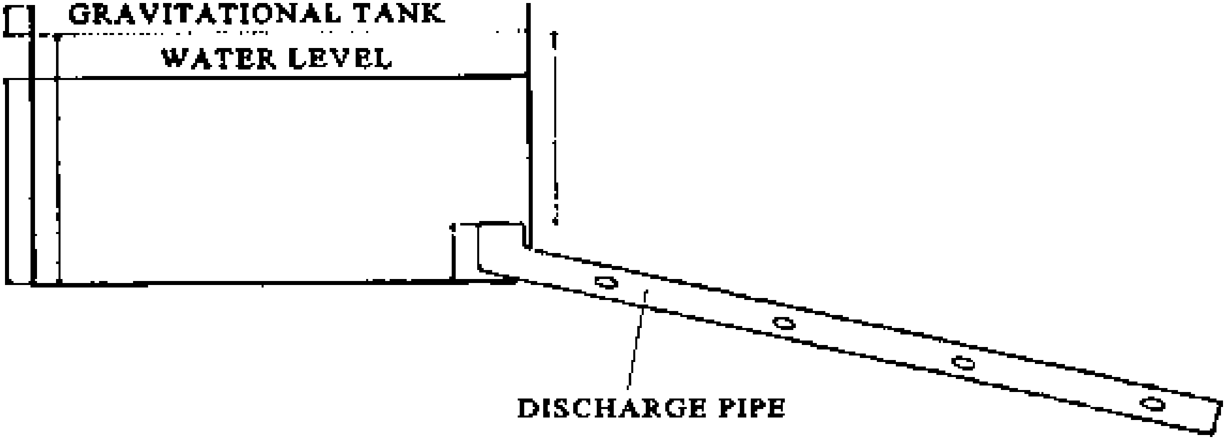
The materials normally used in the construction of the water storage tanks are gravel, cement, and reinforced concrete. The siphons are usually built of a flexible plastic material; PVC is not recommended.

**Figure 39: Schematic of an Automatic Surge Flow Irrigation System *(Diabeto).***




Source: P. Martinez Austria and R.A. Aldama, "Dispositive de Control para la Aplicación del Riego Intermitente," *Revista Ingenieria Hidráulica en México,* Mayo-Agosto, 1991.

**Figure 40: Schematic Representation of a Gravitational Tank Irrigation System.**




Source: V.N. García*, Diseño y Aplicación del Riego Intermitente por Gravedad.* Universidad Nacional Autónoma de México, Facultad de Ingeniería, México D.F., 1995 (Tesis para obtener el grado de Doctor en Ingeniería Hidráulica).

The design of these systems must consider irrigation water use, available hydraulic load, topographic characteristics in the area of application, physical dimensions of the irrigated land, slope and location of furrows, and soil characteristics. Design manuals, based on laboratory and field experiments, have been developed in Mexico.

## Extent of Use

This technology has been used primarily in the arid and semi-arid regions of Mexico. The *diabeto* can be used in any gravity irrigation system, but has been particularly useful in the irrigation of 100 to 300 $m^2$ fields, using furrow irrigation, and in domestic gardening. This technology is best suited for small-scale (< 4 ha) irrigation in rural areas. At present, it is widely used only in Mexico.

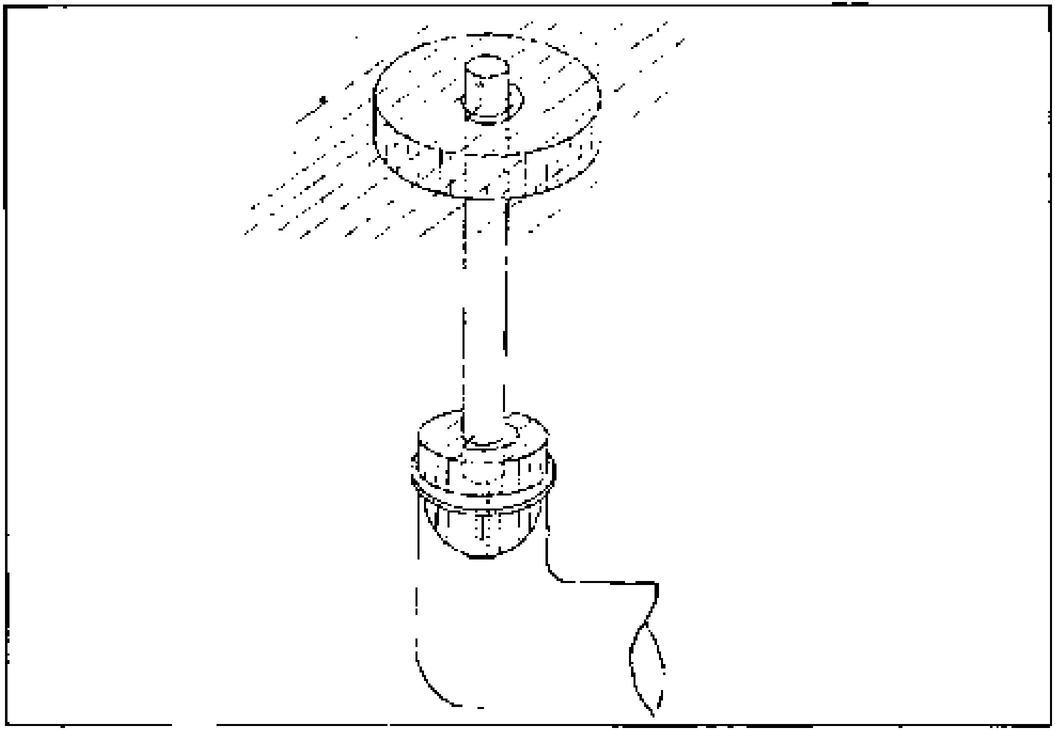
## Operation and Maintenance

The *diabeto* and the gravitational tanks with bottom discharges function automatically, based on flow control devices, and do not need outside energy sources. The water is discharged into a channel that distributes it into the furrows and to the irrigated crops. Maintenance is very simple, requiring only periodic cleaning of the tanks, siphons, and/or discharge pipes.

## Level of Involvement

Up to now, educational institutions, small private agricultural enterprises, and the Mexican Government have promoted this technology. However, it would be desirable if local communities got more involved in implementing it.

**Figure 41: Schematic Representation of an Automatic Fluid Water Control Device used in Gravitational Tanks.**



Source: V.N. García, *Diseño y Aplicación del Riego Intermitente por Gravedad.* Universidad Nacional Autónoma de México, Facultad de Ingeniería, México D.F., 1995 (Tesis para obtener el grado de Doctor en Ingeniería Hidráulica).

## Costs

A surge flow, automatic irrigation device such as the one shown in Figure 37 costs about $600. This includes an 11.25 $m^3$ storage tank, feeding system, and siphon. A device of this size can irrigate up to 4 ha. A similar gravitational tank irrigation system, with the same tank capacity, 150 m of piping, and gates, has an estimated cost of $1 500. A smaller system for domestic gardening can cost around $80. The operation and maintenance costs of these systems are practically nil.

## Effectiveness of the Technology

With the surge flow, automatic irrigation systems and the gravitational tank technologies, irrigation efficiencies of over

75% have been achieved in the state of Zacatecas, Mexico. This represents a significant improvement over the 25% rate reported using traditional irrigation technologies. A saving of about 25% in energy consumption costs has also been observed.

**Suitability**

The technology is recommended for arid and semi-arid areas where low precipitation and high evaporation rates prevail, and where small storage areas and depleted aquifers exist.

**Advantages**

- This technology can utilize water from small wells of limited capacity, reused wastewater, and small streams.

- Hydraulic energy is used as the driving force;

these systems do not require external energy sources.

- The systems are low-pressure.

- Irrigation time and labor force requirements are small, as the systems are automatic.

- The technology is low in cost.

- It is easy to operate and maintain.

- It is applicable to small-scale agricultural systems.

- It is more efficient than traditional irrigation systems.

**Disadvantages**

- The technology is not recommended for furrow irrigation in fields with dimensions greater than 200 m long and 25 meters wide, as the volume of water required in such applications will require extremely large storage tanks.

- For greater efficiency, the irrigated lands should be leveled.

## Cultural Acceptability

The technology has been tried and tested in Mexico, although it has the potential to be used in many other countries. Governments and international institutions can help disseminate information on its use.

## Further Development of the Technology

To improve the applicability of this technology to areas using drip irrigation, a device that will automatically mix fertilizers into the water stream provided by the *diabeto* is under development. Also, development of modular systems is under way. Ultimately, the development of educational programs on the implementation and effective use of this technology will be necessary.

## Information Sources

### Contacts

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## 4.4 Dual water distribution

As the name implies, dual distribution systems involve the use of water supplies from two different sources in two separate distribution networks. The two systems work independently of each other within the same service area. Dual distribution systems are usually used to supply potable water through one distribution network and non-potable water through the other. The systems would be used to augment public water supplies by providing untreated, or poorly treated, water for purposes other than drinking. Such purposes could include fire-fighting, sanitary flushing, street cleaning, or irrigation of ornamental gardens or lawns. This system has been used in some Caribbean islands like Saint Lucia and the U.S. Virgin Islands.

## Technical Description

The systems are designed as two separate pipe networks: a potable water distribution system, and a system capable of distributing sea water or other non-potable waters. The system includes distribution pipes, valves, hydrants, standpipes, and a pumping system, if required. Pipes in the systems are generally cast iron or ductile iron, although fiberglass has also been used.

In seawater-supplied systems, pumps are required to lift the seawater to higher elevation storage tanks. Likewise, pumps may be required to lift wastewaters from wastewater sumps or other collection points. The pumping systems consist of a pumping station containing the water intake, a pumping well, and an elevated storage tank for emergency use. The pumps require foot valves, or one-way valves, in order to retain their charge of water. The water is pumped through a manifold into the secondary or alternative distribution system.

The potable-water, or primary, system operates like any other potable-water supply and distribution system, requiring a water source, treatment plant, storage facility, and distribution system. Pumps are generally required to lift potable water from the treatment plant to storage tanks, from which it is distributed by gravity to the point of use.

## Extent of Use

This technology is rarely used. Seawater-based systems have been used in Castries, Saint Lucia, for fire-fighting purposes and in Charlotte Amalie, U.S. Virgin Islands. U.S. Navy bases have installed and operated similar systems in the past. Wastewater-based systems are discussed in Chapter 3, "Wastewater Treatment Technologies and Reuse."

## Operation and Maintenance

Depending on the use (i.e., intermittent use in the case of fire-fighting supplies or regular in the case of irrigation supplies) and water source used (e.g., seawater or wastewater), in the dual distribution system, regular testing of the system is recommended. The seawater-based system used in the U.S. Virgin Islands was tested daily in the past, but is now tested once a week. The pumps are turned on and a by-pass is used to allow the return of seawater to the sea to avoid pressurizing the distribution system. The pumps and engines are routinely serviced according to manufacturers' specifications.

Problems experienced in the operation and maintenance of this system include accidental damage to foot valves and standpipes. In the case of seawater systems, ships have been known to damage foot valves located in the harbor, and, in the case of the distribution systems, vehicles frequently damage hydrants and standpipes, which then have to be replaced. In addition, foot valves require frequent servicing to remove fungal and other growths which can prevent their proper opening and closing and can make it impossible for the pumps to maintain their charge. On the landward side, regular inspection and maintenance of the standpipes and hydrants is required to remove debris from the openings of the hydrants and standpipes, which become clogged as a result of vandalism (persons pushing debris into the hydrant openings). It is also necessary to ensure that the pump engines arc supplied with adequate reserves of oil and fuel, and that the pumps and motors are properly lubricated for optimal operation.

## Level of Involvement

The systems are entirely a government-run operation in most cases. In Saint Lucia, the fire department had direct involvement in the implementation of this technology, which supplies non-potable water for fire-fighting purposes. Variations on this system, involving the reuse of process water, have been implemented by specific industries as a means of reducing their use of raw water.

## Costs

The cost of constructing a new distribution system for seawater (capital costs) would be similar to that for laying regular distribution pipelines (approximately $4/ft of pipe). In effect, the installation of a dual distribution system approximately doubles the cost of construction of the distribution system, although some savings may be achieved if the two systems are installed at the same time (instead of in series, with the non-potable system retrofitted into an existing distribution system).

Pumping costs (operation and maintenance costs) are also similar to those incurred by a typical water utility. For systems that are used intermittently, these costs would only be incurred on the few occasions when fire necessitates pumping and/or when pumps are being tested.

## Effectiveness of the Technology

This technology is highly effective. Seawater is as effective as potable water when used for fire-fighting purposes, but does not result in the drawdown of potable supplies. The system installed in Castries provides sufficient urban coverage and adequate supplies of water to fight most fires in the city. In contrast, public support for the dual distribution system in the U.S. Virgin Islands has diminished, making the system more prone to vandalism and less effective overall.

## Suitability

The technology is suitable only in areas where a supply of raw water is available. This type of system is generally used near the coast where seawater is abundant, or in places where wastewater is readily available as a source of supply. It can also be utilized in areas that have rivers, streams, or other water sources but lack treatment facilities; in other words, in areas supplied with public water but having access to additional water sources that would otherwise go unutilized or underutilized.

## Advantages

- This technology allows the use of cheaper sources of water for non-consumptive purposes, which may currently be served from more expensive, and limited, potable water supplies.

- If used to augment the regular distribution system, it makes more potable water available to the general public.

**Disadvantages**

- A dual distribution system requires that two distribution systems have to be installed, at essentially double the cost of a single system.

- Having non-potable water in a distribution system creates a potential to cross-contaminate the potable water system (while this is of limited concern in seawater systems, accidental consumption of non-potable water from wastewater-based systems could have serious consequences).

- Use of untreated seawater or wastewater to irrigate leafy vegetables could also threaten human health.

- Seawater can be highly corrosive to metal pipes, fittings, and appurtenances; it increases maintenance costs associated with distribution lines and affects toilet and other metal fixtures that come into contact with the water.

- If return flows enter the wastewater stream, the introduction of large volumes of seawater to treatment plants make sewage treatment more difficult since the salts can impair the effectiveness of activated sludge reactors or rotating biofilters, for example.

## Cultural Acceptability

This technology is accepted as a alternative for the supply of non-potable water for use in firefighting, street cleaning, etc. It is generally best suited to areas having a plentiful alternative source of water such as seawater or wastewater. In the latter case, concerns about possible human health effects may arise.

## Further Development of the Technology

Development and use of non-corrosive materials, such as fiberglass, may make this technology more attractive, especially in cases where seawater is the principal source of non-potable water used in the dual distribution system. The use of alternative materials such as PVC in components such as foot valves might reduce potential for fungal growth and other growths that clog or damage the valves. There is also a great need for public awareness, among users, plumbers, and others, to minimize cross-connections and other potential sources of cross-contamination of the potable water supply.

## Information Sources

### Contacts

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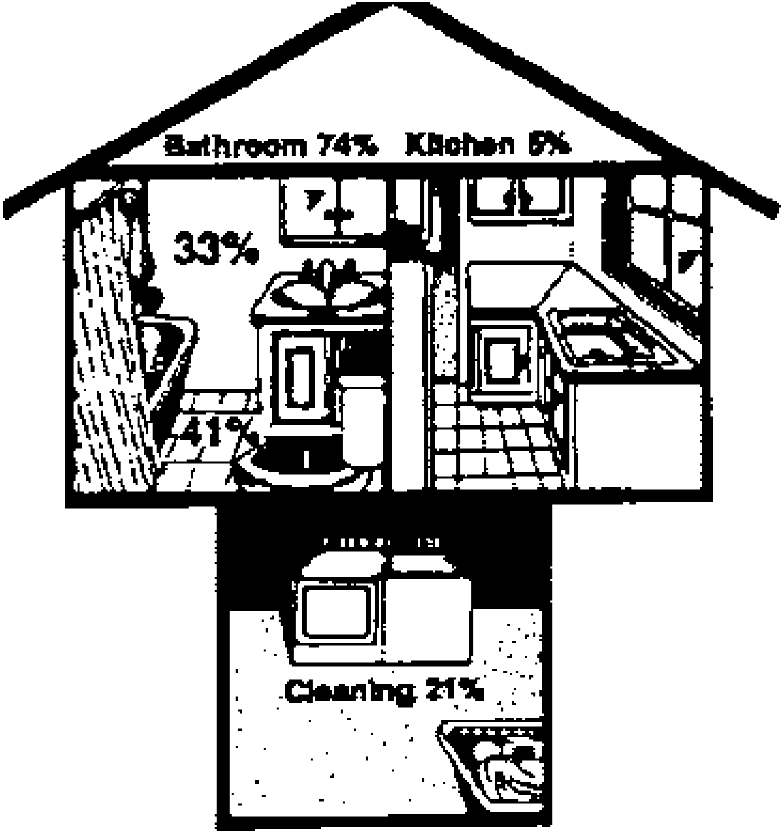
## 4.5 Other water conservation practices

The importance of water conservation and water loss reduction should always be an integral part of the management of freshwater resources and needs to be given prominence in freshwater resources planning. As is suggested by the three interlinking arrows in the recyclable materials symbol, reduction of waste is the first of the several means of resource conservation (the other means being reuse and recycling, both of which are covered elsewhere in this volume). An excellent reference book is *Efficient Water Use,* edited by Hector Garduño and Felipe Arreguín-Cortés.

For water management purposes, the community can be divided into two basic groups: system users (such as households, industry, and agriculture) and system operators (such as municipal, state, and local governments and privately owned suppliers). These users have a choice of a number of different practices, which promote or enhance the efficiency of their use. These practices fall into two basic categories: *engineering practices,* based on modifications to hardware (e.g., plumbing and fixtures) and/or water supply operational procedures, and *behavioral practices,* based on changing water use habits.

Engineering practices are generally technical or regulatory measures, while behavioral practices typically involve market-oriented measures. Collectively, these measures, which affect water use and reduce waste and loss from the source, are known as "demand management" measures. Such measures include leak detection; waste reduction (encouraging consumers to cut out wasteful uses); investment in appliances, processes, and technologies that reduce water input without reducing consumer satisfaction and/or output; treatment of industrial effluents and wastewaters to a standard suitable for recycling and reuse; and reallocation of freshwater resources to the area of greatest social good. The policies that encourage demand management include pricing water at an economic rate, charging for pollution or community-based pollution control practices, regulating and restricting specific water uses, exhorting and informing the consumer of the ways and means of use reduction and recycling, and encouraging water trading among and between users.

**Figure 42: Typical Breakdown of Interior Water Use.**




Source: USEPA, *Cleaner Water Through*

*Conservation,* Washington, D.C., 1995 (Report No. EPA- 841/B-95-002).

## Technical Description

Water conservation practices can be followed by residential users, industrial and commercial users, and agricultural users. They can also be followed by local utilities and/or regional water supply plants. Table 21 shows some of the more common practices recommended for use by the different user groups. A brief description of the most common conservation practices follows.

### Table 21 Recommended Water Conservation Practices

| User Group | Engineering Practices | Behavioral Practices |
|---|---|---|
| Residential | Plumbing changes | Changing water |

| | | |
|---|---|---|
| | | use habits |
| | Low-flush toilets | Pricing |
| | Toilet tank volume displacement devices | Public information and education |
| | Low-flow showerheads | Lawn irrigation scheduling |
| | Faucet aerators | Drought management practices |
| | Pressure reduction devices | |
| | Gray Water reuse landscaping | |
| | Drought-tolerant plants | |
| | Xeriscaped landscapes | |
| Agricultural | Irrigation | Irrigation scheduling |
| | Low volume irrigation technologies | |

| | | |
|---|---|---|
| | Wastewater reuse and recycling | |
| | Soil management | |
| Industrial and commercial | Water reuse and recycling | Monitoring water use |
| | Cooling water recirculation | Enforcing water use practices |
| | Wash water recycling | Educational programs on water |
| | Landscape irrigation | |

Source: USEPA, *Cleaner Water Through Conservation,* Washington D.C., 1995 (Report No. EPA-841/B-95-002).

- Residential Users Conservation Measures

Low-flow plumbing fixtures and retrofit programs are permanent, one-time conservation measures that can be implemented with little or no additional cost over the lifetime of the fixtures. In some cases, these fixtures can even save the residents money over the long term. The most commonly recommended low-flow plumbing fixtures are pressure reduction devices, faucet aerators, toilet displacement devices, low-flush toilets, low-flow showerheads, and plumbing modifications for gray water reuse. A typical breakdown of residential water use is shown in Figure 42.

*Pressure Reduction.* Homeowners can reduce the water pressure in a home by installing pressure reducing valves. A reduction in water pressure can save water in other ways: it can reduce the likelihood of leaking water pipes, leaking water heaters, and dripping faucets.

*Faucet Aerators.* Faucet aerators, which break the flowing water into fine droplets and entrain air while maintaining wetting effectiveness, are inexpensive devices that can be installed in sinks to reduce the volume of water used. Aerators are easily installed and can reduce the volume of water use at a faucet by as much as 60% while still maintaining a strong flow. More efficient kitchen and bathroom faucets that use only 7.5 l/min, in contrast to standard faucets, which use 12 to 20 l/min, are also available.

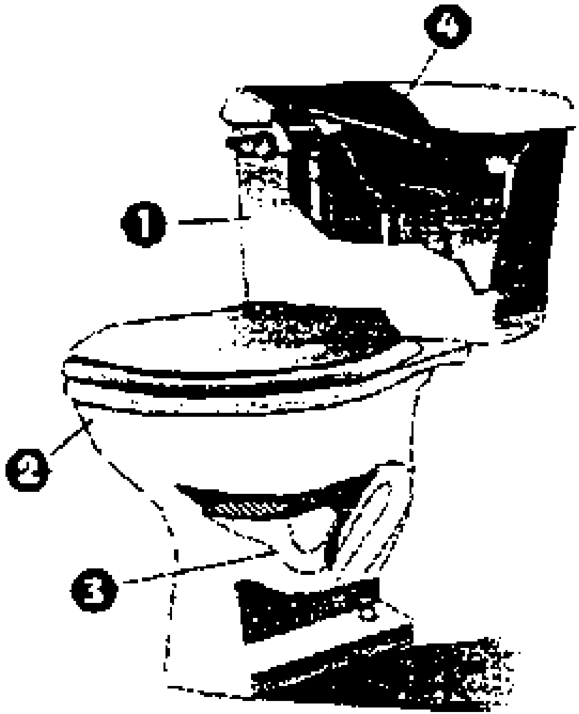
*Toilet Displacement Devices.* Non-toxic bricks or plastic containers (e.g., milk jugs filled with water or pebbles) can be placed in a toilet tank to reduce the amount of water used per flush. By placing between one and three such containers in the tank, more than 41 of water can be saved per flush. A toilet dam, which holds back a reservoir of water when the toilet is flushed, can also be used instead of the displacement device to save water.

*Low-Flush Toilets.* Conventional toilets use 15 to 201 of water per flush, but low-flush toilets use only 61 of water or less. Since low-flush toilets use less water, they also reduce the volume of wastewater produced. A schematic of a low-flush toilet is shown in Figure 43. Even in existing residences, replacement of conventional toilets with low-flush toilets is a practical and economical water-saving alternative.

*Low-Flow Showerheads.* Showers account for about 20% of the total indoor water use in an household. By replacing the standard 18 l/min showerheads with 10 l/min showerheads, which cost less than $5 each, a family of four can save approximately 80,000 l/year. Properly designed low-flow showerheads, currently available, are able to provide the quality of water delivery found in higher volume models.

*Gray Water Use.* Domestic wastewater composed of washwater from kitchen sinks and tubs, clothes washers, and laundry tubs is called gray water. Gray water can be used by homeowners for home gardening, lawn maintenance, landscaping, and other uses that do not require potable water. The level of contamination of gray waters is minimal; however, the plumbing modifications needed to make use of this water should not allow its contamination by wastes from the toilets, which have the potential to spread disease, cause undesirable odors, and result in aesthetic degradation of homestead yards and gardens.

**Figure 43: Gravity Design of a Low-Flush Toilet.**



1. The 6 liter flush design of this gravity toilet has a different flush mechanism.

2. Steep bowl sides and a narrow trapway to allow

the siphoned water to gain velocity for more effective removal of waste.

3. This is where the water pushes waste into the trapway.

4. Stored water flows into the bowl.

Source: USEPA, *Cleaner Water Through Conservation,* Washington B.C., 1995 (Report No. EPA-841/B-95-002).

- Landscaping Water Conservation Practices

*Drought-Tolerant Plants.* Water conservation in landscaping can be accomplished through the use of plants that need little water, thereby saving not only water but labor and fertilizer as well. Careful landscape design can significantly reduce water use; it can also take advantage of native plants which have evolved water-saving or water-tolerant characteristics ideally suited for the local climatic conditions. Use of native plants can also help to minimize the spread of exotic plant species that disrupt local ecosystems. In addition to the selection of the plant species to be used in landscaping, practices such as the use of low precipitation rate sprinklers that have better distribution uniformity, bubbler/soaker systems, and/or drip or point irrigation systems can also conserve water used for landscaping purposes.

*Xeriscaping.* Xeriscaping is an innovative approach to landscaping that promotes water conservation and pollution prevention. Traditional landscapes might incorporate one or two principles of water conservation, but xeriscaping uses planning and design, soil analysis, selection of suitable plants, practical turf areas, efficient irrigation, use of mulches, and appropriate maintenance to create an appropriate landscape for a given climatic condition. Xeriscaping is most successfully practiced in arid and semi-arid areas, where it has proved useful for minimizing irrigation and external maintenance needs while presenting an attractive appearance.

- Agricultural Water Conservation Practices

Water saving irrigation practices fall into three categories: field practices, management strategies, and system modifications. Examples of these practices include, respectively, the chisel plow aeration of extremely compacted soils, furrow diking to prevent uncontrolled runoff, and leveling of the land surface to distribute water more evenly. A number of these practices have been previously detailed in chapters 2 and 3.

*Irrigation Scheduling.* Improved irrigation scheduling can reduce the amount of water required to irrigate a crop effectively by reducing evaporative losses, supplying water when most needed by the irrigated plants, and applying the water in a manner best suited to the plants being irrigated. A careful choice of the rate and timing of irrigation can help farmers to maintain yields with less water. In making scheduling decisions, irrigators should consider:

- The uncertainty of rainfall and the timing of crop water demands.

- The limited water storage capacity of many irrigated soils.

- The finite pumping capacity of most irrigation systems.

- The price of water and changes in water prices as additional operators increase water demand.

*Irrigation Management.* Management strategies involve monitoring soil and water conditions and collecting information on water use and efficiency. The methods include measuring rainfall, determining soil moisture levels, monitoring pumping plant efficiency, and scheduling irrigation. Typical system modifications include the addition of drop tubes to a center pivot irrigation system, retrofitting wells with smaller pumps, installing a surge or demand irrigation system, and/or constructing a tailwater or return flow recovery system.

- Industrial and Commercial Users Water Conservation Practices

Water recycling is the reuse of water for the same application for which it was originally used. Recycled water might require treatment before it can be reused. Cooling water recirculation and washwater recycling are the most widely used water recycling practices. The following guidelines should be used when considering water reuse and recycling in industrial and commercial applications:

- Identification of water reuse opportunities: Are there areas within the factory or in the production process that currently use water only once that would be amenable to reuse?

- Determination of the minimum water quantity needed for the given use: Are there areas within the factory or in the production process where more water is being supplied than is needed to accomplish the purpose?

- Identification of wastewater sources that satisfy the water quality requirements: Does the process require potable water or water of a lesser standard? Can the same result be achieved with lower-quality water?

- Determination of how the water can be transported to the new use: What modifications, if any, in the process or factory may be needed to permit recovery and recirculation/recycling of the water currently sent to waste? What additional treatment may be necessary to reuse this water? What is the relative cost of the required modifications versus the cost of the raw water over the life of the modifications?

*Cooling Water Recirculation.* Recycling water within a recirculating cooling system can greatly reduce water consumption by using the same water to perform several cooling operations. The water savings are generally sufficiently substantial to result in an overall cost saving to industry. Such savings can be even greater if the waste heat is used as a heat source elsewhere in the manufacturing process. Three cooling water conservation approaches are typically used to reduce water consumption: evaporative cooling, ozonation, and heat exchange.

*Washwater Recycling.* Another common use of water by industry is in the use of fresh or deionized water for removing contaminants from products and equipment. Deionized water can generally be recycled after its first use, although the reclamation treatment cost of recycling this water may be as great as or greater than the cost of purchasing raw water from a producer and treating it. The same processes required to produce deionized water from municipal water can be used to produce deionized water from used washwater. It is also possible to blend used washwater with raw water, which also would result in an overall water saving. The reuse of once-used deionized water for a different application within the same factory should also be considered as a water conservation option. For example, used washwater may be perfectly acceptable for washing vehicles or the factory premises.

- Water Conservation Practices for Water Utilities

Common practices used by water supply utilities include metering, leak detection, repairing water lines, well capping, retrofitting programs, pricing, wastewater reuse, and developing public education programs and drought management plans.

*Metering.* The measurement of water use with a meter provides essential data for charging fees based on actual customer use. Submetering may also be used in multiple-unit operations such as apartment buildings, condominia, and mobile homes to indicate water use by individual units within a complex. In such cases, the entire complex of units might be metered by the main supplier, while the individual units might be monitored by either the owner or the water utility.

*Leak Detection.* It has been estimated that in many distribution systems up to half of the water supplied by the water treatment plant is lost to leakage; even more may be lost due to unauthorized abstraction. One way to detect leaks and identify unauthorized connections is to use listening equipment to survey the distribution system, identify leak sounds, and pinpoint the locations of hidden underground leaks. Metering can also be used to help detect leaks in a system. It is not unusual for unaccounted water losses to drop by up to 36% after the introduction of metering and leak detection programs.

*Water Distribution Network Rehabilitation.* A water utility can improve the management and rehabilitation of its water distribution network by a well-planned preventive maintenance program based on a sound knowledge of the distribution network. This knowledge is often embodied in a distribution system database that includes the following data:

- An inventory of the characteristics of the system components, including information on their location, size, and age and the construction material(s) used in the network.

- A record of regular inspections of the network, including an evaluation of the condition of mains and degree of corrosion (if any).

- An inventory of soil conditions and types, including the chemical characteristics of the soils.

- A record of the quality of the product water in the system.

- A record of any high or low pressure problems in the network.

- Operating records, such as of pump and valve operations, failures, or leaks, and of maintenance and rehabilitation costs.

- A file of customer complaints.

- Metering data.

Through the monitoring of such records, advance warning of possible problems can be achieved. For example, excessive water use, or numerous complaints or demands for spare parts, could be early warning signs of an impending breakdown in the system. This system should also include a regular program of preventive maintenance to minimize the possibility of system failures.

*Well Capping.* Well capping is the sealing of abandoned wells. In the case of artesian wells, rusted casings can spill water in a constant flow into drainage ditches, resulting in evaporative loss or runoff losses. In non-artesian wells, uncapped abandoned wells form points of entry for contaminants into the groundwater system.

*Pricing.* Placing an economic value on freshwater is the principal means of achieving water conservation. Pricing provides a financial incentive to conserve water. Rate structures may be variable and/or graduated, with prices fixed on the basis of class of service (residential versus industrial or agricultural, for example) and quantity used (for example, the unit price for quantities below 400 l/day might be significantly lower than for quantities which exceed that amount for a single-family residence). Pricing has the advantage of minimizing the costs of overt regulation, restrictions, and policing, while providing a high degree of freedom of choice for individual water customers.

*Retrofit Programs.* Retrofitting involves the replacement of existing plumbing fixtures with equipment that uses less water. The most successful water-saving fixtures are those which operate in the same manner as the fixtures being replaced; for example, toilet tank inserts, faucet aerators, and low flow showerheads do not significantly change the operation of the systems into or onto which they are placed, but they do result in substantial water savings.

*Water Audit Programs.* Various types of audits can be undertaken. For example, residential water audits may involve sending trained water auditors into participating households, free of charge, to encourage water conservation efforts, or providing them with record sheets to note down their water use for external analysis. Water audits may also be undertaken in commercial and industrial facilities, and may be combined with an assessment of the potential for implementing water reuse and recycling programs. A pre-implementation and post-implementation water audit in factories adopting a reuse and recycling program would be a valuable means of demonstrating and quantifying the water savings achieved.

*Public Information and Education.* Public information and education programs can be undertaken to inform the public about the basics of water use and conservation. Programs should be developed for specific applications and may be targeted at specific user groups or age groups; for example, at housekeepers, to encourage domestic water conservation, or at schoolchildren, to provide information on the wider implications of water conservation for future consumption, the environment and other uses. Basic information should include the following:

- How water is delivered and how wastewater is disposed of.
- The costs of water and water supply services.
- Why water conservation is important.

The programs should provide guidance on how the user groups and individuals can participate in conservation efforts. It should be noted that there is a large body of public information and education materials available, particularly in the United States, which may be obtained from a variety of public agencies and NGOs at little or no cost and form the basis of a local public awareness initiative.

- Drought Management

Given the vagaries of the modem climate, in this period of climate change, it seems that droughts may be more severe or extensive than is the past. Many water conservation projects constructed to alleviate drought-induced water shortages are themselves victims of drought. Whether this may simply reflect changes in land use within a watershed that allow less water to infiltrate into the groundwater system, or results from population growth, which places greater demands on finite water resources, is not clear and rarely proved. In any case, many communities are currently experiencing a need to have drought management plans in place to ensure the greatest possible availability of freshwater during periods of below average rainfall.

*Drought Management Planning.* When rainfall is less than usual, there is less water to maintain normal soil moisture levels, stream flows, and reservoir levels and to recharge groundwater. Because of these varied sources and the multiple demands placed upon freshwater resources, a drought management plan should address a range of issues, from political and technical matters to public involvement. Some of the components of a typical drought management plan include the following:

- Identification of the available water resources.

- Tabulation of the multiple sectoral demands for freshwater.

- Description of possible shortfalls between supply and demand.

- Definition of the management measures required for various eventualities, and an agreed allocation schedule in the event that water rationing becomes necessary.

- Provision for user and public involvement in the drought management program.

- Promulgation of legislation, agreements, rules, and procedures to ensure a timely and equitable response to the onset of drought conditions.

- Issuance of a drought management event plan and public information materials to make it known.

*Demand Management.* Demand management is closely linked with water conservation practices. Table 22 shows, in summary form, short-term measures that can be used to reduce demand during periods of drought and the expected levels of reduction. These measures may also be considered in concert with other conservation measures noted above.

**Table 22 Short-Term Measures to Reduce Water Demand and Their Effectiveness**

| **Creation of Public Awareness: 0-15%** | **Voluntary Measures: 15-25%** | **Mandatory Measures (after a drought determination): 25-39%** |
|---|---|---|
| Explain water conservation practices. | Encourage voluntary restrictions on use. | Adopt regulatory measures. |
| Implement a public information program. | Conduct water audits of water-intensive customers. | Develop water rationing, with penalties.<br>Restrict annexations and new connections. |
| Intensify conservation efforts. | Implement conservation-related rate structures. | |

Source: Ramesh Bhatia, et al., *Water Conservation*

*and Reallocation: Best Practice Cases In Improving Economic Efficiency and Environmental Quality,* Washington, D.C., World Bank, 1995 (A World Bank-ODI Joint Study).

## Extent of Use

Water conservation measures have been practiced primarily in the United States, although some Latin American countries have implemented specific measures. For example, in Brazil, the pharmaceutical, food processing, and dairy industries were required to pay effluent charges that contributed to reductions in water use and wastewater production of between 42% and 62%. In Mexico, increased water prices contributed to an increase in wastewater reuse and the recycling of cooling water.

Chile is the only country in the region with a comprehensive water law that has encouraged the development of water markets. The 1981 National Water Law established secure, tradable, and transferable water use rights for both surface and groundwaters. As a result, during periods of low rainfall, farmers shift from the production of water-intensive crops, such as corn and oilseeds, to higher-valued and less water-intensive crops, such as fruits and vegetables.

Water recycling is used at a Container Corporation of America Mill in Santa Clara, California (U.S.A), that manufactures paperboard from the recycled fibers of newspapers, corrugated cardboard clippings, and ledger paper. Historically, water has been used in this process for a variety of purposes. In recent years, however, the mill has begun recycling water used in its rinsing processes after clarification. The mill has also installed a closed loop cooling tower, which has resulted in an additional reduction in water use. These water conservation and use efficiency practices have resulted in an estimated saving of approximately 2.8 million l/day, compared to its 1980 water use rates. These water reductions amount to approximately 900 million l/year and saved the company approximately $348 200 per year.

### Operation and Maintenance

Given the variety of measures that might be undertaken to address conservation needs within a specific geographic area, of which a number are mechanical but many may be technological or informational, it is difficult to identify specific operational requirements. However, some of the more obvious requirements include the following: low-flow water conservation devices require periodic maintenance and repair; leak detection equipment and meters require periodic testing and repair; drought and water conservation management strategies, such as pricing and user charges, require monitoring and enforcement; and well-capping programs require monitoring and trained personnel in order to be effective. Maintenance requirements range from regular inspections of mechanical devices to the review of legislation and conservation plans to ensure their continued relevance.

**Level of Involvement**

The installation and maintenance of low-flow household and irrigation devices may require governmental incentives in order to be accepted. In some cases, employees of the water utility may install and maintain these systems at little or no charge in order to effect the desired water savings. Alternatively, government regulations may be necessary to provide incentives for the implementation of industrial and agricultural water conservation measures. Government action is required in the promulgation of plumbing codes for new construction that will contribute to the adoption of residential water conservation measures. Government or utility involvement is also needed for leakage detection and the repair of distribution systems. Metering, in addition to requiring technical personnel and equipment to be effective, generally requires governmental action to implement and government authority to establish or regulate water tariffs. However, community participation and voluntary conservation are a key element if this technology is to be effective.

**Costs**

The cost of water conservation measures varies with the cost of any equipment required and with size and location. The cost of replacing a conventional toilet with a low-flush toilet is about $250 per unit. Low-flow showerheads, in contrast, cost about $5 each. Meter installation costs range from about $200 for interior meters to $500 for external meters. Leak control has been estimated at $40/million liters.

Costs associated with water conservation are often offset by cost savings incurred after implementation. For example, the use of treated wastewater for cooling at an industrial plant in California, U.S.A., resulted in a saving of $150 000 in 1989, while modifications to the sinks in a computer manufacturing plant in Denver, Colorado, resulted in a saving of $81 000, also in 1989. Close monitoring of water use in a packing facility in Santa Clara, California, produced an annual saving of $40 000. Elsewhere, the introduction of water markets in Chile in 1993 increased agricultural profits by $1.5 billion.

**Effectiveness of the Technology**

Water conservation measures are highly effective. However, this technology may not be too popular with consumers, who may be asked to pay a higher price for the water they consume, and can be, politically, very unpalatable. Nevertheless, studies carried out in Seattle, Washington, U.S.A., reported the following results from water conservation measures:

- According to detailed data on the performance of low-flow water devices in 308 single-family residences, indoor per capita water use dropped

6.4% after low-flow showerheads were installed.

- Easily installed aerators reduced water use at a faucet by as much as 60% while still maintaining a strong flow.

- A reduction in water pressure from 100 pounds per square inch (psi) to 50 psi at an outlet resulted in a water flow reduction of about one-third of the pre-existing use.

- Gray water reuse saved a volume of water equivalent to that needed to supply more than 7 000 residences and businesses.

- Outdoor water use was reduced by restricting watering times to the early morning or late evening; watering on cooler days, when possible, also reduced outdoor water use. All these measures contributed to reduced evaporative losses.

- As many as 600 l of water were saved when washing a car by turning the hose off between rinses; additional benefits and water savings were achieved by washing the car on the lawn, which both watered the lawn and reduced runoff.

- Sweeping sidewalks and driveways, instead of hosing them down, saved about 200 l of water every 5 minutes.

In other studies, such as an industrial water conservation project in California, the conversion of an industrial process from a single-pass freshwater cooling system to a closed-loop cooling system, with circulating chilled water, has saved an estimated 20 000 to 28 000 l/day, while cities in the hemisphere that have large, old, deteriorating systems, leak detection programs have been especially efficient in minimizing water losses.

## Suitability

Water conservation measures are suitable and recommended for all public water supply systems, industries with high water use, agricultural enterprises, and individual residential users in Latin American countries and the Caribbean islands.

## Advantages

*Residential water users:*

- Low-flow devices result in water use savings of 20% to 40%.

- Pressure reductions save up to 33% of the water normally consumed.

- Conservation-based landscape irrigation practices also produce significant water use savings.

*Industrial/commercial users:*

- Water recycling greatly reduces water use.

- Deionized water can be recycled after its first use at little or no additional cost, using the same equipment used to produce the deionized water from the municipal supply.

- Proper scheduling of landscape irrigation optimizes water use by minimizing evaporative losses.

*Agricultural users:*

- Water savings can be achieved through a combination of field practices, monitoring, and system modifications.

- Wastewater reuse can produce significant water savings. *Water supply plants:*

- Widespread leakages and illegal connections may account for 30% to 50% of the water loss in a distribution system.

- Metering allows for greater accountability and assists in the development of a pricing structure that is fair and appropriate to the individual water supply system and that provides incentives for conservation.

- Equipment repairs to water mains and valves, and capping unused wells, can reduce unnecessary water loss, and prevent contamination of both piped water and groundwater.

- Retrofit programs can produce long-term savings of water and money.

**Disadvantages**

*Residential users:*

- The initial cost of low-flow devices can be high.
- Changes or modifications in water use habits are not readily accepted.

*Agricultural users:*

- Low-volume irrigation systems may be costly in some cases.
- The use of wastewater for irrigation may pose potential health risks.

*Industrial/commercial users:*

- Modifications to manufacturing processes may be required in some cases, incurring an initial capital charge to the user.

- Changes in the piping system within a plant can be costly.

*Water supply plants:*

- Implementation of leak detection, control and metering is costly.
- Meters and leak detection devices require regular maintenance.

**Cultural Acceptability**

Most conservation measures have been applied in response to government regulations or conservation programs. As was noted above, public acceptance is limited despite the economic benefits.

## Further Development of the Technology

Improved equipment for use in leak detection and metering is required. Such devices need to be more robust and less costly. Meters should be able to withstand tampering. It would also be desirable for low-flow plumbing devices to be more cost effective so as to be more attractive to consumers. Implementation of educational programming on the necessity and the economic and environmental benefits of water conservation is also likely to lower consumer resistance to water conservation technologies.

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**Table 23 Summary of Alternative Technologies Presented in the *Source Book***

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# 5.1 Rainwater harvesting in Honduras

## Technical description

The harvesting of water from the surface of roofs for domestic or agricultural uses is a technology employed in developing countries, particularly in the Central American region and specifically in Honduras, by rural communities and marginal urban areas that do not have access to conventional water supply systems. This technology is described in Part B, Chapter 1, "Freshwater Augmentation Technologies."

- Domestic Use

The system basically involves collecting the water that falls on the zinc, asbestos, or tile roof of a house during rainstorms, and conveying it by an aluminum, PVC, wood, or plastic drain or collector to a nearby covered storage unit or cistern, as shown in Figure 1.

Currently the most common container is a metal drum or barrel with a capacity of some 200 liters (54-gallons), set up at the foot of a fall-pipe. This is enough to supply a family for four to five days with 7 liters per person per day, with the possibility of using more than one storage barrel. Particularly when the resident owns the property, a larger storage unit can be built with sufficient capacity - some 9 cubic meters - to meet the dry-season demand of a family of six or seven people.

- Agricultural Use (Irrigation and Animal Drinking Troughs)

This involves collecting water that falls on the roofs of agricultural installations or on the land (microbasins) and piping it to a nearby covered or open storage or impoundment. Harvesting for specialized livestock facilities (confinement, processing, etc.) is a concept similar to the harvesting-storage system for domestic use.

For large-scale watering or irrigation, where the quality of the water is not a limiting factor, a harvesting area has to be selected where irrigation ditches or piping are built leading to a collection dam in which water is stored when it rains. This dam can include wood, stone, or sand filters to prevent obstructions in the irrigation system or physical pollution of the reservoir.

## Extent of Use

The range of the technology could be limited to places with minimum rainfall of 600 mm per year - and no maximum limit - preferably concentrated over a few months.

This technology for domestic use can be found throughout the country but to a moderate extent, except in the zone, particularly in the departments of Valle and Choluteca (Pacific watershed), where for different reasons of a cultural and climatic nature, the population feels more pressure to supply itself with water, thereby resulting in a very high potential for water demand for human consumption.

For agricultural use, this technology is used extensively, preferably in the cattle-raising valleys of the center and south of the country, primarily through the construction of earthen dams over seasonal channels containing rainwater, which serve to provide water to numerous cattle ranches.

The establishment of both uses has increased substantially over the last 10 years primarily as a result of competition for water service in those areas where the land is used intensively.

## Operation and Maintenance

Operation and maintenance are very simple and consist particularly in cleaning the harvesting system at the beginning of the winter, filtering foreign matter, and maintaining the storage container.

For domestic purposes, operation and maintenance of the system basically involve performing two main tasks:

- Cleaning the roof at the beginning of each rainy season to remove any type of trash and foreign matter, usually by using the water from the first rains; and

- Cleaning the tank at the end of the rainy season. Both operations require a maximum of three days' work per season.

For livestock and irrigation purposes, additional efforts are required because the collection area and storage volume are larger. When microbasins are used, the collection area and piping systems must be maintained with permanent vegetation to filter sediment and refuse. The reservoirs should be drained with the first rainfall to eliminate summer concentrations and should be kept clean and weeded.

When dams are used for watering animals it is preferable to convey the water through pipes to cement or wooden troughs. If the dams are used directly, the cattle should not be allowed to enter the reservoirs and excrement should be prevented from being dragged in by rainwater. For irrigation reservoirs, filters should be installed for sediments, seeds, or obstructions of the piping or distribution mechanisms.

The reservoirs should be surrounded by windbreaks to reduce evaporation and if they are made of cement they could be roofed or covered with plastic sheets.

**Level of Involvement**

The systems mentioned are for individual - not communal - use, and sometimes are set up thanks to promotion by a state agency or NGO.

The resources used come from the beneficiaries, particularly those with sufficient funds, and when the system is for communal use, for potable water, it is financed by the members of the community. As far as is known, there is not much participation by the central government or private business, with the exception of the "Water for the People" program, which carried out similar projects in the southern part of the country, using uncovered storage tanks.

Agricultural systems for irrigation are developed by individuals, usually with technical assistance from the Water Resource Administration, some international agencies, and NGOs. Financing comes from development funds for irrigation microprojects or from the individuals themselves.

Impoundments for cattle primarily require agricultural equipment for the construction of earthen dams and are decided upon and financed by the ranchers themselves.

The Development and Adaptation Unit of the Ministry of Natural Resources, in coordination with the CATIE project in Nicaragua and Guatemala, initiated some projects in the central zone.

**Costs**

Analyses conducted by the Pan American Health Organization/Pan American Center for Sanitary Engineering and Environmental Sciences (CEPIS) estimated that the cost of harvesting systems using the roofs of dwellings was US$107 for a 5 $m^3$ tank, which would amount in the case at hand to approximately US$241 for a 9 $m^3$ tank.

For storage systems for agricultural use, 350 to 1.500 $m^3$ of water per quarter hectare need to be stored for 15 to 60 days, which involves reservoirs costing from US$1.500 to US$4.000, i.e., similar to the cost of reservoirs for cattle troughs, which contain almost twice the volume.

**Effectiveness of the Technology**

Harvesting water from rainwater collection systems for human use is considered the most appropriate technology in areas that do not have aqueducts to supply the community with continuous and reliable service. Properly treated and maintained roofs are the best choice as a collection surface, because their location protects the water from pollution, which is typical in ground-level collection surfaces. With this technology, pollutants can be reduced by 80 to 90%.

For example, with precipitation of 700 mm per year and a collection area of 100 $m^2$, 28 to 30 $m^3$ can be stored over a five-month cycle with 40% efficiency - which can benefit a family of 10 during the dry season at a cost of some $2 per $m^3$ of water.

For agricultural use, a 1.000 $m^2$ collection area and rainfall of 700 mm per year, 420 $m^3$ could be collected with losses of 40%, which would be enough to irrigate a family market garden of some 300 $m^2$ in a production cycle of highly profitable crops.

**Suitability**

Because of the homogeneous cultural and productive conditions in Honduras, the use of the technology is recommended for the entire country. It is particularly recommended in areas where groundwater is polluted by seawater intrusion and where run-off from rivers and watercourses is minimal. In general, the lack of precipitation during the dry season, the poor quality of river water, and the distance between consumers makes this the most attractive solution.

In isolated areas with high precipitation, such as Gracias a Dios, Islas de la Bahía, and the Atlantic coast, it should be promoted for the purpose of obtaining higher quality water and avoiding high water transportation costs.

**Advantages**

- The water collected is of higher quality and safer than that in rivers and watercourses, and therefore reduces medical costs.

- It is an independent system and therefore very appropriate for isolated and disperse communities or settlements.

- It uses local construction materials and labor.

- Sources of energy are not needed to operate the systems.

- The owner/user can easily maintain the systems.

- The water is convenient and accessible; valuable time and effort are saved in collecting and/or hauling water, particularly for the household's women and young people.

- It provides a supply of water to meet future agricultural needs.

**Disadvantages**

- The high initial cost of building the permanent storage facilities could be a prohibitive obstacle to some families; the use of a barrel is more likely, but the volume of water available is then limited.

- The quantity of water available depends on rainfall and the surface of the roof, and additional sources of water are almost always needed. For long periods of drought it is necessary to store excessively large volumes of water.

- The mineral-free water is tasteless and could cause nutritional deficiencies; people prefer to drink water rich in minerals.

- For livestock use, it is important to operate the reservoir properly to avoid pollution of the water by the animals themselves.

- Open reservoirs are systems that promote proliferation of, and provide refuge to, disease vectors and pests.

## Future Development of the Technology

The water harvesting technology for human purposes could be vastly improved with the addition of unit nitration and purification systems and of the conduit to the tank. In this way, at least the quality of water for human consumption would be guaranteed. Since the addition of these unit systems has a direct impact on the family economy, the use of stone filters and earthen pots to keep the water cool is recommended. This technology is widely known and used in the country to increase the supply of safe water free of bacteria and other pathogens.

It is necessary to implement programs to disseminate, demonstrate, and promote the use of the technology. Special funds should be established to finance the programs, and the technology could be included on a large scale in rural or urban housing development programs and in comprehensive rural development programs.

## Information Sources

### Contacts

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***Walter Santos,*** Centre de Entrenamiento de Desarrollo Agrícola (CEDA), Dirección de Recursos Hídricos, Comayagua, Honduras.

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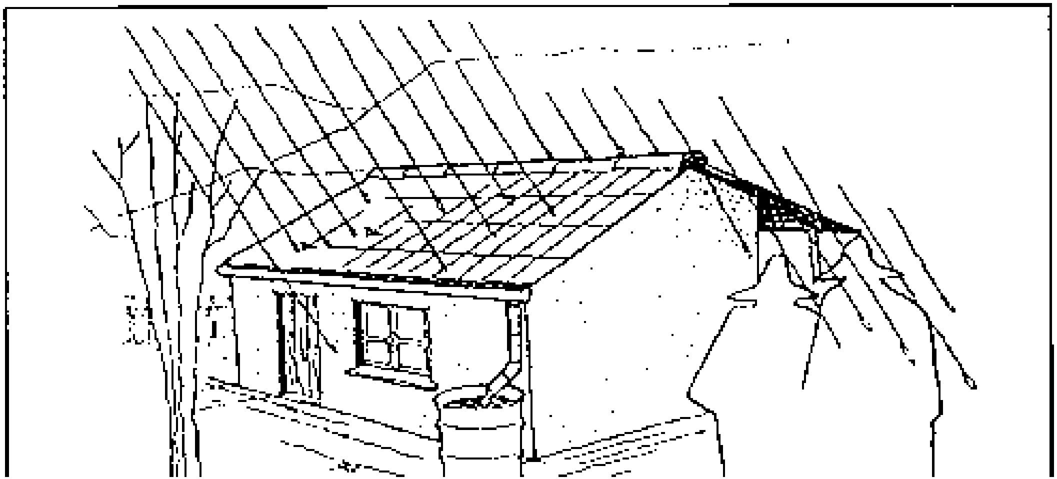
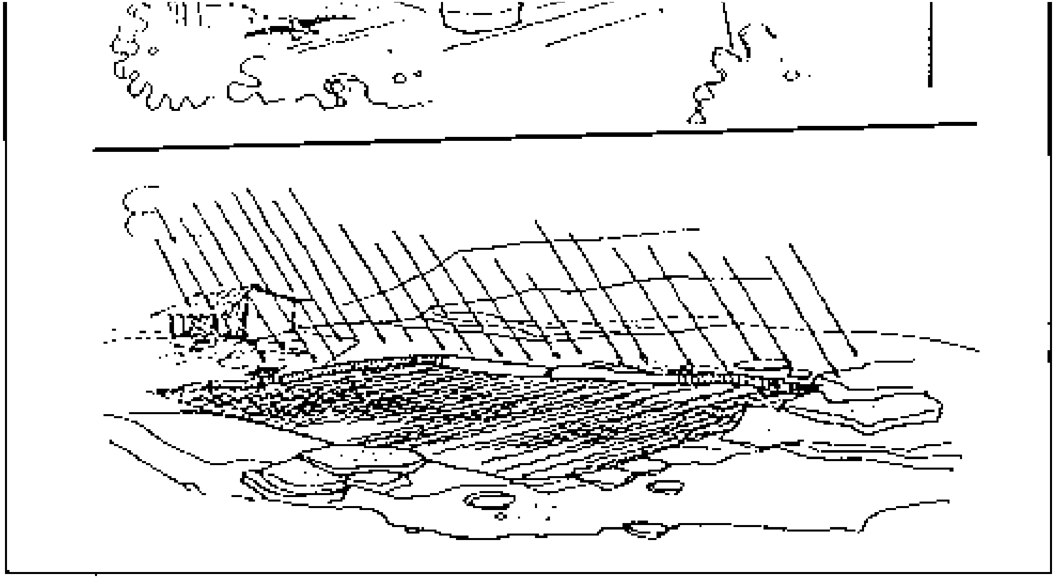
**Figure 44: Storage of harvested rainwater in Honduras: in a drum (top) or an impoundment (bottom).**





Source: Ernesto Bondy Reyes, Director General of Water Resources, Ministry of Natural Resources, Honduras.

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## 5.2 Fog harvesting in Chile

The far north of Chile, between the cities of Arica (latitude 18° S) and La Serena (latitude 29° S), is classified as an arid or semi-arid zone, depending on the rainfall. The Antofagasta area (latitude 23° S), on the eastern edge of the Pacific Anticline, is a desert climate with virtually no rainfall. In these areas, natural watercourses are few and highly seasonal. Hence, alternative sources of freshwater are required.

Special atmospheric conditions occur along the arid coast of Chile and southern Peru, where clouds settling on the Andean slopes produce what is known locally as *camanchacas* (thick fog). The clouds that touch the land surface can be "milked" or "harvested" to obtain water. This technology is described in Part B, Chapter 1, "Freshwater Augmentation Technologies."

**Technical Description**

To capture the water from fog, rectangular obstacles constructed of polypropylene mesh are employed. These are usually placed perpendicular to the prevailing flow of the clouds. The "fog harvesters" are positioned 1.5 m above the ground, and are supported on vertical posts. The size of the harvesters depends on the topographical conditions and the purpose for which the water is to be used.

Drops of water collect on the mesh, coalesce, and flow by gravity along a plastic conduit at the bottom of the mesh to a receptacle for later treatment (if required) and distribution.

This technology is being used in the area of Paposo (latitude 25 °S), 180 km south of the city of Antofagasta, in the Paposo Protected Forest Area administered by the National Forestal Corporation (CONAF). The site is 750 m above sea level. In this area, CONAF is operating a Research and Development Center for the Study of Flora, Fauna, and Human Activities. A research facility has been built, housing two park rangers. This facility is supplied with water by a fog harvester, which is described in detail below.

***Type and design a/harvester.*** The harvester is a multiple (three) screen type, forming a single structure with a useful surface area of 144 $m^2$ (see Figure 6). It is composed of two independent structures, one holding the posts upright and the other supporting the mesh. Each of the structures has its own separate anchoring system. The mesh employed is the Raschel 35% shade-type.

*Post supports.* The structure is supported by eucalyptus posts impregnated with copper sulfate and creosote, 7 m long, with diameters tapering from 30 cm to 15 cm. The base of each post rests in a hole 0.80 m x 0.80 m x 1.0 m filled with rounded stones of approximately 20 cm diameter and sand. The posts are further supported by a system of cables held in place by cone-shaped anchors. Four posts supported by ten anchors are provided for the installation. The holes for the post anchors are excavated at a linear distance of 5.75 m from the base of the posts, or at the end of a cable describing an angle of 45° relative to the posts. Galvanized steel cables connect the anchors and the posts (all cables are 6 x 7, 3/16-inch k-stem steel, shark type). The cables are attached to the buried cone-shaped anchors by means of a 1.8 m, 5/8-inch diameter bar extending from the anchor to the point of cable attachment immediately above the soil surface. The posts are installed 10m apart, and are also interconnected with the 3/16-inch cable. These cables are attached to the posts by means of 5/8-inch diameter, 7-inch-long eye bolts using 5/8-inch coupling flanges.

***Mesh supports.*** The mesh is supported by cables at the top and bottom of each panel. These cables are fixed to two cone-shaped anchors which are independent of those supporting the posts. Two intermediate 1/8-inch-diameter plastic-coated cables pass through the center and are interwoven with the mesh thread.

***Mesh attachment.*** The mesh is attached to the posts with two moisture-treated smooth-planed boards, 4.3 m long x 7 cm x 3.5 cm. The mesh is wrapped very tightly between the two boards and held with galvanized bolts, 5/8-inch in diameter and 15 inches long, which pass through the post, the boards and the mesh. The cable that supports the mesh from the top passes through two pulleys mounted on the end posts, which provide the structure with a measure of flexibility vis-a-vis the force of the wind. For its entire length, the lower cable is encased in a high-density polyethylene tube which passes through a gap between the two boards holding the mesh onto the posts. This cable is extremely important as it supports not only the mesh but also the channel that collects the water.

***Water channel attachment.*** The channel is made of 110 mm diameter PVC pipe, from which one-quarter of the circumference has been removed along the entire length. The tube is suspended, cut side uppermost, from the lower cable using 2.16 mm galvanized wire, attached at various points to provide increased strength. At each end, the PVC tube is fitted with a 110 mm x 40 mm cap. The water flows out of the tube, via a T-junction and a 3/4-inch polyethylene pipe, to a storage tank (cistern).

***Storage lank.*** The storage tank used with this system is a 30 $m^3$ closed cistern, built of waterproofed reinforced concrete, and equipped with flow control and cleaning valves. The cistern also has a hermetically sealed inspection hatch, and is built entirely below grade.

## Extent of Use

This technology is of relatively limited applicability. While it lends itself to use along the coastal zone of northern Chile and southern Peru, wherever the hills are higher than the base of the cloud layer, it requires a specific combination of climatic and topographical conditions for best results. Such combinations of climate and topography are uncommon, but do exist outside of this region, as is shown in Figure 7.

## Operation and Maintenance

Operation is simple, requiring only periodic inspection of the collection channels and the water supply lines to prevent blockages. Few other difficulties are experienced in the operation of this technology, the most common being that strong winds may cause the mesh to come loose. This problem can be easily resolved provided it is detected in a timely manner. Problems with the support structure are unlikely if it is properly constructed. There is generally no difficulty in obtaining replacement parts if needed. The operation and maintenance of this technology do not require any specific level of training unless it is necessary to purify the water, but even then this is usually a simple process.

## Level of Involvement

Depending on the proposed use of the water, government organizations may be directly involved in implementation and maintenance of the technology. Nevertheless, this technology may be easily constructed and installed by individuals using readily available materials.

## Costs

The cost of the fog harvesting system was as follows:

| | |
|---|---|
| Post support structure | $3020 |
| Mesh support structure | $2089 |
| Storage tank | $5710 |

For purely reference purposes, the initial capital cost per $m^2$ of mesh installed was $90, with maintenance and operation costing approximately $600/year. The resulting unit cost of production is $1.4 l/$m^3$.

**Effectiveness of the Technology**

The average annual volume of water harvested was 2.5 l/$m^3$/day in the Antofagasta area.

**Advantages**

- The system requires a low level of investment, and is inexpensive to operate and maintain;

- It is modular in construction, allowing production to be increased incrementally as funds become available or as demand grows.

- It has no significant impact on the environment.

## Disadvantages

- The availability of sites at which to install the fog harvesting system is limited.

- While the technology has few environmental impacts, the harvesting structures may be visually intrusive.

## Future Development of the Technology

While the technology meets the need for small volumes of water, future development work should be directed toward increasing the yield from the harvesters for larger-scale applications. In particular, if this goal is to be achieved, studies need to be aimed at designing spatial distribution systems that will increase the flow of fog into the collection area. Also, it is important to bear in mind that, while the technology has proved satisfactory, its successful implementation depends on the existence of the correct combination of geographical and meteorological conditions. Thus, a study of ambient meteorological parameters must precede any proposed application of this technology, not only to determine if the correct combination of topography and climate exists but also to contribute to the understanding of these factors so that their occurrence may be predicted. A sociocultural development project should also be conducted at the same time to ensure that an appropriate organization exists to manage the system in an appropriate and efficient manner.

## Information Sources

### Contacts

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## 5.3 Underground dams in Brazil

*Climatic instability in northeast Brazil has more to do with* *irregular rainfall than with drought.* The lack of a reliable water supply to meet even basic needs is a serious hindrance to human settlement in rural areas. Like other semi-arid regions of the world, the semi-arid tropical region of Brazil has shallow, rocky soils with low water retention capacity, a low organic material content, and a high susceptibility to erosion.

There are various options for creating and tapping water reserves in this region. Surface reservoirs are the most commonly used, since geological conditions are conducive to a high degree of surface drainage. However, evaporative losses are high. Another option is to make use of groundwater. However, the underlying crystalline bedrock lacks the porous structure necessary to store a large volume of water and maintain a high rate of extraction. To overcome these shortcomings, a further option, that of creating artificial aquifers using underground dams has been devised as a means of storing large quantities of good quality water for family or community needs, for use by animals, or even for small-scale irrigation. Under semi-arid tropical conditions, alluvial pools are a widespread phenomenon. This natural pooling of water, very common in watersheds with crystalline bedrock, lends itself to the building of underground dams in the surficial alluvium. Such dams have the advantages of being able to store larger volumes of water than the natural aquifers in this area, and of being less susceptible to evaporative losses as the water is stored underground. The use of these underground dams also takes advantage of the naturally occurring alluvium (Monteiro, 1984). This technology is described in Part B, Chapter 1, "Freshwater Augmentation Technologies."

## Technical Description

An underground dam is any structure designed to contain underground flow, from a natural aquifer or from an artificial one, built with an impermeable barrier. Two major types have been distinguished in the literature: underground or submersible dams and submerged dams (Santos and Frangipani, 1978; Silva and Rego Neto, 1992), both shown in Figure 45. Underground or submersible dams are defined as dams with walls that begin at the impermeable layer and extend above the surface of the alluvium, causing pools to form upstream during rainy periods. Water is stored both above and below the alluvial surface. The wall of a submerged dam, on the other hand, is entirely enclosed in the alluvium, and water is stored in the saturated soil. These types of dams have been built in northeast Brazil since the turn of the century to augment rural water supplies.

The dam wall, also called an impermeable plate, intercepts the flow of underground and/or surface waters, creating and/or raising the water table and pool elevation within an alluvial area. The dam wall is the main component of this technology. It extends from the bedrock or other subsurface impermeable layer up to, or beyond, the surface of the alluvial soil. It can be built of various materials, such as layers of compressed clay; packed mud; masonry; polyethylene or PVC plastic canvas; concrete; or a combination of materials.

- Construction of an Underground Dam

***Site selection.*** The first step is site selection. Information on the soil distributions in an area is used to identify the best site. Sites with alluvial soils no more than 3 m to 4 m deep, of medium to coarse texture, and having a gradient of no more than 5% are preferred. Such sites may coincide with natural drainage routes, known as creeks, which carry large amounts of rainwater runoff in the region. In order to make optimal use of creek beds, a knowledge of the soil profile, and hence the depth to the impermeable layer, is necessary. Once a group of sites has been identified on the basis of topography, a further selection should be made on the basis of the salt content of the surface water and the average annual flow rates. Sites that have high salinities and high flow rates that could jeopardize the dam structure should be excluded from further consideration.

***Topographic survey.*** Once a site has been selected on the basis of the topographic, salinity, and flow rate criteria, an on-site topographic survey should be performed, using 20 m x 20 m quadrants, to better determine the situation of the components. In systems that do not include a natural watercourse, this determination should include the delineation of the catchment area and location of the wall. For schemes that are being built for agricultural purposes, it is also necessary to locate the planting area to be served from the dam.

***Construction of the wall.*** In the area chosen for the dam wall, a gutter, or cut-off trench, is dug across, or perpendicular to, the bed of the river or drainage route, down to the impermeable layer; its width depends upon the depth of the impermeable layer, the type of soil, and the material to be used in building the wall. In very dry, sandy alluvia, banks with low cohesion may constantly collapse, making excavation difficult and requiring the use of a trenching shield or other type of support to prevent slumping of the trench walls. Nevertheless, areas of sandy alluvium are desirable as dam sites because the water table is easily found there. It may be necessary to control the level of the water table by pumping so that excavation down to the impermeable layer may proceed. Some materials that can be used in constructing the wall include the following:

- Layers of clay. The clay should be deposited in the trench in uniform, 10 cm thick layers, moistened, and compressed to about half that thickness (5 cm). This is usually done by hand using wooden blocks. Multiple layers are placed and compressed, until the clay layers reach the surface of the soil.

- Packed mud. The mud, called "ambor" by farmers in the western part of Rio Grande do Norte, is a mixture of mud and water, similar to that used in rural areas to build mud huts, which is deposited evenly in the trench up to the surface of the soil.

- Masonry. A double row of bricks, joined with a cement-and-sand mortar (1:4 ratio), is used to form a vertical wall. The space between the wall and the downstream slope of the cut should be filled. The upstream side of the wall should be plastered with cement-and-sand mortar (1:3 ratio) and sealant (sica) diluted with water (1:15 ratio). The bricks in this wall must be well-baked and salt-free to minimize the risk of dam failure or seepage.

- Stone. In very rocky areas, masonry bricks can be replaced with stones joined with cement-and-sand mortar (1:4 ratio). The stones should be properly set in the mortar, leaving no crevices where seepage could occur. It is recommended that the wall be plastered with cement-and-sand mortar (1:3 ratio) and sealant diluted with water (1:15 ratio). Because the stones are less regular than bricks, use of this material normally requires more skilled manpower to ensure the integrity of the structure.

- Plastic canvas. It is also possible to use an artificial fabric core in this technology. When doing so, however, it is recommended that a mud-and-water plaster be used on the downstream side of the trench to smooth the slope cut and to prevent sharp stones, roots, etc., from puncturing the fabric. At the bottom of the trench, on the upstream side, a small gutter (20 cm x 20 cm) should be dug in the impermeable layer, and a similar gutter dug in the soil surface at the top of the trench, on the downstream side. These gutters are used to secure and seal the ends of the plastic canvas, using the same mud mortar as in the plaster. Care should be taken, when laying the canvas, to avoid stretching it; to lay it in low wind and non-extreme temperature conditions, so as to minimize expansion and contraction effects; and to protect it from sharp surfaces. If the canvas is pierced, it should be patched with a piece of plastic and an adhesive appropriate for the material.

- Management of Underground Dams

Soil and water management in underground dams has been the subject of much discussion, primarily as it relates to the potential for salination. In order to avoid salinity problems, a discharge pipe should be placed at the bottom of the dam, on top of the impermeable layer. At the upstream end, this pipe passes through the wall parallel to the trench floor and to the thalweg of the water course. At the downstream end, the pipe connects to a vertical pipe, which functions as the abstraction point as well as an overflow/outlet. Water can be pumped or drained through the vertical pipe and discharged for use or onto the soil as waste. The pipe allows an annual drawdown of the dam as a means of removing dissolved salts.

**Figure 45 a: Cross-section of an Underground or Submersible Dam.**

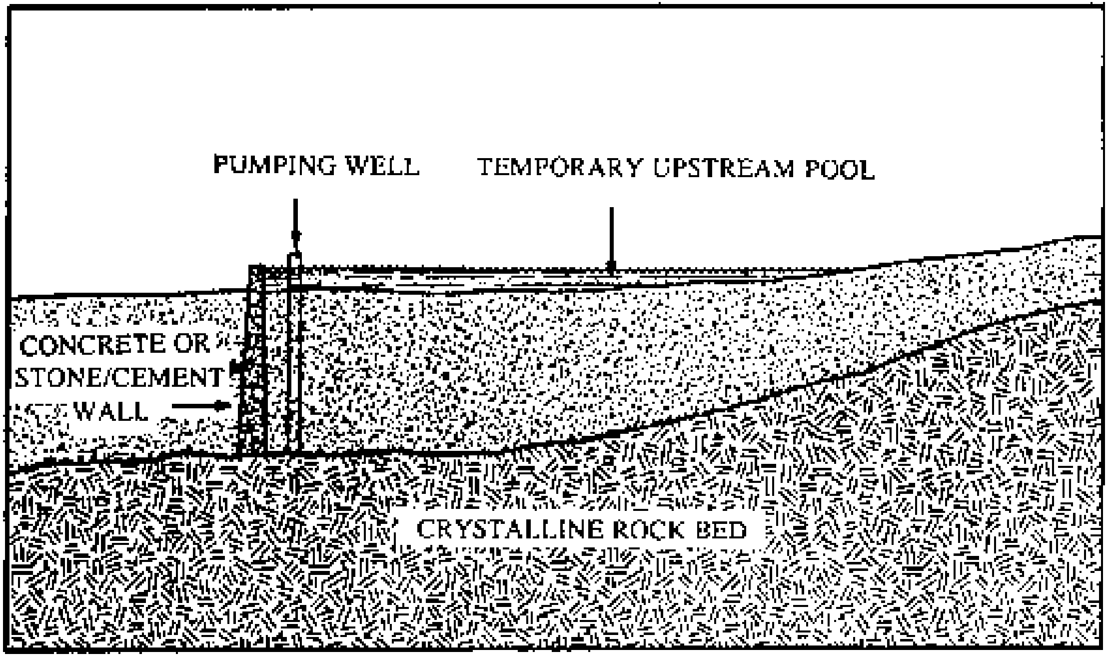
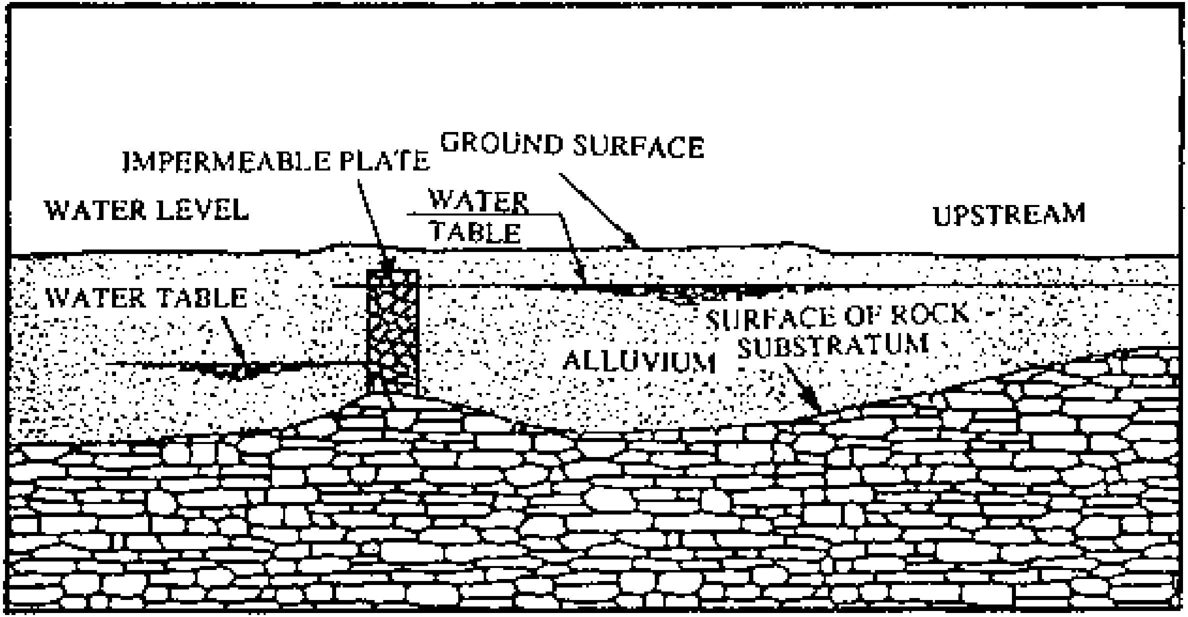



**Figure 45 b: Cross-section of a Submerged Dam.**




Source: J-P. dos Santos, and A. Frangipani, "Barragens Submersas - Uma Alternativa para o Nordeste Brasileira," in *Congreso Brasileiro de Geología de Engenharia,* vol. 2, "São Paulo," 1978, pp. 119-126 (Anais ABGE, 1).

## Extent of Use

Underground dams are an option for rural areas that lack more traditional sources of water for agricultural and other uses. They are widely used in the semi-arid region of Brazil, and may be used in other semi-arid regions where similar conditions occur.

## Operation and Maintenance

While an underground dam is a simple technology which does not require any particular level of training to operate or maintain, it does require some degree of care in siting and construction. Certain factors must be taken into account when building underground dams, including the average rainfall in the region, the average rates of flow of rivers/streams or drainage lines, the porosity and texture of the soil in the area, the salinity of the water, the aquifer storage capacity, and the depth of the impermeable layer.

Farmers in the western region of Brazil are generally satisfied with the operation of the underground dams. Problems that have arisen have generally done so in other areas of Brazil and primarily relate to aspects of dam construction. Some of the problems have had to do with water loss by seepage through the dam wall, which is likely to be caused by the dam wall's not extending to the impermeable layer. Other construction-related problems have to do with the drainage ditches that provide water to underground dam sites not located on natural watercourses. Where the ditches have not been adequately sized to cope with high flows, problems such as erosion and contamination of the artificial aquifer during the rainy season may result. Generally, these problems can be solved by rural extension technicians.

As with any technology, the users must be familiar with its operating principles to take full advantage of it.

## Level of Involvement

Underground dams are under construction throughout the semi-arid region of Brazil, with funding from state and municipal governments and from farmers.

## Costs

The costs involved in building underground dams vary depending on such factors as length of the wall, materials used, depth of the impermeable layer, and availability of manpower. An underground dam with a drainage area of 1.0 ha, built with a polyethylene plastic canvas wall, costs an average of $500.00. If 4mm PVC canvas is used for the wall instead, the dam will cost about $1 700.00.

## Effectiveness of the Technology

Although simple to build, underground dams must be constructed with considerable care if they are to work effectively. For example, the dam wall should extend all the way down to the impermeable layer to prevent seepage; when plastic canvas is used for the wall, every effort should be made to prevent punctures, and, should they occur, the canvas should be patched with a piece of the same plastic and an appropriate glue. The canvas should never be left uncovered and exposed to direct sunlight, as it easily dries out and may split. A drainage ditch should also be provided as a means of managing the salinity of the impounded water.

**Suitability**

Underground dams can be introduced throughout the semi-arid region. Given the agroecological and socioeconomic conditions that inhibit agricultural development in the area, this technology has the potential to take maximum advantage of the available water. Underground dams have been accepted throughout the semi-arid northeast region of Brazil because of their benefit to users. Their use is primarily by farmers, owing to the relatively high cost of building them.

## Advantages

- Underground dams are based on a simple technology, are inexpensive to build, and can make use of locally available materials and manpower.

- Once water has been stored in the alluvial soils, they have low evaporation rates compared to surface water reservoirs.

- They can be combined with other technologies, such as soil and water conservation techniques, and dug wells upstream.

## Disadvantages

- Because underground dams store water within the alluvial soil profile, their capacities are low compared with those of conventional dams.

- Given the socioeconomic circumstances of farmers in the semi-arid tropical region of Brazil, the cost of building these dams is a real obstacle to the widespread adoption of this technology.

## Further Development of the Technology

In order to make the technology more acceptable for farmers and other users, certain matters must be addressed, such as the development of alternative construction materials having a lower capital cost, the provision of training programs for farmers in the proper management of soil and water resources, and the introduction of selection criteria for appropriate crops to grow with water supplied from underground dams.

## Information Sources

## Contacts

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