Source Book of Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean

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UNEP - International Environmental Technology Centre
United Nations Environment Programme

This *Source Book* will also be issued as a volume in the IETC Technical Publication Series by UNEP International Environmental Technology Centre, Osaka/Shiga, Japan, 1997.

Unit of Sustainable Development and Environment
General Secretariat, Organization of American States
Washington, D.C., 1997

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Preface

The Latin American and Caribbean countries have seen growing pressure on water resources, with increasing demand and costs, for agricultural, domestic and industrial consumption. This has brought about the need to maximize and augment the use of existing or unexploited sources of freshwater. There are many modem and traditional alternative technologies for improving the utility and augmenting the supply of water being employed in various countries, but with limited application elsewhere due to the lack of information transfer among water resources managers and planners.

The *Source Book of Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean* was prepared by the Unit of Sustainable Development and Environment of the General Secretariat of the Organization of American States (OAS) as part of the joint United Nations Environment Programme (UNEP) Water Branch and International Environmental Technology Centre (IETC) initiative to provide water resource managers and planners, especially in developing countries and in countries with economies in transition, with information on the range of technologies that have been developed and used in the various countries throughout the world.

This information was gathered through surveys carried out on a regional basis - in Africa, Western Asia, East and Central Europe, Latin America and the Caribbean, and Small Island Developing States. The results, including this *Source Book*, will be compiled into a Global Source Book on Alternative Technologies for Freshwater Augmentation to be used throughout the countries of the world.

It is hoped that the technologies summarized here will be useful in the sustainable development of the countries of Latin America, the Caribbean and other regions.

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Latin America and the Caribbean - Map NO 3453 United Nations

List of acronyms

$	U.S. dollars
ASAE	American Society of Agricultural Engineers (U.S.)
ASCE	American Society of Civil Engineers (U.S.)
AWWA	American Water Works Association (U.S.)
CATHALAC	Centro del Agua del Trópico Húmedo para América Latina y el Caribe
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza (Costa Rica)
CEHI	Caribbean Environmental Health Institute (Saint Lucia)
CEPIA	Centro de Proyectos Integrales Andinos (Peru)
CESTA	Centro Salvadoreño de Tecnología Apropiada (El Salvador)
CIAS	Centro de Investigación Agropecuaria Salcedo (Peru)
CIDIAT	Inter-American Center for Development and Environmental and Territorial Research
CIP	Centro Internacional de la Papa
CMI	Caribbean Meteorological Institute
CONAF	Corporación Nacional Forestal (Chile)
CONICET	Consejo Nacional de Ciencia y Tecnología (Argentina)
CPATSA	Centro de Pesquisa Agropecuária do Trópico Semi-Árido (Brazil)
CREA	Centro de Reconversión del Azuay, Cañar y Morona Santiago (Ecuador)
CRL	Consumer Research Laboratory (U.K.)
DAEE	Departamento de Agua y Energia Elétrica (Brazil)
DGRH	Dirección General de Recursos Hídricos (Honduras)
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária (Brazil)
ESCAP	Economic and Social Commission for Asia and the Pacific (of the United Nations)
FAO	Food and Agriculture Organization (of the United Nations)
FUDECO	Fundación para el Desarrollo de la Región Centro Occidental (Venezuela)
GS/OAS	General Secretariat of the Organization of American States
IADIZA	Instituto Argentino de Investigación de las Zonas Aridas
IDA	International Desalination Association
IDB	Inter-American Development Bank
IDRC	International Development Research Centre (Canada)
IETC	International Environmental Technology Centre (of the United Nations Environment Programme)
IHH	Instituto de Hidráulica e Hidrología (Bolivia)

IICA	Instituto Interamericano de Cooperación para la Agricultura
IICT	Instituto de Investigaciones de Ciencias Técnicas (Argentina)
IIDSA	Instituto de Investigación para el Desarrollo Social del Altiplano (Peru)
INADE	Instituto Nacional de Desarrollo (Peru)
INCYTH	Instituto Nacional de Ciencia y Técnica Hídrica (Argentina)
INDRHI	Instituto Nacional de Recursos Hidráulicos (Dominican Republic)
INIAA	Instituto Nacional de Investigación Agropecuaria y Agroindustrial (Peru)
INRENA	Instituto Nacional de Recursos Naturales (Peru)
INSIVUMEH	Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología (Guatemala)
ISA	Instituto Superior de Agricultura (Dominican Republic)
IWRN	Inter-American Water Resources Network
MARNR	Ministerio del Ambiente y de los Recursos Naturales Renovables (Venezuela)
NAPHCC	National Association of Plumbing, Heating and Cooling Contractors (U.S.)
NGO	Non-governmental Organization
NRECA	National Rural Electric Cooperative Association (U.S.)
OMM	Organización Meteorológica Mundial
PAHO	Pan American Health Organization
PELT	Proyecto Especial Lago Titicaca (Peru/Bolivia)
PISA	Proyecto de Investigación de Sistemas Agropecuarios Andinos (Peru)
PIWA	Programa Interinstitucional de Waru Waru (Peru)
PROMAF	Programa Manejo de Agua a Nivel de Finca (Dominican Republic)
SNEP	Service National d'Eau Potable (Haiti)
UAEM	Universidad Autónoma del Estado de México (Mexico)
UFRN	Universidad Federal do Rio Grande do Norte (Brazil)
UMSA	Universidad Mayor de San Andrés (Bolivia)
UNA	Universidad Nacional del Altiplano (Peru)
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USAID	United States Agency for International Development
USDE/OAS	Unit of Sustainable Development and Environment, Organization of American States
USEPA	United States Environmental Protection Agency
VITA	Volunteers in Technical Assistance (U.S.)
WHO	World Health Organization
WMO	World Meteorologial Organization


LATIN AMERICA AND
THE CARIBBEAN
UNITED STATES OF AMERICA
MEXICO
GULF OF MEXICO
BAHAMAS
Turks & Caicos Is
CUBA
Cayman Is
DOMINICAN REP.
HAITI
Puerto Rico
U.S. Virgin Is.
British Virgin Is.
ANTIGUA AND BARBUDA
Montserrat
Guadeloupe
DOMINICA
Martinique
SAINT LUCIA
BARBADOS
SAINT VINCENT AND THE GRENADINES
GRENADA
TRINIDAD AND TOBAGO
SAINT KITTS AND NEVIS
JAMAICA
BELIZE
HONDURAS
GUATEMALA
EL SALVADOR
NICARAGUA
COSTA RICA
PANAMA
CARIBBEAN SEA
Netherlands Antilles
ATLANTIC OCEAN
VENEZUELA
GUYANA
SURINAME
Fr. Guiana
COLOMBIA
ECUADOR
PERU
BRAZIL
BOLIVIA
PACIFIC OCEAN
Galapagos Is.
Equator
Aruba
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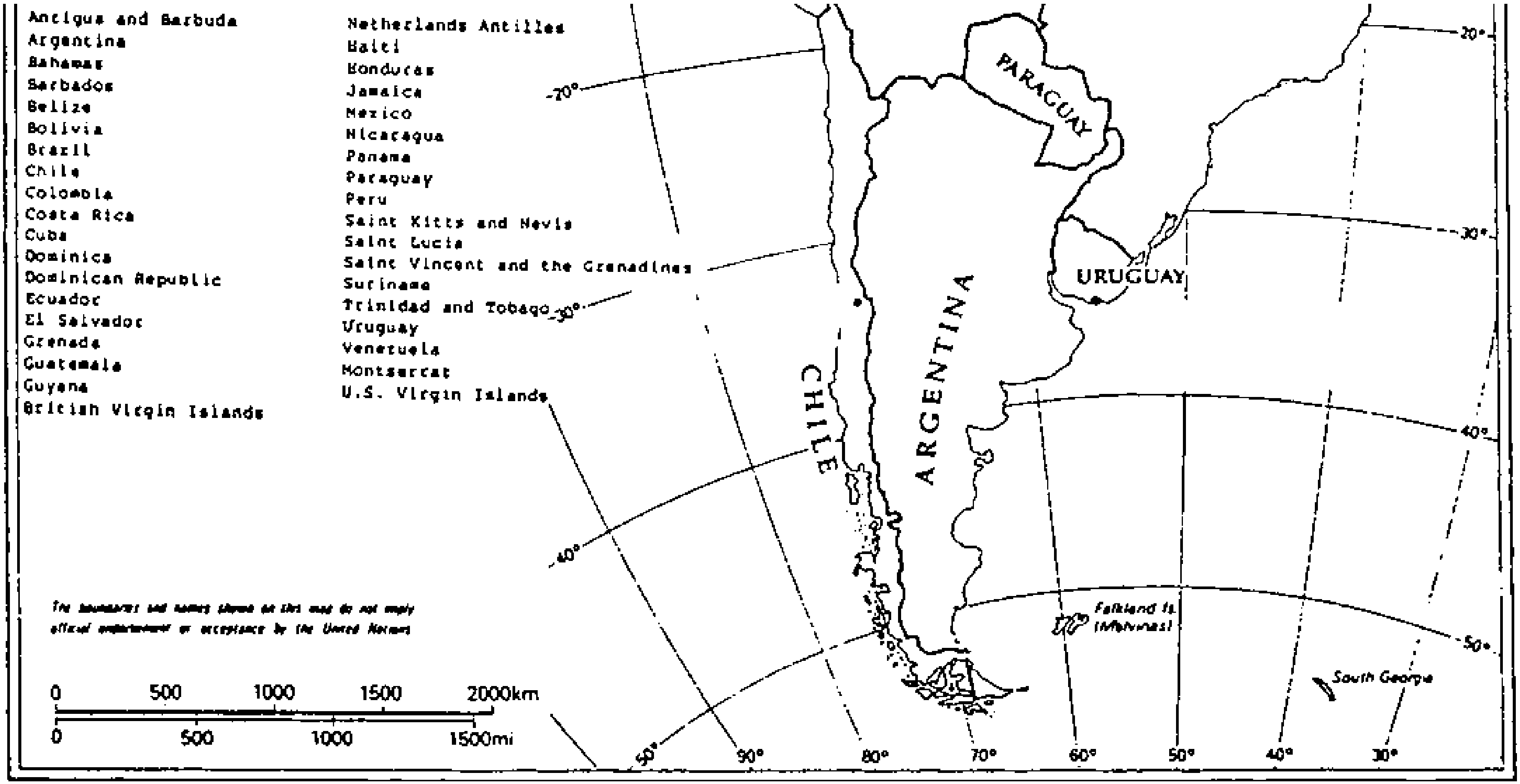
Antigua and Barbuda
Argentina
Bahamas
Barbados
Belize
Bolivia
Brazil
Chile
Colombia
Costa Rica
Cuba
Dominica
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Ecuador
El Salvador
Grenada
Guatemala
Guyana
British Virgin Islands
Netherlands Antilles
Haiti
Honduras
Jamaica
Mexico
Nicaragua
Panama
Paraguay
Peru
Saint Kitts and Nevis
Saint Lucia
Saint Vincent and the Grenadines
Suriname
Trinidad and Tobago
Uruguay
Venezuela
Montserrat
U.S. Virgin Islands
PARAGUAY
URUGUAY
ARGENTINA
CHILE
Falkland Is. (Malvinas)
South Georgia
The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations
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1. Background

Growing demands for water and the increasing costs of water supply are resulting in a need for countries to maximize the use of their existing water supplies and make use of hitherto unexploited freshwater resources. Numerous techniques, modem and traditional, for improving the use, and augmenting the availability, of water resources have been developed and implemented in different parts of the world. These include, among others, wastewater reuse and recycling, desalination, and rainwater harvesting. In many developing countries, the application of these technologies has been limited by lack of information on the approaches available and how well they work.

In Latin America and the Caribbean, even where rainfall is abundant, access to clean water has been restricted by the contamination of water resources, the lack of adequate storage facilities, and the absence of effective delivery systems. In the Caribbean, many small island states also face severe constraints in terms of both the quantity and the quality of freshwater due to their particular geographical, geological, topographic, and climatic conditions.

Chapter 18 of Agenda 21, the Action Programme of the United Nations Conference on Environment and Development (UNCED, held in Rio de Janeiro, Brazil, in 1992), deals with the utilization of appropriate technologies in water supply and sanitation. Improved access to information on environmentally sound technologies has been identified as a key factor in developing and transferring technologies to and among developing countries. Chapter 34 of Agenda 21 addresses this need by promoting the transfer of environmentally sound technologies, through improved cooperation and building capacity, among developing countries. The primary means of transferring environmentally sound technologies is through improved access to technical information that will enable developing countries to make informed choices that will lead to the adoption of technologies appropriate to their situations.

To provide the basis for such informed choices, the United Nations Environmental Programme (UNEP), in cooperation with the Unit of Sustainable Development and Environment (USDE) of the General Secretariat of the Organization of American States (OAS), undertook the Project on Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean. An agreement to execute the project was signed by the two organizations in May 1995. UNEP is represented in the project by the Water Branch, located in Nairobi, Kenya, and by the International Environmental Technology Centre (IETC), in Shiga, Japan.

To gather the information necessary to develop an inventory of available technologies, UNEP and the OAS sponsored two Workshops on Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean. The first, for Latin American countries, was held from September 19 to 22, 1995, in Lima, Peru, hosted by the Instituto Nacional de Recursos Naturales (INRENA). The second, for Caribbean countries, took place from October 24 to 27, 1995, in Christ Church, Barbados, hosted by the Caribbean Meteorological Institute (CMI). Both Workshops were supported by the Inter-American Program of the OAS Inter-American Center for Development, Environment, and Territorial Research (CIDIAT). The results form the contents of this *Source Book of Technologies for Freshwater*

Augmentation in *Latin America and the Caribbean.* The technologies listed in the present volume will be compiled by UNEP, together with those from other regions, to form a Global Source Book on Technologies for Freshwater Augmentation in Developing Countries.

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2. Objectives

The main objective of this project was to prepare a comprehensive inventory of technologies available in Latin America and the Caribbean for augmenting and maximizing the use of existing freshwater resources in order to assist water resource planners and managers, in both governmental and nongovernmental organizations and institutions, by providing them with information on different types of technologies. This objective is outlined in the UNEP 1994/95 workplan under the subprogrammes Environmental Management of Freshwater Resources, and Technology Transfer. These actions are undertaken in support of chapters 18 and 34 of Agenda 21 and are consistent with the Global Programme of Action on Small Island Developing States (the Barbados Declaration). The project encourages access to, and transfer of, environmentally sound technology as an essential requirement for sustainable development. Other objectives include meeting the need of planners in Latin America and the Caribbean to maximize and augment freshwater resources using technologies appropriate to the region; providing planners in Latin America and the Caribbean with accurate information on different technologies which can be used to augment and maximize freshwater resources; improving information exchange on appropriate technologies; and enhancing the capabilities of Latin America and the Caribbean countries to address problems of freshwater scarcity.

3. Organization of the source book

The *Source Book* has four sections. Part A presents the background to the project, its objectives, and the methodology used to prepare it, and also summarizes the results of the Workshops held in Barbados and Peru. Part B, Chapters 1 through 4, deals specifically with the alternative technologies identified in the two Workshops. These include technologies for freshwater augmentation, water quality improvement, wastewater treatment and water reuse, and water conservation. Because the specific technologies summarized in each of these groupings are frequently used in more than one application, the sectoral applications of each of the technologies are shown in tabular form in Part A below. Part C, Chapter 5, presents case studies of selected technologies which have been successfully utilized in the region. Part D presents various supplemental materials, including a list of participants at the Workshops and conversion factors, that may be useful to the reader.

For each of the technologies in Part B, a profile is presented. Each profile consists of the following elements:

Technical Description, describing the technology and indicating design considerations and labor and material requirements needed for its implementation.

Extent of Use, characterizing the extent to which the technology is applied in the region and giving examples of the types of areas in which it is used.

Operation and Maintenance, describing the skills required for the operation and maintenance of the technology.

Level of Involvement, describing the level of involvement by government, private-sector organizations, community organizations, and households needed to implement and maintain the technology.

Costs, indicating, where possible, the range of representative capital and annual operating and maintenance costs in absolute terms (expressed in United States dollars of 1995 as unit costs of output; e.g., \$ per m^3 of water).

Effectiveness, describing the ability of the technology to accomplish the objective (s) of the application, using quantitative measures if possible.

Suitability, describing the geographic areas where the technology is suitable for application.
Advantages, listing the technical and social advantages of the technology.

Disadvantages, listing the social and technical disadvantages impeding the use of the technology and, in particular, noting any environmental impacts associated with the implementation of the technology.

Cultural Acceptability, describing any cultural factors inhibiting or limiting the application of the technology.

Further Development of the Technology, describing any additional development needed for this technology to be applied in other areas.

Information Sources, listing the information sources used to prepare the profile, including the name, title, organizational affiliation, address, telephone/fax number (s), and E-mail address of the experts, managers, and consultants who can provide information, and a selected bibliography.

Part C presents selected case studies. The purpose of the case studies is to highlight technologies that have been successfully adopted. The case study also provides insight into the cultural, social, and economic factors that facilitated the implementation of the technology.

Finally, Part D contains an acknowledgment of the national and international agencies and organizations that contributed to the preparation of this *Source Book*, the list of participants in the two Workshops and their contributions, and a table of conversion factors between metric and English units.

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4. How to use the source book

This Source Book is a reference document. It is intended to present a comprehensive overview of the alternative technologies for freshwater augmentation, water quality improvement, wastewater treatment and reuse, and water conservation most commonly used in Latin America and the Caribbean. The technologies focus on the use of freshwater for human and animal consumption, agriculture, and industrial use, especially in arid and semi-arid areas.

For additional information on specific technologies, resource people and relevant books and publications are included in the bibliography at the end of each section. The resource people listed work with the various technologies and have expressed a willingness to cooperate in their dissemination and implementation, hi addition, farther details about the technologies may be obtained from the Unit of Sustainable Development and Environment of the Organization of American States, 1889 F Street, N.W., 3rd. Floor, Washington, D.C. 20006, U.S.A., telephone +1 (202) 458-3556, fax +1 (202) 458-3560, E-mail: regional_development@oas.org.

5. Survey methodology

The methodology used to prepare the *Source Book* included the following steps:

- Identification of the institutions dealing with alternative technologies for augmenting or maximizing freshwater resources in Latin America and the Caribbean to participate in the Workshops.

- Identification of national experts at these institutions to catalogue, through field surveys, the technologies used in each country of the region.

- Completion of an intensive survey of the literature on technologies used in the region to augment freshwater resources.

- Identification of an international consultant to compile the *Source Book.*

- Preparation of the draft table of contents and submission by the consultant for comment to the UNEP Water Branch in Nairobi and the UNEP Regional Office for Latin America and the Caribbean in Mexico City, Mexico.

- Discussion of the reports to be presented at the Workshops by the national consultants.

- Preparation and implementation of the two Workshops with the participation of national consultants and specialists from international and regional organizations. The main objectives of the Workshops were (1) to identify alternative technologies utilized in the region for freshwater augmentation, and to present technology profiles and case studies; (2) to analyze the technologies presented and to select technologies and case studies which should be included in the Source Book; and (3) to analyze the proposed contents of the Source Book including the table of contents.

- Compilation of the results of the literature, field surveys, and the Workshops into a draft.

- Submission of the draft to the UNEP Integrated Water Programme for comment.

- Revision and publication.

- Evaluation of the project with the UNEP Integrated Water Programme and the International Environmental Technology Center, formulation of follow-up activities, and promotion of the use of appropriate technologies for augmenting freshwater resources in the region through specific workshops and demonstration projects.

The final reports of the Workshops held in Peru (in Spanish) and Barbados (in English) were prepared by the Unit of Sustainable Development and Environment of the General Secretariat of the Organization of American States. The results of the literature survey are lodged with the Unit of Sustainable

Development and Environment of the OAS at its offices in Washington, D.C., U.S.A.

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6. Summary of the findings

Besides being listed in tabular form below, the findings are presented as one-page summaries on pages 9-32 and as detailed descriptions and case studies in Parts B and C.

- In the table, the technologies are presented by technological group (freshwater augmentation, water quality improvement, wastewater treatment and reuse, and water conservation), showing the specific technologies used; the sector (s) in which they are employed (agriculture: irrigation and/or livestock, domestic water supply, and industry and/or mining); and the countries in which they are applied.

- The one-page summaries give the attributes of each technology within the technological group, including a description of the technology, the extent of its use, the state of its development, and its operational characteristics (cost, effectiveness, suitability for use in various climatic settings, cultural acceptability, advantages and disadvantages, and need for governmental involvement).

- In Part B each technology is described in detail, with information on its use and application on the regional level, while in Part C selected technologies are described in detail at the country level.

Thus, it is possible for the user to obtain a comprehensive overview of the technologies presented by reference to the tabular summary, and a detailed understanding of a particular technology by reference to Parts B and C. Technologies of particular interest can be extracted for use in developing freshwater resource management plans by reference to the one-page summaries. Use of these summaries will allow several promising technologies to be examined "side by side".

7. Recommendations

The participants of the Workshops on Alternative Technologies for Freshwater Augmentation in Latin America (Lima, 19-22 September 1995) and the Caribbean (Barbados, 24-27 October 1995), considering that:

- Several of the alternative technologies presented in the meetings have proved to be successful in different countries and could be widely shared through national, regional, and international technical programs and projects.

- The greatest problems facing countries wishing to implement alternative technologies to augment freshwater resources in Latin American and the Caribbean include:

  - the difficulty of sharing information about successful technologies;

  - the lack of awareness about the existence and importance of these technologies at several decision-making and public participation levels;

  - existing economic limitations;

  - the lack of interinstitutional, multi-disciplinary, and intersectoral coordination;

  - the absence of adequate legislation; and

  - the failure to properly assess the impact of introduced alternative technologies on existing situations,

Subscribed to the following recommendations:

- To establish national, regional, and international programs for the diffusion of alternative technologies. The *Source Book of Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean* proposed by UNEP through the International Environmental Technology Centre (IETC) and the Integrated Water Program, and coordinated by the General Secretariat of the Organization of American States (GS/OAS), can be the first step in disseminating such information. The Inter-American Water Resources Network (IWRN), whose Technical Secretariat is housed in the Unit of Sustainable Development and Environment (USDE) of the GS/OAS, will be an important means of information dissemination.

- To promote the participation of the affected communities involved in the process of planning, designing, implementing and maintaining alternative technologies to augment water resources.

- To establish mechanisms which will allow governmental, nongovernmental, and academic organizations, research groups, regional and international organizations, industries and private enterprises to coordinate efforts geared toward implementation of successful alternative technologies within each country.

• To use programs of international cooperation, such as the Program of Horizontal Cooperation of the GS/OAS, to promote the exchange of specialists and technicians among the different countries, and to share, identify, or transfer the most successful technologies for freshwater augmentation.

ALTERNATIVE TECHNOLOGIES USED IN LATIN AMERICA AND THE CARIBBEAN

Technological Group	**Technology**	**Sector of Use**			**Countries of Use (as presented at the Workshops)**
		Agriculture: Irrigation and/or Livestock	**Domestic Water Supply**	**Industrial and/or Mining**	
FRESHWATER AUGMENTATION	*Rainwater harvesting*				
	• roof catchments	x	x		Argentina, Barbados, Brazil, British Virgin Islands, Costa Rica, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Montserrat, Netherlands Antilles, Paraguay, Saint Lucia, Suriname, Turks and Caicos, US Virgin Islands.
	• *in situ*	x			Argentina, Brazil, Paraguay.
	Fog harvesting	x	x	x	Chile, Ecuador, Mexico, Peru.
	Runoff collection				

• paved and unpaved roads	x			Argentina, Brazil, Venezuela.
• surface structures	x	x	x	Argentina, Aruba, Brazil, Chile, Costa Rica, Dominican Republic, Ecuador, Panama, Saint Lucia, Suriname, Venezuela.
• underground structures	x			Brazil.
Flood diversion	x			Argentina, Brazil, Venezuela.
Water conveyance				
• marine vessels		x		Antigua, Bahamas, Barbuda.
• pipelines, rural aqueducts, water tankers	x	x	x	Costa Rica, Dominican Republic, Ecuador, Jamaica, Panama, Saint Lucia.
Artificial recharge of aquifers				

	• infiltration barriers and canals, water traps, cutoff waters, surface runoff drainage wells, septic tanks, effluent disposal wells, and diversion of excess flow from irrigation canals into sinkholes.	x	x		Argentina, Brazil, Paraguay, Barbados, Jamaica, Netherlands Antilles.
	Groundwater pumping using non-conventional energy sources				
	• hydraulic pumps, hydraulic ram, rope pumps, hand pumps, windmill driven pumps, and photovoltaic pumps.	x	x		Argentina, Bolivia, El Salvador, Haiti, Honduras, Panama, Peru.
WATER QUALITY IMPROVEMENT	*Desalination*				
	• reverse osmosis	x	x	x	Antigua and Barbuda, Argentina, Bahamas, Brazil, British Virgin Islands, Chile, Turks and Caicos, U.S. Virgin Islands.
	• distillation		x	x	Antigua and Barbuda, Aruba, Chile, Netherlands Antilles, U.S. Virgin Islands.
	Clarification				

	• plants and plant material		x		Bolivia, El Salvador, Guatemala, Peru.
	Disinfection				
	• boiling		x		Dominican Republic, Ecuador.
	• chlorination		x		Guatemala, Montserrat.
	Filtration				
	• residential filters, slow sand filters, rapid sand filters, dual and multimedia filters		x		Dominican Republic, Ecuador, El Salvador, Guatemala, Mexico.
WASTEWATER TREATMENT & REUSE	*Wastewater Treatment*				
	• *oxidation ponds, stabilization lagoons, septic tanks, anaerobic filtration, sludge layer systems, hydroponic cultivation/root zone treatment, activated sludge in vertical reactors*	x			Aruba, Brazil, Colombia, Dominican Republic, Mexico, Netherlands Antilles.
	Wastewater Reuse	x		x	Argentina, Barbados, Brazil, Guatemala, Jamaica.
WATER CONSERVATION	*Water Conservation*				
	• raised beds and *waru-waru* cultivation	x			Peru

	• small scale clay pot and porous capsule irrigation systems	x			Argentina, Bolivia, Ecuador, Panama, Dominican Republic.
	• automatic surge flow and gravitational tank irrigation systems	x			Mexico.
	• dual water distribution systems		x		Saint Lucia, U.S. Virgin Islands, Turks and Caicos Islands.
	• other	x	x	x	Brazil, Chile, Jamaica, Venezuela.

Name of Technology: Rainwater Harvesting from Rooftop Catchments	**1.1**
Sector: Domestic water supply; some agriculture	**Technology Type:** Freshwater Augmentation

Technical Description: There are three components to a rainwater harvesting system: the collection area, the conveyance system, and the storage facility. The collection area is usually the individual rooftop of a house or other building. Large communal catchments including hillsides and airport runways may also be used. The conveyance system is a series of gutters that carry the rainwater from the collection area to the cistern. The cistern or storage facility varies from steel drums and polyethylene tanks of various sizes to underground concrete tanks. It could be a part of the home or constructed separately, above ground or subterranean. The amount of water that can be collected depends upon the effective area of the collection surface, the volume of storage, and the amount of rainfall.

Extent of Use: This technology is widely used in Latin America and the Caribbean, mainly for domestic purposes. In some Caribbean islands, such as the U.S. Virgin Islands, use of rainwater harvesting systems has been mandated by the government and the specifications for the systems are overseen by the national agency.

Operation and Maintenance: Operation requires little attention. Maintenance includes periodic cleaning, preferably with a chlorine solution; repair of occasional cracks in the cistern; regular cleaning of the gutters; and inspection to ensure that the system is free of organic matter.	**Level of Involvement:** Government participation varies in the different countries of Latin America and the Caribbean. In areas where the government regulates the design and use of the system, participation is high; elsewhere, participation is generally low. As long as the system remains inexpensive, community participation will increase.
Costs: Costs vary depending on the location storage facilities location and type of materials used. Costs can range from as low as $2 to $5/1 0001 collected. Generally, this is considered to be a very cost-effective technology.	**Effectiveness of Technology:** Rainwater harvesting is widely used, generally inexpensive, and very effective, especially in the Caribbean, where cisterns provide the principal source of water for many homes, and has been an excellent source of emergency water.
Suitability: Most suitable in arid and semi-arid regions with no public water supply. Suitability decreases as other sources of water supply become available.	**Cultural Acceptability:** Rainwater harvesting is widely acceptable.
Advantages: » Rooptop systems are easy and, in general, inexpensive to construct, owner operated and managed. » They are an essential back-up water supply in times of emergency. » They often lead to better building foundations when cisterns are included in substructure. » Rainwater quality may be higher than that of other water sources. » Rainwater provides an excellent freshwater supply where surface and groundwaters are unavailable, scarce, or contaminated.	**Disadvantages:** » Rainfall is not a dependable water supply source during droughts. » Rainwater may be contaminated by animals and organic matter. » The cost of constructing a home with a cistern is higher. » Standing water in the cistern may provide potential breeding sites for mosquitoes; contaminated systems may create some health risks. » In some cases, initial costs are higher. » Public utility revenues may be slightly reduced.

Further Development of Technology: There is a need for better quality control of rainwater harvesting systems, for promoting rainwater harvesting as an alternative and supplement to utility water, for assistance in building large-capacity storage tanks, and for developing proper regulatory guidelines for cisterns.

Information Sources: Final Report of the Workshop on Alternative Technologies for Freshwater Augmentation in the Caribbean (Barbados, 24-27 October 1995), and Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Peru, 19-22 September 1995), OAS/UNEP.

Name of Technology: Rainwater Harvesting *in situ*	**1.2**
Sector: Agriculture and livestock	**Technology Type:** Freshwater Augmentation

Technical Description: This technology consists of using topographic depressions, either natural or artificial, to store rainwater where it falls for future use. Construction of furrows and raised beds is a normal practice in this technology.	
Extent of Use: This technology is used extensively in northeastern Brazil, in the Chaco region of Paraguay, and in Argentina, primarily for livestock watering and agricultural purposes.	
Operation and Maintenance: Once the area is properly prepared, little maintenance is required. Maintenance includes keeping the area free of debris and unwanted vegetation.	**Level of Involvement:** Government agencies and agricultural organizations are involved.
Costs: Principal costs are in preparing the site. Costs range between $ 180 and $2 000 in Brazil; and up to $4 500 in Paraguay.	**Effectiveness of Technology:** Rainwater harvesting increases water supplies for irrigation and livestock watering. In some cases, it has been used effectively for domestic supply.
Suitability: In arid and semi-arid regions of low topographic relief for cultivation and livestock watering.	Cultural Acceptability: This technology has been practiced for many years by the agricultural communities of Brazil, Paraguay, and Argentina, and should be accepted in other countries with similar topographic and climatic conditions.
Advantages: » *In situ* harvesting requires little additional labor. » Systems can be constructed prior to or after planting. » *In situ* harvesting makes better use of rainwater for irrigation. » Retaining water on-site provides flexibility in soil utilization. » It also provides artificial recharge for aquifers.	**Disadvantages:** » *In situ* harvesting cannot be implemented where the slope of the land is greater than 5%. » It is difficult to implement on rocky soils. » The area needs to be cleared and earthworks created. » The technology works best in highly impermeable soils with natural topographic relief. » Evaporation will decrease the effectiveness of water storage in low areas.
Further Development of Technology: There is a need for improvements in the equipment used for soil preparation and the development of new soil conservation practices.	
Information Sources: Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September 1995), OAS/UNEP.	

Name of Technology: Fog Harvesting	**1.3**
Sector: Domestic water supply; agriculture	**Technology Type:** Freshwater Augmentation and livestock; industrial

Technical Description: The water in fog can be harvested through simple systems known as fog collectors. Factors to be considered when establishing a system include the fog water content, the frequency of fog in the geographic area under consideration, and the overall design of the system. Fog collectors are made of fine nylon net strung between poles in areas known to have frequent fogs. The nets face into the wind. These systems can be made up of individual panels, each with a surface area of up to 48 m^2, or they can be composed of a group of joined panels. Water droplets in the fog condense on the net and, when enough have gathered, coalesce and run off into a conveyance system which carries the water to a cistern or other storage area.

Extent of Use: This technology is primarily utilized in mountainous coastal regions with high levels of fog and recurring winds, such as those found in Chile, Peru, Ecuador, and Mexico. It also has been utilized in arid countries (such as the Middle East) around the world.

Operation and Maintenance: Maintenance includes tightening the nets, cables and cable fasteners periodically, cleaning or replacing the nets as wear occurs, and ensuring that the conveyance system and cisterns are free from contamination by cleaning periodically with chlorine and calcium chloride.	**Level of Involvement:** Community participation is recommended at all levels so that the shared maintenance costs are kept low and the users feel a sense of responsibility for the system. Government subsidies may be necessary, particularly in the early stages.
Costs: Costs vary from region to region. Often, the most expensive item is the conveyance system connecting the collection nets to the storage area. Installation costs average about $90 per m^2 of mesh, but may vary with the efficiency of the system, the pipeline length, and the size of the storage tank. Production costs in Chile are around $3/1 000 l.	**Effectiveness of Technology:** Fog harvesting is one of the most effective water augmentation technologies for arid and mountainous areas (30% of the water contained in fog can be harvested). Its use, however, is limited by the length of the fog season and the capacity of storage tanks.
Suitability: In coastal, arid, mountainous regions where fog is common and other sources of water supply are not available.	**Cultural Acceptability:** This is a relatively new, largely experimental technology. Acceptability may be limited until its effectiveness has been demonstrated.
Advantages: » Fog harvesters are easy to install and, in general, less expensive than most other sources of potable water. » They can create viable communities in inhospitable areas. » Water quality is better than existing water sources used for agricultural and domestic purposes.	**Disadvantages:** » A pilot project must first be undertaken to evaluate the feasibility of fog harvesting in any given region » A back-up system is recommended in case fog conditions change. » High costs may result from pipeline lengths required.

Further Development of Technology: The distribution system should be made more cost-effective; the design of the collectors needs to be improved and made more durable; and the community should receive basic information about this technology before it is implemented in order to utilize it effectively.
Information Sources: Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September 1995), OAS/UNEP.

Name of Technology: Runoff Collection from Paved and Unpaved Roads	**1.4**
Sector: Agriculture Technology	**Type:** Freshwater Augmentation
Technical Description: Runoff from paved and unpaved roads can be collected in drainage ditches or street gutters, and stored temporarily. This water may then be transported through conduits and underground galleries to cultivation areas where it is used. In some cases, the water may be kept in swales and used for forestation projects along roadways. In some situations, the roadways themselves may be used as dikes for water diversion.	
Extent of Use: This technology of runoff capture and storage has been used in semi-arid areas of Brazil, Argentina, and Venezuela, primarily for agricultural purposes.	
Operation and Maintenance: Ditches and swales must be cleared of debris. Control of insects in standing water may be required.	**Level of Involvement:** Government participation is expected when the collected water is used for forestation. Private participation is common in the agricultural sector.
Costs: A forestation project in Argentina using water from 1 km of paved roadway cost $2 000. Costs are generally low and justifiable in terms of water supply benefits.	**Effectiveness of Technology:** Using water from this source, carob trees grew by an average of 30 cm/yr, while pepper trees grew by an average of 35 cm/yr, during the period between 1985 and 1995 in a plantation in Mendoza, Argentina.
Suitability: In arid and semi-arid regions where the runoff from the roadways is normally lost from the system.	**Cultural Acceptability:** Use of road runoff is well accepted by public works agencies in arid and semi-arid regions.

Advantages:	Disadvantages:
» Runoff collectors are easy to operate and maintain. » Runoff collection may enhance the growth of native flora. » It enhances the ability to cultivate lands in arid and semi-arid areas. » Collectors have a low cost, especially if installed at the time the roadways are constructed. » They may reduce erosion and sedimentation problems if properly designed and operated.	» Runoff-based systems may require irrigation of plants during the dry season and drought periods (i.e., a secondary water source). » Irrigated areas and water storage areas need to be fenced to control animal grazing. » The technology requires appropriate soil conditions to be implemented. » Water collected from roadways may be contaminated by litter and debris deposited on road surfaces, and by chemical pollutants deposited by vehicular traffic, especially in urbanized areas.

Further Development of Technology: This technology should be combined with other runoff collection and storage technologies, such as *in situ* and regional impoundments, in order to be most effective.

Information Sources: Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September 1995), OAS/UNEP.

Name of Technology: Runoff Collection using Surface and Underground Structures	**1.5**
Sector: Agriculture and livestock; domestic water	**Technology Type:** Freshwater Augmentation supply, industry and mining

Technical Description: There are two types of structures commonly used: local impoundments and dams. Local impoundments are storage ponds dug into the ground, while dams are designed to increase the storage capacity of areas of a river or stream by intercepting runoff and storing it for future use. Three types of dams are generally used: earth dams, rockfill dams, and concrete arch dams. Their use is typically dictated by the subsurface geology, available materials, and length of storage required. Local impoundments, in contrast, are often dug into the soil in naturally impervious areas, or lined with clay or other material so as to be made impermeable. The shape of the structures is usually rectangular or round. A filter or chlorinator unit should be added if the water in the impoundment is used for domestic supply. Construction site criteria for both types of structures are similar.

Extent of Use: Runoff collection has been used throughout Latin America and the Caribbean. Argentina, Brazil, Costa Rica, Ecuador, Panama, and Venezuela have built dams and impoundments to increase water supplies for domestic use and irrigation. Aruba and Suriname have also been involved in the development of similar projects.

Operation and Maintenance: Collection areas should be impermeable to avoid loss of water. Periodic testing of soil permeability is advisable. Control of sedimentation is necessary. Proper maintenance of instrumentation and the distribution system is required; operation and maintenance of the system by trained personnel is desirable.	**Level of Involvement:** Government participation is essential in the site selection, design, and construction of large projects; small projects may be built privately, but should be subject to government inspection and regulation. Large private organizations involved in hydroelectric power production or agricultural production may be substituted for governmental involvement in the construction and operation of these structures.
Costs: Costs vary depending on the size and type of the structure. In Ecuador, costs range between \$0.10 and \$2/m^3 of water stored; in Argentina, costs range between \$0.60 and \$1.20/m^3 of water stored. In Brazil, a 3 000 m^3 project cost \$2 000.	**Effectiveness of Technology:** The effectiveness of this technology is measured by the degree to which the technology meets demands for water through the additional storage provided: in Argentina, an increase in irrigation efficiency of between 5% and 15% was observed; in Brazil, a 90% increase in industrial water demand was met; and in Suriname, the availability of water increased tenfold while the saltwater wedge of the Suriname River moved 30 km downstream.
Suitability: In areas where the temporal and spatial distribution of rainfall is highly variable, and additional storage is required to meet demand.	**Cultural Acceptability:** This is a widely accepted technology, given preferential use, where applicable, by engineers and local communities.
Advantages: » Runoff collection allows agricultural production in arid and semi-arid areas. » Structures may provide a source of water for hydroelectric power production. » The technology may promote and enhance the native flora and fauna of an area. » Pollutants are generally diluted. » Perennial flows may reduce salt water intrusion in coastal areas. » Impoundments provide recreational opportunities.	**Disadvantages:** » Dam construction requires the availability of land to be inundated, and suitable topography. » Surface structures are subject to high evaporative losses. » Structures require impermeable soils. » Structures have high construction costs. » There is a risk of flooding adjacent lands during wet periods. » Dams may have significant environmental impacts both upstream and downstream, including alteration of flooding regimes, scour and sediment deposition patterns, and micro-climatic conditions. » There is a risk of flooding due to dam failure.

Further Development of Technology: Research has improved the efficiency of dam and reservoir construction and operation techniques. Further improvements to reduce the costs of construction, especially of small schemes, and increase the efficiency distribution systems are required. Methods to reduce evaporative losses are needed.

Information Sources: Final Report of the Workshop on Alternative Technologies for Freshwater Augmentation in the Caribbean (Barbados, 24-27 October 1995), and Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September 1995), OAS/UNEP.

Name of Technology: Flood Diversion	**1.6**
Sector: Agriculture and livestock	**Technology Type:** Freshwater Augmentation
Technical Description: Flood diversion structures are used to divert flood waters for water supply augmentation. Transverse dikes, small-scale diversion structures *(toroba)*, and water traps are commonly used. Both transverse dikes and water traps are built of clay or other impermeable materials across portions of streams or rivers. The *toroba* built of wooden poles, vegetation residue and logs, are used to divert stormwater runoff.	
Extent of Use: Transverse dikes have been used in São Paulo State, Brazil; water traps have been used in the Province of Mendoza, Argentina; and *toroba* have been developed and used in the state of Falcón, Venezuela.	
Operation and Maintenance: Diversion structures are generally simple to operate. Maintenance is required to repair diversion structures, especially after heavy rainfalls. Extremely large flood events may require replacement of the structures. Mitigation of erosion is necessary, especially in the vicinity of wing walls.	**Level of Involvement:** Small-scale structures can be constructed by local communities with technical support from government or large private enterprises. Dikes and water traps require government and private-sector involvement.
Costs: The cost of dikes varies from about $10 000 to several millions, depending on the scale of the project. Water traps for small projects in Argentina have an estimated cost of $130 to $170. The *toroba*, being constructed of natural materials, have a negligible cost.	**Effectiveness of Technology:** In addition to providing water supply as needed, this technology has been successful in reducing erosion and increasing groundwater recharge.
Suitability: In large river basins where sufficient volumes of water can be diverted.	**Cultural Acceptability:** This is a widely accepted technology for water supply augmentation and erosion control: among engineers. Its acceptance among local communities is variable.

Advantages:	Disadvantages:
» Diversion to storage makes use of flood waters. » Structures provide a basis for sedimentation and erosion control when properly operated. » Structures may serve as a source of groundwater recharge. » Structures reduce water velocities in streams. » This technology may contribute to biodiversity protection and ecosystem restoration. » The retention of soils may improve soil fertility.	» This technology is disruptive to vegetation cover during construction. » Structures may fail or be damaged when subjected to conditions that exceed design storm conditions. » Structures may have adverse environmental impacts on aquatic flora and fauna.

Further Development of Technology: Additional data collection is needed to improve structure performance. Educational programs to encourage the use of this technology as a river basin management tool should be implemented.

Information Sources: Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September 1995), OAS/UNEP.

Name of Technology: Water Conveyance by Marine Vessels	**1.7**
Sector: Domestic water supply	**Technology Type:** Freshwater Augmentation

Technical Description: Water transport by marine vessels is used when water must be moved between islands or across the sea. Barges are a very efficient means of transportation, but storage tanks must be (1) properly sized so that shipping costs are effective, and (2) properly designed to prevent surges during transportation. The barges are usually pulled by tugs. Once the destination is reached, the storage tanks are emptied and water is either pumped directly into the distribution system or distributed to consumers on tanker trucks.

Extent of Use: This technology is suitable for all regions as long as there is adequate space along the shoreline for the barge to unload and onshore for the facilities needed to store and distribute the water to consumers. Barging of freshwater using marine vessels has been used to augment supplies in Antigua, the Bahamas, and other Caribbean islands.

Operation and Maintenance: The biggest factors influencing this system are inclement weather and mechanical failure. Each of these causes the loss of several working days a year in a typical barge operation. Also, machinery often needs to be replaced, which leads many owners to carry duplicate parts in the event of a breakdown. Generally, skilled personnel are not required, apart from the barge pilot.	**Level of Involvement:** The costs involved in this technology are so high that only public utilities, government agencies, or companies that have a high number of consumers, such as resorts or industries, can afford to use it.
Costs: Costs of water conveyance by marine vessels are high compared to other systems. However, if large quantities are shipped on a regular basis, costs decline. Also, creating the distribution infrastructure can be quite expensive if some component is not already in place. Estimated costs of shipping water to the Bahamas are $5.80/1 000 gal. shipped (including fuel).	**Effectiveness of Technology:** Due to its high cost, shipping freshwater has had mixed results. Some countries have had less expensive and better results with desalination while other countries have found it less costly to build the necessary infrastructure to supply all their domestic water needs by transported water.
Suitability: On small islands where marine vessels are readily available and water is scarce.	**Cultural Acceptability:** Not widely acceptable, in view of the high costs, compared with other technologies.
Advantages: » This technology has a short start-up time (3-6 months). » It does not require highly skilled personnel. » It is not as expensive as desalination plants.	**Disadvantages:** » Weather has a big impact on efficiency. » The cost of transportation is high, often prohibitively so. » Product quality is not guaranteed. » This technology needs an adequate distribution infrastructure.

Further Development of Technology: Infrastructure must be developed for distribution. However, it is difficult to justify this cost when most countries rarely use this technology.

Information Sources: Final Report of the Workshop on Alternative Technologies for Freshwater Augmentation in the Caribbean (Barbados, 24-27 October 1995), OAS/UNEP.

Name of Technology: Water Conveyance by Pipelines, Rural Aqueducts, and Water Tankers	**1.8**
Sector: Domestic water supply; agriculture; industry and mining	**Technology Type:** Freshwater Augmentation

Technical Description: Conveyance of water by pipelines involves the transfer of water from ground and surface water sources in an area where the available resources exceed demand to an area where demand exceeds available resources. The system of conveyance may be gravity-flow or pumped.

Extent of Use: Water conveyance in pipelines, rural aqueducts, and tanker trucks is found throughout Latin America and the Caribbean. Water tankers are utilized primarily in areas served by aqueducts. Interbasin transfer schemes using pipelines have been used in Jamaica and Panama to supply water to rural areas.	
Operation and Maintenance: Maintenance of aqueducts requires some technical skills and periodic repairs and cleaning of the system.	**Level of Involvement:** Water distribution projects have a high level of government participation. Planning and design of these systems usually involves private consultants. Community participation may be required in the operation and maintenance of the systems.
Costs: Costs vary depending on the complexity of, and materials used to construct, the system.	**Effectiveness of Technology:** The technology is very effective in Jamaica and Panama, where 30% to 40% of the water used in one basin is transferred from an adjacent basin.
Suitability: In regions where there is an "excess" of water in one area and a "deficit" in another; this situation is common in many countries.	**Cultural Acceptability:** It is a well-accepted technology in areas with insufficient water supply.
Advantages: » Water tankers are less complex than other systems. » Pipelines and rural aqueducts allow for large shipments of water, can improve irrigation, and can transform previously underdeveloped areas into potential areas for agroindustrial enterprise development.	**Disadvantages:** » Prices of water from water tankers are high. » Water tankers require adequate road infrastructure. » Pipelines involve high capital costs, and require skilled workers. » Interbasin transfer could cause environmental impacts.
Further Development of Technology: Development of improved, low-cost pipe materials would increase the use of this technology. Better quality control and training of local users is necessary.	
Information Sources: Final Report of the Workshop on Alternative Technologies for Freshwater Augmentation in the Caribbean (Barbados, 24-27 October, 1995), and Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September 1995), OAS/UNEP.	

Name of Technology: Artificial Recharge of Aquifers	**1.9**
Sector: Domestic water supply; agriculture	**Technology Type:** Freshwater Augmentation

Technical Description: There are several different artificial recharge techniques used in Latin America and the Caribbean: infiltration basins and canals; water traps; cutwaters; surface runoff drainage wells; septic tank system effluent disposal wells; and the diversion of excess flows from irrigation canals into sinkholes. Infiltration canals utilize high circulation velocities to eliminate waste buildup, resulting in higher infiltration rates. Water traps are designed for use under conditions of infrequent rainfall and are used to increase productivity *in-situ*. Cutwaters are excavations built on top of permeable strata in areas without rivers or creeks. Drainage wells divert runoff for storage purposes. Soak-aways utilize wastewater discharged from septic tanks. Sinkhole injection of excess flows diverts water flow into a reception basin, where the water is treated and recharged.

Extent of Use: The different variations of this technology have been widely used throughout Latin America and the Caribbean. Use will most likely increase as water demands increase and surface water resources become less available.

Operation and Maintenance: Most of the techniques require minimal maintenance. However, sinkhole injection systems can require extensive cleaning and repairs.

Level of Involvement: There is extensive participation by both governments and the private sector in the implementation of this technology. Generally, the government provides financing and technical expertise, while the private sector is responsible for the initial development and maintenance of the technology once it is in place.

Costs: The reported costs of infiltration basins is $0.20/m^3, while water traps in Argentina have been reported to cost between $ 13 3 and $ 167 per trap. The initial capital cost of a cutwater has been estimated at $6 300 for a 5 700 m^3 cutwater; maintenance costs for cutwaters tend to decline with time. The initial capital cost of a sinkhole-based application in Jamaica was approximately $15 000, with maintenance costs estimated at $6 000.

Effectiveness of Technology: All of the technologies have been successfully utilized over the years in different regions. Some have been particularly successful in arid regions. The low cost and low maintenance requirements make this an attractive option. In addition, the salinity in aquifers is often reduced, thereby leading to a wider range of uses for the water.

Suitability: Some variations are better suited to specific climatic zones: water traps are successful in arid regions; cutwaters, because they are primarily used in conjunction with rainwater, are successful in more humid areas; and the utilization of sinkholes as injection points is most successful in karst areas.

Cultural Acceptability: There are no cultural limitations on the use of these technologies. They are a well-accepted practices.

Advantages:	**Disadvantages:**
» The techniques are easy to master and easy to operate. » Additional materials to extend or augment these systems are relatively cheap. » The technology can improve aquifer water quality, even reducing salinity. » It is advantageous in arid regions, where surface water resources are scarce. » It has a low cost and requires low maintenance.	» Wells are often not maintained. » There may be high nitrate levels in the groundwater, especially in agricultural areas. » Aquifers may be degraded if the quality of injected water is poor. » Sustained use of water from aquifers may not be economically feasible unless they can be recharged. » Use of water from aquifers may deplete the water table and destroy local soils and vegetation.

Further Development of Technology: The system design should be improved to eliminate the possibility of contamination and increase recharge efficiency; there should be greater knowledge of sedimentation processes.

Information Sources: Final Report of the Workshop on Alternative Technologies for Freshwater Augmentation in the Caribbean (Barbados, 24-27 October 1995), and Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September 1995), OAS/UNEP.

Name of Technology: Groundwater Pumping Using Non-Conventional Energy Sources	**1.10**
Sector: Domestic water supply; agriculture	**Technology Type:** Freshwater Augmentation

Technical Description: A variety of water pumps use non-conventional energy sources. These include hydraulic pumps, windmill-driven pumps, and photovoltaic pumps. The hydraulic pump uses the hydrologic energy from streams. Hydraulic rams work by altering water pressures to elevate water to a higher level. The rope pump is attached to a pipe axis, which rotates by turning a handle. Handpumps are widely utilized and can be placed above or below ground and operate in much the same way as the rope pump. Windmill-driven pumps use wind power to turn a rotor, which, in turn, moves the pump pistons. Photovoltaic pumps utilize solar radiation to power the electric pump motors.

Extent of Use: Non-conventional energy sources are used throughout both Latin America and the Caribbean to pump water. The technique used varies according to local topographical and geological conditions. The hydraulic pump is primarily limited to high volume rivers, while the hydraulic ram, rope pump, and windmill pump can be easily adapted to most conditions. In contrast, the photovoltaic pump needs an area with consistent and high irradience. Honduras, with its varying terrain and high levels of sunlight, provides ideal conditions for the use of photovoltaic pumps.

Operation and Maintenance: The operation of most of these pumping systems does not require highly skilled personnel or a high level of maintenance. However, most of the systems require frequent oiling and protection of exposed metal surfaces, as well as valve cleaning. Photovoltaic systems may require new parts and frequent checks.	**Level of Involvement:** Central governments have had little involvement in supporting non-conventional pumping technologies. The primary participants are local communities and NGO's, which have provided the necessary technical and financial support.
Costs: The capital cost of the hydraulic ram pump increases in proportion to the size of the pump. The average initial cost of a windmill pump is from $800 to $1 000, while the photovoltaic pump requires an initial investment of $6 000 to $ 12 000. Given the high costs and lack of government funding for some of these techniques, the extent of utilization is restricted in many areas.	**Effectiveness of Technology:** The yield of the rope pump depends on the user's physical condition. The windmill pump's efficiency is in direct proportion to the speed of the wind (higher wind speeds yield higher output).
Suitability: In areas where conventional energy sources such as fossil fuels are scarce, expensive, or unavailable.	**Cultural Acceptability:** Widely accepted in most rural areas.
Advantages: » These pumps have low installation and maintenance costs. » They have a negligible environmental impact. » Rope pumps do not require skilled labor and have low contamination levels. » Windmill-driven pumps are easy to install and can withstand inclement weather. » Photovoltaic pumps are easy to install, reliable, long-lasting, and adaptable, having low maintenance and a readily available energy source.	**Disadvantages:** » Hydraulic pumps may suffer damage due to their proximity to river beds and currents. » Hydraulic rams are limited to small irrigation areas. » Rope pumps cannot lift water higher than the surface of the well. » Windmill-driven pumps cannot easily extract water from depths greater than 20 m. » Replacement parts for photovoltaic systems are usually imported, making repairs difficult and costly. » Initial and maintenance costs of photovoltaic pumps are high.

Further Development of Technology: People should be trained in the use and maintenance of these pumps; the design of the connections should be improved; quality control mechanisms should be developed; and corrosion resistance of exposed parts needs to be enhanced.

Information Sources: Final Report of the Workshop on Alternative Technologies for Freshwater Augmentation in the Caribbean (Barbados, 24-27 October, 1995), and Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September 1995), OAS/UNEP.

Name of Technology: Desalination by Reverse Osmosis	**2.1**

Sector: Domestic water supply; industry and mining; agriculture	**Technology Type:** Water Quality Improvement
Technical Description: Desalination reduces the salt content of saline water to minimal levels, generally less than 1 000 mg/l. Suitable saltwater sources are seawater and brackish water. Reverse osmosis forces saline water through a semi-permeable membrane, which removes salt ions from the water. A concentrated salt solution remains on one side of the membrane while pure water collects on the other side. Energy is required to create the pressure needed to force saline water through the membrane. There are two by-products of desalination using reverse osmosis: brine and pure water. Brine may be discharged into aquifers or diluted with effluent and sprayed over golf courses or other public areas. Pure water can be used for domestic, agricultural, or industrial purposes.	
Extent of Use: Desalination plants exist in many Caribbean countries and in many rural areas of South America. On many Caribbean islands, desalinated water has become the main source of drinking water. However, the expansion of this technology remains limited due to the high energy costs involved.	
Operation and Maintenance: Day-to-day monitoring by trained personnel is required. The most important maintenance required includes repair and adjustment of pumps; cleaning and replacement of membranes and filters; calibration of instruments; replenishment of the necessary chemicals; and acquisition and maintenance of an inventory of parts for the system.	**Level of Involvement:** Due to the high costs involved, only public water supply companies with large numbers of consumers, and industries, have undertaken desalination. In most cases, government involvement includes paying for land, taxes, and providing assistance in plant operations.
Costs: Costs depend on the location, plant size, and type of water being desalinated (seawater being the most expensive). Other major costs, apart from the high initial capital investment, include energy, replacement parts, and skilled labor to operate the plants. In the Bahamas production cost ($\$/m^3$) ranges between 4.60 and 5.10. In rural areas of Brazil, 0.12 to 0.37.	**Effectiveness of Technology:** Over time, reverse osmosis systems have become more efficient, and improvements in desalination technology have reduced costs. The technology is being increasingly used by the industrial sector. Current reverse osmosis membranes can separate 98% of the salt from water with a dissolved solids level of 25 000-30 000 mg/l, using pressures of 13.6 to 19.0 atm. These membranes are guaranteed to work for five years before requiring replacement.
Suitability: In coastal areas and on small islands where other conventional methods are not practicable.	**Cultural Acceptability:** This is an expensive technology, generally acceptable in situations where economic necessity dictates its use.

Advantages:	Disadvantages:
» A reverse osmosis plant is a simple, prepackaged system that can be easily installed. » Operation and maintenance costs are low when the system is properly utilized. » The water source is "unlimited". » Inorganic contaminants can be easily removed. » Plant size can easily be expanded. » The system has a negligible environmental impact if brine is properly disposed of.	» The membrane may fail if not maintained properly. » Inclement weather may interrupt the desalination process. » Reverse osmosis requires a high level of material, equipment, and spare part support which may not be locally available. » Brine must be disposed of. » Reverse osmosis plants require a dependable energy source. » This technology is expensive when compared to other technologies.

Further Development of Technology: This technology can be improved by developing higher quality membranes, capable of operating at lower pressures and less susceptible to clogging than the present, high pressure systems; by making the systems easier to operate; and by employing combination technologies such as the reliable and low-cost centrifugal reverse osmosis system developed in Canada.

Information Sources: Final Report of the Workshop on Alternative Technologies for Freshwater Augmentation in the Caribbean (Barbados, 24-27 October 1995), and Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September 1995), OAS/UNEP.

Name of Technology: Desalination by Distillation	**2.2**
Sector: Domestic water supply; industry and mining; agriculture	**Technology Type:** Water Quality Improvement

Technical Description: Distillation separates freshwater from saline water by heating it until water vapor is produced. The water vapor is then condensed to produce freshwater. In distillation plants, boiling occurs at lower temperatures than "normal" by manipulating pressures and recycling heat through the interchange of condensation heat and vaporization heat. There are three major types of distillation processes: multiple-stage flash processes (MSF), multieffect distillation processes (MED), and vapor compression processes (VP).

Extent of Use: Distillation plants are used in the Caribbean, particularly in the U.S. Virgin Islands and Curaçao, and in some Latin American countries mainly to provide potable water to local communities and for industrial purposes.

Operation and Maintenance: This technology requires skilled personnel and high levels of maintenance. Maintenance includes repair of cracks in the system; removal of biological growth in the system; cleaning and inspection of the vacuum system, pumps, and motors; and the addition of anti-corrosive chemicals to the water to avoid corrosion and equipment breakdown.	**Level of Involvement:** Participation in this technology has been limited to use in the private sector by some foreign firms. As a consequence, most of the water processed by distillation is used industrially. Costs are still too high for more general use by government utilities. However, it is expected that this technology could spread rapidly if costs are lowered.
Costs: Costs vary depending on the type of distillation process used, plant capacity, salinity level, and the skill level of local personnel. Costs usually increase when plant size increases. Current distillation costs reportedly range between $1.47/m^3 in Chile and $4.31/m^3 in The Netherlands Antilles.	**Effectiveness of Technology:** The multi-stage flash process (MSF) is generally considered to be more effective than distillation by reverse osmosis. Although desalination is fairly expensive compared to other methods of obtaining freshwater, it is very efficient when properly maintained, producing water of high quality.
Suitability: This technique is used in the Middle East, North Africa, and the Caribbean. However, plant operation and implementation is limited by the lack of fuel, chemicals, spare parts, and trained personnel.	**Cultural Acceptability:** This technology is generally viewed as highly technical and expensive. It is acceptable for small projects of limited scope located near the coast.
Advantages: » Distillation plants can be fully automated and, except for brine disposal, have a minimal environmental impact. » When they are operated properly, maintenance costs are low. » Low temperature distillation reduces energy requirements and production costs. » High quality water can be produced.	**Disadvantages:** » Some techniques require large energy inputs, regardless of plant size. » Brine disposal may be a problem. » Distillation requires a high level of technical skill and training. » Distillation requires the use of chemicals and other materials which must be handled carefully.

Further Development of Technology: Future development includes reduced costs and improvement of system efficiency; reduction in required operating temperatures; ensuring a high level of thermal efficiency; and reduction of overall energy costs.

Information Sources: Final Report of the Workshop on Alternative Technologies for Freshwater Augmentation in the Caribbean (Barbados, 24-27 October 1995), OAS/UNEP.

Name of Technology: Clarification using Plants and Plant Material	**2.3**
Sector: Domestic water supply	**Technology Type: Water Quality Improvement**

Technical Description: Two applications of native plants are used to improve water quality. Bean, peach, or coconut seeds are used to prepare solutions that act as coagulant or clarifying agents. The second application involves the use of aquatic plants such as cattails, totora, water hyacinths, and duckweeds in wetland ecosystems to purify water and treat wastes. Aquatic plants can absorb many chemical compounds and remove suspended solids. For this system, 1 m^2 of plants is required for each m^3/day of water treated. Factors to be considered when designing the system include the volume and flow rate of water to be treated, the initial concentrations of chemicals in the water, the desired water quality of the effluent to be discharged, and any subsequent use of the treated water.

Extent of Use: The use of native plant materials for water treatment is prevalent throughout Central and South America for treatment of river water for domestic use. Aquatic plants are a low-cost, low-energy system that is particularly well suited to hot climates. A number of water-hyacinth-based systems are being used in Mexico to remove chemical contaminants from water, and totora is used in both Bolivia and Peru to treat wastewater from small communities. Wetland systems may have potential for treating wastewater from larger communities. Wetlands may also be of use as a means of pretreating surface waters prior to use for domestic supply.

Operation and Maintenance: Operation and maintenance are simple and there are few requirements. The totora treatment system may require infrequent harvesting plants or dredging the sediments; the water-hyacinth-based system requires regular removal of excess plants and the addition of a low levels of chlorine to disinfect the effluent. In wetlands, mosquito breeding should be avoided. This is easy to do if personnel are aware of mosquito habitats.

Level of Involvement: This technology is utilized primarily by the private sector in rural areas, and by universities and governments for research and development purposes. Some governments have dedicated financial and technical resources to the development of aquatic plant systems for wastewater treatment.

Costs: There is little information on the seed treatment systems. The main cost involves acquiring the seeds. The costs for implementation, operation, and management of the totora system range from insignificant in Bolivia to $65 000 per system in Peru. The cost of wetland treatment systems rises in proportion to the amount of wastewater treated.

Effectiveness of Technology: Seed treatment has proved particularly effective in the clarification of turbid waters. In general, the higher the initial turbidity, the higher the rate of removal. With aquatic plants, heavy metals can be removed very quickly, while the absorption of other elements may require a longer retention time.

Suitability: In areas with concentrations of plants having coagulant properties and/or areas where wetlands exist or can be established.

Cultural Acceptability: There are no cultural barriers to the use of this technology.

Advantages:	Disadvantages:
» This technology has a very low cost, and is easy to implement and use. » It is easy to construct and generally requires a small surface area, depending on the volume of water or wastewater to be treated. » Plants can absorb heavy metals. » Wetland systems can produce fertilizer (mulch), economically important plant materials, and animal food supplements.	» Plant seeds may not be readily available. » Totora systems may require high initial investments. » Aquatic systems need appropriate climatic conditions, sometimes requiring construction of a greenhouse. » Metals or toxic substances may accumulate in the plants and require proper disposal. » Water hyacinth may grow too quickly, clogging waterways or creating stagnant water which fosters mosquito breeding.

Further Development of Technology: Research should be conducted to identify similar qualities in other species of plants, and to improve the efficiency of the plants after several cleanings. The appropriate density of aquatic plants for treating certain types of waters should be determined.

Information Sources: Final Report of the Workshop on Alternative Technologies for Freshwater Augmentation in the Caribbean (Barbados, 24-27 October 1995), and Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September 1995), OAS/UNEP.

Name of Technology: Disinfection by Boiling and Chlorination	**2.4**
Sector: Domestic water supply	**Technology Type:** Water Quality Improvement

Technical Description: Disinfection of water for domestic purposes can be accomplished by boiling or chlorination. Boiling kills most of the pathogenic organisms that cause waterborne diseases. Chlorination of water may be accomplished by several methods. In gas chlorination, a chlorinator meters the gas flows and mixes it with water. The mixture is injected into wastewater to disinfect it. A floating chlorinator has also been developed which administers doses of hypochlorite tablets. However, the safety of the resulting water has been questioned. As a result, gas chlorinators are more common. Hypochlorination uses a chemical metering pump to inject chlorine solutions of different strengths into wastewater. The dosing rate is constant and the hypochlorinator can operate under pressures as great as 100 psi.

Extent of Use: Boiling is applicable at the household level, and it is considered a short-term or emergency method. As for chlorination, this method is practiced throughout the world. Because chlorine is available at low cost, easy to use, and easy to procure, it is the most common system of disinfection in the Caribbean. Usually, it is recommended that chlorine be manufactured locally. This may constitute a limitation on its use, especially when using seawater, since seawater contains heavy metal ions which interfere with the stability of the chlorine solutions produced.

Operation and Maintenance: Periodic cleaning and replacement of flasks, adjustment of dosage levels and checking the residual chlorine levels, periodic replacement of chemicals, and clearing of the tubing of all sludge and crusts are required.	**Level of Involvement:** Boiling is used at the individual level only. Small chlorination systems are managed by the private sector, while medium-sized systems or larger usually involve a public utility company. Large systems sometimes require government involvement.
Costs: Boiling costs depend on the cost of the energy used. Chlorination systems vary depending on the location and the type of system used: gas chlorination systems are usually more expensive than hypochlorination systems. Generally, costs increase in proportion to the amount of water treated.	**Effectiveness of Technology:** Boiling is recommended only as secondary technology. Chlorination efficiency depends on the initial quality of water being chlorinated and the chlorination method used. Gas chlorination is more efficient. However, hypochlorination is preferred by users since it is easier to use.
Suitability: Boiling is most suitable in rural areas where more sophisticated treatment methods are not available, and/or in case of emergency. Chlorination is considered universally suitable.	**Cultural Acceptability:** A widely accepted technology, recognized especially as a means of preventing the spread of waterborne diseases.
Advantages: » Boiling is a simple and effective means of disinfecting small amounts of water for personal consumption. » Chlorination systems are easy to construct, reliable, and affordable. » Floating chlorinators may be adapted for small communities. » Dosages and amounts of residual chlorine can be controlled in gas chlorinators.	**Disadvantages:** » Boiling requires considerable energy. » Chlorine gas is corrosive and potentially fatal in large quantities. » Chlorination may form potentially carcinogenic chlorinated hydrocarbons. » Chlorine oxidizes ammonia and other metals, and can cause explosions if not properly handled. » Hydrochlorinated compounds can cause fires when they come in contact with organic materials.

Further Development of Technology: Chlorination technologies can be improved through improved handling and distribution methods, utilization of other compounds not as reactive as chlorine, and development of more cost-effective processes.

Information Sources: Final Report of the Workshop on Alternative Technologies for Freshwater Augmentation in the Caribbean (Barbados, 24-27 October 1995), and Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September 1995), OAS/UNEP.

Name of Technology: Filtration	**2.5**
Sector: Domestic water supply use	**Technology Type:** Water Quality Improvement

Technical Description: Filtration systems are used to purify water for domestic consumption. There are several types of filters in use throughout Latin America and the Caribbean, including residential filtration systems, slow and rapid sand filtration systems, quarry filters, and vertical-flow filtration systems. Residential filters for household use are made with local materials, and partially remove contaminants. Slow sand filters are boxes with a layer of sand which can process between 2.5 and 6.0 m^3/m^2/day. Rapid sand filters can process 50 times as much water as slow sand filters.

Extent of Use: Filters are widely used throughout Latin America and the Caribbean in areas where poor quality water can cause waterborne diseases if not treated. The types of filtration systems used depend on local conditions. Most areas use a combination of filter types.

Operation and Maintenance: Most filters have low maintenance requirements, and only need periodic changing or cleaning of the filtering medium. Rapid sand filtration plants are more complicated and require constant monitoring by trained personnel who must backwash the filters for optimal performance.	**Level of Involvement:** The technology is often introduced by governments or NGOs. Implementation involves the entire community. In many countries, the private sector has also become involved in implementation.
Costs: Costs of residential filters vary according to size. Slow sand filters and rapid sand filters generally decrease in construction and maintenance costs as filter size increases to serve larger populations. Construction costs of sand filters average between $7 (rapid sand filters) and $22 (slow sand filters) per capita of population served for populations of 500 to 2 499; and between $3 (rapid sand filters) and $7 (slow sand filters) per capita of population served for populations greater than 50 000.	**Effectiveness of Technology:** Filters vary in efficiency in decreasing the level of contamination in the water. Residential filters may pass some contaminants after treatment, whereas quarry filters can remove up to 90% of the bacteria. Sand filters have generally proved most effective at slower filtration rates, with up to 99% of the bacteria being removed. In vertical-flow pre-filters, turbidity and color reductions are in the ranges of 23% to 45% and 34% to 56%, respectively.
Suitability: In most regions, but primarily in urban and rural areas where water quality is poor.	**Cultural Acceptability:** This technology is well accepted as an effective method of treatment at the household and municipal levels.
Advantages: » Filters have a low construction cost, and are easy to install and operate. » In general, there is little or no chemical use or power source required. » Skilled personnel are not usually required. » Filters adequately meet local household needs. » They have minimal environmental impacts. » Large quantities of washwater are not needed.	**Disadvantages:** » Filtering media may not be available locally. » Some filtration methods require skilled personnel. » Some filtration methods require pre-treatment. » Sand filters must be washed; a backwash facility is needed and some sand may need to be stored before it can be washed. » There may be a lack of quality control in rural areas. » Filtration is not effective for highly contaminated water, or water contaminated with dissolved substances.

Further Development of Technology: A more efficient filtration medium needs to be researched and developed; educational programs should also be implemented in rural areas to encourage the use of disinfectants with filtration systems.

Information Sources: Final Report of the Workshop on Alternative Technologies for Freshwater Augmentation in the Caribbean (Barbados, 24-27 October 1995), and Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September 1995), OAS/UNEP.

Name of Technology: Wastewater Treatment Technologies	**3.1**
Sector: Agriculture; landscape irrigation; industry, and mining	**Technology Type:** Wastewater Treatment and Reuse

Technical Description: Wastewater treatment technologies can be categorized into three main groups: mechanical, aquatic, and terrestrial. Mechanical treatment systems require mechanical devices to perform the treatment function and include technologies such as oxidation, extended aeration, sequencing batch reaction, and trickling filtration. Aquatic treatment systems use lagoons or wetlands as the fundamental treatment unit and include technologies such as facultative lagoons, aerated lagoons, and hydrograph-controlled holding ponds, and may occur in combination with sand filtration systems, constructed wetlands, and aquaculture systems. Terrestrial systems involve the use of large parcels of land to treat wastewater by infiltration and include technologies such as slow-rate infiltration, rapid infiltration, overland flow, and subsurface infiltration systems. Other methods commonly used include activated sludge, biological vertical reactors, and septic tank systems. Most of these systems are aerobic, although some, such as septic tanks and anaerobic filtration systems, are anaerobic. Facultative lagoons and some activated sludge systems are both aerobic and anaerobic, the former being aerobic at the surface and anaerobic at the bottom, and the latter alternating aerobic and anaerobic sludge tanks.

Extent of Use: These technologies have been extensively used in most Latin American and Caribbean countries. Argentina, Bolivia, Brazil, Colombia, Curaçao, Chile, Jamaica, Mexico, and Saint Lucia have used different types of terrestrial and aquatic treatment systems, usually combined with wastewater reuse technologies. Chile, Colombia and Barbados have activated sludge plants, while Brazil has used biological vertical reactors.

Operation and Maintenance: Most of the systems require careful operation and some degree of maintenance, including preventive maintenance. Periodic cleaning, removal of algae and oily materials, and disposal of dried sludges are necessary in most systems. Wetland systems require periodic removal of plants and sediments. If hydroponic cultivation is practiced, use in combination with a dual water use technology is recommended.	**Level of Involvement:** Government involvement is essential in the implementation of most of these technologies. The private sector, particularly the tourism industry, has used treatment plants in conjunction with water reuse technologies. Selection and construction of appropriate technologies is usually initiated by government, with operation and maintenance being undertaken by the private sector.
Costs: Capital costs of these systems vary depending on the degree of mechanical complexity. Treatment plant costs range between $3 and $1 l/gal/day of wastewater treated. Lagoon system costs range from $1 to $5/gal/day. Terrestrial system costs range from $4 to $8/gal/day.	**Effectiveness of Technology:** Aerobic technologies effectively remove 90% to 95% of the biological oxygen demand (BOD) and suspended solids. Anaerobic technologies remove between 25% and 60% of the BOD and suspended solids. Wetland systems and hydroponic cultivation systems remove between 65% and 75% of the organic matter.
Suitability: Mechanical treatment systems are suitable in urban areas and for regional use in areas where space is a constraint. Aquatic and terrestrial systems are suitable in areas where space is available.	**Cultural Acceptability:** Most Latin American countries do not recognize the need to treat wastewaters for the protection of their natural and water resources.
Advantages: Mechanical treatment systems have: » High treatment efficiencies. » Minimal land requirements. » A wide range of applicability in communities of various sizes. Aquatic treatment systems have: » Low capital costs. » Low operation and maintenance costs. Terrestrial treatment systems have: » The potential to provide groundwater recharge. » Low operation and maintenance costs. » A requirement for a low level of technically trained human resources. » An ability to be incorporated into water reuse schemes.	**Disadvantages:** Mechanical treatment systems have: » High capital costs. » A need for sludge disposal. » A need for qualified human resources for optimal operation and maintenance. » High energy requirements. Aquatic treatment systems have: » A requirement for a large land area. » Undesirable odors under certain conditions. » A need for some mechanical devices, depending on the topography of the treatment plant site. » A need for further development prior to large-scale application. Terrestrial treatment systems have: » A requirement for a large land area with permeable soils.

	» A requirement for the establishment of a suitable, water-tolerant vegetative cover to extract nutrients and retain soils on site. » High initial costs. » Relatively low efficiencies of treatment.

Further Development of Technology: New advances in wastewater treatment technologies are under way to improve efficiencies and reduce costs. Their application in situations requiring complex treatment in developing countries requires further analysis.

Information Sources: Final Report of the Workshop on Alternative Technologies for Freshwater Augmentation in the Caribbean (Barbados, 24-27 October 1995); Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September 1995), OAS/UNEP; Ernesto Perez, Technology Transfer Chief, USEPA, Atlanta, Georgia, U.S.A.

Name of Technology: Wastewater Reuse Systems	**3.2**
Sector: Agriculture; landscape irrigation; industry and mining	**Technology Type:** Wastewater Treatment and Reuse

Technical Description: Wastewater reuse technologies produce an effluent suitable for irrigation or industrial purposes. Secondary treatment is the minimum requirement for the reuse of wastewaters for irrigation of food crops that are to be processed, and for irrigation of lawns and golf courses. Caution is required to avoid contamination of potable water wells. Additional filtration and chlorination/disinfection is required if wastewaters are used for irrigation of pastures and unprocessed food crops. A distribution system is usually required to convey the treated wastewaters from the Wastewater treatment facility to the areas of reuse. Cross-contamination between distribution systems conveying potable water and treated wastewater should be avoided.

Extent of Use: This technology is commonly used by resort hotels in the Caribbean islands to irrigate golf courses. Treated wastewaters have been used in Chile for agricultural irrigation, and in Brazil as cooling waters for mining operations.

Operation and Maintenance: Operation and maintenance is minimal and primarily related to the distribution system and the wastewater treatment facilities. Clogging of pipes can be a problem; cleaning of pumps and filters is more frequent when using wastewater as a raw supply.	**Level of Involvement:** Primarily used in the private sector; encouragement of wastewater reuse by the government is necessary. Government is involved in the setting of guidelines for water reuse and monitoring its performance, primarily to avoid public health impacts.

Costs: Cost savings may be expected from the use of this technology, although cost estimates have not been reported. Expenses are related to operation of the treatment facilities and the need for a dual distribution system.	**Effectiveness of Technology:** The effectiveness of this technology is in the improvement of water quality in natural watercourses where wastewater was previously discharged. In Jamaica, significant reductions in BOD, nutrient concentrations, and faecal coliform levels occurred when wastewater reuse was implemented at a resort hotel.
Suitability: For applications such as watering of golf courses and lawns, cooling of industrial and mining equipment, and irrigation of non-edible crops.	**Cultural Acceptability:** A large percentage of domestic water users are afraid of using reclaimed wastewater, primarily for health reasons. Time, public information, and successful experimental applications will be needed before this technology is widely implemented.
Advantages: » Demand for potable water drawn from raw water sources is reduced. » Smaller treatment facilities are required. » Environmental impacts associated with wastewater discharges are reduced. » Water pollution of freshwaters and coastal waters is reduced. » Capital costs are relatively low. » Operation and maintenance requirements are simple. » Reuse facilitates frequent watering of lawns, golf courses, and non-edible crops in water-scarce areas.	**Disadvantages:** » Reuse can result in groundwater contamination. » Human contact with irrigated effluents can cause skin irritations and other public health problems. » Reuse requires installation of a second distribution system, which increases capital and operation and maintenance costs. » It is inefficient during the wet season. » Gases produced during extended wastewater treatment operations can cause chronic health problems if not controlled.
Further Development of Technology: Expansion of experimental facilities to full-scale implementation is required. Dual distribution systems should be incorporated into new developments to make use of reclaimed wastewater.	
Information Sources: Final Report of the Workshop on Alternative Technologies for Freshwater Augmentation in the Caribbean (Barbados, 24-27 October 1995), and Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September 1995), OAS/UNEP.	

Name of Technology: Raised Planting Beds and *Waru-Waru* Cultivation	**4.1**
Sector: Agriculture	**Technology Type:** Water Conservation

Technical Description: This technology is a combination of the rehabilitation of marginal soils, drainage improvement, increased water storage, more efficient use of radiant energy, and attenuation of the effects of frosts. The technology consists of a system of embankments and channels. The embankments serve as raised beds for cultivation, while the channels are used for water storage. Water uptake in the raised beds is by diffusion and capillary movement of water from the channels. There are three types of raised beds, the use of which is determined by the source of the water: rain-driven systems, fluvial systems, and phreatic systems. Design considerations include the depth of the water table, soil characteristics, and climatic conditions.	
Extent of Use: This technology has been used in the Lake Titcaca drainage basin in Peru and Bolivia for irrigation of potatoes and quinoa.	
Operation and Maintenance: Periodic reconstruction of the embankments is needed to repair eroded areas. Cultivation in raised beds of different heights can mitigate erosion of soils during torrential downpours. Animals should be excluded from cultivated areas. Use of fungicides and insecticides may be required.	**Level of Involvement:** This technology has been promoted, with technical assistance provided, by governmental agencies in Peru. NGOs have also assisted in implementing this technology in Bolivia. Farmers are responsible for the operation and maintenance of these systems.
Costs: The cost of establishing this technology for the cultivation of potatoes in Peru was $14.60/ha cultivated. Once established, the technology operates well for a period of three years, after which it should be reconstructed or extensively overhauled.	**Effectiveness of Technology:** Preliminary results suggest an increase in crop production. Effectiveness is affected by climatic conditions.
Suitability: In areas with extreme climatic variation, ranging from droughts to floods, mountainous areas, and arid regions.	**Cultural Acceptability:** This is an ancient and traditional technology, well accepted in the countries where it is used.
Advantages: » This technology mitigates the effects of extreme climatic variability. » It has a low cost. » It increases production of selected crops.	**Disadvantages:** » The technology has a relatively short lifespan before reconstruction is required. » Appropriate soil texture and composition are required. » It requires maintenance and period repair.
Further Development of Technology: Despite its ancient heritage, this technology is experimental. Application in other regions with different climatic and soil conditions should be evaluated.	
Information Sources: Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September 1995), OAS/UNEP.	

Name of Technology: Small-Scale Clay Pot and Porous Capsule Irrigation	**4.2**

Sector: Agriculture	**Technology Type:** Water Conservation
Technical Description: This is a low-volume irrigation technology that uses clay pots or porous capsules, interconnected by plastic pipes, to deliver water to the soil. This ancient irrigation system has been modernized and applied in water-scarce areas. Clay pots are open at the top and are usually constructed from locally mined clay, or clay and sand, baked in home kilns or ovens. Capsules are closed and sometimes work under pressure, being regulated by a constant-level tank or reservoir. The number of pots or capsules required is a function of the volume of the container and the area of cultivation, soil conditions, and climatic conditions.	
Extent of Use: This technology has been used in small-scale irrigation projects in arid and semi-arid areas of Argentina, Bolivia, Brazil, Ecuador, and Mexico. It is also used during drought periods in tropical countries including Guatemala, the Dominican Republic, and Panama.	
Operation and Maintenance: Operation is simple, requiring only the opening and closing of valves to replace the water in the clay pots and porous capsules that has been used for irrigation. Installation requires care, especially in soil preparation. Hydrostatic pressures should be maintained at a constant level. Replacement of pots and capsules is required every 3 to 5 years. Maintenance includes checking for leaks when pressures cannot be maintained.	**Level of Involvement:** Community participation is essential to the implementation of this technology. Government institutions may participate in field testing of this procedure.
Costs: Costs vary according to the materials used and type of system employed. In Brazil, the cost of using clay pots was estimated at $1 300/ha, and of using porous capsules at $1 800/ha.	**Effectiveness of Technology:** Use of this technology has improved the stability of soils. Tests performed in Panama with the cultivation of fruit trees resulted in a yield of 6 fruits per plant or three times the yield obtained using conventional methods. In Bolivia, significant increases in the yield of potatoes were reported.
Suitability: In arid and semi-arid areas for small-scale agricultural applications, and in drought-prone areas.	**Cultural Acceptability:** This technology is gaining acceptance in agricultural communities in arid and semi-arid regions. It has been well accepted as a technology for use in household gardens.
Advantages: » This technology has a low cost. » It improves agricultural production. » It reduces infiltration losses. » It eliminates unwanted weeds. » The systems are easy to operate and maintain. » It can reduce the use of artificial fertilizers. » It prevents soil erosion. » It has minimal environmental impact.	**Disadvantages:** » The technology is difficult to use in rocky soils. » Broken pots or capsules can disrupt operation. » Acquisition of pots or capsules may be difficult in certain areas. » It is only applicable in small-scale applications.

Further Development of Technology: Improvements in the construction of the capsules by using a mixture of materials to increase or maintain porosity are proposed. Extension of the technology to larger-scale applications is required, as is educational programming to promote the use and benefits of the technology.

Information Sources: Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September, 1995), OAS/UNEP.

Name of Technology: Automatic Surge Flow and Gravitational Tank Irrigation	**4.3**
Sector: Agricultural use	**Technology Type:** Water Conservation

Technical Description: This technology was developed to provide intermittent irrigation supplies for small-scale agriculture. The automatic surge flow irrigation system consists of a tank kept at a certain head and equipped with one or more siphons. Water for irrigation use is provided by siphoning water from the tank when required. The gravitational tank system is a similar system equipped with a discharge pipe, gate and float valve which allows the cyclical opening and closing of the gate. The design of these systems must consider irrigation water use, available hydraulic head, topography of the irrigated area, dimensions of the irrigated parcel, and soil characteristics.

Extent of Use: This technology has been used extensively for irrigation of small-scale plots of up to 4 ha in arid and semi-arid areas of Mexico.

Operation and Maintenance: These systems function automatically, using flow control devices, and need no external energy source. Maintenance is simple, requiring periodic cleaning of tanks, siphons, and discharge pipes.	**Level of Involvement:** The Mexican government, through educational institutions and small private agricultural enterprises, has promoted the use of this technology.
Costs: Capital costs of a surge flow automatic irrigation system capable of irrigating an area of 4 ha, manufactured in Mexico, was $600. The cost of a similar system using the gravitational tank was $1 400. The gravitational tank system has a longer life expectancy and greater efficiency of operation.	**Effectiveness of Technology:** Irrigation efficiencies of up to 75% have been achieved in the State of Zacatecas, Mexico. This is 50% higher than the irrigation efficiencies achieved with traditional systems. Savings in energy costs of up to 25% have also been reported.
Suitability: In arid and semi-arid areas with small storage areas and depleted aquifers.	**Cultural Acceptability:** It is well accepted in the areas of Mexico where it has been used and tested.

Advantages:	Disadvantages:
» This technology uses hydrologic energy as a driving force; it requires no external power source. » It can use small wells, streams or reclaimed water as the water source. » It has a low cost. » Irrigation time and labor requirements are reduced. » It is more efficient than traditional irrigation techniques. It is easy to operate and maintain.	» This technology is suitable for small-scale irrigation only. » Significant preparation of the land is required; irrigated parcels should be levelled for best results.

Further Development of Technology: A fertilizer dispensing device is presently being developed as an additional element of the gravitational tank irrigation system. Informational programming on the utilization and efficiency of these systems is required.

Information Sources: Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September, 1995), OAS/UNEP.

Name of Technology: Dual Water Distribution	**4.4**
Sector: Domestic water supply	**Technology Type:** Water Conservation

Technical Description: This technology involves the use of water supplies from two different sources, delivered to the user in two separate distribution systems. The supply of potable water is provided through one distribution system, and non-potable water through a separate system. The non-potable water is used for fire-fighting, sanitary flushing, and irrigation/watering. In most cases, the non-potable water source is either seawater or treated wastewater. The system requires a duplicate distribution system comprising pipes, pumping stations, and control valves. The piping is generally ductile or cast iron or fiberglass.

Extent of Use: The system is used in the Caribbean islands, on Saint Lucia and the U.S. Virgin Islands, to supply water for fire-fighting and street cleaning.

Operation and Maintenance: Problems have been experienced with this technology: valves have needed frequent servicing to remove fungal growths, pumps and motors consume much fuel and oil, and frequent testing of the systems is required to ensure efficient operation in the event of an emergency.	**Level of Involvement:** This technology is a government operation.

Costs: The cost of building a dual distribution system is almost exactly double that of building a single sourced system. The cost depends on the area served and the intended use of the system.	**Effectiveness of Technology:** This technology is highly efficient in supplying water for fire-fighting and street cleaning.
Suitability: In areas where a secondary source of water (usually seawater) is available and plentiful. Islands and coastal areas are best suited for implementation of this technology.	**Cultural Acceptability:** It is acceptable as an alternative source of supply for non-potable use; however, concerns about possible human health impacts due to cross-contamination of supplies remain.
Advantages: » It allows use of secondary water supplies, unsuited to potable use, for non-potable purposes. » The volumes of water and wastewater requiring treatment are reduced. » This technology leaves more potable water available for domestic consumption.	**Disadvantages:** » The cost of this technology can be twice that of a single-sourced distribution network. The public health risk due to cross-contamination of supplies is increased. » Seawater sources are highly corrosive and can increase maintenance requirements and costs. » Maintenance is more difficult and costly due to the greater number of pumps, pipes and valves, and the need to prevent cross-contamination. » Should seawater-based effluents be returned to a wastewater treatment facility, the efficiency of the plant may decline.

Further Development of Technology: Development of corrosion-resistant pipes, pumps and valves, and the use of fiberglass as a substitute for iron piping, would increase the use of this technology; use of PVC pipes, values and fittings would reduce maintenance requirements; and reduced costs of materials for a dual distribution system would encourage more widespread use of this technology by making it more cost-effective.

Information Sources: Final Report of the Workshop on Alternative Technologies for Freshwater Augmentation in the Caribbean (Barbados, 24-27 October, 1995) and Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September, 1995), OAS/UNEP.

Name of Technology: Other Water Conservation Practices	**4.5**
Sector: Domestic water supply; agriculture; industry and business	**Technology Type:** Water Conservation

Technical Description: Water conservation practices vary depending on the use. Residential users can conserve water by using low-flow plumbing fixtures, sometimes provided at reduced prices by water utilities through retrofit programs. The most common domestic low-flow devices are low-flush toilets, low-flow showerheads, pressure reduction valves, tap aerators, and the reuse of grey water in household gardens. Landscape water conservation practices include the use of low-volume sprinkler systems and xeriscaping. Agricultural water conservation practices include soil compaction and levelling, diking to prevent runoff, and selection of irrigation rates and schedules to minimize evaporative losses. Industrial and commercial water conservation practices include water recycling, particularly in cooling systems and washing of equipment. Regional water supply companies and water utilities can encourage water conservation by programs of leak detection and repair, programs of distribution network maintenance and rehabilitation, metering and pricing policies, well-capping, retrofit programs, drought management planning, and public awareness programming, focussing on demand and supply management by their customers/users.	
Extent of Use: Most of the conservation measures have been used in the U.S.A., particularly in water-stressed states such as Arizona, California and Florida. Some Latin American countries, including Brazil, Chile, and Mexico, have used water recycling. Chile has encouraged the development of a water market which has resulted in a shift toward less water-intensive agricultural practices.	
Operation and Maintenance: Low-flow water conservation devices require maintenance and repair. Leak detection equipment and meters require periodic calibration and maintenance.	**Level of Involvement:** Installation and maintenance of low-flow household devices may require government incentives to promote acceptability to the consumer. Government regulations and incentives are necessary in order to implement most water conservation measures. Agricultural extension efforts may be needed to encourage outdoor water conservation practices such as irrigating in the early morning or late afternoon to minimize evaporative losses. Community participation, especially in voluntary conservation of water, is a necessary prerequisite for a successful water conservation program.
Costs: The cost of low-flow devices is usually higher than that of conventional fixtures, although long-term savings usually more than compensate for the added cost. Significant savings have been reported by industrial users adopting water recycling systems.	**Effectiveness of Technology:** Water savings of 20% to 80% have been documented. A reduction in water pressure of 50% can result in a water saving of about 33% of the preexisting use. Early morning or late afternoon irrigation can result in measurable water savings. The conversion to a recycling cooling system in an industrial plant in the state of California, U.S.A., resulted in an estimated water saving of 20 000 to 28 000 l/day.

Suitability: In all areas, but particularly in high water-use sectors, such as industries and agricultural operations, in drought-prone areas. The technology is well suited to individual water users in developing countries.	**Cultural Acceptability:** Most water conservation measures have been implemented as a result of government regulation. Nevertheless, most practices have been well-accepted, especially by users who realize an economic benefit, although industrial, agricultural, and commercial users have been more receptive to these benefits than domestic users.
Advantages: » Low-flow devices produce significant water savings over conventional fixtures. » Water recycling significantly reduces industrial water use. Leak detection and metering can reduce water use by 30% to 50%. » Metering introduces accountability for water use. » Pricing schemes provide economic incentives for water conservation.	**Disadvantages:** » Initial cost of low-flow devices is higher than for conventional fixtures. » Use of treated wastewater for irrigation poses some degree of health risk. Modification of manufacturing processes and/or changes to plumbing/piping can make recycling costly to implement. » Implementation of leak detection and metering systems is costly and will affect the price of water in the short term.

Further Development of Technology: Low-flow plumbing devices need to be made more cost-effective; improvements in equipment used in leak detection and metering are needed to increase durability and efficiency; and widespread implementation of public awareness programs to encourage water conservation, and focussing particularly on its economic and environmental benefits, is needed.

Information Sources: Informe Final del Seminario-Taller sobre Tecnologías Alternativas para Aumentar la Disponibilidad de Agua en América Latina (Lima, Peru, 19-22 September, 1995), OAS/UNEP, and USEPA, "Cleaner Water Through Conservation," Washington, D.C., 1995 (Report 841/8-95-002).

1.1 Rainwater harvesting from rooftop catchments

The application of an appropriate rainwater harvesting technology can make possible the utilization of rainwater as a valuable and, in many cases, necessary water resource. Rainwater harvesting has been practiced for more than 4, 000 years, and, in most developing countries, is becoming essential owing to the temporal and spatial variability of rainfall. Rainwater harvesting is necessary in areas having significant rainfall but lacking any kind of conventional, centralized government supply system, and also in areas where good quality fresh surface water or groundwater is lacking.

Annual rainfall ranging from less than 500 to more than 1 500 mm can be found in most Latin American countries and the Caribbean. Very frequently most of the rain falls during a few months of the year, with little or no precipitation during the remaining months. There are countries in which the annual and regional distribution of rainfall also differ significantly.

For more than three centuries, rooftop catchments and cistern storage have been the basis of domestic water supply on many small islands in the Caribbean. During World War II, several airfields were also turned into catchments. Although the use of rooftop catchment systems has declined in some countries, it is estimated that more than 500 000 people in the Caribbean islands depend at least in part on such supplies. Further, large areas of some countries in Central and South America, such as Honduras, Brazil, and Paraguay, use rainwater harvesting as an important source of water supply for domestic purposes, especially in rural areas.

Technical Description

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

A conveyance system usually consists of gutters or pipes that deliver rainwater falling on the rooftop to cisterns or other storage vessels. Both drainpipes and roof surfaces should be constructed of chemically inert materials such as wood, plastic, aluminum, or fiberglass, in order to avoid adverse effects on water quality.

The water ultimately is stored in a storage tank or cistern, which should also be constructed of an inert material. Reinforced concrete, fiberglass, or stainless steel are suitable materials. Storage tanks may be constructed as part of the building, or may be built as a separate unit located some distance away from the building. Figure 1 shows a schematic of a rooftop catchment system in the Dominican Republic.

- All rainwater tank designs (see Figures 2a and 2b) should include as a minimum requirement:
    - A solid secure cover

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

Additional features might include:

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

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

- Is there a real need for an improved water supply?

- Are present water supplies either distant or contaminated, or both?

- Do suitable roofs and/or other catchment surfaces exist in the community?

- Does rainfall exceed 400 mm per year?

- Does an improved water supply figure prominently in the community's list of development priorities?

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

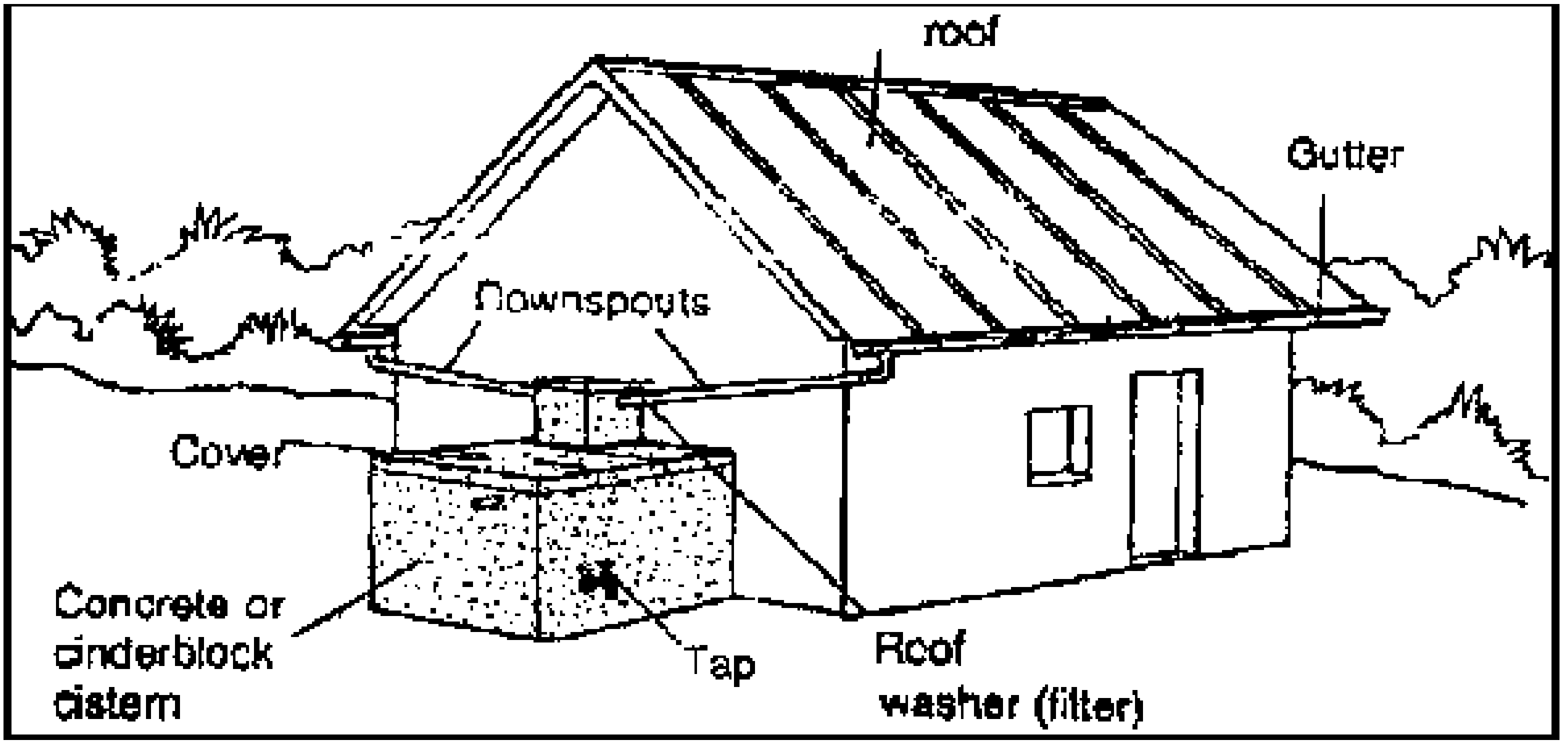
- What alternative water sources are available in the community and how do these compare with the rooftop catchment system?

- What are the economic, social, and environmental implications of the various water supply alternatives (e.g., how able is the community to pay for water obtained from other sources; what is the potential within the community for income generating activities that can be used to develop alternative water sources; does the project threaten the livelihood of any community members, such as water vendors?)

- What efforts have been made, by either the community or an outside agency, to implement an improved water supply system in the past? (Lessons may be learned from the experiences of the previous projects.)

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

Figure 1: Schematic of a Typical Rainwater Catchment System.



Source: José Payero, Professor-Researcher, Department of Natural Resources, Higher Institute of Agriculture (ISA), Dominican Republic.

Extent of Use

Rainwater harvesting is used extensively in Latin America and the Caribbean, mainly for domestic water supply and, in some cases, for agriculture and livestock supplies on a small scale. In Brazil and Argentina, rainwater harvesting is used in semi-arid regions. In Central American countries like Honduras (see case study in Part C, Chapter 5), Costa Rica, Guatemala, and El Salvador, rainwater harvesting using rooftop catchments is used extensively in rural areas.

In Saint Lucia, storage tanks are constructed of a variety of materials, including steel drums (200 l), large polyethylene plastic tanks (1 300 to 2 300 l), and underground concrete cisterns (100 000 to 150 000 l).

The Turks and Caicos Islands have a number of government-built, public rainfall catchment systems. Government regulations make it mandatory that all developers construct a water cistern large enough to store 400 l/m^2 of roof area.

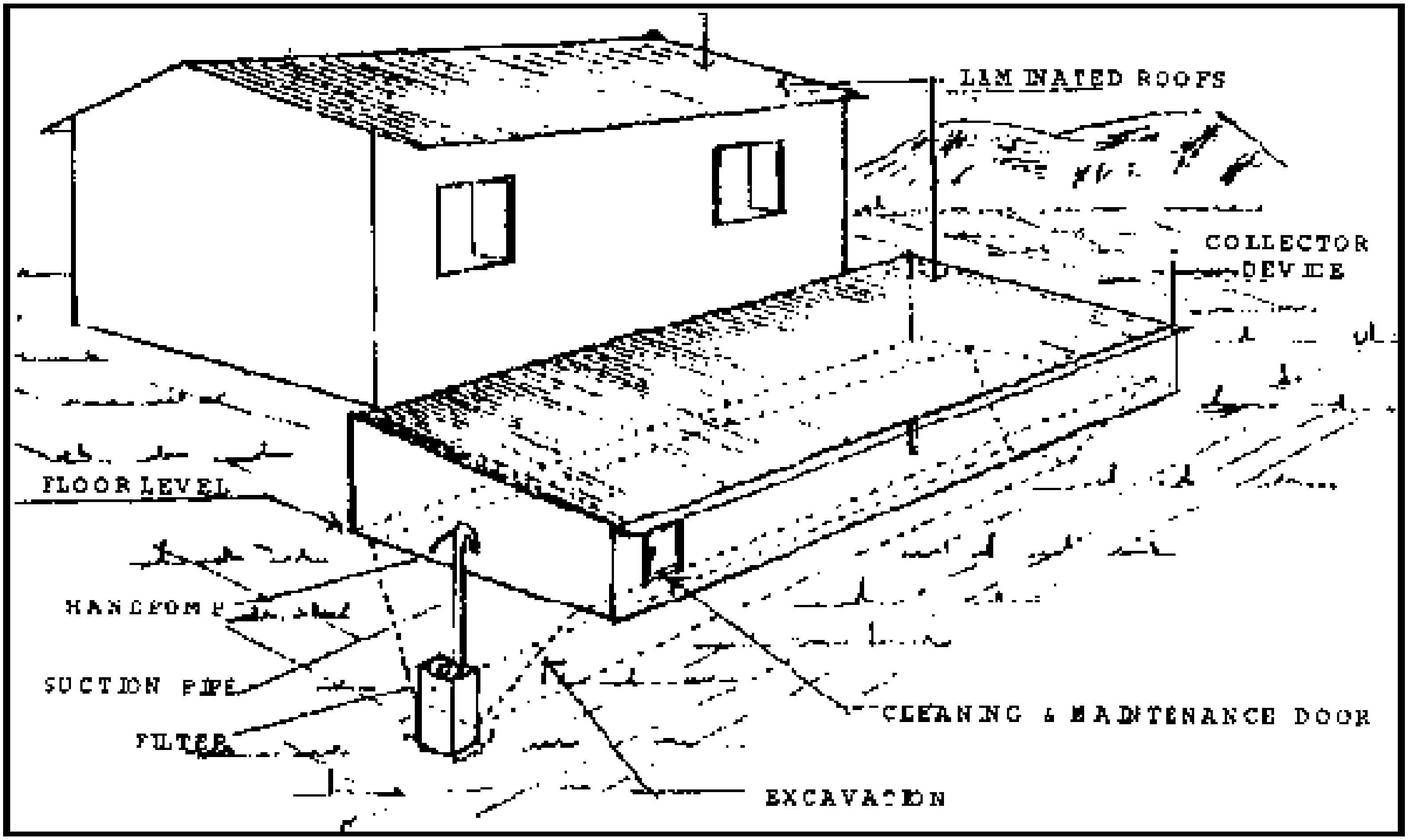
Rooftop and artificially constructed catchments, such as the one at the former United States naval base on Eleuthera, are commonplace in the Bahamas. One settlement (Whale Cay) has a piped distribution system based on water captured from rooftops. On New Providence, most of the older houses collect rainwater from rooftops and store it in cisterns with average capacities of 70 000 l. Industries also use rooftop rainwater, and a preliminary assessment has been made of using Nassau International Airport as a catchment. In multistoried apartment buildings and other areas serving large concentrations of people (such as hotels and restaurants), water supplies are supplemented by water from rooftop catchment cisterns.

The Islas de la Bahía off the shores of Honduras meet a substantial portion of their potable water needs using rainwater from rooftop catchments. Similarly, rooftop catchments and cistern storage provide a significant water supply source for a small group of islands off the northern coast of Venezuela.

In a recent rural water-supply study, the continued use of rooftop and artificially constructed catchments was contemplated for those parts of rural Jamaica lacking access to river, spring, or well water sources. It is thought that more than 100 000 Jamaicans depend to a major extent on rainwater catchments.

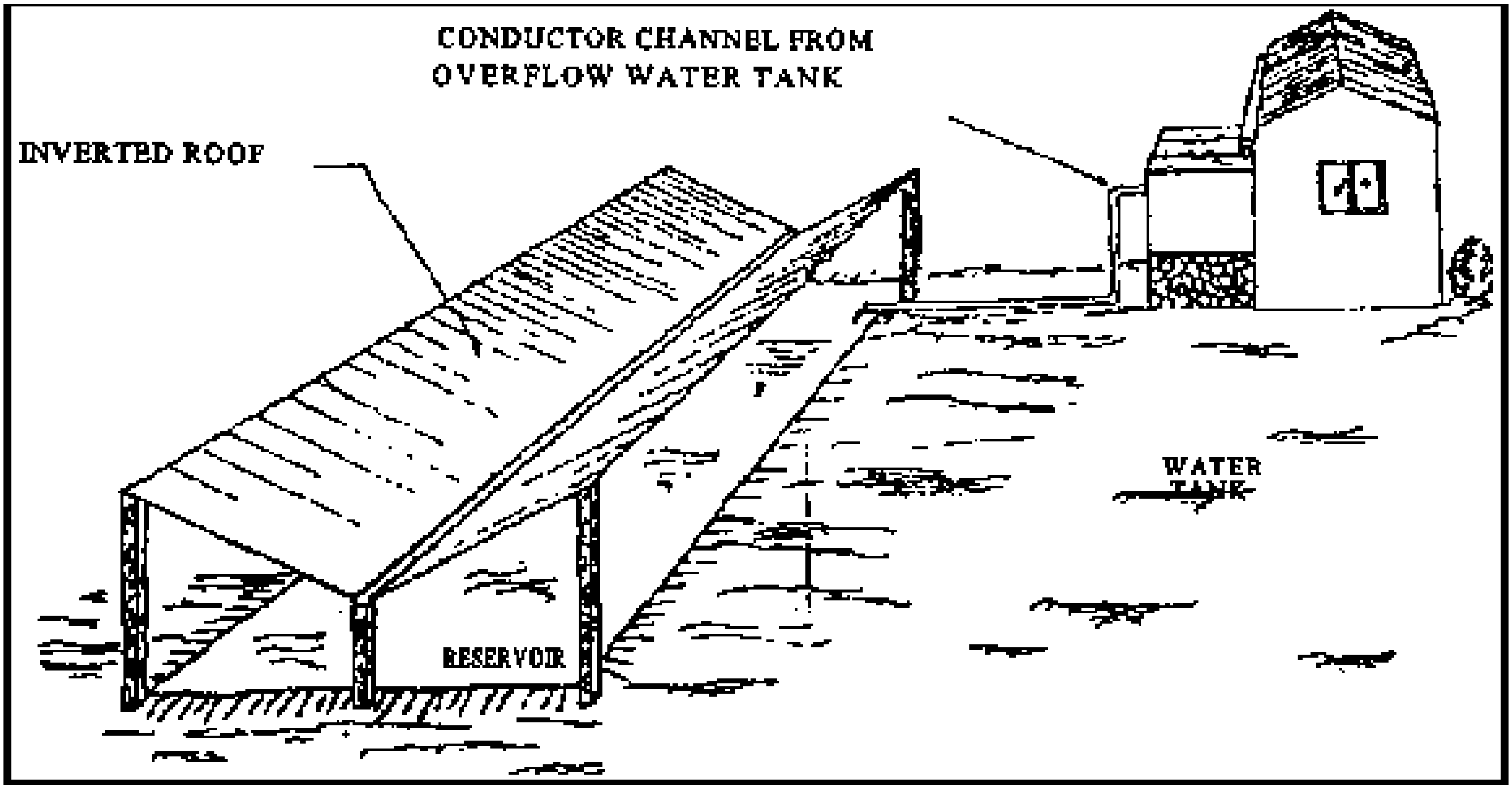
Operation and Maintenance

Figure 2A: Schematic of a Cistern



Source: Walter Santos, Center for Training in Agricultural Development, Bureau of Water Resources, Comayagua, Honduras.

Figure 2B: Schematic of a Storage Tank Reservoir



Source: Walter Santos, Center for Training in Agricultural Development, Bureau of Water Resources, Comayagua, Honduras.

Rainwater harvesting systems require few skills and little supervision to operate. Major concerns are the prevention of contamination of the tank during construction and while it is being replenished during a rainfall. Contamination of the water supply as a result of contact with certain materials can be avoided by the use of proper materials during construction of the system. For example, in Montserrat, where 95% of the houses in the medium to high density areas are roofed with oil-based bitumen shingles, consumers are strongly discouraged from using this source of supply for drinking purposes. Use of alternative roofing materials would have avoided this problem. The main sources of external contamination are pollution from the air, bird and animal droppings, and insects. Bacterial contamination may be minimized by keeping roof surfaces and drains clean but cannot be completely eliminated. If the water is to be used for drinking purposes, filtration and chlorination or disinfection by other means (e.g., boiling) is necessary. The following maintenance guidelines should be considered in the operation of rainwater harvesting systems:

- A procedure for eliminating the "foul flush" after a long dry spell deserves particular attention. The first part of each rainfall should be diverted from the storage tank since this is most likely to contain undesirable materials which have accumulated on the roof and other surfaces between rainfalls. Generally, water captured during the first 10 minutes of rainfall during an event of average intensity is unfit for drinking purposes. The quantity of water lost by diverting this runoff is usually about 14l/m^2 of catchment area.

- The storage tank should be checked and cleaned periodically. All tanks need cleaning; their designs should allow for this. Cleaning procedures consist of thorough scrubbing of the inner walls and floors. Use of a chlorine solution is recommended for cleaning, followed by thorough rinsing.

- Care should be taken to keep rainfall collection surfaces covered, to reduce the likelihood of frogs, lizards, mosquitoes, and other pests using the cistern as a breeding ground. Residents may prefer to take care to prevent such problems rather than have to take corrective actions, such as treating or removing water, at a later time.

- Chlorination of the cisterns or storage tanks is necessary if the water is to be used for drinking and domestic uses. The Montserrat Island Water Authority constructed a non-conventional chlorination device with a rubber tube, plywood, a 1.2 m piece of PVC tubing, and a hose clip to chlorinate the water using chlorine tablets.

- Gutters and downpipes need to be periodically inspected and cleaned carefully. Periodic maintenance must also be carried out on any pumps used to lift water to selected areas in the house or building. More often than not, maintenance is done only when equipment breaks down.

- Community systems require the creation of a community organization to maintain them effectively. Similarly, households must establish a maintenance routine that will be carried out by family members.

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

- Fencing of the paved catchment to prevent the entry of animals, primarily livestock such as goats, cows, donkeys, and pigs, that can affect water quality.

- Cleaning the paved catchment of leaves and other vegetative matter.

- Repairing large cracks in the paved catchment as a result of soil movement, earthquakes, or exposure to the elements.

- Maintaining water quality at a level where health risks are minimized. In many systems, this involves chlorination of the supplies at frequent intervals.

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

Level of Involvement

The level of governmental participation varies in the countries of Latin America and the Caribbean. In some Caribbean islands, governments regulate the design of rainwater harvesting systems. In the U.S. Virgin Islands, the law requires that provision be made in the construction of all new buildings for the capture and storage of rainfall coming into contact with their roofs. The law requires that roofs be guttered and that cisterns be constructed having a volume that depends on the size of the roof, the intended use of the structure, and the number of floors. For a typical single-level, residential building, the law requires that 400 1 of storage be provided for each m^2 of roof area. Cistern construction is further regulated by the Virgin Islands Building Code to insure the structural integrity of these cisterns, which usually form an integral part of building foundations. As of January 1, 1996, all new residences in Barbados are required to construct water storage facilities if the roof area or living area equals or exceeds 3 000 square feet. They will also be mandatory for all new commercial buildings with a roof area of 1 000 square feet or more. A rebate of $0.50 per gallon of installed tank capacity, up to the equivalent of 25% of the total roof area, will be given as an incentive by the Barbados Water Authority.

Cisterns are likely to continue to be a principal source of water for residences in several Caribbean islands. Even if mandatory requirements are removed, their use will remain widespread, as they provide a water supply that residents consider to be safe, sufficient, and inexpensive.

Costs

The cost of this technology varies considerably depending on location, type of materials used, and degree of implementation. In Brazil, the cost of a 30m^3 cistern in rural areas of the Northeast is around $900 to $1 000, depending on the material used. In the U.S. Virgin Islands, costs as low as $2 to $5/1 000 1 are reported. Construction costs for underground cisterns can vary tremendously, based on the size and the amount of excavation required. In Saint Lucia, the average cost of a 1, 5001 plastic tank is $125.

In the Chaco region of Paraguay, two different types of cisterns have been used for rainwater harvesting: cisterns or storage tanks called *aljibes,* and cutwater cisterns called *tajamares.* The capital cost of a 30 m^3 cistern *(aljibe)* in Paraguay has been reported to be $2 000, while the construction of a 6 000 m^3 *tajamar*, including windmill-driven pumps and distribution piping, has been estimated at $8 400.

Effectiveness of the Technology

Rainfall harvesting technology has proved to be very effective throughout several Latin American countries and most of the Caribbean islands, where cisterns are the principal source of water for residences. Cisterns are capable of providing a sufficient supply for most domestic applications. The use of rainwater is very effective in lessening the demand on the public water supply system in the British Virgin Islands. It also provides a convenient buffer in times of emergency or shortfall in the public water supply. Also, because of the hilly or mountainous nature of the terrain in the majority of the British Virgin Islands, combined with dispersed housing patterns, rainfall harvesting appears to be the most practical way of providing a water supply to some residents. In many countries it is very costly, and in some cases not economically feasible, to extend the public water supply to all areas, where houses are isolated from one another or in mountainous areas.

Steep galvanized iron roofs have been found to be relatively efficient rainwater collectors, while flat concrete roofs, though highly valued as protection from hurricanes, are very inefficient. Rooftop catchment efficiencies range from 70% to 90%. It has been estimated that 1 cm of rain on 100 m^2 of roof yields 10 0001. More commonly, rooftop catchment yield is estimated to be 75% of actual rainfall on the catchment area, after accounting for losses due to evaporation during periods when short, light showers are interspersed with periods of prolonged sunshine. Likewise, at the other extreme, the roof gutters and downpipes generally cannot cope with rainfalls of high intensity, and excess water runs off the roof to waste during these periods.

Suitability

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

Advantages

- Rainwater harvesting provides a source of water at the point where it is needed. It is owner operated and managed.

- It provides an essential reserve in times of emergency and/or breakdown of public water supply systems, particularly during natural disasters.

- The construction of a rooftop rainwater catchment system is simple, and local people can easily be trained to build one, minimizing its cost.

- The technology is flexible. The systems can be built to meet almost any requirements. Poor households can start with a single small tank and add more when they can afford them.

- It can improve the engineering of building foundations when cisterns are built as part of the substructure of the buildings, as in the case of mandatory cisterns.

- The physical and chemical properties of rainwater may be superior to those of groundwater or surface waters that may have been subjected to pollution, sometimes from unknown sources.

- Running costs are low.

- Construction, operation, and maintenance are not labor-intensive.

Disadvantages

- The success of rainfall harvesting depends upon the frequency and amount of rainfall; therefore, it is not a dependable water source in times of dry weather or prolonged drought.

- Low storage capacities will limit rainwater harvesting so that the system may not be able to provide water in a low rainfall period. Increased storage capacities add to construction and operating costs and may make the technology economically unfeasible, unless it is subsidized by government.

- Leakage from cisterns can cause the deterioration of load bearing slopes.

- Cisterns and storage tanks can be unsafe for small children if proper access protection is not provided.

- Possible contamination of water may result from animal wastes and vegetable matter.

- Where treatment of the water prior to potable use is infrequent, due to a lack of adequate resources or knowledge, health risks may result; further, cisterns can be a breeding ground for mosquitoes.

- Rainfall harvesting systems increase construction costs and may have an adverse effect on home ownership. Systems may add 30% to 40% to the cost of a building.

- Rainfall harvesting systems may reduce revenues to public utilities.

Cultural Acceptability

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

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

Further Development of the Technology

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

- Development of first-flush bypass devices that are more effective and easier to maintain and operate than those currently available.

- Greater involvement of the public health department in the monitoring of water quality.

- Monitoring the quality of construction at the time of building. Other development needs include:

- Provision of assistance from governmental sources to ensure that the appropriate-sized cisterns are built.

- Promotion of rainwater harvesting as an alternative to both government- and private-sector-supplied water, with emphasis on the savings to be achieved on water bills.

- Provision of assistance to the public in sizing, locating, and selecting materials and constructing cisterns and storage tanks, and development of a standardized plumbing and monitoring code.

- Development of new materials to lower the cost of storage.

- Preparation of guidance materials (including sizing requirements) for inclusion of rainwater harvesting in a multi-sourced water resources management environment.

Information Sources

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1.2 Rainwater harvesting in situ

In arid and semi-arid regions, where precipitation is low or infrequent during the dry season, it is necessary to store the maximum amount of rainwater during the wet season for use at a later time, especially for agricultural and domestic water supply. One of the methods frequently used in rainwater harvesting is the storage of rainwater *in situ.* Topographically low areas are ideal sites for *in situ* harvesting of rainfall. This technique has been used in the arid and semi-arid regions of northeastern Brazil, Argentina, and Paraguay, primarily for irrigation purposes. The *in situ* technology consists of making storage available in areas where the water is going to be utilized.

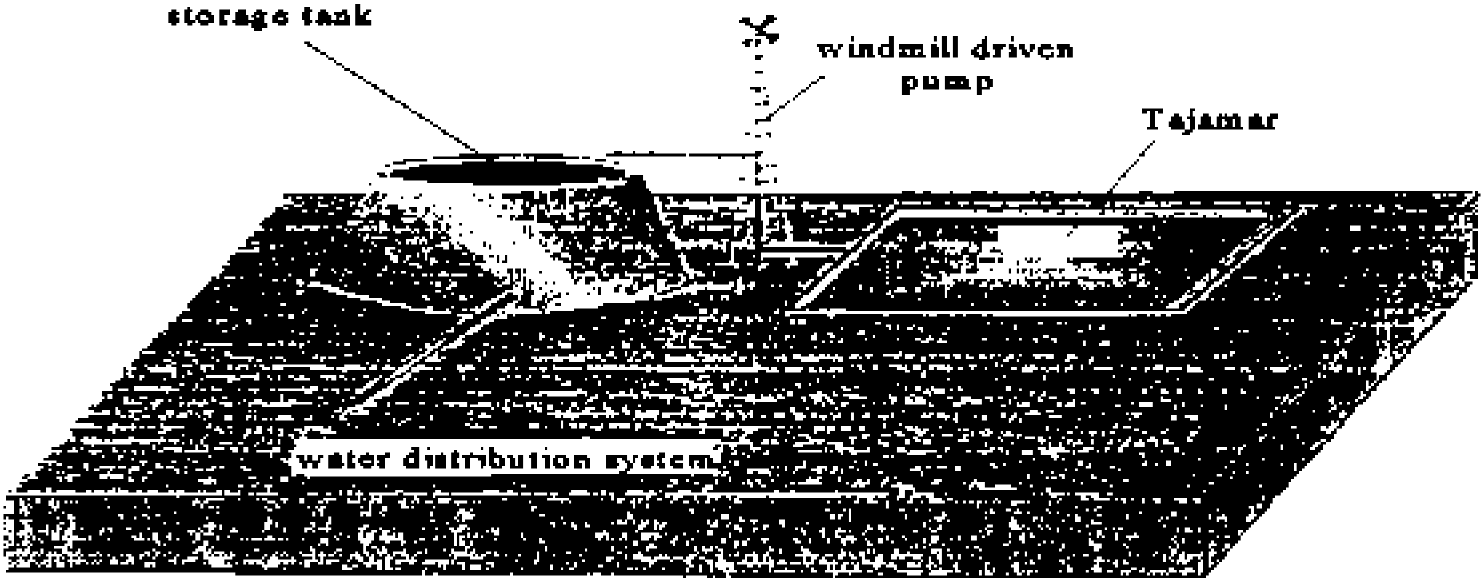
Technical Description

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

• Use of Topographic Depressions as Rainfall Harvesting Areas

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

Figure 3: Low Topography Rainfall Harvesting Areas (*Tajamar*).



Source: Eugenio Godoy V., National Commission on Integrated Regional Development of the Paraguayan Chaco, Filadelfia, Paraguay.

• Use of Furrows as Rainwater Storage Areas

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

• The *Guimares Duque*

The *Guimares Duque* method was developed in Brazil during the 1950s, and uses furrows and raised planting beds, on which cross cuts to retain water are made using a reversible disk plow with at least three disks. The furrows are usually placed at the edge of the cultivation zone (Figure 5).

Extent of Use

This technology has been extensively used in northeastern Brazil, in the Chaco region of Paraguay, and in Argentina. It can be used to augment the water supply for crops, livestock, and domestic use. With the mechanization of agriculture, its use has diminished, but it is still recommended for regions where the volume of rainfall is small and variable. The approach used depends primarily on the availability of equipment, the nature of the agricultural and livestock practices, and the type of soil.

Water stored in *tajamares* is normally used for livestock watering and may be used for domestic consumption after filtration and/or chlorination. Individual *tajamares* have also been used as a means of artificially recharging groundwater aquifers. *Tajamares* built in the Paraguayan Chaco have produced up to 6 800 m^3/yr for aquifer recharge.

Operation and Maintenance

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

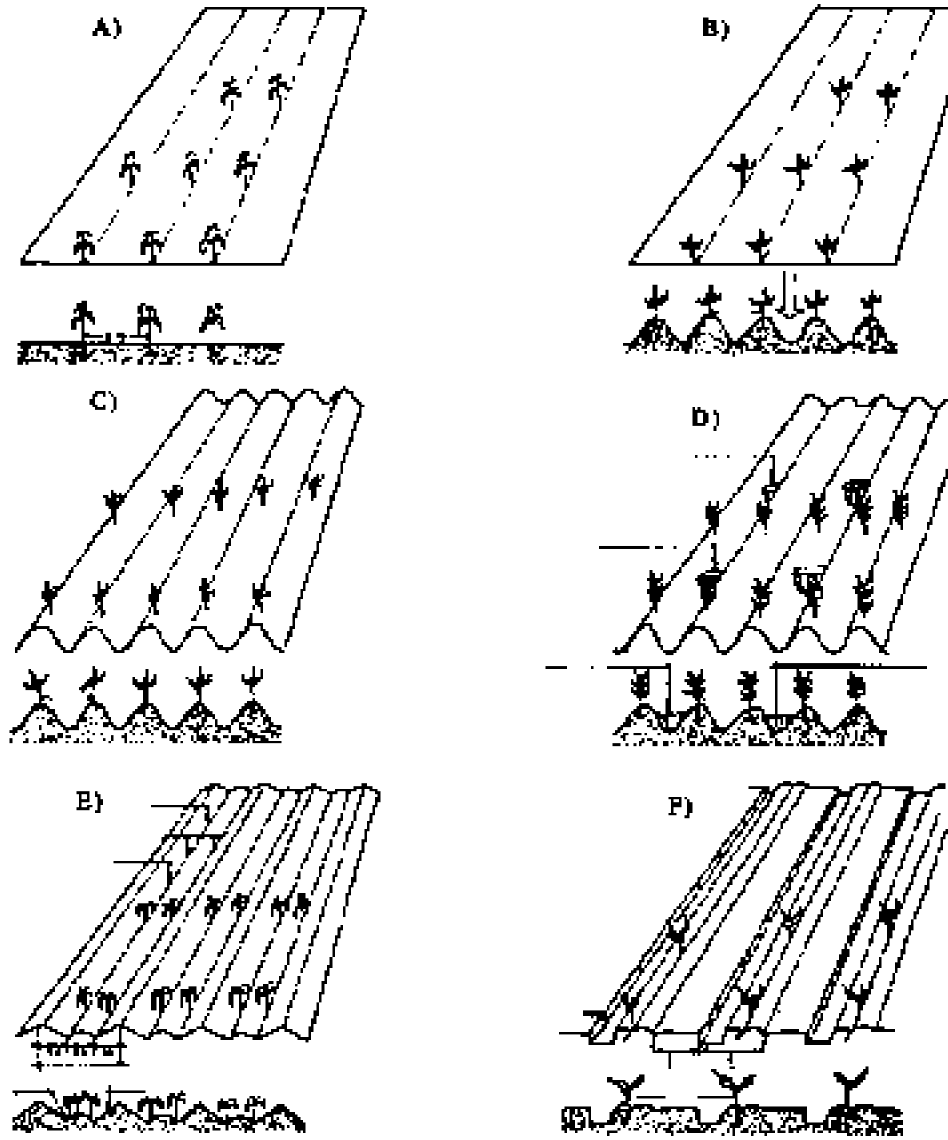
Level of Involvement

This technology is simple and easy to use. Governmental organizations and the agricultural community generally work together to support and promote the *in situ* rainwater storage. Educational and information programs should be provided to inform users of the benefits of this technology, and the means of implementing rainwater harvesting while preventing soil loss.

Costs

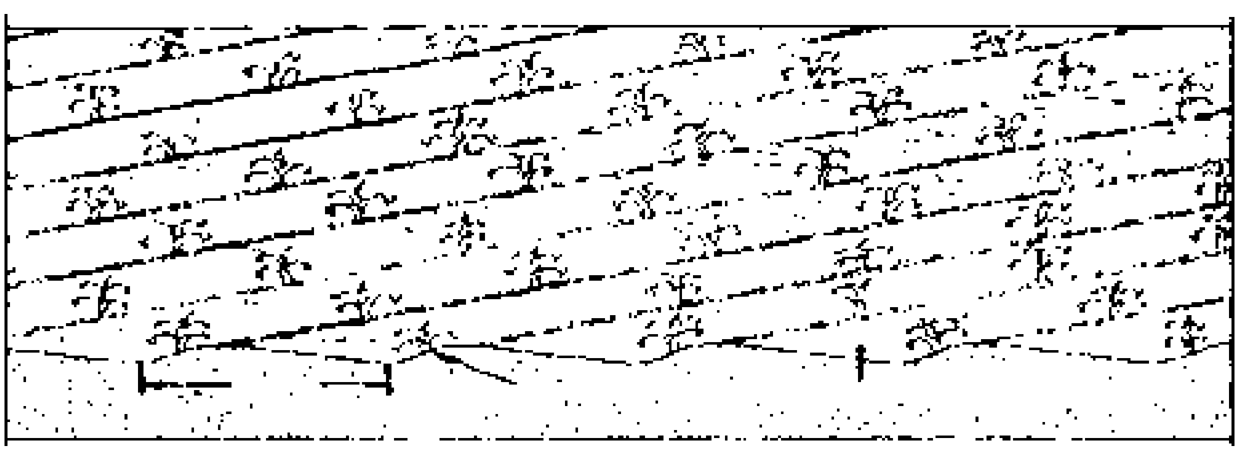
The costs of *in situ* rainwater collection systems are minimal. The main cost of this technology is in the equipment and labor required to build the fences and furrows. Table 1 shows representative costs reported for different methods of site preparation in cultivated areas of Brazil. Further, the construction cost of a *tajamar* in Paraguay has been reported at $4 500. This cost includes not only the cost of soil preparation, but also the cost of ancillary equipment such as the storage tank and windmill shown in Figure 3.

Figure 4: Site Preparation Methods for *in situ* Rainwater Harvesting in Northeastern Brazil.



Source: Everaldo Rocha Porto, Luiza Teixeira de Lima, and Alderaldo de Souza Silva, EMBRAPA-CPATSA, Petrolina, PE, Brazil.

Figure 5: *Guimares Duque* Site Preparation Method.



Source: José dos Anjos Barbosa, EMBRAPA, Petrolina, PE, Brazil, 1995.

Table 1 Estimated Cost (S) of Different Site Preparation Methods for Rainwater Collection Areas in Agricultural Areas of Brazil

Method	Basic Equipment	Animal Traction	Total	Hourly Cost of Implementation
Flat terrain trenches	150.00	300.00	450.00	0.96
Post-planting furrows	80.00	300.00	380.00	0.90
Pre-planting furrows	180.00	70.00	250.00	0.90
Furrows with barriers	180.00	70.00	250.00	0.90
Inclined raised beds	1 500.00	1 000.00	2 500.00	12-15
Furrows in partial areas	100.00	80.00	180.00	0.70
Guimarães Duque method	-	-	-	12-15

Effectiveness of the Technology

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

Suitability

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

Advantages

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

Disadvantages

- *In situ* rainwater harvesting cannot be implemented where the slope of the land is greater than 5%.
- It is difficult to implement in rocky soils.
- Areas covered with stones and/or trees need to be cleared before implementation.
- The additional costs incurred in implementing this technology could be a factor for some farmers.

- It requires impermeable soils and low topographic relief in order to be effective.
- The effectiveness of the storage area can be limited by evaporation that tends to occur between rains.

Cultural Acceptability

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

Further Development of the Technology

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

Information Sources

Contacts

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1.3 Fog harvesting

This innovative technology is based on the fact that water can be collected from fogs under favorable climatic conditions. Fogs are defined as a mass of water vapor condensed into small water droplets at, or just above, the Earth's surface. The small water droplets present in the fog precipitate when they come in contact with objects. The frequent fogs that occur in the arid coastal areas of Peru and Chile are traditionally known as *camanchacas*. These fogs have the potential to provide an alternative source of freshwater in this otherwise dry region if harvested through the use of simple and low-cost collection systems known as fog collectors. Present research suggests that fog collectors work best in coastal areas where the water can be harvested as the fog moves inland driven by the wind. However, the technology could also potentially supply water for multiple uses in mountainous areas should the water present in stratocumulus clouds, at altitudes of approximately 400 m to 1 200 m, be harvested.

Technical Description

Full-scale fog collectors are simple, flat, rectangular nets of nylon supported by a post at either end and arranged perpendicular to the direction of the prevailing wind. The one used in a pilot-scale project in the El Tofo region of Chile consisted of a single 2 m by 24 m panel with a surface area of 48 m^2. Alternatively, the collectors may be more complex structures, made up of a series of such collection panels joined together. The number and size of the modules chosen will depend on local topography and the quality of the materials used in the panels. Multiple-unit systems have the advantage of a lower cost per unit of water produced, and the number of panels in use can be changed as climatic conditions and demand for water vary.

The surface of fog collectors is usually made of fine-mesh nylon or polypropylene netting, e.g., "shade cloth," locally available in Chile under the brand name Raschel. Raschel netting (made of flat, black polypropylene filaments, 1.0 mm wide and 0.1 mm thick, in a triangular weave) can be produced in varying mesh densities. After testing the efficiency of various mesh densities, the fog collectors used at El Tofo were equipped with Raschel netting providing 35% coverage, mounted in double layers. This proportion of polypropylene-surface-to-opening extracts about 30% of the water from the fog passing through the nets.

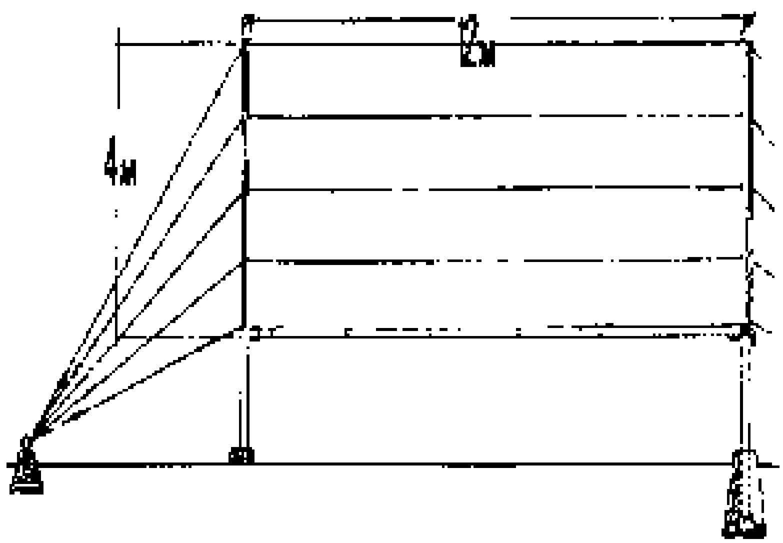
As water collects on the net, the droplets join to form larger drops that fall under the influence of gravity into a trough or gutter at the bottom of the panel, from which it is conveyed to a storage tank or cistern. The collector itself is completely passive, and the water is conveyed to the storage system by gravity. If site topography permits, the stored water can also be conveyed by gravity to the point of use. The storage and distribution system usually consists of a plastic channel or PVC pipe approximately 110 mm in diameter which can be connected to a 20 nun to 25 nun diameter water hose for conveyance to the storage site/point of use. Storage is usually in a closed concrete cistern. A 30 m^3 underground cistern is used in the zone of Antofagasta in northern Chile. The most common type of fog collector is shown in Figure 6.

Storage facilities should be provided for at least 50% of the expected maximum daily volume of water consumed. However, because the fog phenomenon is not perfectly regular from day to day, it may be necessary to store additional water to meet demands on days when no fog water is collected. Chlorination of storage tanks may be necessary if the water is used for drinking or cooking purposes.

Extent of Use

Fog harvesting has been investigated for more than thirty years and has been implemented successfully in the mountainous coastal areas of Chile (see case study in Part C, Chapter 5), Ecuador, Mexico, and Peru. Because of a similar climate and mountainous conditions, this technology also can be implemented in other regions as shown in Figure 7.

Figure 6: Section of a Typical Flat, Rectangular Nylon Mesh Fog Collector. The water is collected in a 200 l drum.



Source: *G.* Soto Alvarez, National Forestry Corporation (CONAF), Antofagasta, Chile.

In Chile, the National Forestry Corporation (CONAF), the Catholic University of the North, and the Catholic University of Chile are implementing the technology in several regions, including El Toro, Los Nidos, Cerro Moreno, Travesía, San Jorge, and Pan de Azúcar. The results of the several experiments conducted in the northern coastal mountain region indicate the feasibility and applicability of this technology for supplying good-quality water for a variety of purposes, including potable water and water for commercial, industrial, agricultural, and environmental uses. These experiments were conducted between 1967 and 1988 at altitudes ranging from 530 m to 948 m using different types of fog water collectors. The different types of neblinometers and fog collectors resulted in different water yields under the same climatic conditions and geographic location. A neblinometer or fog collector with a screen containing a double Raschel (30%) mesh was the most successful and the one that is currently recommended.

In Peru, the National Meteorological and Hydrological Service (SENAMHI) has been cooperating with the Estratus Company since the 1960s in implementing the technology in the following areas: Lachay, Pasamayo, Cerro Campana, Atiquipa, Cerro Orara (Ventinilla-Ancón), Cerro Colorado (Villa María de Triunfo), and Cahuide Recreational Park (Ate-Vitarte), and in southern Ecuador the Center for Alternative Social Research (CISA) is beginning to work in the National Park of Machalilla on Cerro La Gotera using the Chilean installations as models.

Operation and Maintenance

Operating this technology is very simple after once the fog collection system and associated facilities are properly installed. Training of personnel to operate the system might not be necessary if the users participate in the development and installation of the required equipment. A very important factor in the successful use of this technology is the establishment of a routine quality control program. This program should address both the fog collection system and the possible contamination of the harvested water, and include the following tasks:

- Inspection of cable tensions. Loss of proper cable tension can result in water loss by failing to capture the harvested water in the receiving system. It can also cause structural damage to the collector panels.

- Inspection of cable fasteners. Loose fasteners in the collection structure can cause the system to collapse and/or be destroyed.

- *Inspection of horizontal mesh net tensions.* Loose nets will lead to a loss of harvesting efficiency and can also break easily.

- *Maintenance of mesh nets.* After prolonged use, the nets may tear. Tears should be repaired immediately to avoid having to replace the entire panel. Algae can also grow on the surface of the mesh net after one or two years of use, accumulating dust, which will cloud the collected water and cause offensive taste and odor problems. The mesh net should be cleaned with a soft plastic brush as soon as algal growth is detected.

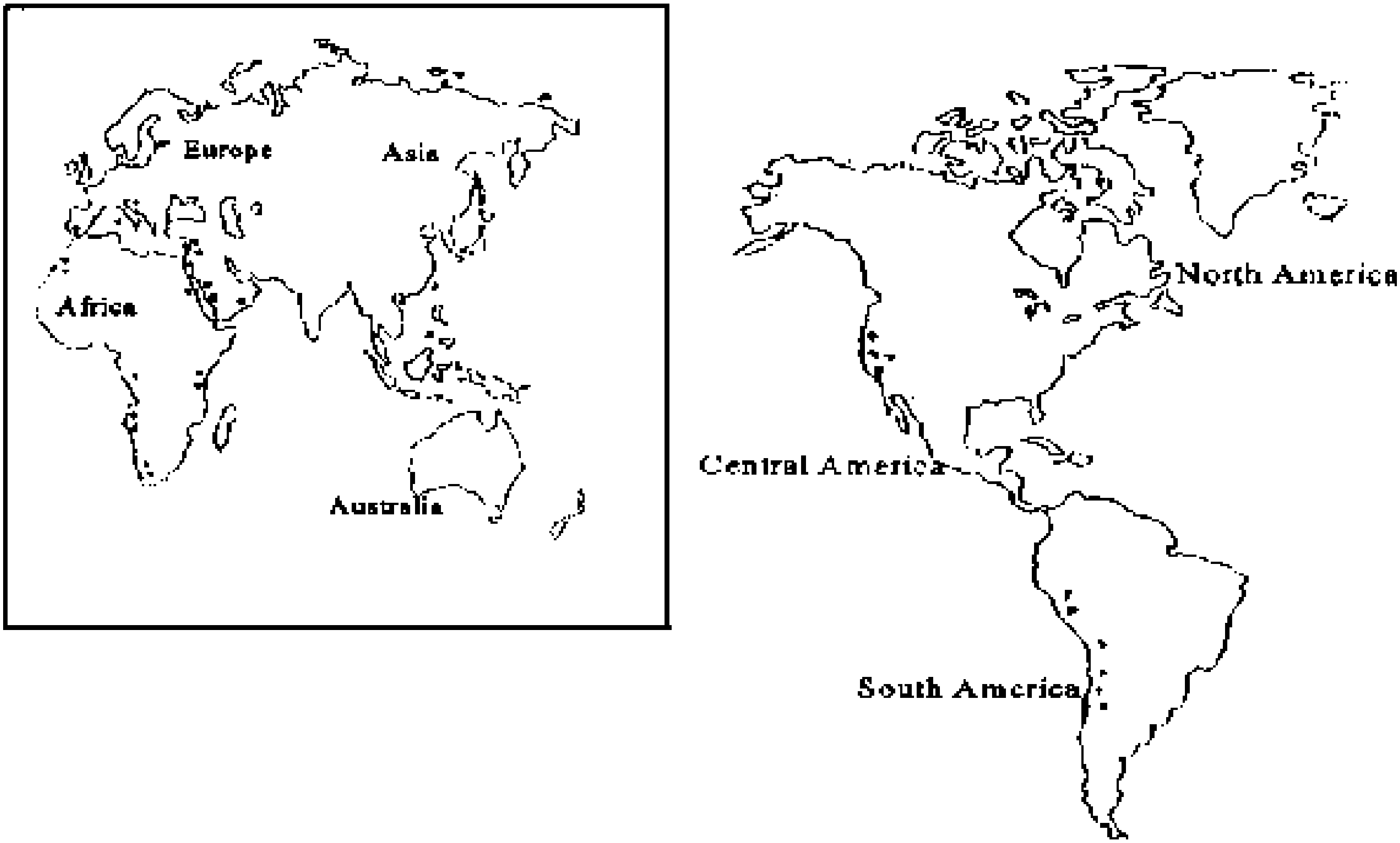
- *Maintenance of collector drains.* A screen should be installed at the end of the receiving trough to trap undesirable materials (insects, plants, and other debris) and prevent contamination of water in the storage tank. This screen should be inspected and cleaned periodically.

- *Maintenance of pipelines and pressure outlets.* Pipelines should be kept as clean as possible to prevent accumulation of sediments and decomposition of organic matter. Openings along the pipes should be built to facilitate flushing or partial cleaning of the system. Likewise, pressure outlets should be inspected and cleaned frequently to avoid accumulation of sediments. Openings in the system must be protected against possible entry of insects and other contaminants.

- *Maintenance of cisterns and storage tanks.* Tanks must be cleaned periodically with a solution of concentrated calcium chloride to prevent the accumulation of fungi and bacteria on the walls.

- *Monitoring of dissolved chlorine. A* decrease in the concentration of chlorine in potable water is a good indicator of possible growth of microorganisms. Monitoring of the dissolved chlorine will help to prevent the development of bacterial problems.

Figure 7: Locations Where Fog Harvesting Has Been or Can Be Implemented.



Source: W. Canto Vera, et al. 1993. *Fog Water Collection System.* IDRC, Ottawa, Canada.

Level of Involvement

In applying this technology, it is strongly recommended that the end users folly participate in the construction of the project. Community participation will help to reduce the labor cost of building the fog harvesting system, provide the community with operation and maintenance experience, and develop a sense of community ownership and responsibility for the success of the project. Government subsidies, particularly in the initial stages, might be necessary to reduce the cost of constructing and installing the facilities. A cost-sharing approach could be adopted so that the end users will pay for the pipeline and operating costs, with the government or an external agency assuming the cost of providing storage and distribution to homes.

Costs

Actual costs of fog harvesting systems vary from location to location. In a project in the region of Antofagasta, Chile, the installation cost of a fog collector was estimated to be $90/m^2 of mesh, while, in another project in northern Chile, the cost of a 48 m^2 fog collector was approximately $378 ($225 in materials, $63 in labor, and $39 in incidentals). This latter system produced a yield of 3.0 l/m^2 of mesh/day. The cost of a fog harvesting project constructed in the village of Chungungo, Chile, is shown in Table 2. The most expensive item in this system is the pipeline that carries the water from the fog collection panel to the storage tank located in the village.

Maintenance and operating costs are relatively low compared to other technologies. In the project in Antofagasta, the operation and maintenance cost was estimated at $600/year. This cost is significantly less than that of the Chungungo project: operating costs in that project were estimated at $4 740, and maintenance costs at $7 590 (resulting in a total cost of $12 330/year).

Both the capital costs and the operating and maintenance costs are affected by the efficiency of the collection system, the length of the pipeline that carries the water from the collection panels to the storage areas, and the size of the storage tank. For example, the unit cost for a system with an efficiency of 2.0 l/n^/day was estimated to be $4.80/1 0001. If the efficiency was improved to 5.0 l/m^2/day, then the unit cost would be reduced to $1.90/1 0001. In the Antofagasta project, the unit cost of production was estimated at $1.41/1000 l with a production of 2.5 l/m^2/day.

Table 2 Capital Investment Cost and Life Span of Fog Water Collection System Components

Component	Cost ($)	%of Total Cost	Life Span (Years)
Collection	27680	22.7	12
Main pipeline	43787	35.9	20
Storage (100m^3 tank)	15632	12.8	20
Treatment	2037	1.7	10
Distribution	32806	26.9	20
TOTAL	121 942	100.0	

Source: Soto Alvarez, Q. National Forestry Corporation, Antofagasta, Chile.

Effectiveness of the Technology

Experimental projects conducted in Chile indicate that it is possible to harvest between 5.3 l/m^2/day and 13.4 l/m^2/day depending on the location, season, and type of collection system used. At El Tofo, Chile, during the period between 1987 and 1990, an average fog harvest of 3.0 l/n^/day was obtained using 50 fog collectors made with Raschel mesh netting. Fog harvesting efficiencies were found to be highest during the spring and summer months, and lowest during the winter months. The average water collection rates during the fog seasons in Chile and Peru were 3.0 and 9.0 l/m^2/day, respectively; the lengths of the fog seasons were 365 and 210 days, respectively. While this seems to indicate that higher rates are obtained during shorter fog seasons, the practical implications are that a shorter fog season will require large storage facilities in order to ensure a supply of water during non-fog periods. Thus, a minimum fog season duration of half a year might serve as a guideline when considering the feasibility of using this technology for water supply purposes; however, a detailed economic analysis to determine the minimum duration of the fog season that would make this technology cost-effective should be made. In general, fog harvesting has been found more efficient and more cost-effective in arid regions than other conventional systems.

Suitability

In order to implement a fog harvesting program, the potential for extracting water from fogs first must be investigated. The following factors affect the volume of water that can be extracted from fogs and the frequency with which the water can be harvested:

- **Frequency of fog occurrence,** which is a function of atmospheric pressure and circulation, oceanic water temperature, and the presence of thermal inversions.

- **Fog water content,** which is a function of altitude, seasons and terrain features.

- **Design of fog water collection system,** which is a function of wind velocity and direction, topographic conditions, and the materials used in the construction of the fog collector.

The occurrence of fogs can be assessed from reports compiled by government meteorological agencies. To be successful, this technology should be located in regions where favorable climatic conditions exist. Since fogs/clouds are carried to the harvesting site by the wind, the interaction of the topography and the wind will be influential in determining the success of the site chosen. The following factors should be considered in selecting an appropriate site for fog harvesting:

Global Wind Patterns: Persistent winds from one direction are ideal for fog collection. The high-pressure area in the eastern part of the South Pacific Ocean produces onshore, southwest winds in northern Chile for most of the year and southerly winds along the coast of Peru.

Topography: It is necessary to have sufficient topographic relief to intercept the fogs/clouds; examples, on a continental scale, include the coastal mountains of Chile, Peru, and Ecuador, and, on a local scale, isolated hills or coastal dunes.

***Relief in the surrounding areas**:* It is important that there be no major obstacle to the wind within a few kilometers upwind of the site. In arid coastal regions, the presence of an inland depression or basin that heats up during the day can be advantageous, as the localized low pressure area thus created can enhance the sea breeze and increase the wind speed at which marine cloud decks flow over the collection devices.

Altitude: The thickness of the stratocumulus clouds and the height of their bases will vary with location. A desirable working altitude is at two-thirds of the cloud thickness above the base. This portion of the cloud will normally have the highest liquid water content. In Chile and Peru, the working altitudes range from 400 m to 1 000 m above sea level.

Orientation of the topographic features: It is important that the longitudinal axis of the mountain range, hills, or dune system be approximately perpendicular to the direction of the wind bringing the clouds from the ocean. The clouds will flow over the ridge lines and through passes, with the fog often dissipating on the downwind side.

Distance from the coastline: There are many high-elevation continental locations with frequent fog cover resulting from either the transport of upwind clouds or the formation of orographic clouds. In these cases, the distance to the coastline is irrelevant. However, areas of high relief near the coastline are generally preferred sites for fog harvesting.

Space for collectors: Ridge lines and the upwind edges of flat-topped mountains are good fog harvesting sites. When long fog water collectors are used, they should be placed at intervals of about 4.0 m to allow the wind to blow around the collectors.

Crestline and upwind locations: Slightly lower-altitude upwind locations are acceptable, as are constant-altitude locations on a flat terrain. But locations behind a ridge or hill, especially where the wind is flowing downslope, should be avoided.

Prior to implementing a fog water harvesting program, a pilot-scale assessment of the collection system proposed for use and the water content of the fog at the proposed harvesting site should be undertaken.

Low cost and low maintenance measurement devices to measure the liquid water content of fog, called neblinometers, have been developed at the Catholic University of Chile (Carvajal, 1982). Figure 8 illustrates four different types of neblinometers: (a) a pluviograph with a perforated cylinder; (b) a cylinder with a nylon mesh screen; (c) multiple mesh screens made of nylon or polypropylene mesh; and (d) a single mesh screen made of nylon or polypropylene mesh. The devices capture water droplets present in the fog on nylon filaments that are mounted in an iron frame. The original neblinometer had an area of 0.25 m^2 made up of a panel with a length and width of 0.5 m, and fitted with a screen having a warp of 180 nylon threads 0.4 mm in diameter. The iron frame was 1.0 cm in diameter and was supported on a 2.0 m iron pole. These simple devices can be left in the field for more than a year without maintenance and can be easily modified to collect fog water samples for chemical analysis.

In pilot projects, use of a neblinometer with single or multiple panels having a width and length of one meter, fitted with fine-mesh nylon or polypropylene netting is recommended. It should be equipped with an anemometer to measure wind velocity and a vane to measure wind direction. The neblinometer can be connected to a data logger so that data can be made available in computer-compatible formats.

Advantages

- A fog collection system can be easily built or assembled on site. Installation and connection of the collection panels is quick and simple. Assembly is not labor intensive and requires little skill.

- No energy is needed to operate the system or transport the water.

- Maintenance and repair requirements are generally minimal.

- Capital investment and other costs are low in comparison with those of conventional sources of potable water supply used, especially in mountainous regions.

- The technology can provide environmental benefits when used in national parks in mountainous areas, or as an inexpensive source of water supply for reforestation projects.

- It has the potential to create viable communities in inhospitable environments and to improve the quality of life for people in mountainous rural communities.

- The water quality is better than from existing water sources used for agriculture and domestic purposes.

Disadvantages

- This technology might represent a significant investment risk unless a pilot project is first carried out to quantify the potential rate and yield that can be anticipated from the fog harvesting rate and the seasonably of the fog of the area under consideration.

- Community participation in the process of developing and operating the technology in order to reduce installation and operating and maintenance costs is necessary.

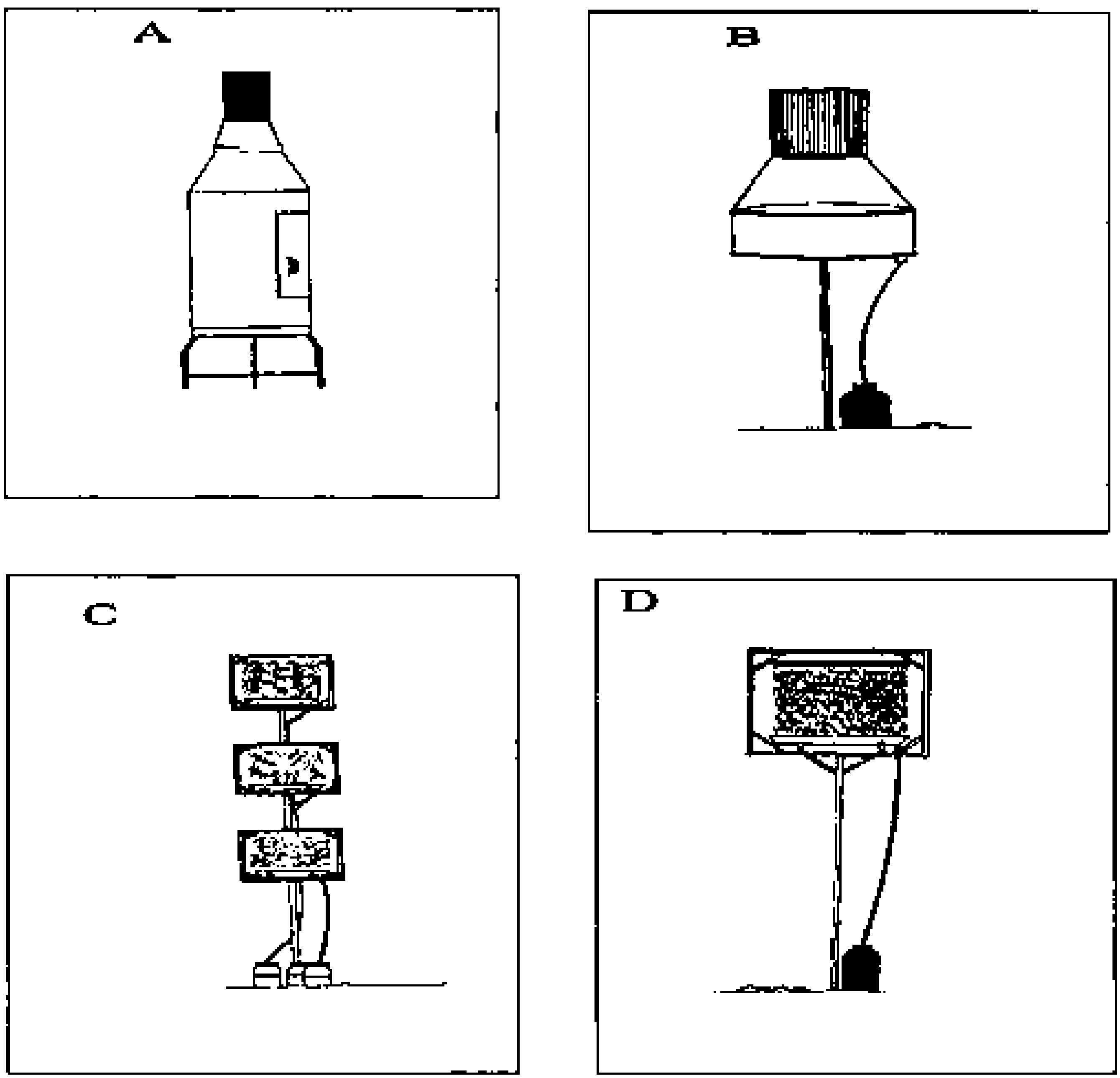
- If the harvesting area is not close to the point of use, the installation of the pipeline needed to deliver the water can be very costly in areas of high topographic relief.

- The technology is very sensitive to changes in climatic conditions which could affect the water content and frequency of occurrence of fogs; a backup water supply to be used during periods of unfavorable climatic conditions is recommended.

• In some coastal regions (e.g., in Paposo, Chile), fog water has failed to meet drinking water quality standards because of concentrations of chlorine, nitrate, and some minerals.

• Caution is required to minimize impacts on the landscape and the flora and fauna of the region during the construction of the fog harvesting equipment and the storage and distribution facilities.

Figure 8: Types of Neblinometers.



Source: G. Soto Alvarez, National Forestry Corporation, Antofagasta, Chile.

Cultural Acceptability

This technology has been accepted by communities in the mountainous areas of Chile and Peru. However, some skepticism has been expressed regarding its applicability to other regions. It remains a localized water supply option, dependent on local climatic conditions.

Future Development of the Technology

To improve fog harvesting technology, design improvements are necessary to increase the efficiency of the fog collectors. New, more durable materials should be developed. The storage and distribution systems needs to be made more cost-effective. An information and community education program should be established prior to the implementation of this technology.

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1.4 Runoff collection from paved and unpaved roads

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

Technical Description

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

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

In the Province of Mendoza, Argentina, runoff is collected and stored in drainage ditches or V-shaped swales along paved roadways. Water harvested in this manner is used primarily to cultivate trees planted in the swales. The trees most commonly planted along the roadsides are carob and pepper trees.

Paved roads are used also as dikes to divert runoff into impoundments along the roadsides, as is done on the Macanao Peninsula in Venezuela.

Extent of Use

This method of runoff capture has been used in semi-arid regions of Brazil, Argentina, and Venezuela.

Operation and Maintenance

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

Figure 9: A Schematic Representation of Runoff Collection from Paved and Unpaved Roads, Using Underground Galleries for Storage.

Source: Everaldo Rocha Porto, EMBRAPA-CPATSA.

Level of Involvement

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

Costs

In Argentina, a forestation project on both sides of a 1 km stretch of paved road cost about $2 000. Costs will vary as a function of the length of roadway treated and the characteristics of the pavement. Provision of a distribution system, if required, could increase the cost per kilometer substantially.

Effectiveness of the Technology

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

Suitability

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

Advantages

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

Disadvantages

- Plants may require supplemental irrigation during dry periods.

- Animals must be kept away from the plantings to avoid plant damage.
- It requires appropriate soil conditions.
- Water collected from roadways may be contaminated by litter and debris and in the urbanized areas by chemical pollutants from vehicles.

Cultural Acceptability

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

Further Development of the Technology

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

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1.5 Runoff collection using surface and underground structures

Runoff water can be successfully stored in artificial reservoirs, or intercepted and impounded by small dams. An extensive body of literature on the design of local impoundments and dams exists, since this technology has been used extensively throughout the world. In applying this technology in developing countries, both the lack of materials and skilled labor in certain regions and the cost must be taken into consideration.

Technical Description

Local impoundments are storage pools dug into the ground to store surface water runoff for use at a later date. Dams are designed to increase the storage capacity of rivers or streams, intercepting runoff and keeping it in storage for later use. The main difference is that dams are built where flowing water already exists, while local impoundments are essentially for harvesting and storing local rainfall runoff. These impoundments can dry out during drought periods; reservoirs behind dams usually do not.

General features of dams. Earth or rockfill dams consist of a foundation, which is either earth or rock; an embankment, resisting both the vertical and the horizontal loads; an impervious core; and a shell. The purpose of the core (membrane) is to hold back water. Depending on the structural requirements of the dam, the core can be located at the center, upstream from the center, or, in the case of certain rockfill dams, on the upstream face. When the foundation is not capable of resisting underseepage, it is necessary to extend the core down into the foundation to a depth where impervious materials are reached. Such an extension of the core is termed a cutoff.

The purpose of the shell is to provide structural support for the core and to distribute the loads over the foundation. An internal drain is an essential feature of all but the smallest dams, where the downstream shell may be so pervious that it can act as a drain. Riprap is required to cover the upstream face to prevent erosion or the washout of fine particles from the shell by wave action. Ordinarily, the riprap extends from above the maximum waterline to just below the minimum waterline. If the downstream face is subject to inundation, it also requires riprap protection.

Three types of dams are commonly used:

- Earth dams, which are constructed of compacted dirt or earth fill with flat side slopes.
- Rockfill dams, with relatively loose, open embankments of natural rock, with dimensions suitable for stability.
- Concrete arch dams, which have a concrete wall built in the form of a horizontal arch curved upstream, and anchored into the bedrock by abutments on both sides of the valley.

***Impoundment** description and components.* Artificial impoundments are often dug below the ground surface in a soil which is naturally impervious or treated to become impervious. The shape of the impoundment may be rectangular, square, circular, or quasi-circular, depending on the desired depth and capacity of the pool. The side slopes may range from 2:3 to 1:2 (vertical:horizontal) depending on the types and angle of repose of the soils. Impoundments may be dug by hand or machine. The capacities of typical impoundments of this type range between 500 m^3 and one million m^3 depending on the availability of runoff and the demand for water. A filtration plant or chlorination unit may be added if the water from is to be used for domestic consumption.

Criteria for construction sites. Criteria for a good dam and impoundment site include the following:

- Topography which permits the enclosure of a large volume of stored water.
- Strong and impervious rock formations and soils which permit a sound foundation.
- No existing roads or buildings.
- Availability of construction and fill materials near or within the site.
- Short distances between the reservoir and the agricultural lands to be irrigated or other potential points of use.

Extent of Use

Dams and impoundments are extensively used in Latin American countries and in some Caribbean islands. For example, both Argentina and Aruba use such facilities to collect and store runoff. This is one of the most productive freshwater augmentation technologies. In the northeastern region of Brazil, for example, dams and local impoundments have been built for water supply and irrigation purposes, as shown in Figures 10 and 11. In Panama, this technology has been applied on a regional basis in the provinces of Hen-era, Los Santos, and Coclé. In Suriname, an artificial lake. Lake Brokopondo, was built after the construction of the Apolaka Dam on the Suriname River in 1964. The lake is used as a source of water for hydroelectric power generation. In Venezuela, this technology has been applied to augment water supplies from the Monón River. In Costa Rica, it has been used in the Chorotega region for hydroelectric power generation and for irrigation supply purposes along the Arenal River. In Argentina, impoundments have been constructed on several rivers for hydroelectric power generation and irrigation supply purposes. In Ecuador, reservoirs have been used extensively for water supply and flood control purposes. On Aruba, there are 32 possible catchment areas which are suitable for reservoirs, dams, or storage tanks. Underground barriers were built in Brazil to confine and better utilize surficial aquifers (see case study in Part C, Chapter 5).

Operation and Maintenance

The collection area should be highly impermeable to reduce infiltration losses, and the impoundment should be provided with an overflow device to avoid flooding of adjacent lands during heavy rains. A sedimentation basin at the inlet of the impoundment is also recommended.

In general, most of the construction work is done with local materials, which facilitates maintenance. Dams and reservoir facilities should be inspected at least once a year. Operation of the dam and related facilities, such as pumping stations, hydroelectric power generators, or sluice gates, should be by trained personnel.

In cases where the impounded water is used for hydroelectric production, as in Lake Brokopondo, Suriname, the reservoir level needs to be managed within a predetermined range of elevations. Excessive growths of water hyacinth or other aquatic plants may occur in some lakes and local impoundments, such as Lake Brokopondo, and in extreme cases may interfere with reservoir operations, clogging mechanical devices and increasing local evapotranspiration rates. Further, thermal stratification, which is common in warm water lakes, may lead to deoxygenation in the hypolimnion or bottom waters of the lake. Use of this water can create corrosion problems in the hydroelectric power plants.

Where the user community is not immediately adjacent to the reservoir or dam and a distribution system is required, proper operation and maintenance of the system are essential to avoid leaks, stoppages, and/or other water losses.

In Brazil, large and complex systems, like the one operated by the State of Sao Paulo (to collect and store water and then redistribute it for multiple uses), are equipped with highly sophisticated hydro-meteorological and telemetry systems to provide real-time information to operators on the status of the system, water levels, and water flows. The operation and maintenance of these systems require highly trained personnel.

Figure 10: Dam or Reservoir System used for Irrigation Purposes in Northeastern Brazil.

Source: L. de L. Brito, et. al., "Barragem Subterranea. I. Construção e Manejo," *EMBRAPA-CPATSA Boletim, Pesquisa* 36, 1989.

Figure 11: A Schematic Representation of an Underground Barrier in Brazil.

Source: L. de L. Brito, et. al., "Barragem Subterranea. I. Construção e Manejo," *EMBRAPA-CPATSA Boletim de Pesquisa* 36,1989.

Level of Involvement

Government participation is essential in the construction phase of reservoir and dam systems. In some cases, private companies involved in hydroelectric power generation and large agricultural enterprises are also capable of building these systems. Small systems can be built by local communities or individuals, usually with government assistance to ensure the integrity of the dam structure and management of the water resource. Operation and maintenance can be performed at the community level. The university community in some countries, such as Ecuador, has also provided technical guidelines in the design and construction of local impoundments.

Costs

The construction cost per cubic meter of water varies considerably depending on the region and the size and type of project. In Ecuador, the average cost was estimated at \$0.93/m^3 of water, but the range was from \$0.10 to \$2.00/m^3.

A reservoir and dam system in northeastern Brazil, with a storage capacity of 3 000 m^3, in a drainage area of 3.8 ha, was built at a cost of \$2 500, including soil preparation for cultivation of 1.5 ha of corn. The construction cost of an underground barrier to facilitate utilization of 1.0 ha of surficial aquifer in Brazil was estimated at \$500.

In Costa Rica, water in excess of base flows from the Arenal River is stored in a reservoir and then used for hydroelectric power generation and in an irrigation system in the Tempisque River basin, where precipitation is considerably less than in the Arenal basin. This 6 000 ha reservoir and irrigation project cost $19.8 million to develop. A second phase of the irrigation project, providing water to 11 600 ha, is estimated to cost $45.4 million. The annual operation and maintenance cost is estimated at $55/ha.

A small-scale, 1 600 m^3 impoundment in Costa Rica cost $1 800.

The cost of reservoirs built in the western region of Argentina ranges between $0.60 and $1.20/$m^3$ of storage capacity. The operation and maintenance costs range between $0.01 and $0.03/$m^3$ of storage capacity.

Effectiveness of the Technology

The effectiveness of this technology can be measured by the amount of water that can be stored in the reservoirs or dams, but it is usually measured as a function of the benefits obtained by the utilization of the additional water. For example, in Mendoza, Argentina, irrigation efficiency increased between 8% and 15% following the construction of a reservoir. In Brazil, water stored in the Sao Paulo area and transferred to the Santista basin supplies 100% of the water demand. Previously, the natural water in the Santista basin was able to supply only 10% of the industrial demand. In the region of Llazhatar, Ecuador, the availability of water for domestic and agricultural use has increased four times, from 6 l/s to 25 l/s. In Suriname, because of the construction of the Afobaka Dam, the minimum discharge to Lake Brokopondo increased ten times, from 20 n^/sec to 224 in/sec. Also, the salinity intrusion in the Suriname River moved 30 km downstream after construction of the Dam. Increased irrigation efficiencies of up to 55% were reported in Costa Rica after the construction of the reservoir in the Arenal River. Judging by these experiences, the use of dams and impoundments is a highly effective technology.

Suitability

These methods are applicable in regions where the time and spatial distribution of rainfall are highly variable and storage is required to meet specific demands, such as water supply for irrigation and hydroelectric power generation. Their suitability depends on favorable topography, geology, and economic conditions.

Advantages

- Impoundments provide water for agricultural production and domestic water use in arid and semi-arid regions.

- Impoundments provide water for hydroelectric power generation and other, non-consumptive uses.

- The flora and fauna of a region, and particularly the fisheries, may be enhanced, although large dams develop a lacustrine fauna over time that gradually replaces the pre-existing riverine fishes.

- The degree of water pollution may be decreased by dilution of contaminants.

- The perennial flows from impoundments could reduce saltwater intrusion in certain rivers by increasing minimum flows and levels.

- Impoundments are ideal for multiple-use water projects.

- Reservoirs can be used as recreational areas.

Disadvantages

- Impoundments require the availability of land with the proper topography, and generally consume valuable agricultural land when the lake basins are filled.

- To minimize seepage losses, impoundments need impermeable soils (soil with less than 15% content of clay).

- Impoundments can lose an average of 50% of the total volume of water stored in the reservoir to evaporation and infiltration in arid and semi-arid areas.

- Construction costs are relatively high.

- There is a risk of possible failure.

- Impoundments can flood adjacent lands during wet periods.

- Impoundments can produce environmental impacts and exacerbate public health and other problems as people and animals are attracted to the lake shores.

Cultural Acceptability

Dams, reservoirs, and impoundments are widely accepted as a water supply augmentation method for developed and developing countries. Both the engineering and the local communities have used this technology in small-scale (e.g., farm dams) and large-scale projects.

Further Development of the Technology

Research has improved the design of local impoundments and small-scale dams, making them more efficient in retaining water, preventing failures, and reducing evaporative losses. Improvements in operation can be very beneficial. Methods to further reduce evaporation should be developed. Impermeable, low cost materials to line the local impoundments and reduce infiltration should also be developed.

Information Sources

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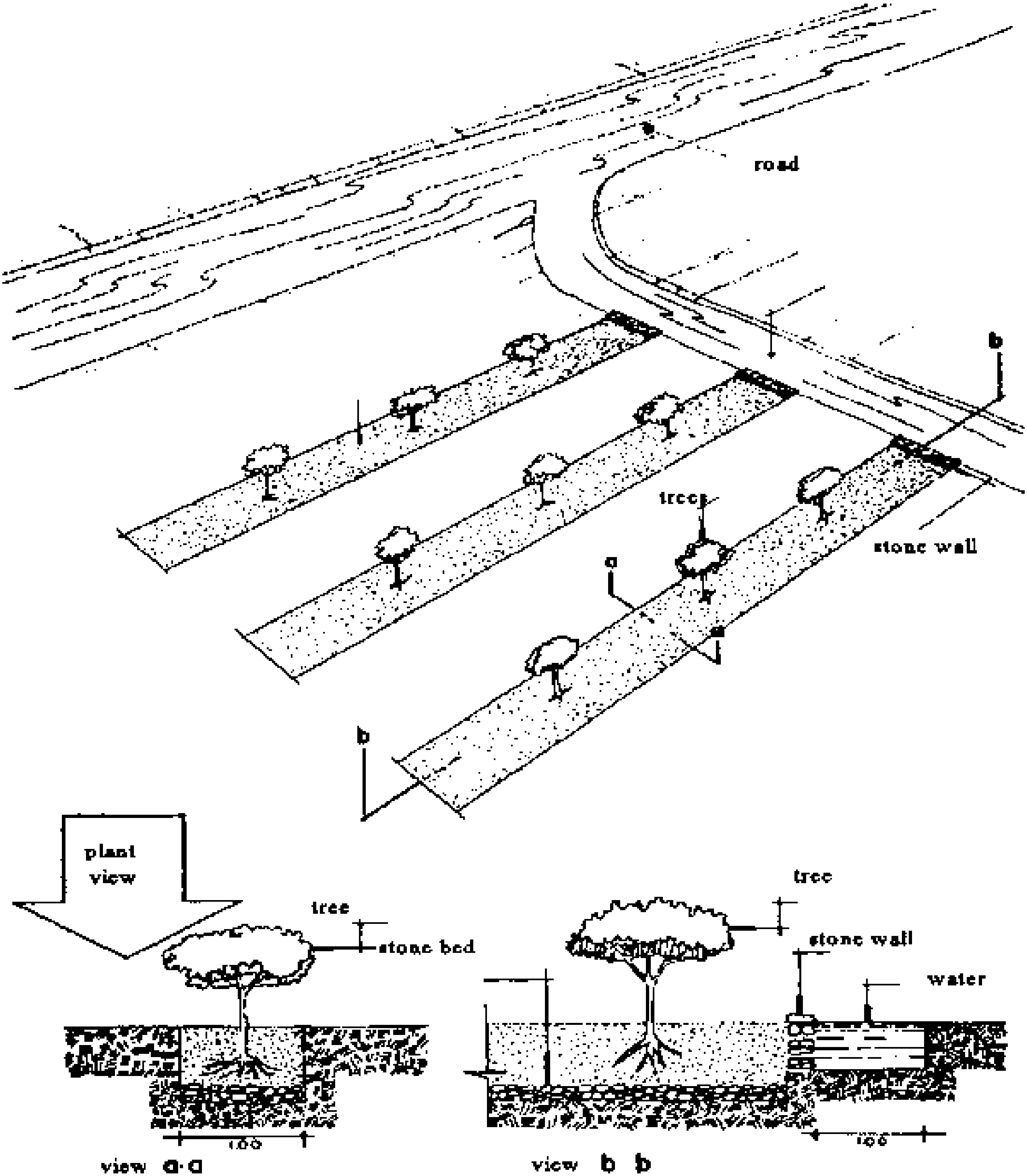
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1.6 Flow diversion structures technical description

Diversion structures route runoff in excess of base flow to storage facilities during wet periods, for later use during dry periods. Flood diversion structures, such as dikes, are also useful methods for mitigating the adverse effect of torrential rains and at the same time capturing the excess water for later use. The following types of structures have been used to divert flood water for water supply augmentation purposes.

- Transverse Dikes

Transverse dikes are built in sections along a river to store excessive runoff. These dikes can be built using material dredged from the river or transported from adjacent lands. The dike material, usually clay or silt, must be highly compacted and in many cases it is advisable to place riprap on the dike to increase its strength and protect it from erosion.

- Homemade Diversion Structures *(toroba)*

Toroba are homemade diversion structures built of wooden poles, taken from trees such as the *curari* and *cuji* in Venezuela, vegetation residues, and logs. The wooden poles are 50 and 130 cm in length and are placed at intervals of 50 cm to 70 cm to define a wall of debris that will divert the runoff. This technique may also increase infiltration to the groundwater.

- Water Traps

Water traps are used to control the deleterious effects of runoff in a river basin and to facilitate water storage and the recharge of aquifers. They are built like an earth dam, usually 1 m to 3 m high, using local materials. The walls are compacted in 20 cm layers using the same equipment as is used to build a dam. The edges are trapezoidal with an embankment slope of 2.5:1 at high water and 2:1 at low water. The bottom width of the water trap is 2.5 m. They are normally located across a river bed, segmenting the channel into compartments. Water traps are usually designed to handle runoff produced during a l-in-5 0-year rainfall. The volume of runoff captured depends upon the catchment area and the intensity of the rainfall.

Extent of Use

Transverse dikes have been used on rivers in the State of Sao Paulo and in the Serra do Mar region, Brazil. Water traps have been used in arid and semi-arid regions, particularly in the Province of Mendoza, Argentina. They have been very useful in reducing sedimentation and limiting the risk of flooding. *Toroba* are used in the State of Falcon, Venezuela. This technique has limited utility, but can be helpful in rural areas that lack technical resources.

Operation and Maintenance

The operation of these types of diversion structures is very simple. They require continual maintenance to repair damage caused by large storms and to control erosion, especially around the abutments, which can breach the dikes and water traps and significantly damage the homemade structures.

Water traps require maintenance during the first few years of operation, until natural vegetation grows again in the area. When rains heavier than the design flow conditions occur, it is possible that the traps will be breached and will need to be rebuilt. All-terrain recreational vehicles used in areas at or near the water traps can cause damage that may need additional maintenance or repair.

Figure 12: A Schematic Representation of a Homemade Structure *(Toroba)* in Venezuela.

Source: Douglas Martinez, FUDECO, Barquisimeto, Venezuela.

Level of Involvement

Homemade structures can be built, operated, and maintained by local communities but may require technical assistance from government agencies and/or nongovernmental institutions and the private sector. Dikes and water traps require the participation of the government and private sector, primarily in management of the volume of water retained behind these structures and in ensuring their safe and sound construction.

Costs

The construction costs of dikes can range from $ 10 000 to millions of dollars, depending on the size of the river, the length and width of the dikes, and the scale of the project. The cost of homemade structures is minimal, since all of the materials are locally available. The cost of a small water trap in Argentina has been estimated at between $130 and $170.

Effectiveness of the Technology

Diversion structures are very effective in reducing sediment erosion, retaining runoff, and encouraging groundwater infiltration. Water traps have been successfully used for more than 25 years in Argentina. They have been very useful in controlling sedimentation, and reducing the risk of flooding, within river basins.

Suitability

Diversion structures are suitable for use in river basins *where* sufficient volumes of water can be diverted and stored for later use. Areas like Serra do Mar in southeastern Brazil, Falcon State in Venezuela, or the San Juan River basin in Argentina are typical areas well suited for the application of this technology.

Advantages

- Diversion structures enable the use of water that normally would run off.
- Diversion structures provide some in-stream control of erosion and sedimentation.
- Diverted water may serve as a source for groundwater recharge.
- Water velocities in river channels are reduced.

- Soil fertility is improved by retaining water on the land surface and reducing soil loss.
- Retention of runoff may contribute to biodiversity and ecosystem restoration by reducing erosion and retaining water on the land surface.

Disadvantages

- Construction of diversion structures may disrupt vegetation.
- Structures may be breached by storms that exceed the design flows/capacities.
- Structures may adversely affect aquatic flora and fauna by altering flow patterns and flooding regimes.

Cultural Acceptability

Flow diversion structures are widely accepted among the engineering community as a method to control erosion and sedimentation, and augment water supply. Greater acceptance by local communities could yield substantial local benefits.

Further Development of the Technology

It is important that more data on the performance and problems of diversion structures be acquired in order to assess and suggest possible improvements. Greater educational programming on the use of this technology as a tool for river basin management should be planned and carried out.

Information Sources

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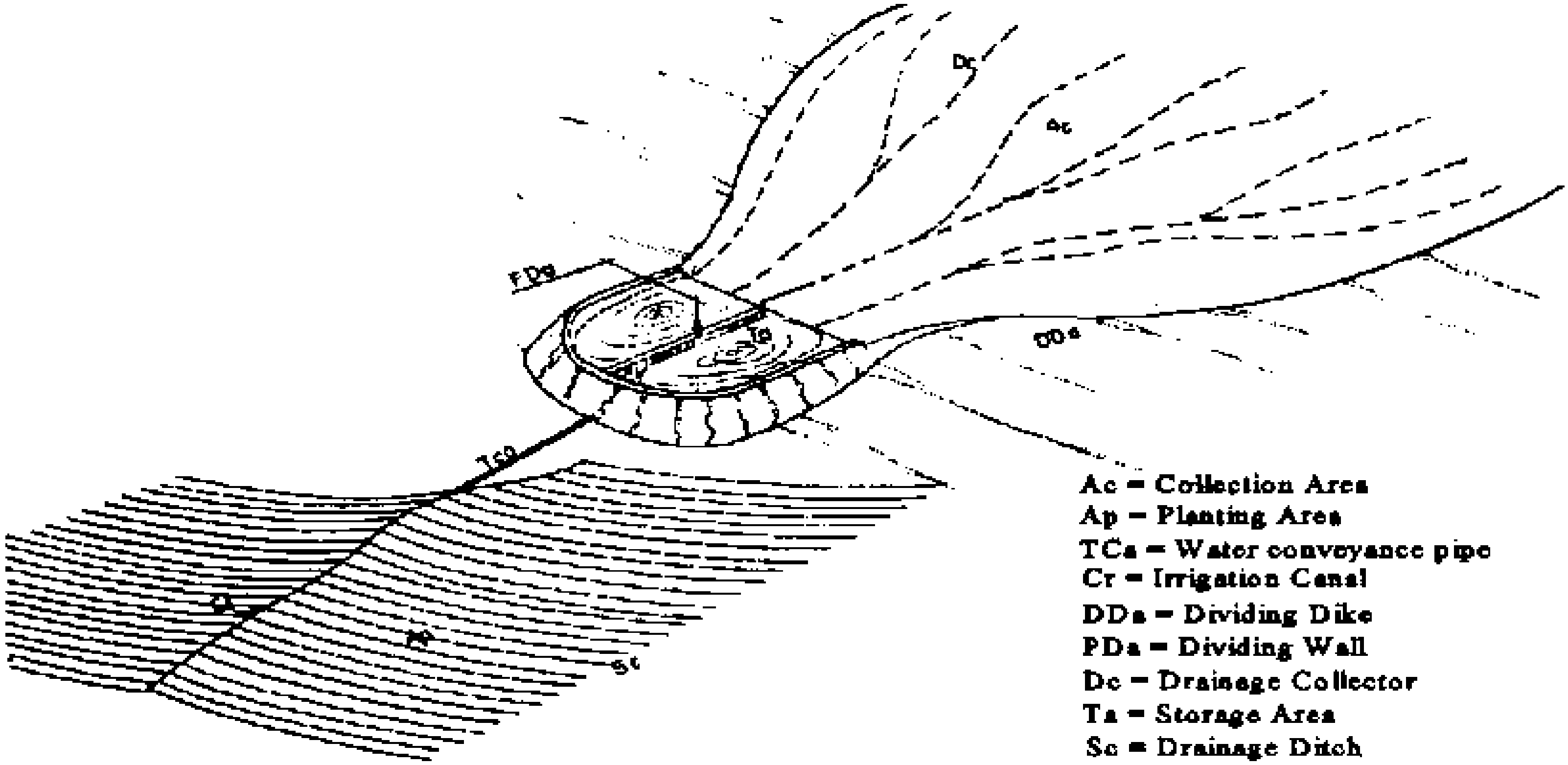
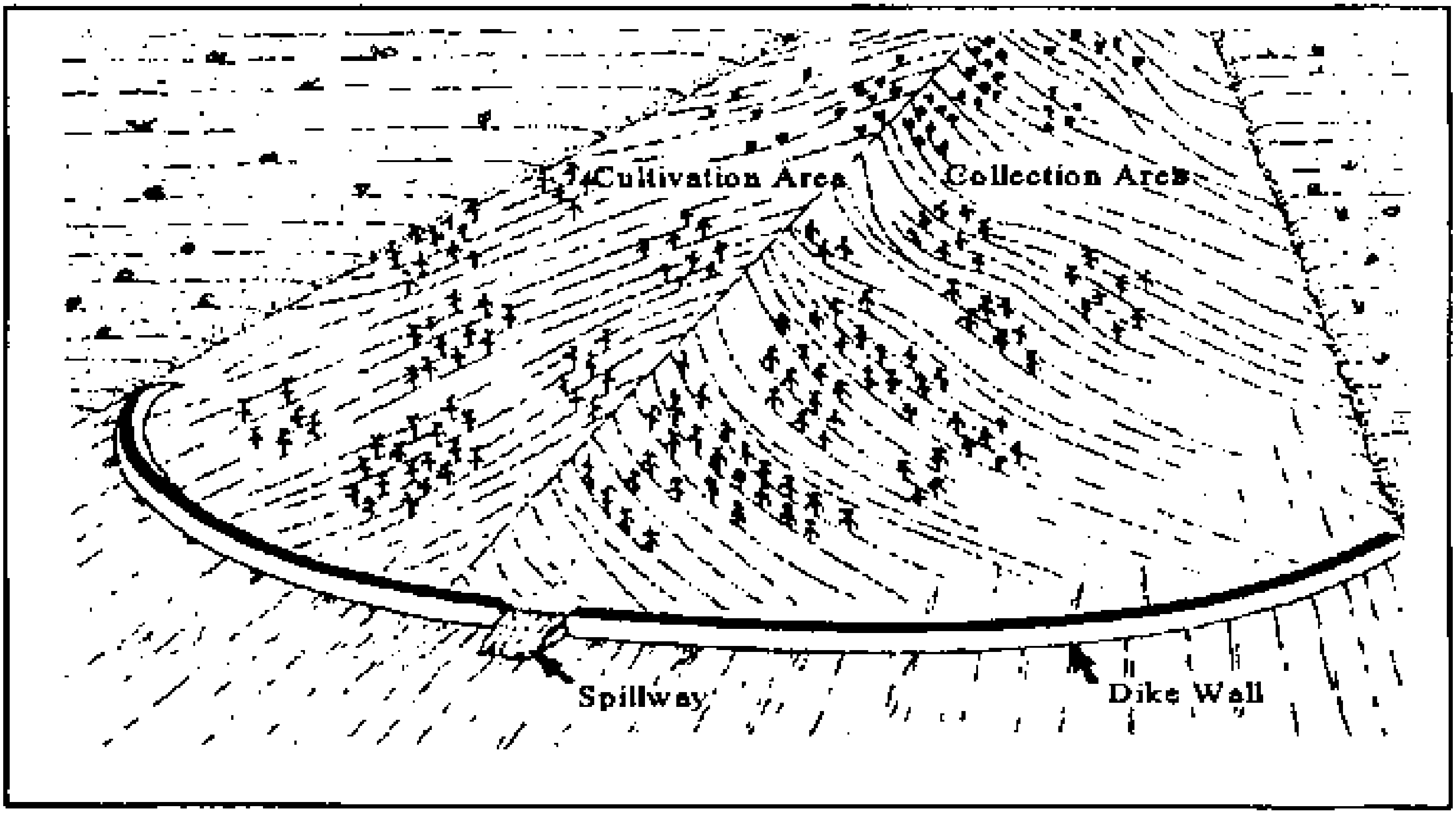


Ac = Collection Area
Ap = Planting Area
TCa = Water conveyance pipe
Cr = Irrigation Canal
DDa = Dividing Dike
PDa = Dividing Wall
Dc = Drainage Collector
Ta = Storage Area
Sc = Drainage Ditch


Cultivation Area
Collection Area
Spillway
Dike Wall

1.7 Water conveyance by marine vessels

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

Technical Description

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

Extent of Use

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

Operation and Maintenance

The main operational problem experienced in the use of marine vessels is weather delays. Based on the experience in the Bahamas, barges are unable to operate on an average of approximately 25 days per year. The second most frequent problem experienced is mechanical breakdown of the vessels, which can halt water transportation for a period of 1 to 7 days per incident. Approximately 15 days per year are lost due to mechanical problems.

The Water and Sewerage Corporation on Andros employs one person, periodically assisted by a second, to manage the charter operation. The need of the Corporation for spare parts is minimal (repairs are undertaken by the charter operator) and the skill level required to fill and empty the barge is very basic. Of greatest concern to the Corporation is assuring the purity of the transported water. The Corporation maintains its own laboratory to test the water, and treatment facilities are available to provide any necessary treatment before the water is introduced into the supply system.

Level of Involvement

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

Cost

Transporting water by marine vessels is generally more costly than other alternatives. However, this form of waterborne transport does have merit during emergencies.

The cost of barging water from the island of Dominica to the island of Antigua is $20/1 000 gal landed in Antigua; to transport the 1 000 gal by truck from the port of St. John costs between $25 and $50.

The key to low-cost water transportation by barge or tanker is transporting large quantities using large tankers continously over the long term. Economies of scale significantly reduce the unit cost of water transported in this manner. However, for this type of transportation to be effective, there must be very efficient loading and unloading facilities. If these do not already exist, they can be very expensive to construct. The shipment cost of water transported in the Bahamas between Andros Island and New Providence is about $3.41/1000 gal, including fuel costs. Factoring in the cost of the shore facilities (the Water and Sewerage Corporation owns both the production facility on Andros and the receiving facility in New Providence), the total cost of the water is approximately $5.84/1 000 gallons shipped.

Effectiveness of the Technology

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

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

Suitability

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

Advantages

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

Disadvantages

- There is a lag period before the technology can be implemented; start-up times to charter a ship are generally about 3 to 6 months.
- Operations are affected by the weather; shipping may be halted when winds are greater than 27 knots and the seas higher than 11 ft.
- The cost of transportation is high and in some cases may be prohibitive.
- Transportation times are relatively slow.
- The quality of the water at the point of use may be difficult to assure, owing to possible contamination by seawater and/or other contaminants during transportation.
- Water must be distributed from the barge to the consumers.

Cultural Acceptability

The use of this technology is well accepted in the Caribbean islands where the water bome transportation of water is feasible.

Further Development of the Technology

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

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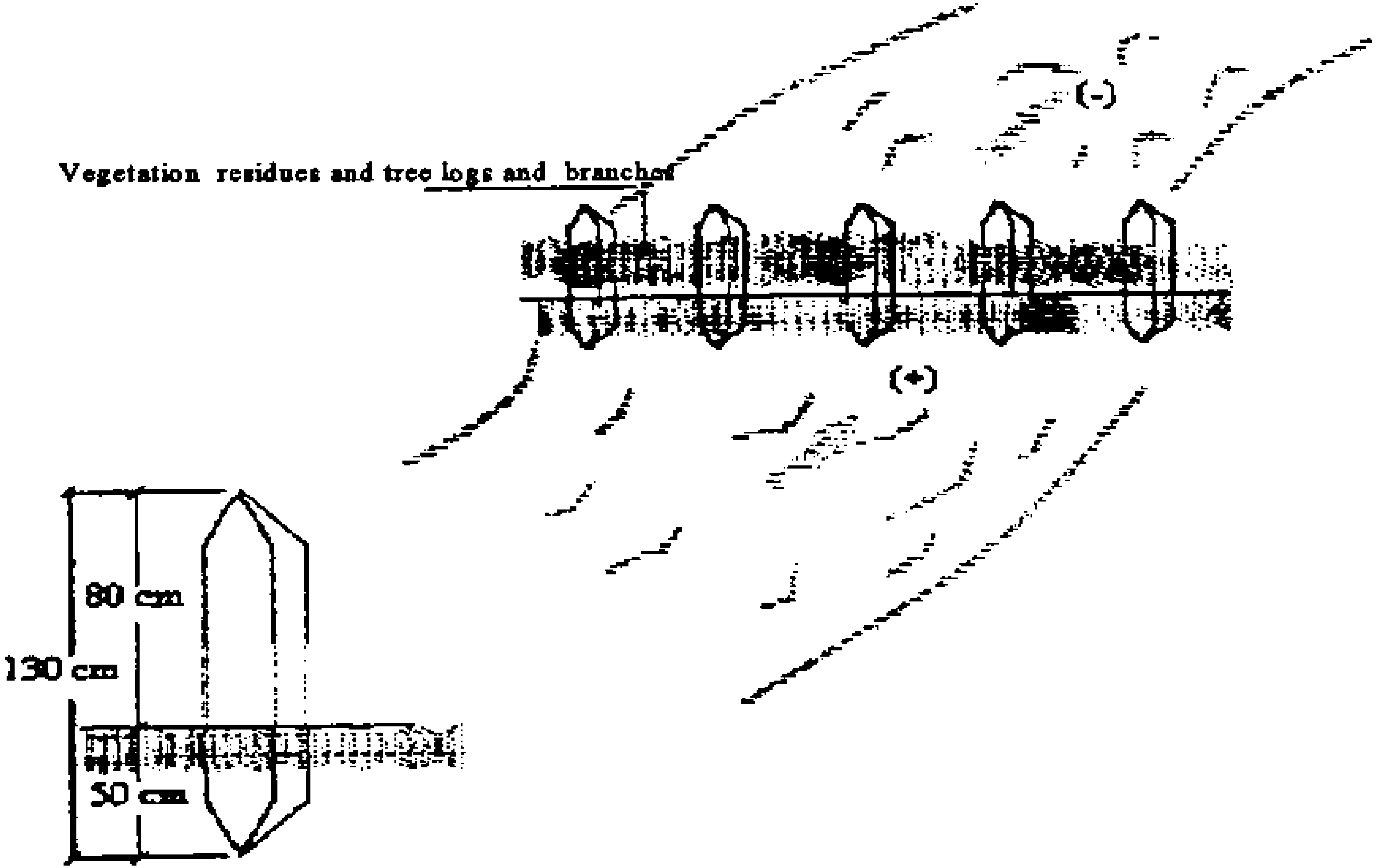
Vegetation residues and tree logs and branches
(-)
(+)
80 cm
130 cm
50 cm

1.8 Water conveyance by pipelines, aqueducts, and water tankers

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

Technical Description

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

• Tanker Trucks

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

• Pipelines

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

• Aqueducts

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

Extent of Use

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

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

Operation and Maintenance

Pipelines and aqueducts, whether operated by gravity or by a pumping system, need regular maintenance and repair of the pumps, pipes, and canals, and periodic upgrading of the facilities. Problems with water leaks, pumps, and storage facilities require immediate attention in order to avoid interruption of services.

Maintenance of the distribution system includes servicing the pumps and other treatment plant components, inspecting the diversion systems and pipelines, repairing leaks, and replacing electrical motors and other moving parts. A number of problems were encountered in the operation and maintenance of a distribution system in Jamaica.

The level of skill needed to operate these systems is medium to high, and involves some technical training of the operators.

Level of Involvement

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

Costs

The costs of these conveyance systems vary depending on their capacity and complexity, as a function of the terrain, the availability of labor, and the demand to be met. For example, in Panama, a small aqueduct system designed to serve a few families cost $500. In Jamaica, the cost of gravity and pumped-source pipeline conveyance system is shown in Table 3.

Table 3 Cost of a Pipeline Water Transfer System

Source Type	Project Capacity	Length of Pipeline	Diameter of Pipeline	Capital Cost
Pumped	45 400 m^3/day	6.5 km	76.0 cm	$30 million
Gravity	104 000m^3/day	30.6 km	96.5 cm	$15 million

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

Effectiveness of the Technology

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

Suitability

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

Advantages

Tanker trucks:

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

Pipeline and aqueduct systems:

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

Disadvantages

Tanker trucks:

- Water prices are increased because of the expense of transporting relatively small quantities by road.
- There is a lack of quality control.
- Water distribution is costly and slow.

- Adequate roads are required to transport water from one region to another.

Pipeline and aqueduct systems:

- The capital cost is high; it usually requires borrowing, thus adding to the country's national debt.

- The skilled personnel needed to operate and maintain the project are not always locally available.

- If the water transported is of poor quality, it will contaminate the water resources of another basin where the necessary treatment to rectify the problem may not be available or affordable.

- River diversion projects can create environmental problems downstream for aquatic life and water users, and can result in the transfer of nuisance species from one basin to another, exacerbating water quality problems throughout a country.

- Transporting large quantities of water can deplete the resources available within the supplying basin.

- Vandalism of the pipeline and appurtenances can occur unless the communities through which the pipeline passes are served by the water supply.

- Environmental impacts, such as threats to endangered species, must be carefully considered and actions taken to minimize negative impacts.

Cultural Acceptability

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

Further Development of the Technology

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

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1.9 Artificial recharge of aquifers

The use of artificial recharge to store surplus surface water underground can be expected to increase as growing populations demand more water, and as the number of good dam sites still available for construction becomes fewer. For example, artificial recharge may be used to store treated sewage effluent and excess stormwater runoff for later use. Groundwater recharge may also be used to mitigate or control saltwater intrusion into coastal aquifers. However, in order to accomplish the uses without deleterious environmental consequences, the optimum combination of treatment methodologies before recharge and after recovery from the aquifer must be identified. It will also be necessary to consider the sustainability of soil-aquifer treatment and health effects of water reuse when using treated wastewater as the recharge medium.

Technical Description

The main purpose of artificial aquifer recharge technology is to store excess water for later use, while improving water quality (decreasing the salinity level) by recharging the aquifer with better water. There are several artificial recharge techniques in use in Latin America and the Caribbean, including infiltration basins and canals, water traps, cutwaters, surface runoff drainage wells, septic-tank-effluent disposal wells, and diversion of excess flows from irrigation canals into sinkholes.

• Infiltration Basins and Canals

This technology has been used extensively in the San Juan River basin of Argentina, where two artificial recharge experiments have been conducted. The first experiment consisted of the construction of infiltration basins, 200 m by 90 m and 1.2m deep. These basins were combined with 9.30 ha of infiltration canals in the second experiment. This system was used to recharge the 10 hm^3 aquifer in the Valley of Tulum. The system of canals was found to be more efficient than the infiltration basins because the high circulation velocities in the canals precluded the settling of fine material and resulted in higher infiltration rates.

• Water Traps

Water traps are used to increase infiltration in streambeds. The traps are earthen dams of variable height, usually 1 m to 3 m, that are constructed of locally available materials. They are normally perpendicular to river banks, depending on the characteristics of the stream system. Water traps are designed to operate during rainfalls of up to a l-in-50-year frequency. They are typically constructed along a 1 km stretch of river, at intervals of 70 m to 100 m. Their storage capacities fluctuate between 250 and 400 m^3. They have an estimated life span of 20 to 25 years, given proper maintenance.

• Cutwaters

This technology can be used in areas where there are no rivers and creeks, such as in the Paraguayan Chaco. Cutwaters are excavations of variable dimensions, used as reservoirs, built in low-lying areas.

Their primary objective is the harvesting of surface waters. Those to be used for artificial recharge are built on top of permeable strata; those for surface water storage are built on impermeable substrates.

• Drainage Wells

The limestone and coral rock formations that comprise the principal aquifer in Barbados consist of very pure calcium carbonate. Drainage wells, or "suckwells", are used to dispose of drainage waters (see Figure 13). The depth of the drainage wells is determined by the well digger and is based on reaching an adequate fissure or "suck" in the rock. They range in area from 16 ft^2 to 36 ft^2, and are either square or circular in shape. They are provided with guard walls of concrete or coral stone above the ground surface and drainage ports or underground pipes or culverts to conduct runoff into the wells.

Figure 13: Suckwell Construction.

Source: Government of Barbados, Stanley Associates Eng. Ltd., and Consulting Engineers Partnership Ltd. *Barbados Water Resources Study,* Vol. 3: *Water Resources and Geohydrology*, 1978.

• Septic Tanks and Effluent Disposal Wells

Another source of artificial groundwater recharge is effluents from septic tanks, using soakaways. The Barbados Water Resources Study of 1978 estimated that about half of the 128 million I/day water used for domestic consumption, or approximately 64 million I/day, is returned to the groundwater as septic tank effluent. The soakaways used for this purpose are very similar to suckwells in design and construction, except that they are used in conjunction with septic tanks and are always covered.

• Sinkhole Injection of Excess Surface Flows

In Jamaica, excess surface runoff is treated and discharged into sinkholes in karstic limestone aquifers. These aquifers are commonly associated with seawater intrusion and are highly saline. The recharged water is monitored through a series of monitoring and production wells. Monitoring is carried out to measure changes in groundwater levels and water quality (salinity levels).

Extent of Use

Artificial recharge has been widely used in several Latin American countries and the Caribbean. It may be expected to be utilized more frequently as demand for water increases and as surface water resources are fully committed.

In Argentina, a system of canals and infiltration basins has been used in the provinces of San Juan, Mendoza, and Santa Fe with relative success. Water traps have also been used in Mendoza. This is an effective technology for use in arid and semi-arid regions.

Cutwaters have been used in the Paraguayan Chaco, where rainwater is the main source of aquifer recharge. This technology is normally used for recharge of surficial aquifers, and its application is limited by the hydrogeologic conditions. In Barbados, suckwells are extensively used for recharge, except in areas on the east coast which lack the necessary coral formations and where the exposed oceanic soil (consisting of a mixture of clay, marl, silt, and sand) has a low permeability. There are probably more than 10 000 suckwells, mostly on private lands or estates. They are at elevations of 20 ft above sea level or higher, and usually are well maintained.

The technology in Jamaica of using sinkholes as injection points is applicable where karstification of a limestone aquifer has taken place. Artificial recharge is suitable for areas upgradient of an aquifer where there is significant water for recharge purposes and land area available for treatment of the runoff before recharge. Treatment consists primarily of settling suspended solids. It is best used in areas where pumping is not needed to move the water to the sinkholes.

Operation and Maintenance

Infiltration basins and canals require minimal maintenance, consisting mostly of avoiding excessive sedimentation in the basins and canals and preventing erosion of canal banks. A bulldozer is often used in the infiltration basins to remove accumulated sediments and to rehabilitate the system.

Water traps require maintenance during the first few years of operation, until the natural vegetation grows again in the area. Intense rainfalls may damage or destroy the traps, and they will have to be rebuilt.

Maintenance of cutwaters is similar to that required in infiltration basins. Runoff from areas with unpaved streets can carry large loads of sediment, which may be deposited in cutwaters and will need to be removed during dry periods.

Road drainage is also a source of water for suckwells in Barbados. These roadside wells are built and maintained by the government. Other suckwells, on residential and plantation lands, are maintained by the landowners. Maintenance is labor-intensive and generally involves the removal of silt, which accumulates at die bottom of the well and may plug the "suck", rendering it useless. Repairs to the guard walls, covers, and iron grilles are also needed. Unfortunately, owing to increased labor costs and declines in profitability at most sites, many of these wells have fallen into a state of disrepair and have been either plugged, stuffed up, or overgrown with trees. Some of these wells have been contaminated by garbage dumped into them.

In sinkhole injection, operations are simple. The canal attendant, who normally resides nearby, visits the site twice a day to read the Parshall flumes, collect water samples, and open or close sluice gates. The earth canals need to be kept clear to ensure maximum delivery of water. The settling basin has to be cleaned of accumulated sediment and vegetative growths once every four to five months. Vandalism, resulting in damage to sluice gates, sinkholes, and monitor wells, is also a problem in the maintenance of the system.

Level of Involvement

In Argentina, most of the experimental use of this technology has been done by the government in both the provinces of San Juan and Mendoza.

In Paraguay, the government, in conjunction with international organizations, has been conducting experiments to quantify the recharge provided by different recharge systems. In general, the implementation and maintenance of these technologies in urban areas have been carried out by municipal governments, but in rural areas by (he private sector.

Both the private sector and the Government of Barbados have been involved in the successful implementation of artificial recharge schemes. The private sector, primarily represented by the sugar industry, has encouraged the development of this technology and provided land, manpower, and water.

The government, represented by the Water Authority, has provided technical expertise and financing.

In Jamaica, there is a cadre of well-diggers who can be contracted by the government, plantation owners, and other landowners to both dig and maintain drainage wells. An ongoing educational program informs landowners of the need to maintain wells on a regular basis, the potential for groundwater recharge from the wells, and the need to monitor contamination of the groundwater.

Costs

The estimated cost of infiltration of surface water in Argentina, using basins and canals, is $0.20/m^3. The basins and canals used in the 1977 experiment in the San Juan River basin incurred a capital cost of $31 300. The comparable cost of water traps in Argentina has been estimated at between $133 and $167. The capital cost of a 5 700 m^3 cutwater, equipped with a 14 m extraction well, is estimated at $6 325. The operation and maintenance cost is estimated at $248 per year. The production costs are estimated to be about $0.30/m^3 for the first five years of operation, $0.17/m^3 for the next five years (five to ten years of operation), and $0.15/m^3 for the following five years (ten to fifteen years of operation).

In Jamaica, the initial capital cost of the sinkhole injection system is estimated at less than $15 000. This cost is primarily related to the construction of the inflow settling basin and channels conveying the runoff water to the sinkholes. Maintenance costs are low, less than $5 000 for the 18-month project (or under $3 500/year).

Effectiveness of the Technology

In Argentina, sites near the San Juan and Mendoza rivers recharged the underlying groundwater aquifer at the rate of 60 l/sec/ha during a three-month period.

Water traps have been successfully used for more than 25 years in Argentina. They have been very useful in reducing sedimentation and risk of flooding.

Cutwaters proved a significant source of water to communities during the droughts of 1993 and 1994 in the Paraguayan Chaco. Recovery of 75% of the infiltrated water has been reported in that region.

Even though groundwater recharge is not the principal intended use of drainage wells, it is a major indirect beneficiary. Infiltration rates in coral rock in Barbados have been estimated at between 6.0 and 6.5 cm/hr and are known to be highest where solution openings (or "sucks") occur.

In Jamaica, total recharge over 18 months amounted to 4 million m^3. Two groundwater mounds were detected downgradient of sinkholes. One mound indicated an increase of 4.1 m in water levels, while at the other the increase was 6.7m. Divergent radial flows developed from both of these mounds. Once recharge ceased, the mounds gradually disappeared over a two-month period. Chloride concentrations in some wells in Jamaica have decreased from 2 300 mg/l to 1 700 mg/l and in others from 170 mg/l to 25 mg/l before reaching an equilibrium at 50 mg/l. In general, most wells influenced by artificial recharge have shown declines in salinity levels.

Suitability

In areas where groundwater is an important component of the water supply, and rainfall variability does not allow for a sufficient level of aquifer recharge by natural means, these technologies provide for the artificial enhancement of the natural recharge. Storage of surface runoff in underground aquifers in arid and semi-arid areas has the advantage of minimizing evaporative losses. However, use of these technologies requires an appropriate geological structure. In areas underlain by igneous rock, the natural fracture lines can be expanded by injection of water under pressure and infusion of a sand slurry into the gaps thus created. Given the cost of this latter measure, however, use of natural limestone or sandstone formations, such as are common in the Caribbean islands, is preferred and most cost-effective.

Advantages

- The technology is appropriate and generally well understood by both the technicians and the general population.
- Very few special tools are needed to dig drainage wells.
- Because of the structural integrity of the coral rock formations, few additional materials are required (concrete, softstone or coral rock blocks, metal rods) to construct the wells.
- Groundwater recharge stores water during the wet season for use in the dry season, when demand is highest.
- Aquifer water can be improved by recharging with high quality injected water.
- Recharge can significantly increase the sustainable yield of an aquifer.
- Recharge methods are environmentally attractive, particularly in arid regions.
- Most aquifer recharge systems are easy to operate.
- In many river basins, control of surface water runoff to provide aquifer recharge reduces sedimentation problems.
- Recharge with less-saline surface waters or treated effluents improves the quality of saline aquifers, facilitating the use of the water for agriculture and livestock.

Disadvantages

- In the absence of financial incentives, laws, or other regulations to encourage landowners to maintain drainage wells adequately, the wells may fall into disrepair and ultimately become sources of groundwater contamination.
- There is a potential for contamination of the groundwater from injected surface water runoff, especially from agricultural fields and roads surfaces. In most cases, the surface water runoff is not pre-treated before injection.
- Recharge can degrade the aquifer unless quality control of the injected water is adequate.
- Unless significant volumes can be injected into an aquifer, groundwater recharge may not be economically feasible.
- The hydrogeology of an aquifer should be investigated and understood before any future full-scale recharge project is implemented. In karstic terrain, dye tracer studies can assist in acquiring this knowledge.

- During the construction of water traps, disturbances of soil and vegetation cover may cause environmental damage to the project area.

Cultural Acceptability

Artificial groundwater recharge is generally well accepted by communities in areas where it is used.

Further Development of the Technology

Potential improvements in artificial recharge technologies include:

- Improvements in the design of pre-injection silt chambers, grease traps, and oil interceptors to reduce the amount of contaminants entering drainage wells.

- Improvements in the design of injection wells to eliminate the use of "sucks".

- Evaluation of groundwater contamination potentials from various sources of artificial recharge, and the adoption of techniques to reduce the associated impacts or risks.

- Improvements in the design of water traps to increase groundwater recharge efficiency.

- A better understanding of the causes and consequences of bacterial and viral contamination of aquifer systems, and the means of minimizing and mitigating such risks.

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1.10 Pumps powered by non-conventional energy sources

Pumping facilities are required wherever water is stored at or below ground level. Conventionally powered pumps, such as diesel and electric pumps, require readily available sources of fossil fuels or electricity. In countries where access to conventional energy is limited by cost or sources of supply, pumps powered by non-conventional energy systems may provide an alternative.

Technical Description

Several types of pumps powered by non-conventional energy have potential utility in Latin American countries. Different types of pumps have been tested with mechanisms fabricated from local materials, using limited fabrication skills and available energy sources. They include the following:

• Hydraulic Pumps

The hydraulic pump or water wheel is driven by the energy of the moving water in a river. The circular movement of the wheel is transmitted via a 1 in. diameter shaft, fitted with an offset arm, to the piston of a small pump. In Peru, typical pumps of this kind have capacities of 0.2 to 6.0 l/sec.

• Hydraulic Ram Pumps

The hydraulic ram is a simple pump, in universal use, driven by the energy produced by differences in hydrostatic pressure, which activates a valve and raises the water. A ram can pump approximately one tenth of the received water volume to a height ten times greater than the intake.

• Rope Pumps

The rope pump consists of a loop of nylon rope with rubber gaskets attached to it. The gaskets slip through the interior of a PVC pipe 1 in. in diameter. The rope pump is operated manually by rotating a wheel, which pulls the rope through the pipe. The effort necessary to turn the handle depends on the length of the pipe and the depth of the water. The length of a pipe 1 in. in diameter can range from 1 m to 12 m. A schematic of a rope pump manufactured in Bolivia is shown in Figure 14.

• Hand Pumps

There are many different variants of the hand pump, with different designs that can be locally built or purchased ready-made. Hand pump systems can be installed below or above ground. Field experiments have been conducted in Bolivia using the INTI direct-action hand pump, the Bolivian equivalent of the Tara pump developed for use in Bangladesh. This pump, as used in Bolivia, has a lifting capacity of up to 15 m, and a ratio of 0.7:1 between the diameters of the interior pipe, which functions as a piston, and the exterior pipe, which conveys the water to the required height, as shown in Figure 15.

• Windmill Pumps

The windmill pump is operated by making use of wind energy. The energy generated by the wind moves a rotor which translates to the vertical movement of a piston in the pump. Water is then drawn up through the internal pipe, reaching heights of up to 7 m, depending on the tower size. Windmill-powered pumps can lift water to a height of 20 m. The pump capacity is a function of wind speed and the suction elevation. At wind speeds of 4 m/s, pump capacities range between 0.5 and 1.5 Vs over suction heights of 20 m and 5 m, respectively. For the same suction heights but twice the wind speed, the capacities range between 3.2 and 4.0 l/s.

Figure 14: Schematic of a Rope Pump.

Source: Freddy Camacho Villegas, Institute of Hydraulics and Hydrology, University of San Andrés (UMSA), La Paz, Bolivia.

Figure 15: Schematic of a Direct-Action Hand Pump.

Source: Freddy Camacho Villegas, Institute of Hydraulics and Hydrology, University of San Andrés (UMSA), La Paz, Bolivia.

• Photovoltaic-Powered Pumps

In spite of the abundance of solar radiation in Honduras, photovoltaic solar energy has not been used as much as expected. A technical assistance program to develop water sources for human consumption on Roatán Island off the Honduran coast used solar panels and a photovoltaic-powered pump system to raise the water to a 13 000 gal, reserve water storage tank. The pumping system consisted of a submersible electric pump directly connected to a photovoltaic cell system and operated continuously whenever there was enough sunshine.

Extent of Use

Demand for hand pumps in individual countries in Latin America and the Caribbean is potentially on the order often of thousands. However, the relatively small, localized markets where this technology is most in demand may not attract the large manufacturers. Thus, there are excellent opportunities for small- and medium-sized firms providing pump sales and servicing. The types of pumps used vary with the applications desired, although their use is widespread.

The use of hydraulic pumps in Honduras is limited to the southern, northwestern, and northern sections of the country, where rivers of sufficient size are located. In contrast, they are widely used in Peru.

Hydraulic ram pumps, operating in lower volume river flows, have been adapted for use in numerous areas of Honduras, including the central zone and the eastern, western, and northwestern sections. This technology is functional for use in rural development, primarily for domestic use, livestock watering, and crop irrigation.

Rope pumps, because of their simplicity of design and ease of construction, are used in many countries. They are usually built locally by the individual operators. These pumps are used extensively in Honduras, Peru, Haiti, and Bolivia.

Windmill-driven pumps are used relatively rarely. Although very functional, they are mainly used for domestic water supply and cattle watering on a small scale. This technology has been used in Peru and the central region of Panama. Windmill pumps of similar design have been used in Honduras and in Centro Las Gavistas, Colombia. In Peru, windmill-powered pumps have 12 arms, 5 m in diameter, which can reach 30 rpm at a height of 6m above the ground. The pump mechanism consists of a reciprocating piston 6 in. in diameter, a cylinder, a casing, and a discharge pipe.

Photovoltaic technology can provide electric power to drive water pumps in areas with abundant insolation. However, its high cost and sophisticated technical requirements limit its use. Most individuals, communities and institutions would find this technology too expensive at its present level of development. Roatán Island, Honduras, in the Caribbean Sea, is not fully served by conventional sources of electricity and for this reason is one of the few places in Honduras where solar pump technology is utilized; four systems provide service to four communities. Photovoltaic-powered pumps have also been tested in Haiti.

Operation and Maintenance

Operation of most of these non-conventional systems is relatively simple, although most require additional labor. Some of the pumps, like the hand and rope pumps, require constant attention to keep them operating efficiently. Most of the pumps require the use of anti-corrosive paints to protect the exposed metal parts, and frequent oiling (twice a month) of the parts of the pump where friction between different parts can be expected. However, it is important to avoid the use of heavy-metal-based (e.g., lead paints) and to avoid contaminating the insides of the pumps with hydrocarbon residues, especially if the water is to be used for human consumption. Such contamination can lead to chronic public health problems. In general the following factors should be considered in the design of a hand pump system:

- Non-wearing parts of the pump must be durable and reliable enough to last at least ten years.

- The wearing parts should be readily accessible, require no special skills to service, be inexpensive to replace, and be of consistent high quality to ensure interchangeability.

- A below-ground system should be as light as possible so that it can be extracted when necessary, even from deep wells, without the need for specialized lifting equipment.

- The impact of corrosion should be minimized by using materials which are inherently corrosion-resistant.

- Pumps should be able to be easily maintained by caretakers drawn from the community who have minimal skills, using a few simple tools and with modest training; this generally means that the pumps should be manufactured, or be capable of being manufactured, in the country of use, primarily to ensure the availability of spare parts.

- Pumps and spare parts should be cost-effective.

- Boreholes must be designed and constructed in a manner appropriate to the capabilities of the pump to be used and suitable for use under local conditions.

- Pumps should be acceptable to the users; i.e., used consistently, viewed positively with few complaints, and not liable to be vandalized.

These features are applicable to the design of all pumping systems.

The need for maintenance varies with the type of pump, from pumps requiring minimal maintenance to pumps requiring almost constant upkeep. The hydraulic pump, which is impelled by the river stream, requires very little maintenance. On the other hand, maintenance is probably the single most important element in hand pump operation. To address this issue, the concept of village-level operation and maintenance (VLOM) was developed to provide local villagers with the option of maintaining the pumps at the community level. The principles of VLOM are embodied in the design criteria set out above. In meeting these criteria, the manufacturing processes and raw materials required for pump maintenance should be already available in the country of use or should be capable of developing as self-supporting, commercial enterprises there.

The four photovoltaic-powered pumping systems in operation on Roatán Island were installed in 1986. Their operation and maintenance are performed by the residents of the communities using the pumps. It is usually a very simple task, consisting of cleaning of the solar panels, protecting the wells from contamination, and occasionally replacing the submersible electric pumps when they fail. These submersible pumps are the component of the system which fails most frequently. During a ten-year period, two pumps have been damaged in each community, requiring an average of a new pump every five years. The rest of the photovoltaic system has only suffered from some corrosion due to the saline environment on the island. In addition, some of the photovoltaic panels have lost some of their efficiency, apparently as a result of construction defects. It is significant to note that, even though two of the communities now have access to electricity service, they continue to power their water supply system with the solar panels.

Level of Involvement

Few governments have participated in the application of non-conventional energy sources to the pumping of water. Most pumping systems using such sources have been developed by local communities in cooperation with NGOs and financed by external agencies, such as USAID. Likewise, whenever system operators have needed technical and financial assistance (for example, to replace a pump), NGOs generally have provided the necessary technical assistance, and financial support has been forthcoming from organizations such as the U.S. Peace Corps and Volunteers in Technical Assistance (VITA), and, in Honduras, the Sandia National Laboratory of the United States.

Costs

The hydraulic ram pump locally manufactured in Honduras costs approximately $200 in local retail establishments, excluding installation costs. The estimated costs of variously sized hydraulic ram pumps in Peru are shown in Table 4. Hydraulic ram pump design criteria should include the volume of water available, lifting height, water gradient, and pumping distance.

Table 4 Estimated Cost ($) of Hydraulic Ram Pumps

Pump size	Equipment	Installation	Annual Maintenance
3/4"	300	30	15
2"	900	90	45
4"	3200	320	160
10"	12000	1200	600

Source: Catholic University of Peru.

The rope pump has an average cost of less than $250, excluding installation and well digging. Materials are **very** simple and may be locally acquired.

The windmill-driven pump is estimated to cost between $800 and $1 000, excluding installation and well excavation, and is available only from specialized suppliers. The manufacturing costs of three different models used in Peru were estimated at $2 700, $3 500, and $6 000 for windmill pumps with a rotor diameter of 3.5 m, 5 m and 10 m, respectively. Installation and maintenance costs were estimated at 15% of the construction cost.

Economics is the principal constraint on the use of the photovoltaic energy technology. Use of this technology usually requires a large initial investment. The difficulties of communication and transportation in rural areas, combined with the relatively few specialized suppliers, increases the initial cost of photovoltaic-powered systems significantly, although recent technological advances are reducing it.

Effectiveness of the Technology

The hydraulic pump can lift water to a maximum height of 25 m. These pumps perform favorably in comparison with other, similar technologies. At river velocities of 2.0 m/sec and discharges of 0.40 m^3/sec, a hydraulic pump can yield enough water to irrigate an area of approximately 1 800 m^2 of crops. Alternatively, the pump can supply 72 dwellings and a population of 500 persons or a cattle shed of 140 cows, with water for domestic or stock-watering use.

The efficiency of the windmill-powered pumps varies directly in proportion to the speed of the wind. At wind speeds ranging from 5 to 18 km/hr, the daily yield varies from 3 to 12 m^3/day, respectively, assuming an average of 6 working hours/day.

Suitability

This technology is suitable for use in regions where fuel or electricity is unavailable. For this reason, these alternatively powered pumps are well suited for use in the rural areas of most Latin American and Caribbean countries.

Advantages

In general, the advantages common to these types of pumping systems are that they do not use combustible fuels, have a low cost to manufacture and are inexpensive to purchase, and incur minimal maintenance requirements. Each of these pumps has a negligible environmental impact. Specific advantages of each type are as follows:

Hydraulic pump

- The technology works 24 hours a day.
- It is usable for pressurized-water irrigation systems (microjet and drip irrigation).

Hydraulic ram pump

- The technology produces a high yield.
- It can be coupled with most water irrigation systems.

Rope pump

- Construction does not require skilled labor.
- The technology has a minimal potential for water contamination.

Windmill-driven pump

- The design is proper for the tropics.
- Windmill arms do not need protection against storms.
- The technology is easy to install.

Photovoltaic pump

- The pump uses a readily available energy source.
- The technology requires little maintenance.
- It is clean, thereby reducing the possibility of contamination.
- No combustible fuels are needed.
- It is easy to install in a relatively short period of time.
- The technology is simple and reliable.
- The solar panels have a long life expectancy.
- It may be incorporated into a flexible, modular system which adapts easily to community needs.

Disadvantages

- Hydraulic pumps and hydraulic ram pumps must be located close to river channels, which makes them vulnerable to flood damage unless the equipment can be removed at short notice.

- The use of hydraulic pumps and hydraulic ram pumps is limited to the irrigation of small areas.

- The rope pump cannot raise water far above the surface of the well; it is limited to wells of less than 8m in depth.

- Windmill-powered pumps are not recommended for agricultural purposes because water extraction is difficult at depths of greater than 20 m.

- Repairs to photovoltaic-powered pumps, particularly in rural areas, may be dependent on imported parts; inventories of critical spares are needed to avoid stoppages due to breakdowns and waiting times while replacements are found.

- The initial cost of a photovoltaic system is considerable, and the regular maintenance may be extensive and costly if storage batteries are involved.

Cultural Acceptability

With the exception of the photovoltaic-powered pumps, the alternative energy sources used to power the pumps are traditional and well accepted by the communities. At this time, the cost of solar-energy-powered systems limits the level of community acceptance.

Further Development of the Technology

Improvements in pump design are needed to increase the efficacy of these technologies. For hydraulic pumps, these include the use of a double turbine to increase the torque from the main axis so that pumps of greater capacity can be used. The rope pump can be improved through changes in the construction and operation of the pumps, particularly in rural areas, to increase the discharge height of the pump. Aspects of hand pumps also need improvement. Some common needs include:

- Development of quality standards and quality control procedures, including simple tests, for PVC pipes manufactured in developing countries.
- Development of design guidelines for plastic, riser main assemblies, including suggested material and dimensional specifications.
- Research on alternative materials for use as non-sliding bearings in practical designs.
- Investigation of the design and manufacture of plastic pump elements to reduce costs and improve the reliability of pump cylinders.
- Development of practical designs for sealless pistons and solid state valves.
- Assessment and development of additional methods for protecting cylinders against sand contamination.
- Development of improved designs for pump rod and riser and connectors.
- Assessment of techniques for preventing corrosion, including cathodic protection, plating techniques, and coating with plastics or rubber.
- Development of reliable, easy-to-release couplings for pump nodes.

Information Sources

Contacts

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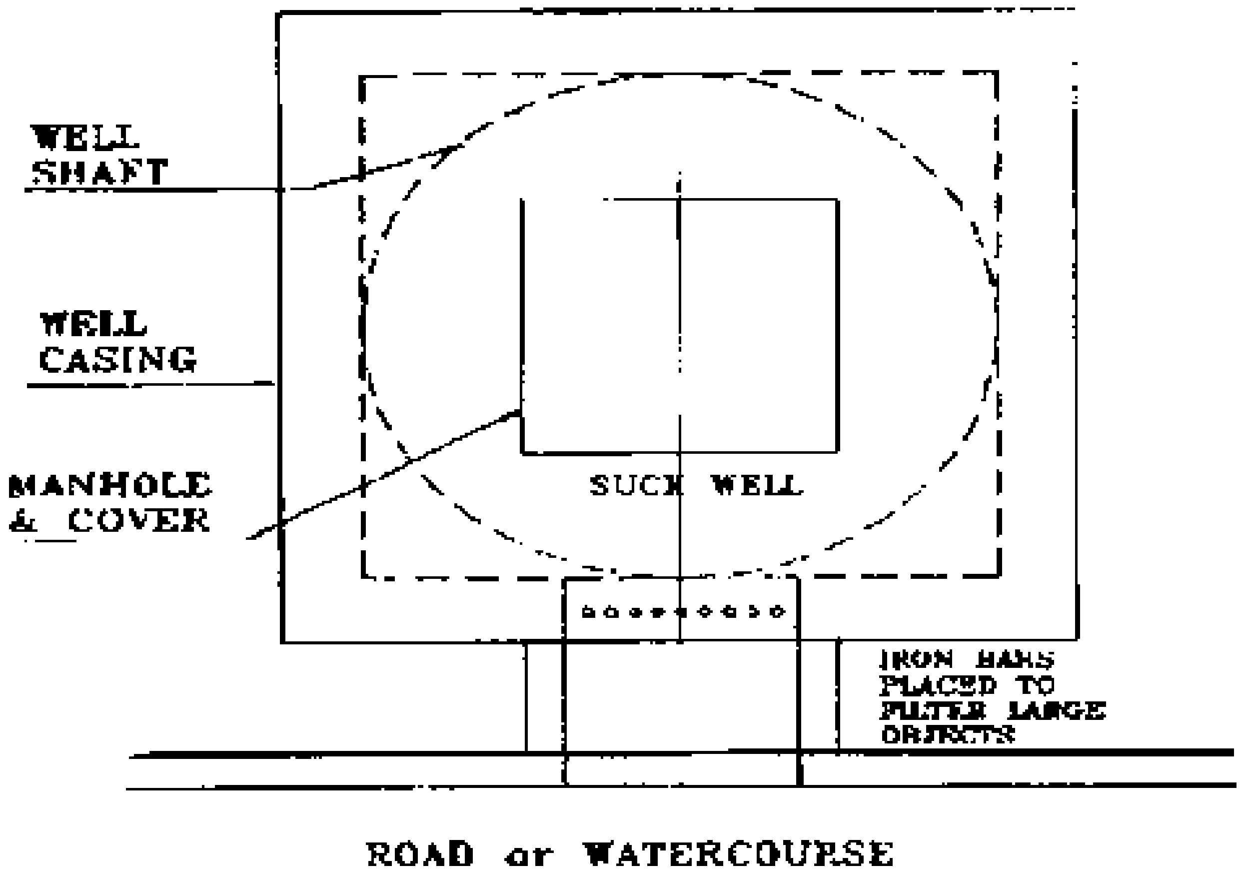
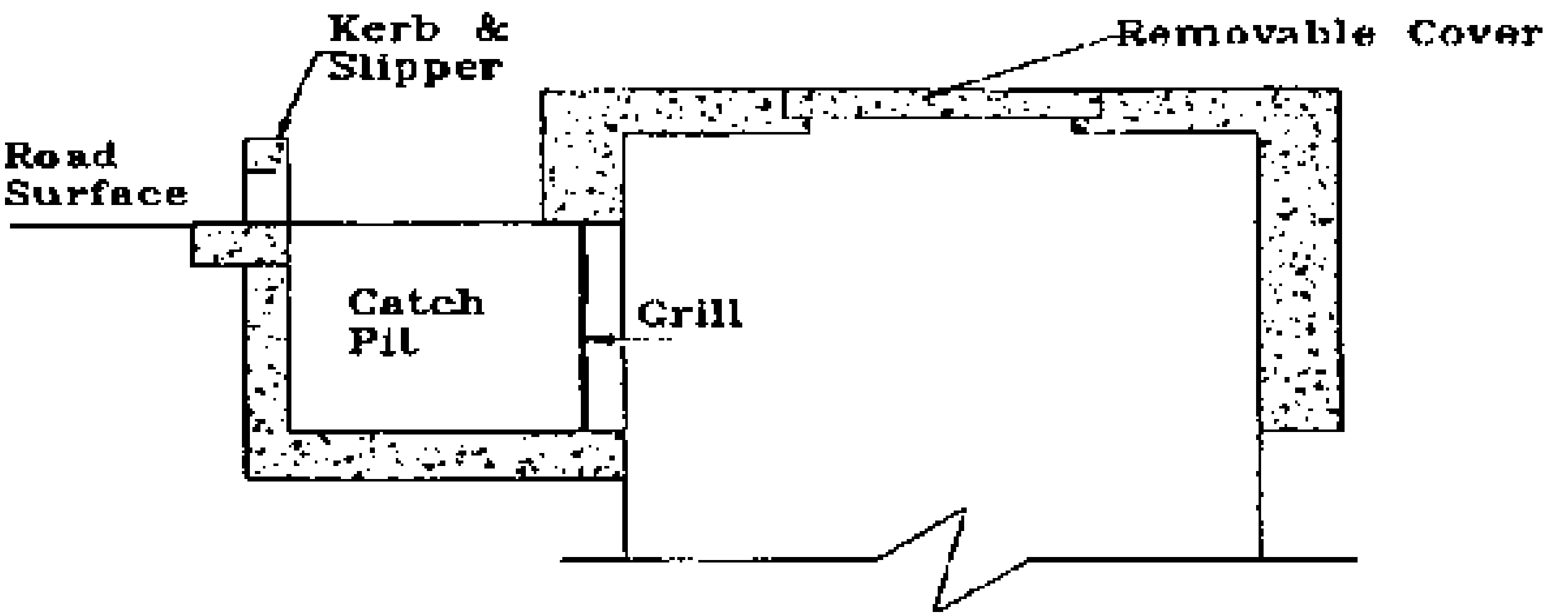

WELL SHAFT
WELL CASING
MANHOLE & COVER
SUCK WELL
IRON BARS PLACED TO FILTER LARGE OBJECTS
ROAD or WATERCOURSE

PLAN VIEW


Kerb & Slipper
Removable Cover
Road Surface
Catch Pit
Grill

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.

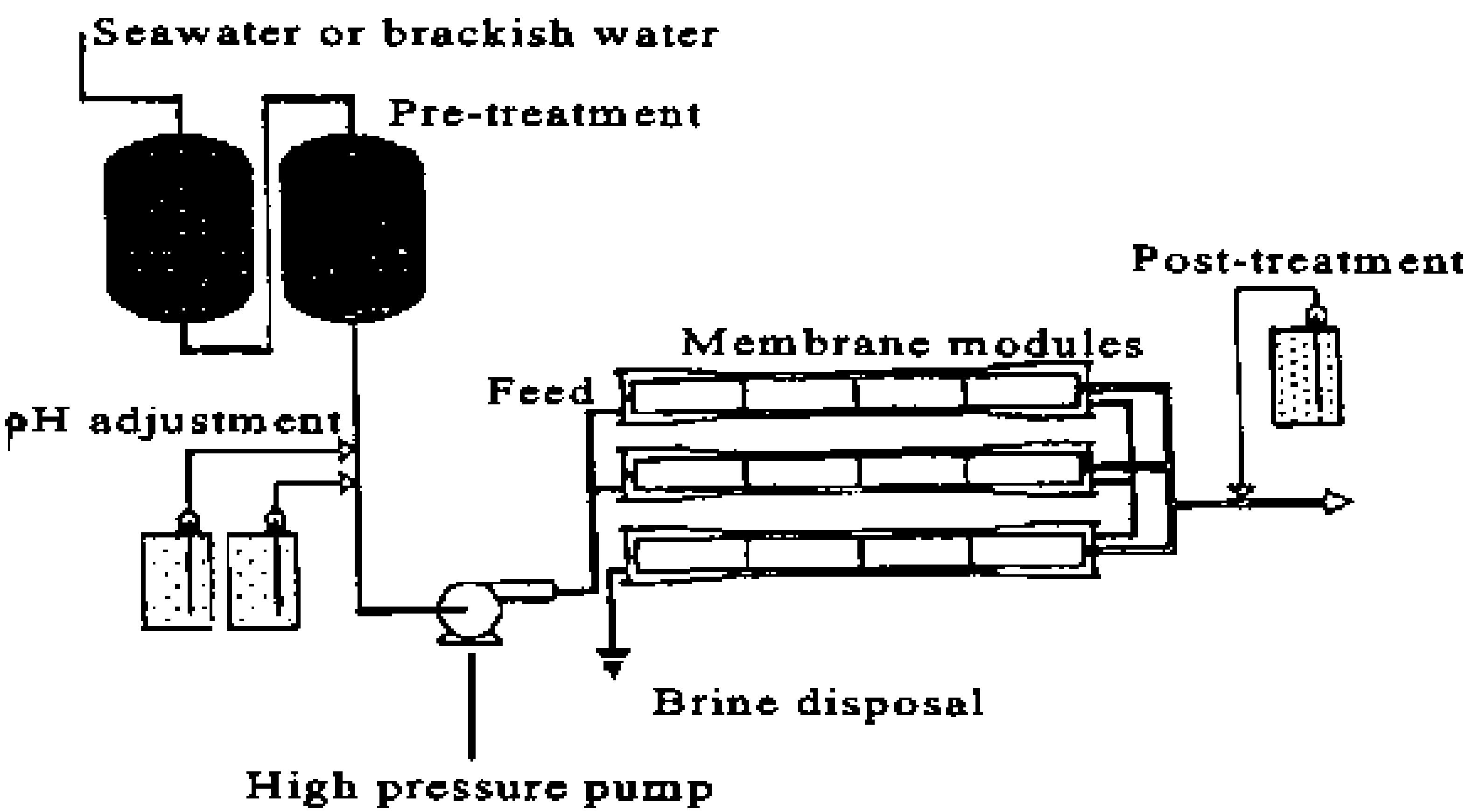
Pretreatment: The incoming feedwater is pretreated to be compatible with the membranes by removing suspended solids, adjusting the pH, and adding a threshold inhibitor to control scaling caused by constituents such as calcium sulphate.

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 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 Islands	1190 - 2642		[b]3.40 - 4.30
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.

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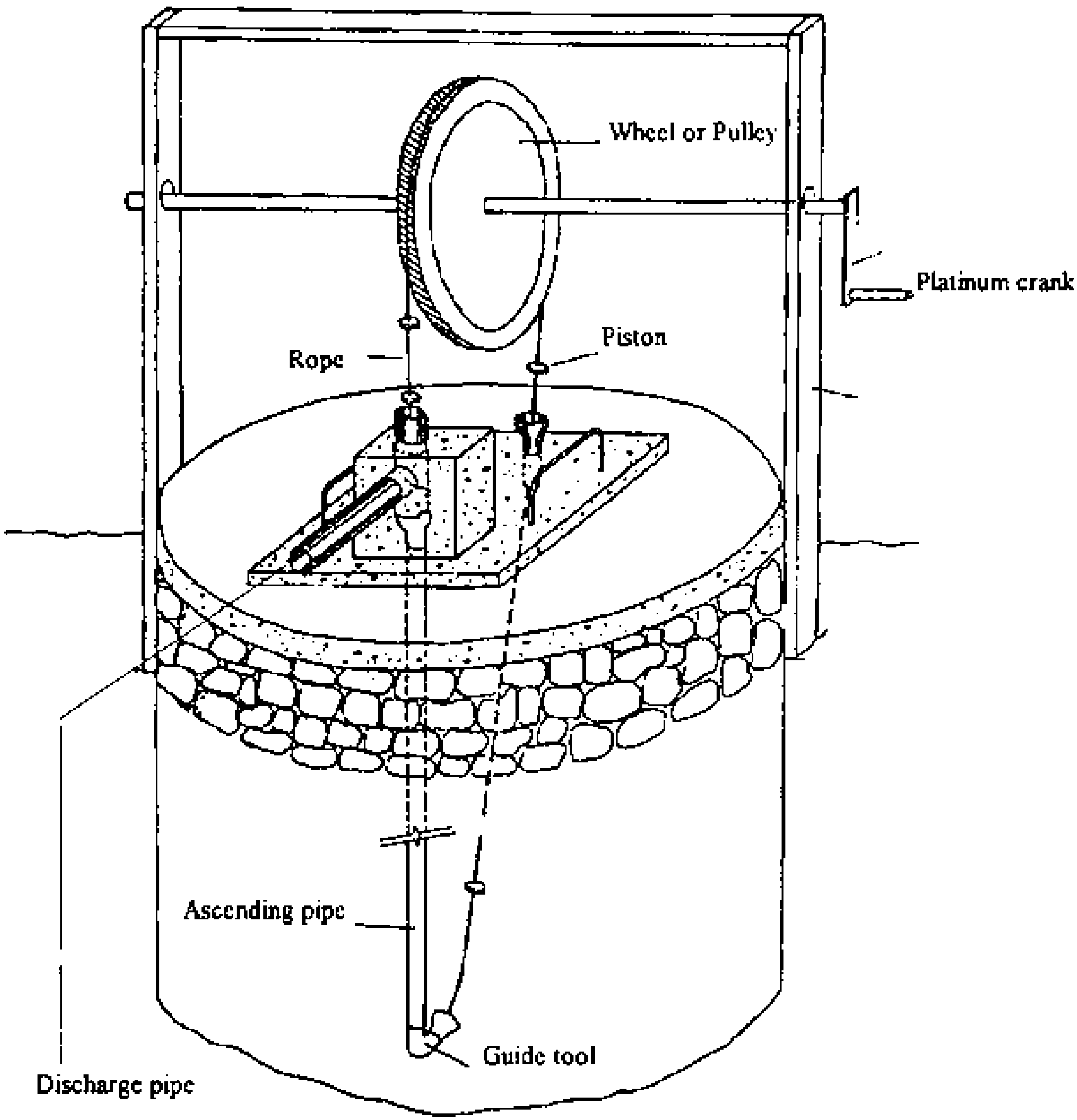
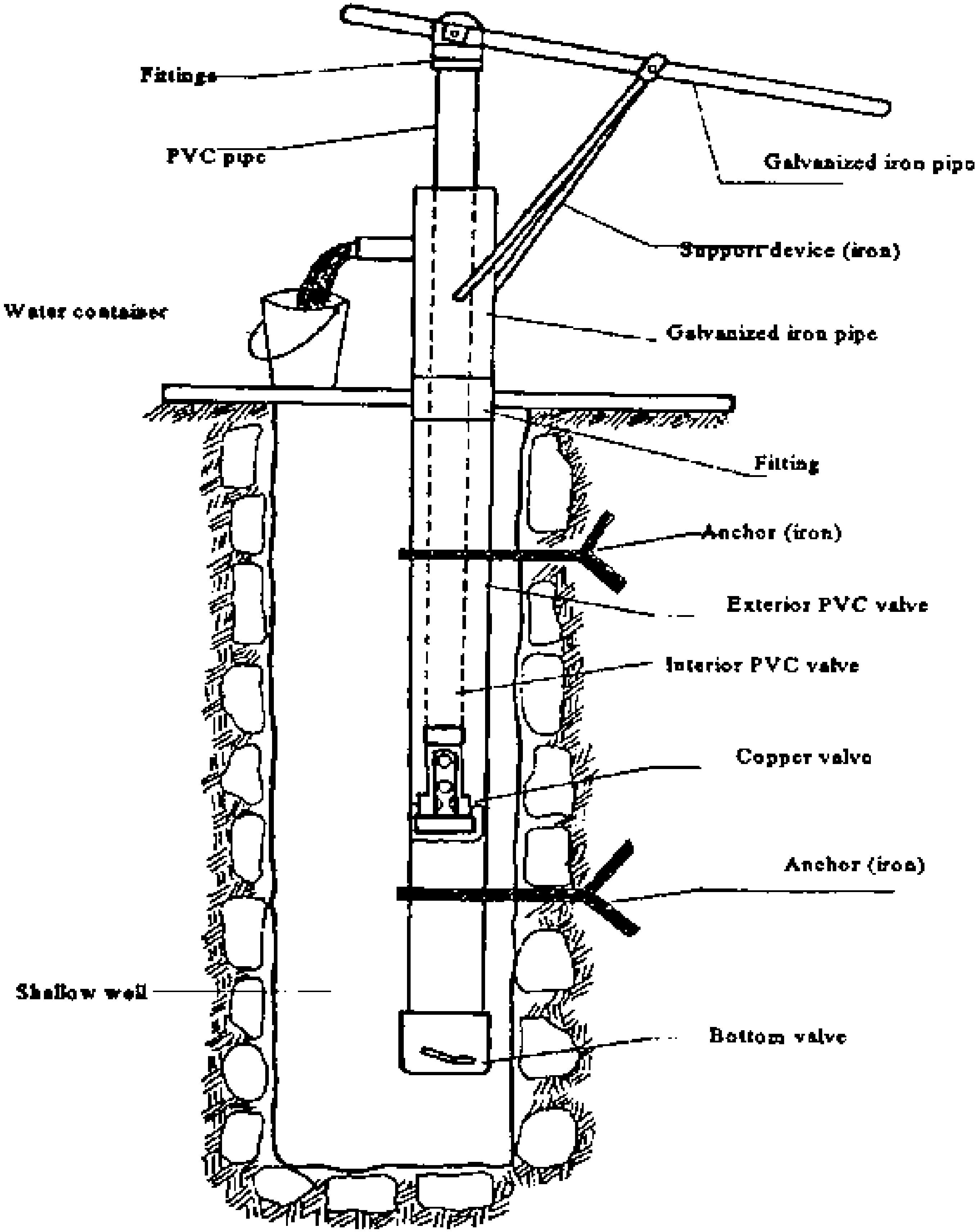

Wheel or Pulley
Platinum crank
Piston
Rope
Ascending pipe
Guide tool
Discharge pipe


Fittings
PVC pipe
Galvanized iron pipe
Support device (iron)
Water container
Galvanized iron pipe
Fitting
Anchor (iron)
Exterior PVC valve
Interior PVC valve
Copper valve
Anchor (iron)
Shallow well
Bottom valve

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

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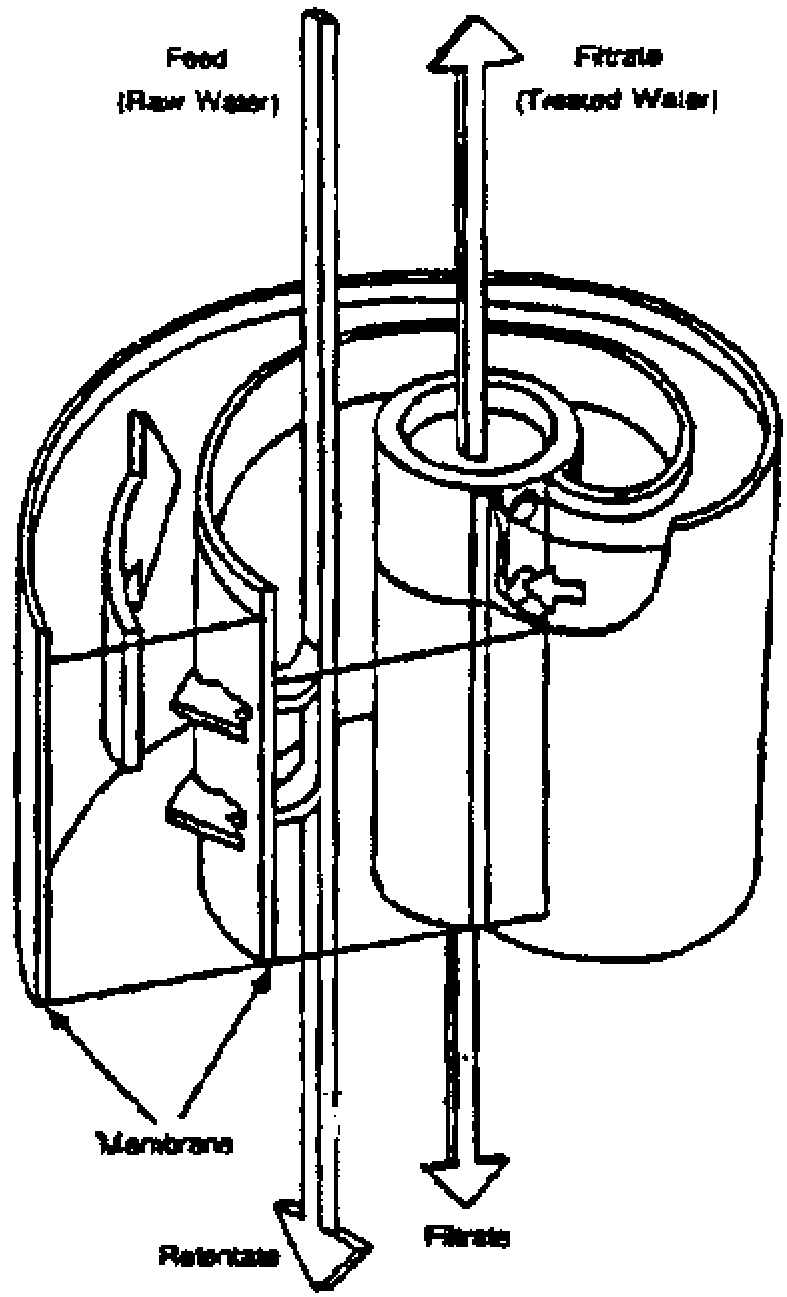
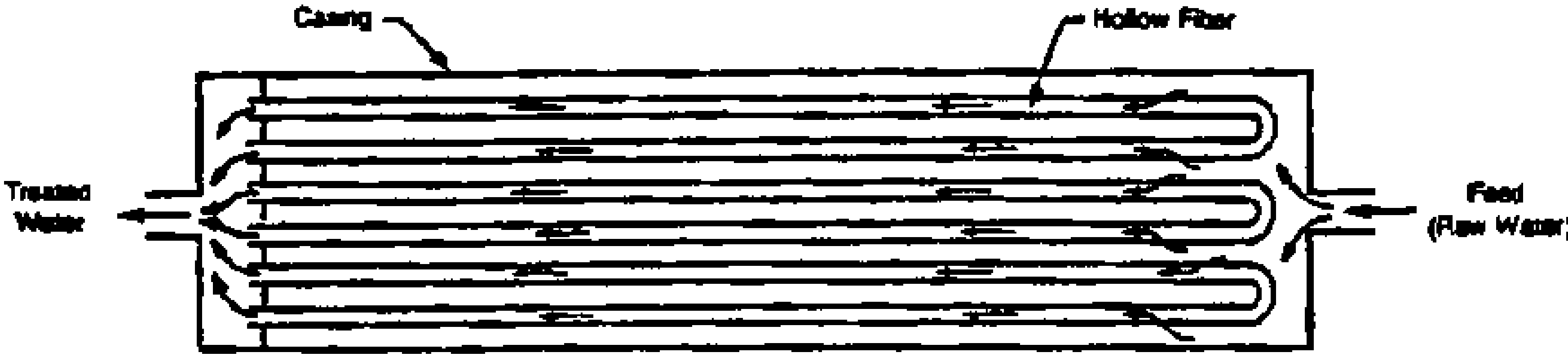


Courtesy of Millipore Corporation

Process Flow Through Spiral-Wound Reverse Osmosis Unit



Hollow-Fiber Reverse Osmosis Unit

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*

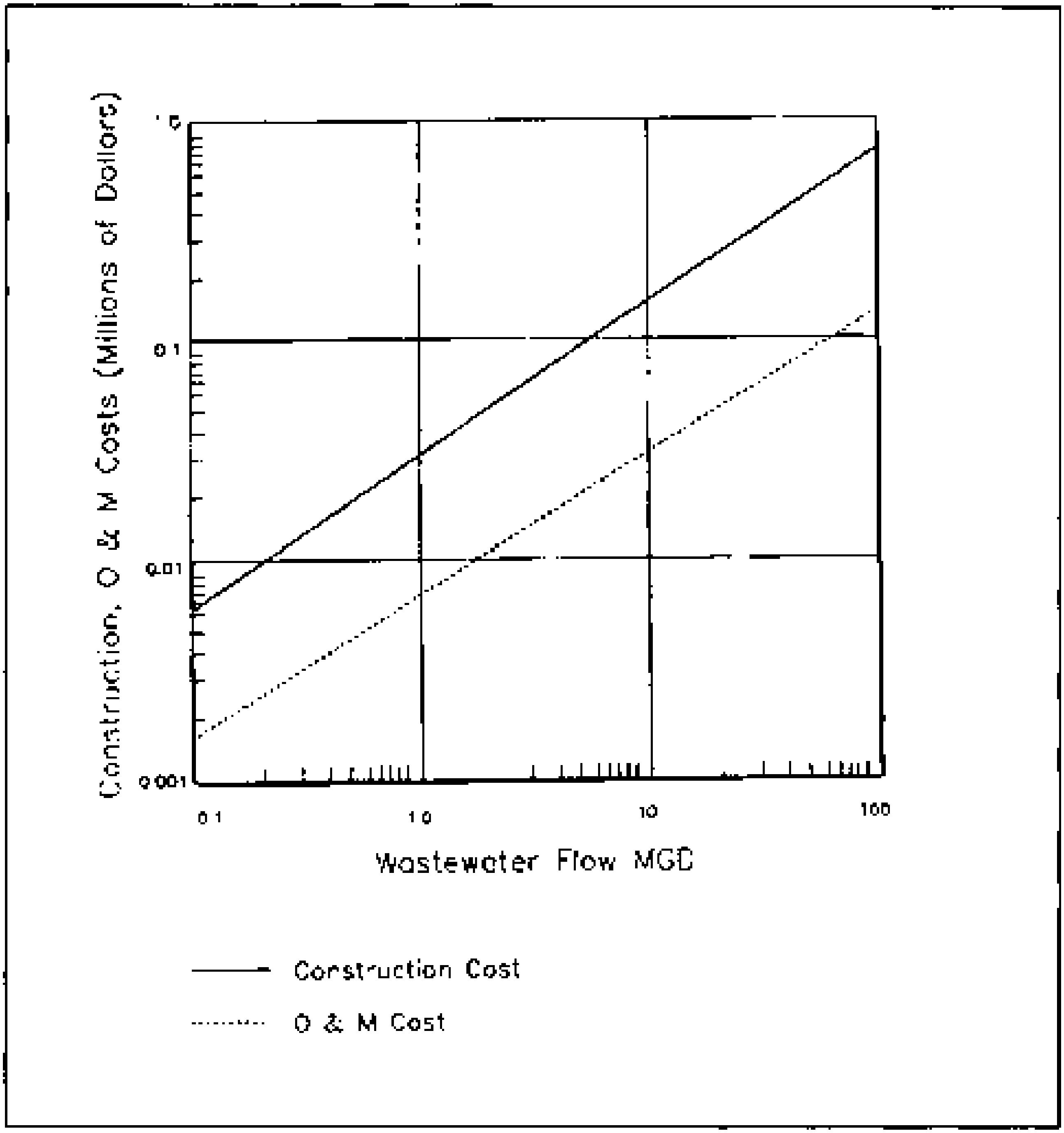
Parameter	Inflows (g)	Outflows (g)	% Removed
Ammonium-N	6.92	2.40	65.30
Ammonia-N	8.45	2.93	65.20
Nitrate-N	2.15	0.21	90.20
BOD	112.60	17.60	84.40

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.



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.

Sources of Information

Contacts

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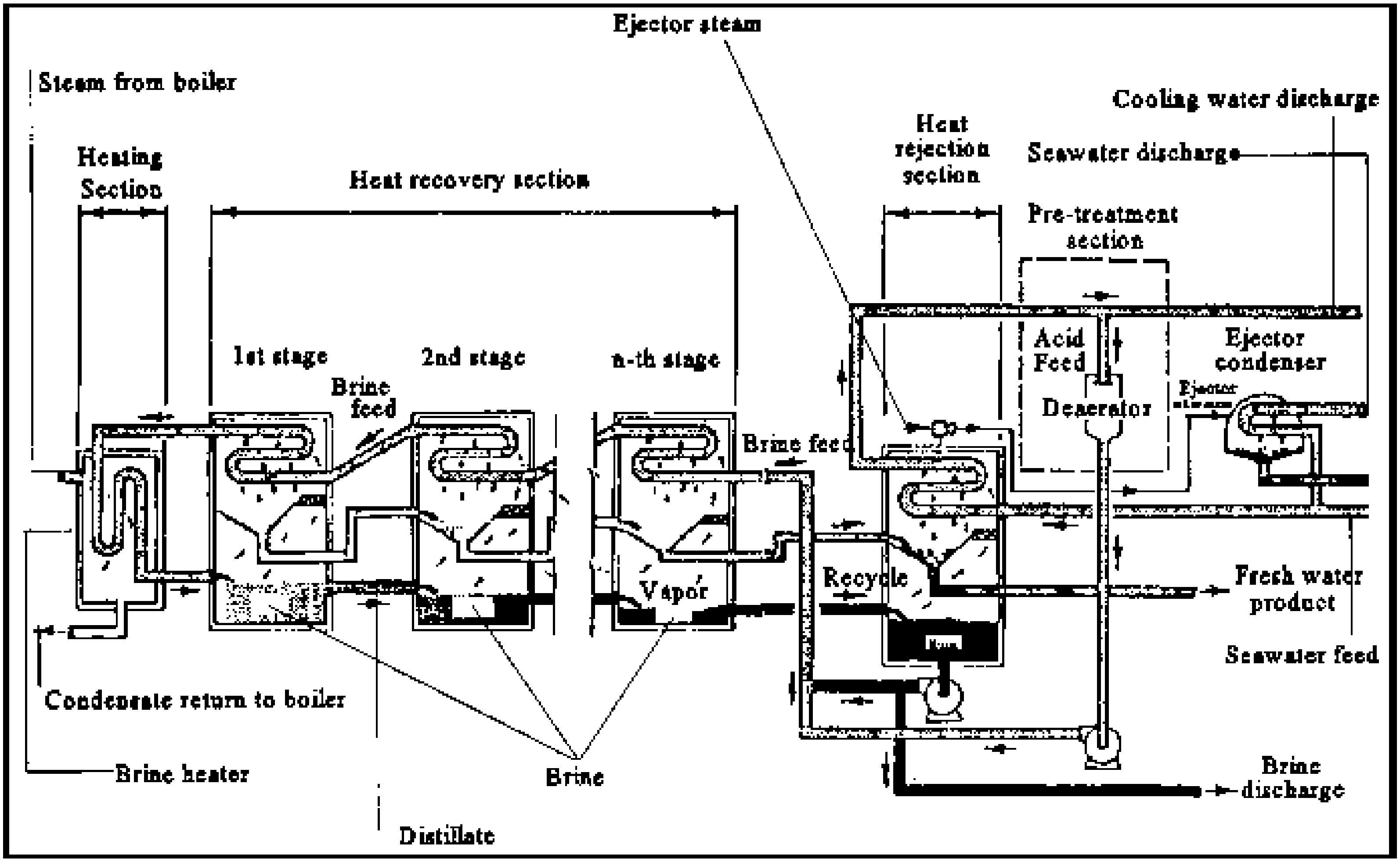
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Heat recovery section
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Seawater discharge
Pre-treatment section
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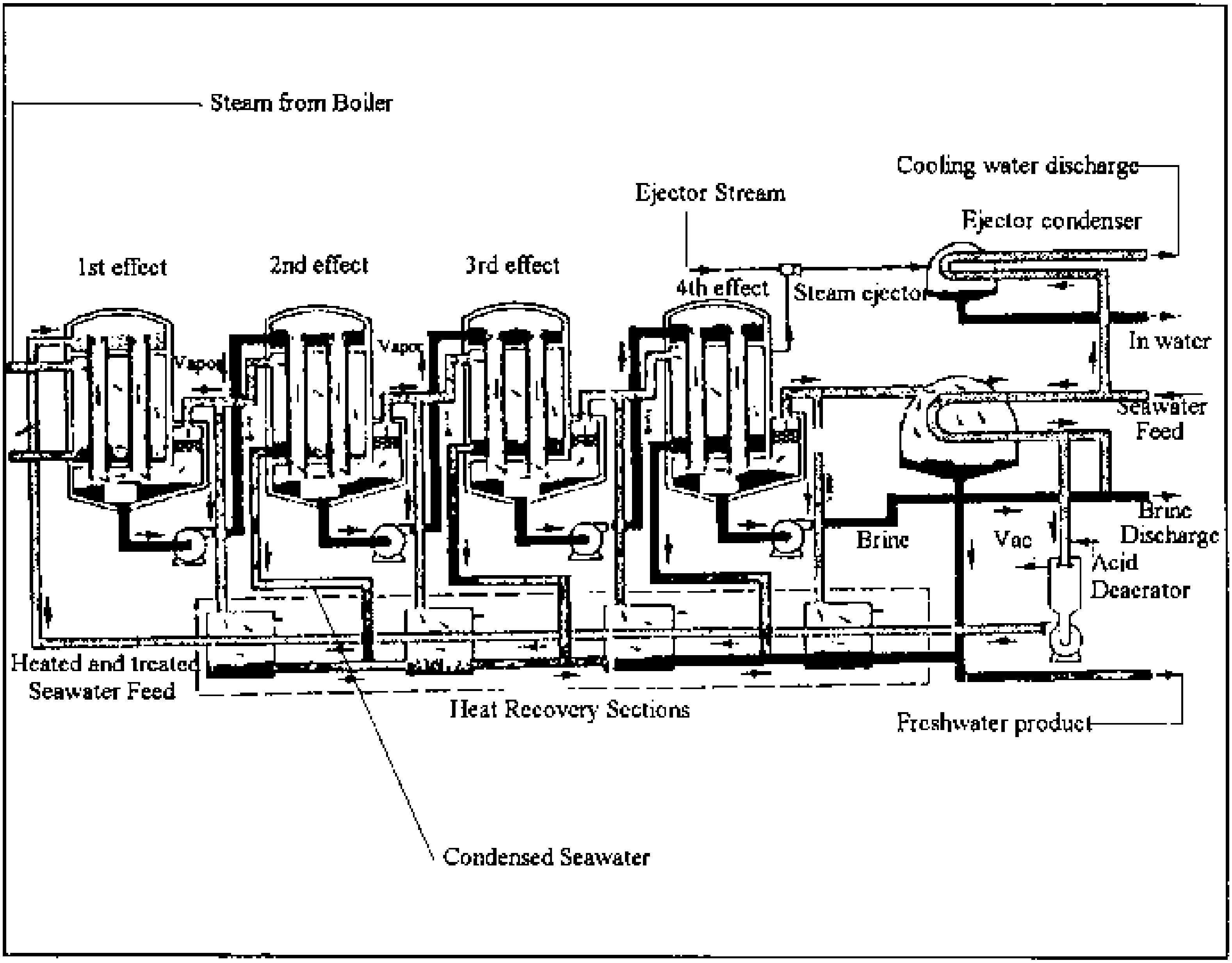
2nd stage
n-th stage
Brine feed
Deaerator
Brine feed
Recycle
Vapor
Fresh water product
Seawater feed
Condensate return to boiler
Brine heater
Brine
Brine discharge
Distillate


Steam from Boiler
Cooling water discharge
Ejector Stream
Ejector condenser
1st effect
2nd effect
3rd effect
4th effect
Steam ejector
In water
Vapor
Vapor
Seawater Feed
Brine Discharge
Brine
Vac
Acid
Deaerator
Heated and treated Seawater Feed
Heat Recovery Sections
Freshwater product
Condensed Seawater

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.

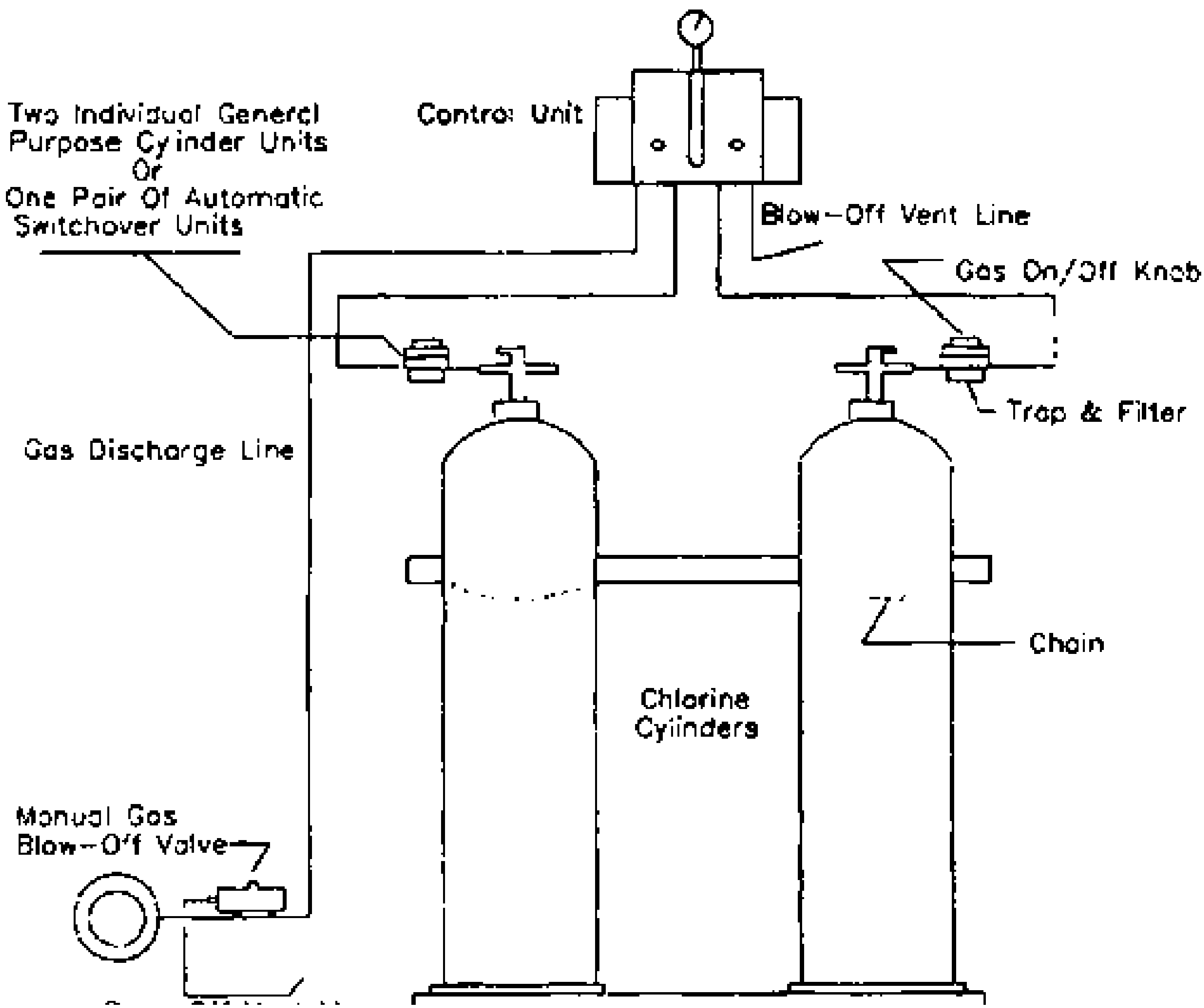
Sodium hypochlorite is available in strengths from 1.5% to 15%, with 3% available chlorine as the typical strength used in water treatment applications. The higher the strength of the chlorine solution, the more rapidly it decomposes and the more readily it is degraded by exposure to light and heat. 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.

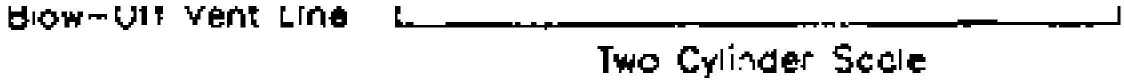
Water-based solutions of either the liquid or the dry form of hypochlorite are prepared in predetermined stock solution strengths. Solutions are injected into the water supply using special chemical metering pumps called hypochlorinators. Positive displacement types are the most accurate and reliable 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 I/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	-
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

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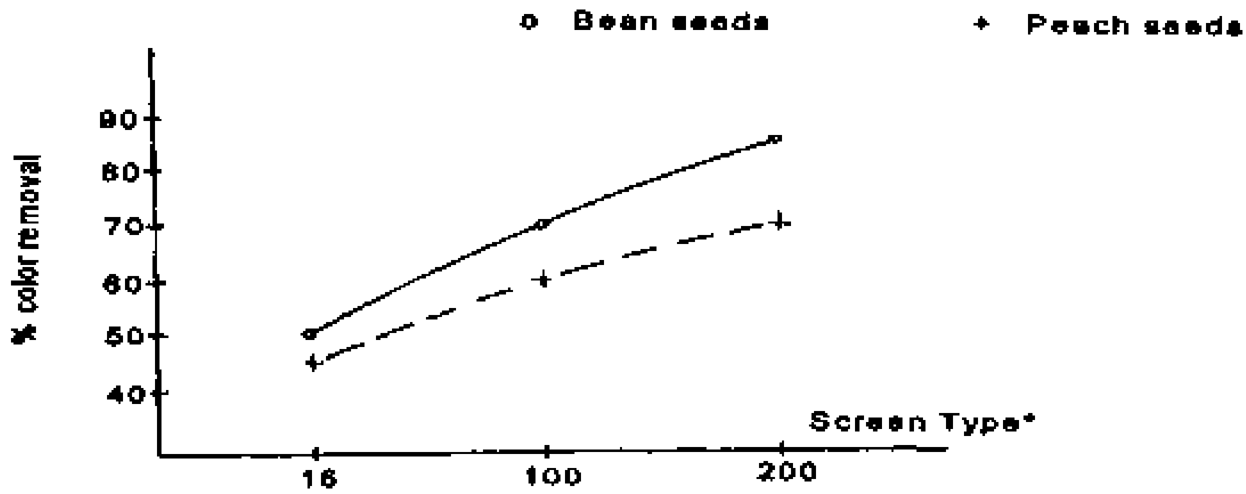

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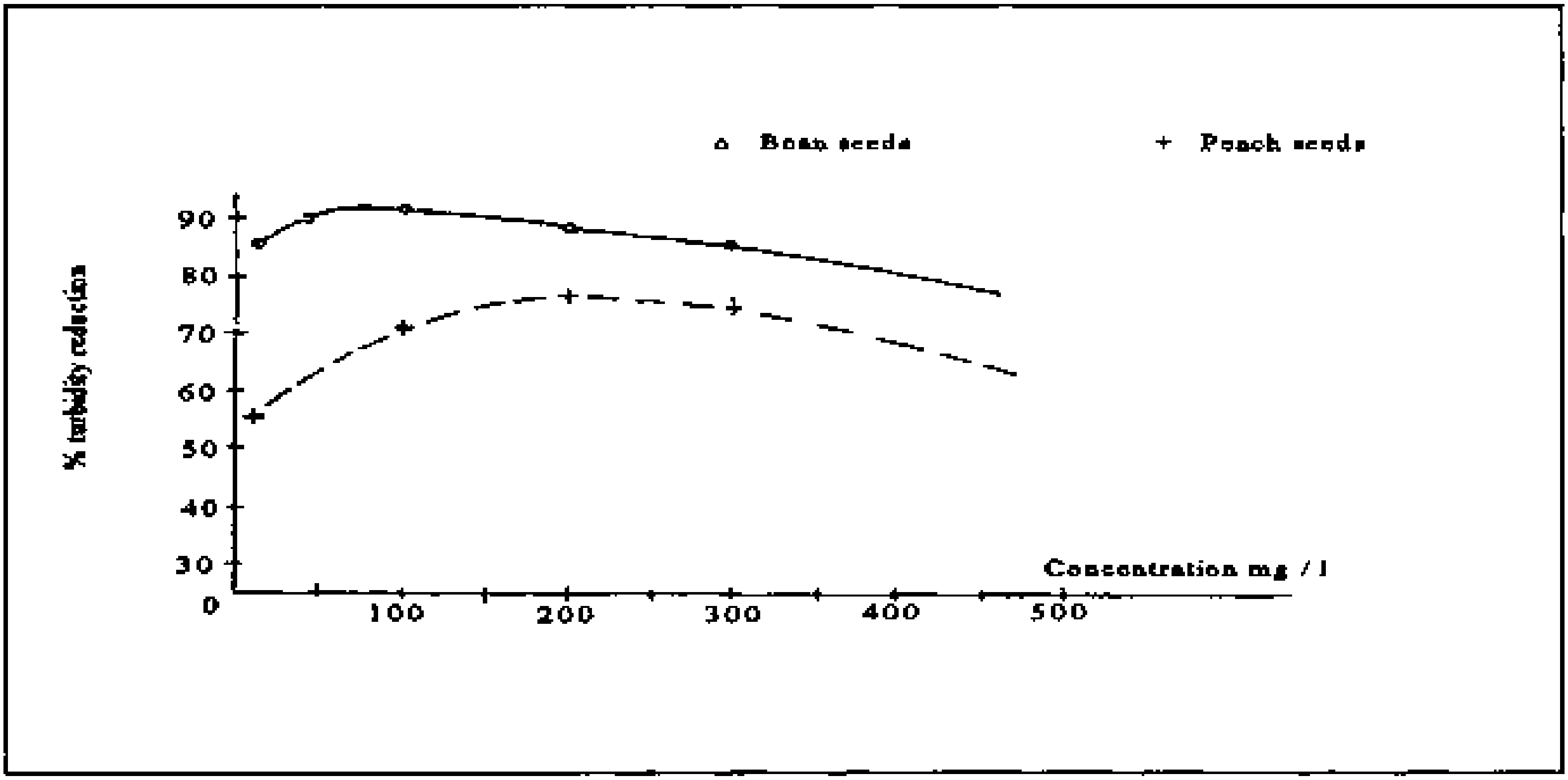
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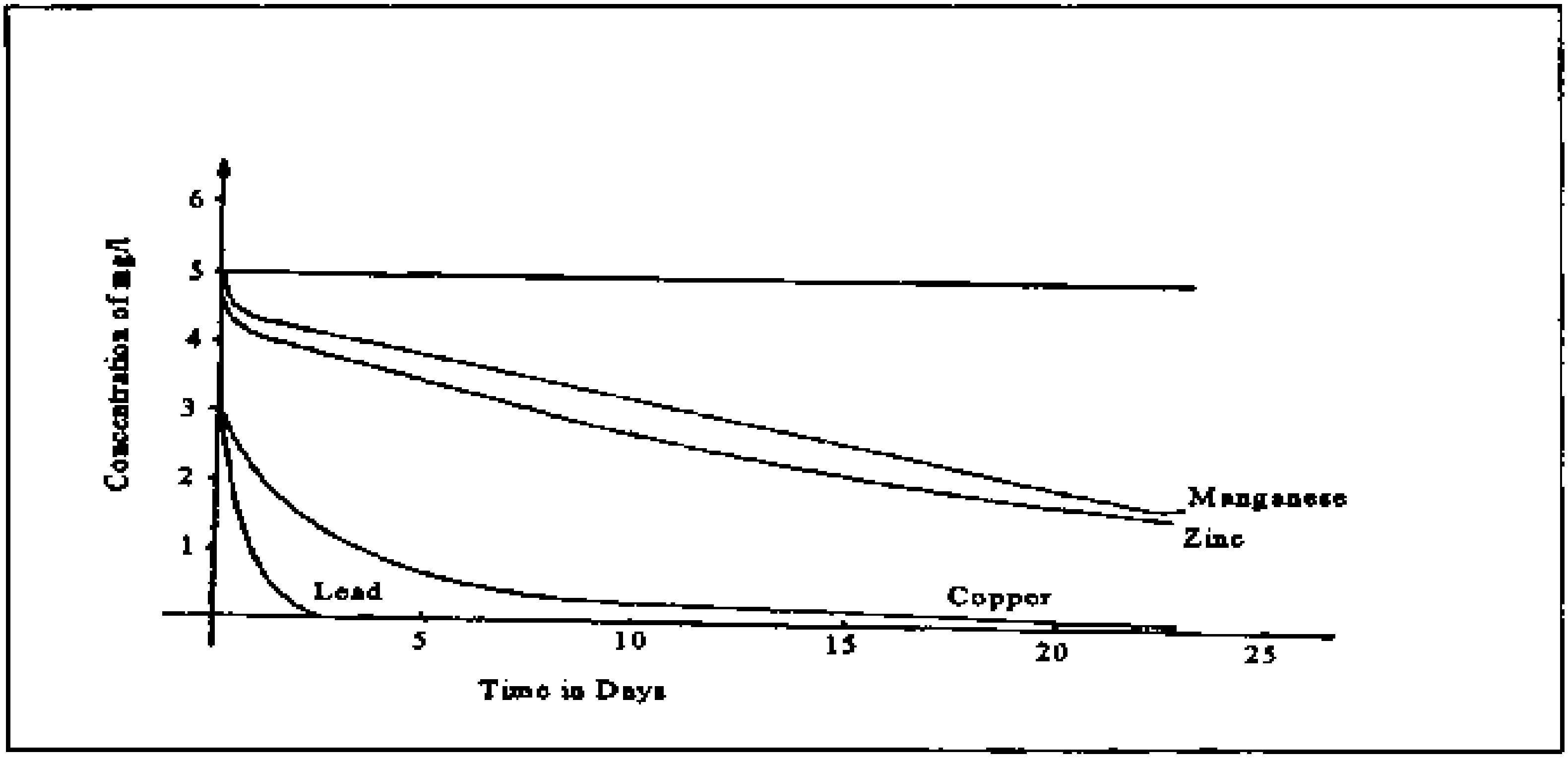
Peach seeds
% turbidity reduction
90
80
70
60
50
40
30
0
100
200
300
400
500
Concentration mg / l


Concentration of mg/l
6
5
4
3
2
1
Manganese
Zinc
Lead
Copper
5
10
15
20
25
Time in Days

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.

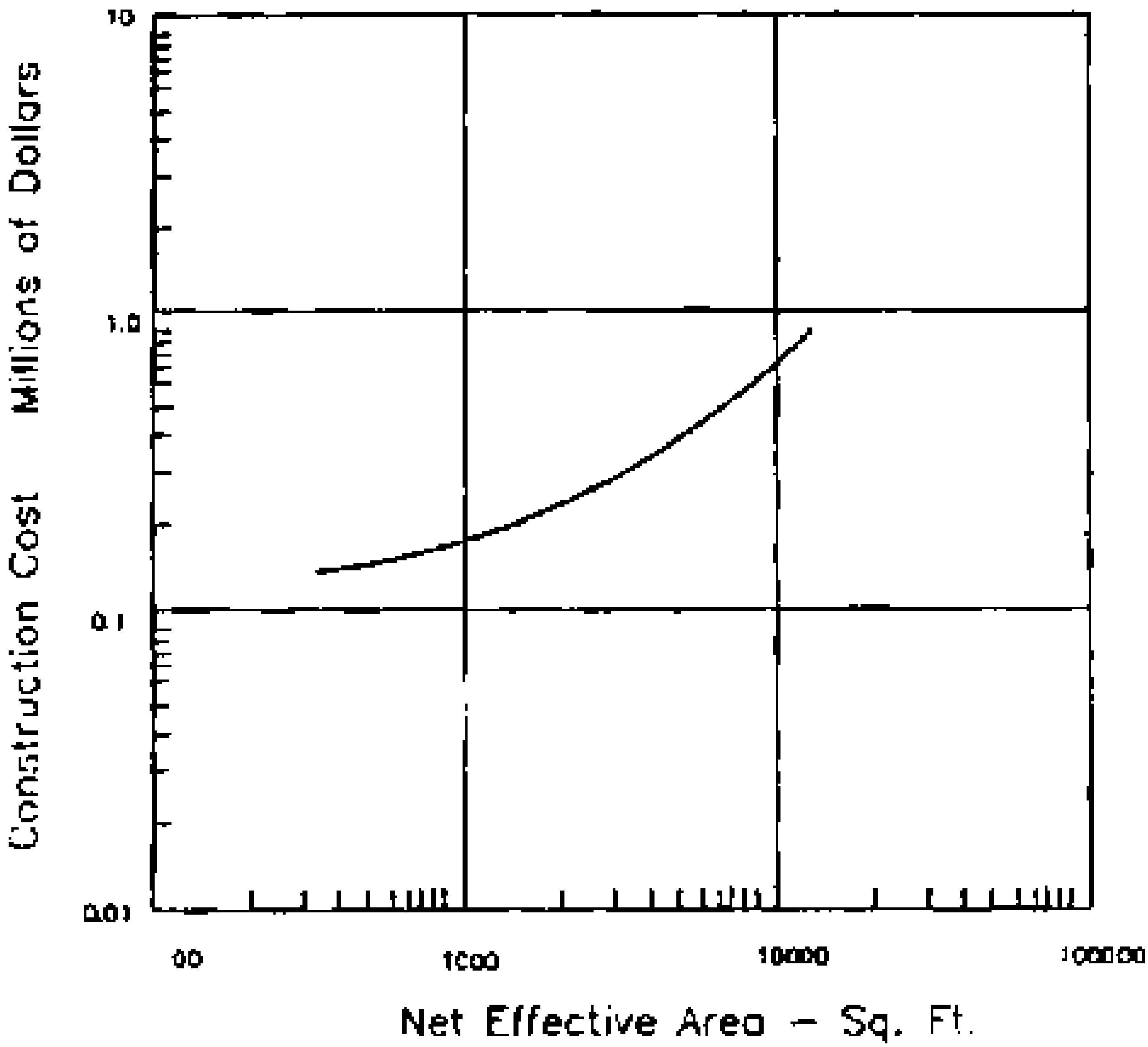
Cultural Acceptability

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.



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 - 14999	Construction	12.19 - 19.28	10.08 - 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.

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Contacts

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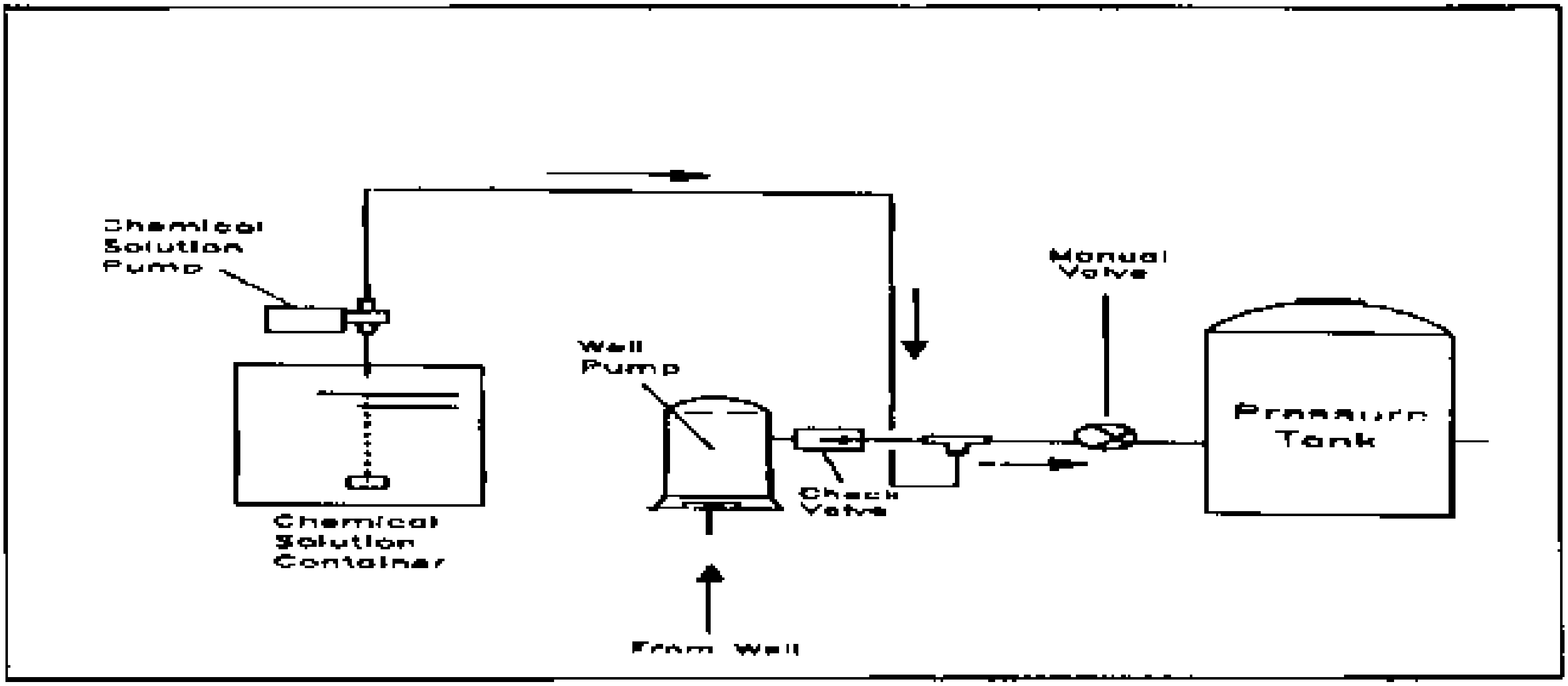
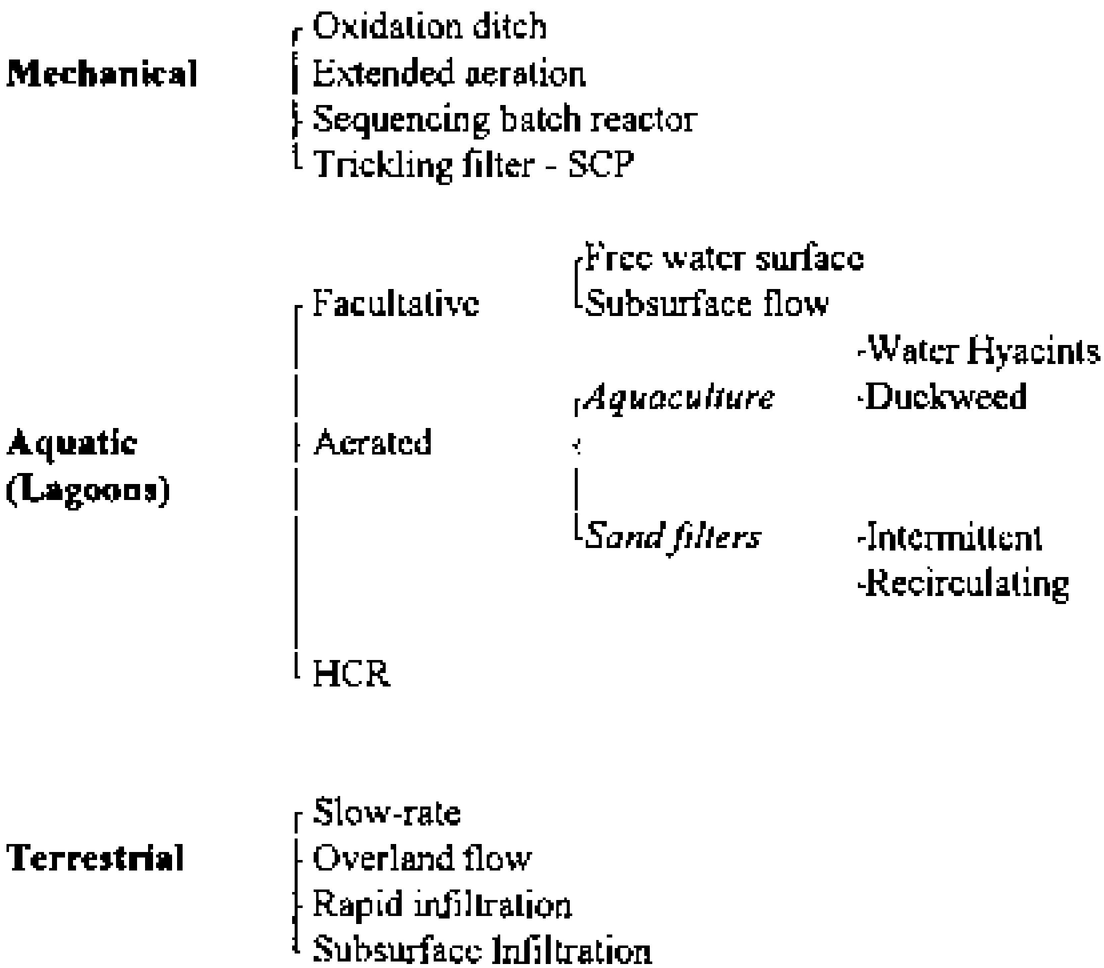

Chemical
Solution
Pump
Chemical
Solution
Container
Well
Pump
Check
Valve
Manual
Valve
Pressure
Tank
From Well

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.



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 pond	Secondary	25-180	4.5-7.5	20-60
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 Infiltration	Subsurface Infiltration	Overland 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 < 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 Volume	Retention Time	Removal 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 filtration	Anaerobic	2 m^3	36 hr	40%-50% 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 Low operation and maintenance costs Low technical manpower requirement	Requires a large area of land May produce undesirable odors
Aerated lagoons	Requires relatively little land area Produces few undesirable odors	Requires mechanical devices to aerate the basins Produces effluents with a high suspended solids concentration
Terrestrial Systems		
Septic tanks	Can be used by individual households Easy to operate and maintain Can be built in rural areas	Provides a low treatment efficiency Must be pumped occasionally Requires a landfill for periodic disposal of sludge and septage
Constructed wetlands	Removes up to 70% of solids and bacteria Minimal capital cost Low operation and maintenance requirements and costs	Remains largely experimental Requires periodic removal of excess plant material Best used in areas where suitable native plants are available
Mechanical Systems		
Filtration systems	Minimal land requirements; can be used for household-scale treatment Relatively low cost Easy to operate	Requires mechanical devices
Vertical biological reactors	Highly efficient treatment method Requires little land area Applicable to small communities for local-scale treatment and to big cities for regional-scale treatment	High cost Complex technology Requires technically skilled manpower for operation and maintenance Needs spare-parts-availability Has a high energy requirement
Activated sludge	Highly efficient treatment method Requires little land area Applicable to small communities for local-scale treatment and to big cities for regional-scale treatment	High cost Requires sludge disposal area (sludge is usually land-spread) Requires technically skilled manpower for operation and maintenance

Information Sources

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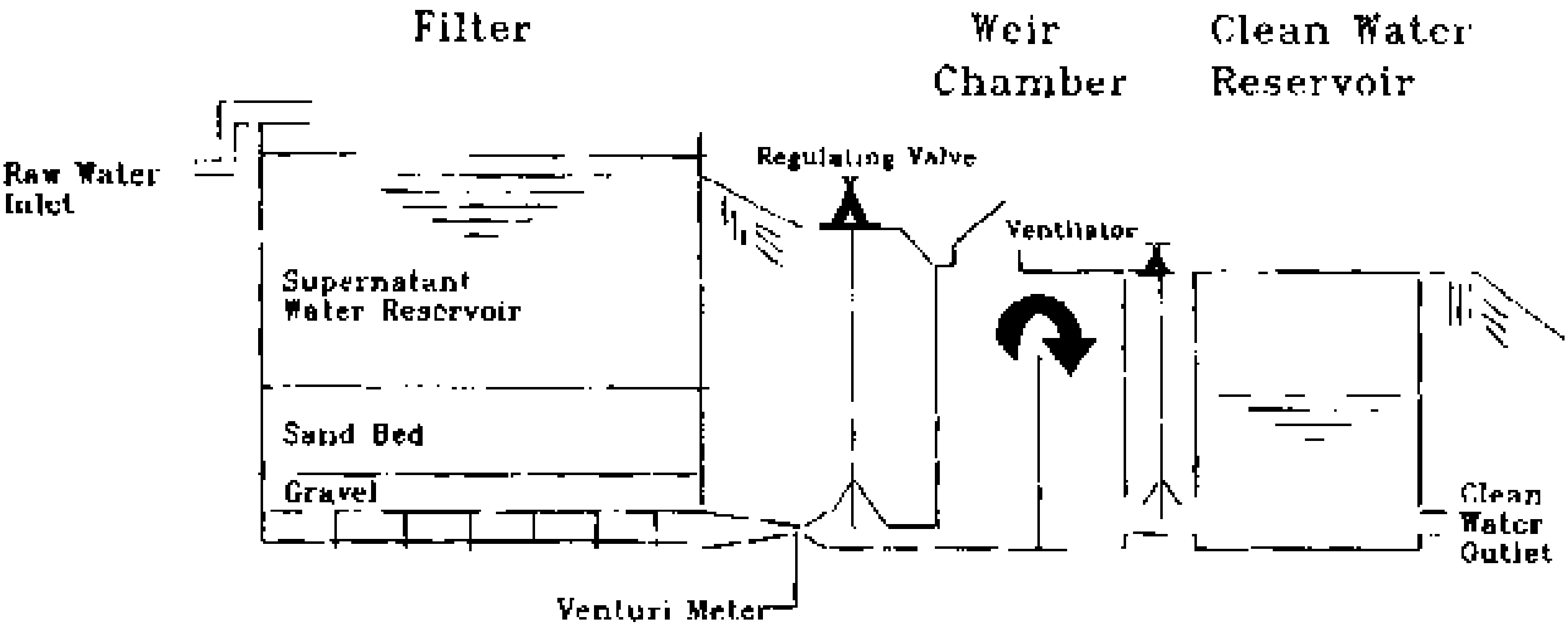
Filter
Weir Chamber
Clean Water Reservoir
Raw Water Inlet
Regulating Valve
Ventilator
Supernatant Water Reservoir
Sand Bed
Gravel
Clean Water Outlet
Venturi Meter

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 usually <30	Many months

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

Type of Reuse	Treatment Required	Reclaimed 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 water supply wells
Pasture for milking animals		BOD ≤ 30 mg/l	BOD weekly	
		SS ≤ 30 mg/l	SS daily	
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	pH = 6-9	pH weekly	300 ft from

	Disinfection	BOD ≤ 30 mg/l	BOD weekly	potable water supply wells
		SS ≤ 30 mg/l	SS daily	
		FC ≤ 200/100 ml	FC daily	100 ft from 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 and use-dependent	Site-specific and use-dependent	Depends on treatment and use	Site-specific

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

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

Contacts

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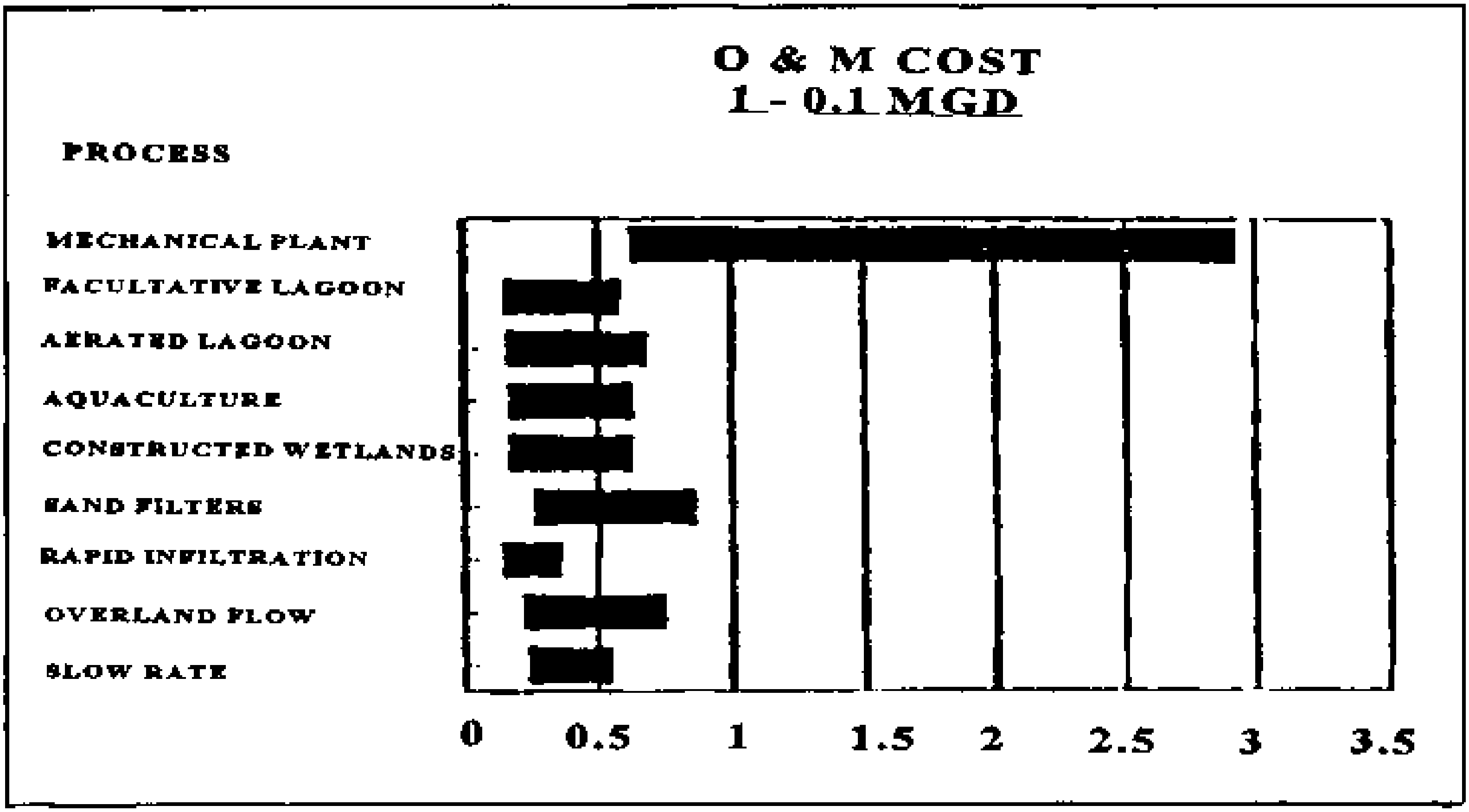
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PROCESS
MECHANICAL PLANT
FACULTATIVE LAGOON
AERATED LAGOON
AQUACULTURE
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SAND FILTERS
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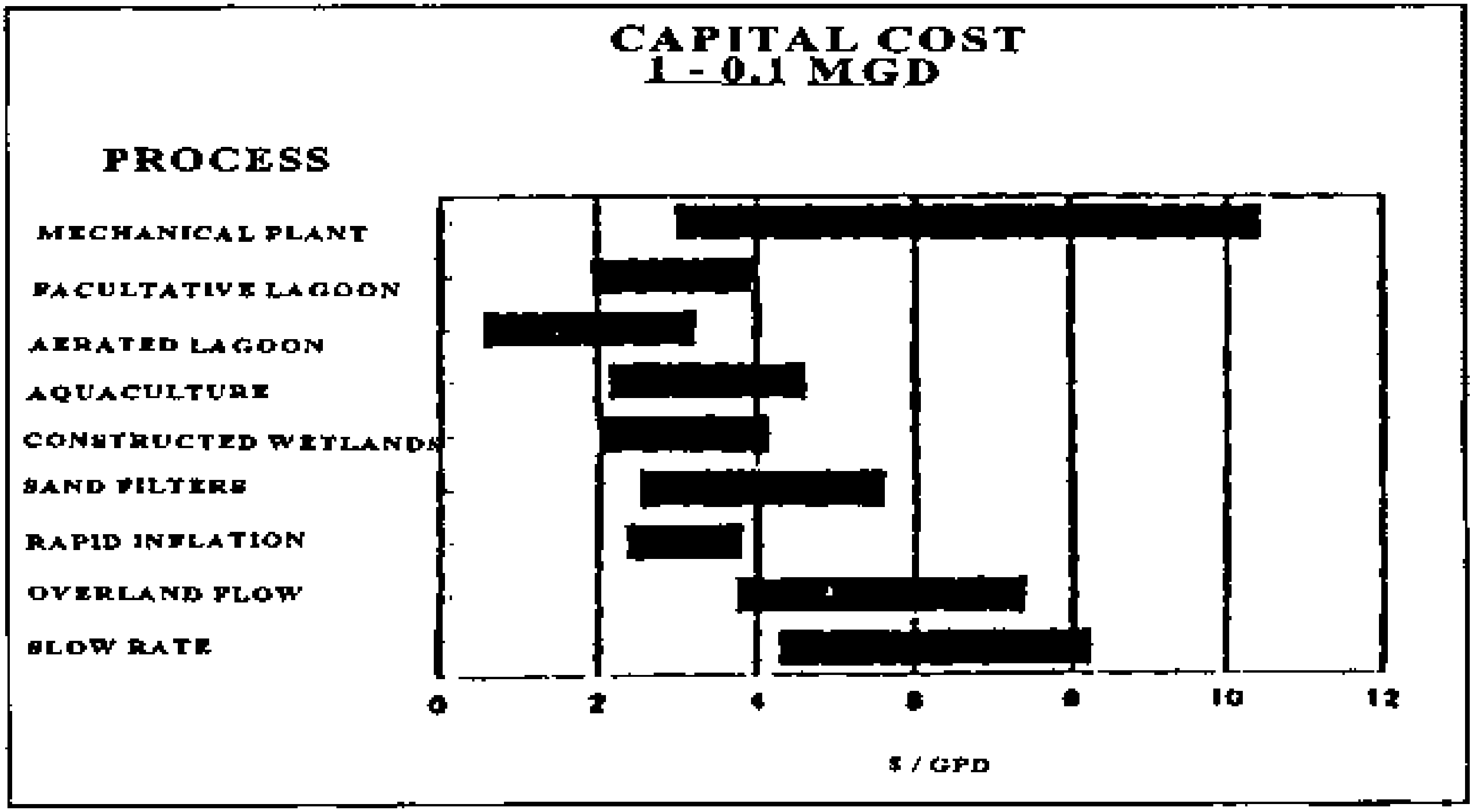
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CONSTRUCTED WETLANDS
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RAPID INFLATION
OVERLAND FLOW
SLOW RATE
0
2
4
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12
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TREATMENT PERFORMANCE

	2ND	ADV	NH3	TP	TN
MECHANICAL SYSTEMS	YES	YES	YES	YES	YES
LAGOONS	YES	NO	NO	NO	NO
SAND FILTERS	YES	YES	YES	NO	NO
CONSTRUCTED WETLANDS	YES	YES	MAYBE	NO	NO
AQUACULTURE	YES	YES	MAYBE	NO	NO
SLOW RATE	YES	YES	YES	YES	YES
OVERLAND FLOW	YES	YES	YES	NO	NO
RAPID INFILTRATION	YES	YES	YES	NO	NO
SUBSURFACE INFILTRATION	YES	YES	MAYBE	YES	NO

● -YES ○ -MAYBE ⊖ -NO

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:

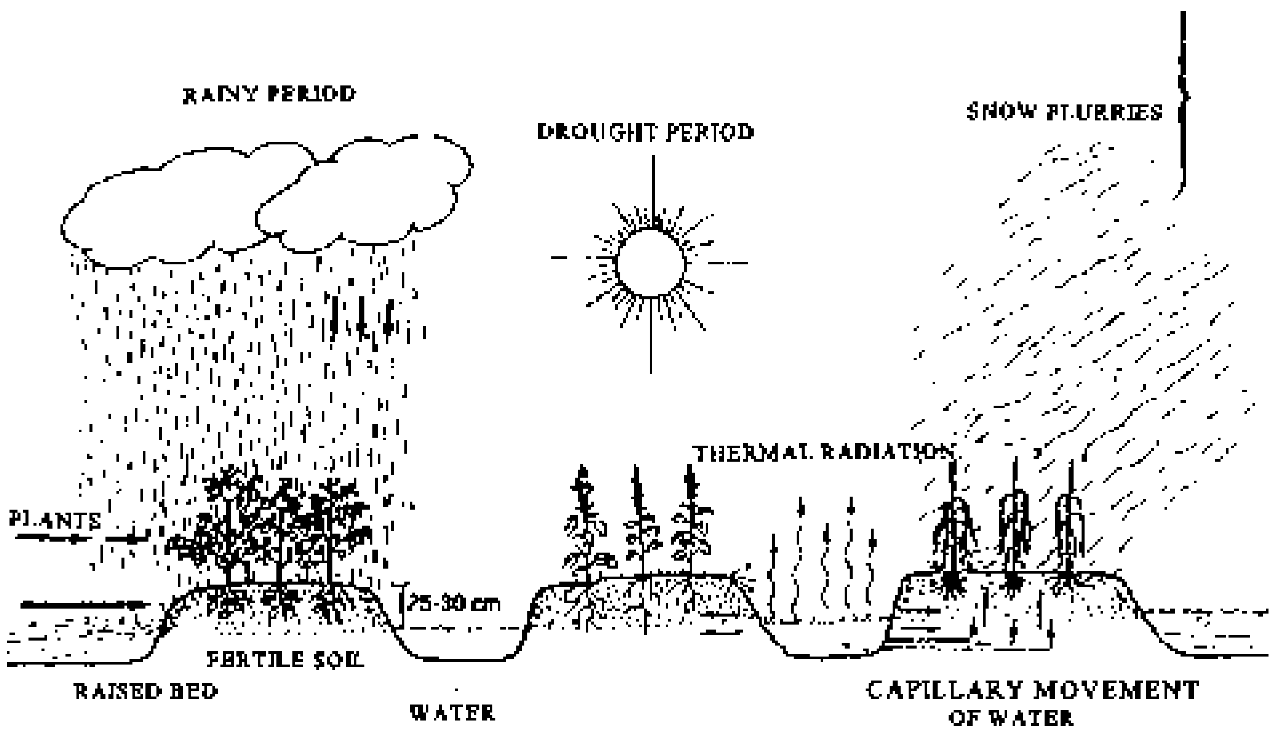
- Depth of the water table, since a high water table increases the height of the embankment required.

- 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.

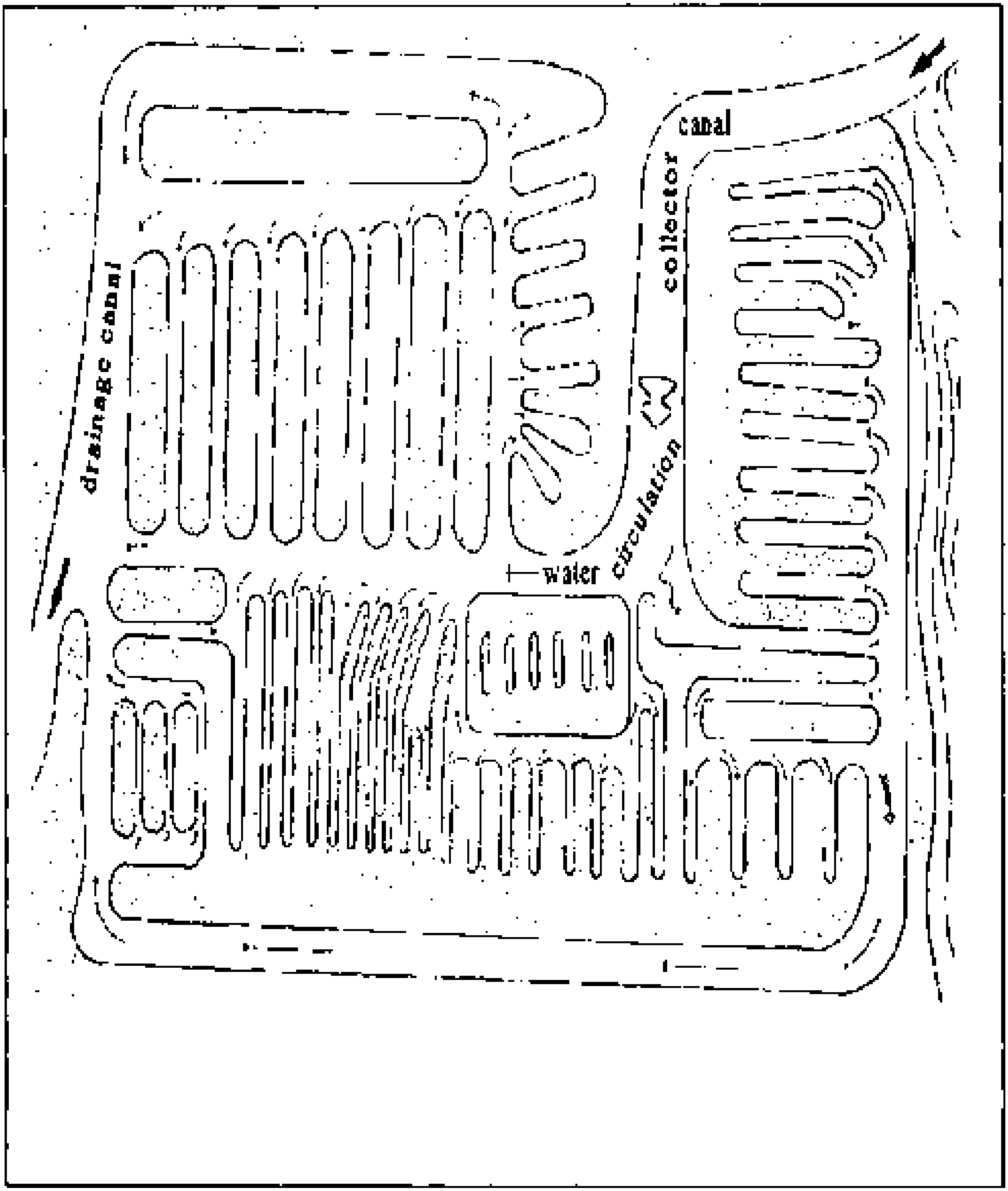
An example of a typical embankment and canal system is shown in Figure 36. Soft fill (e.g., compost or mulch) might be required within the embanked bed to maintain an adequate level of soil moisture.

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



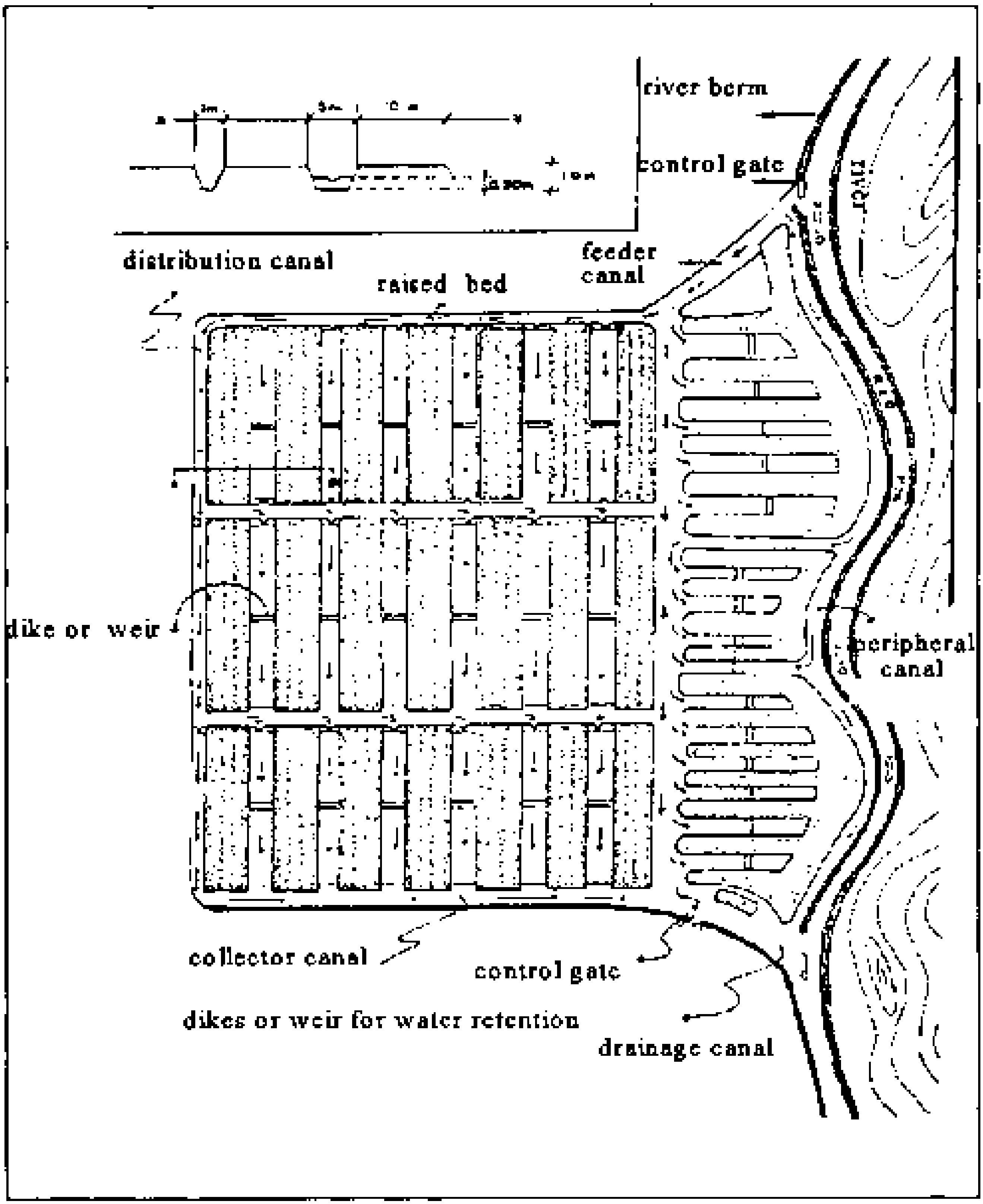
Source: Alipio C. Murilo and Ludgardo L. Mamani, *Manual Técnico de Waru Waru, Para la Reconstrucción, Producción y Evaluación Económica*, Puno, Peru, Programa Interinstitucional de *Waru Waru*, Convenio PELT/INADE-IC/COTESU, 1992.

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



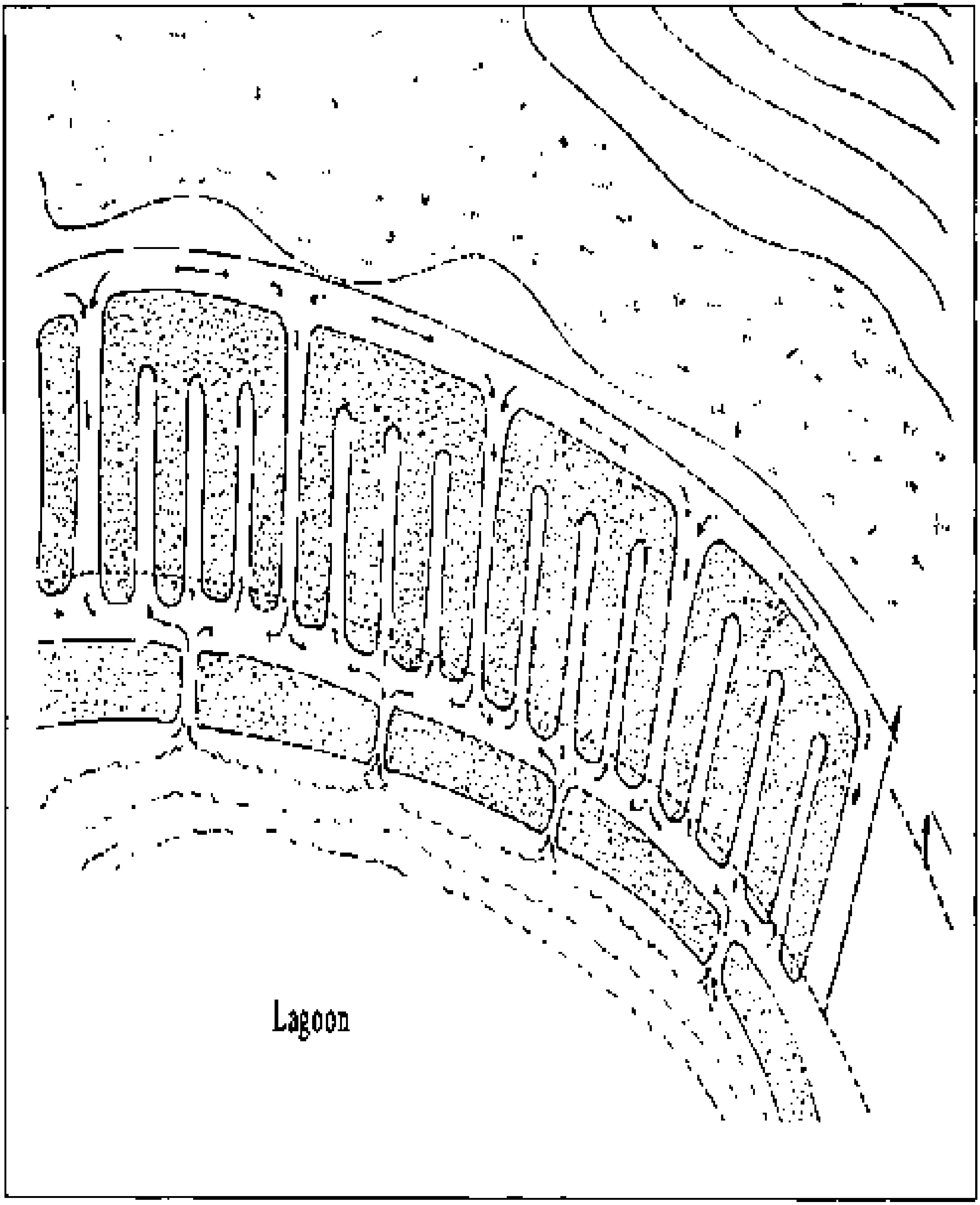
Source: Alipio C. Murilo and Ludgardo L. Mamani, *Manual Técnico de Waru Waru, Para la Reconstrucción, Producción y Evaluación Económica*, Puno, Peru, Programa Interinstitucional de *Waru Waru*, Convenio PELT/INADE-IC/COTESU, 1992.

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.

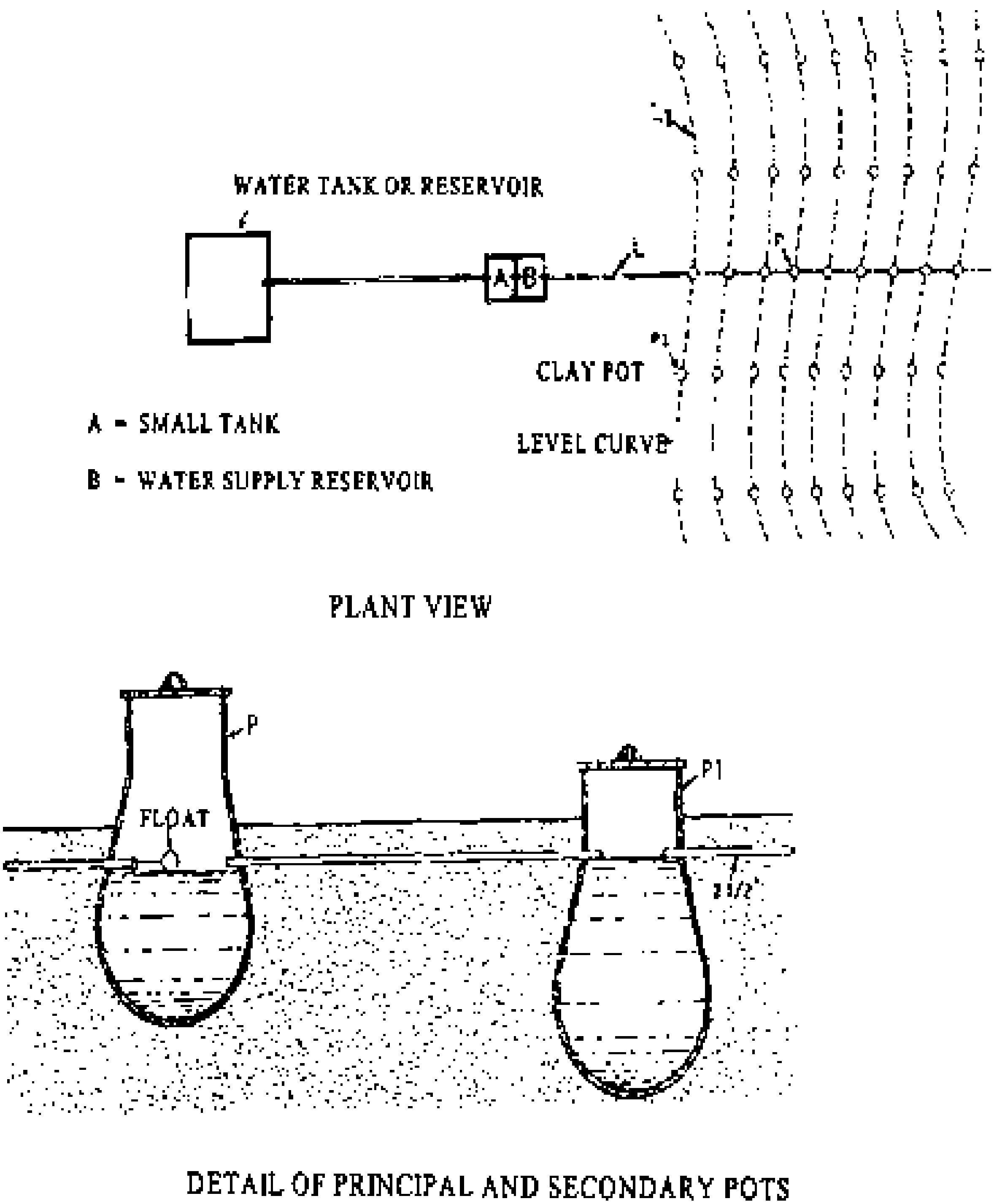
Operation and Maintenance

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

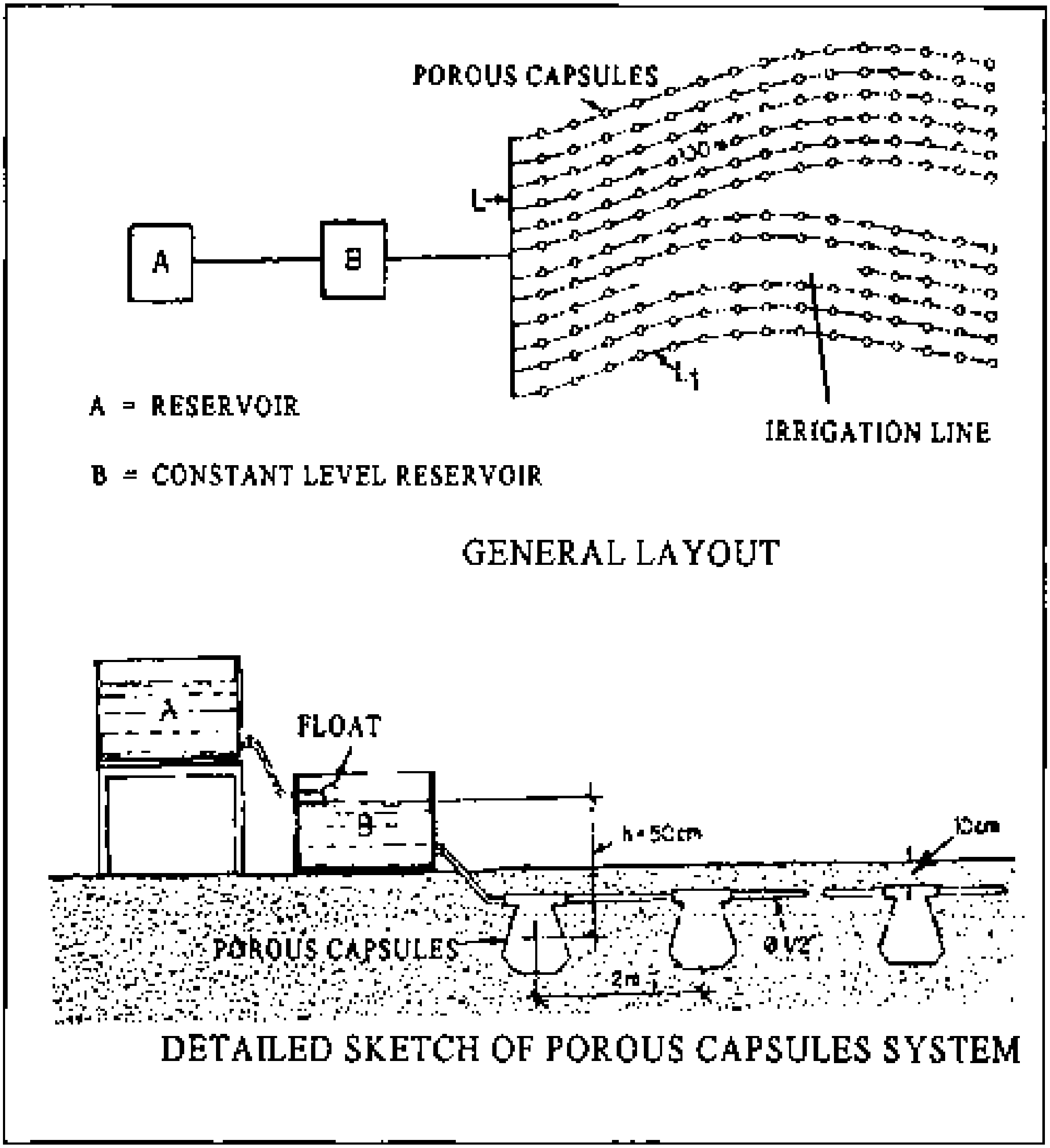
The participation of the community is essential in the implementation of this technology. Further, the support of the government and research institutions is also desirable. In Brazil, the government of the state of Pernambuco built a factory to manufacture porous capsules and developed small areas of 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.



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.



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

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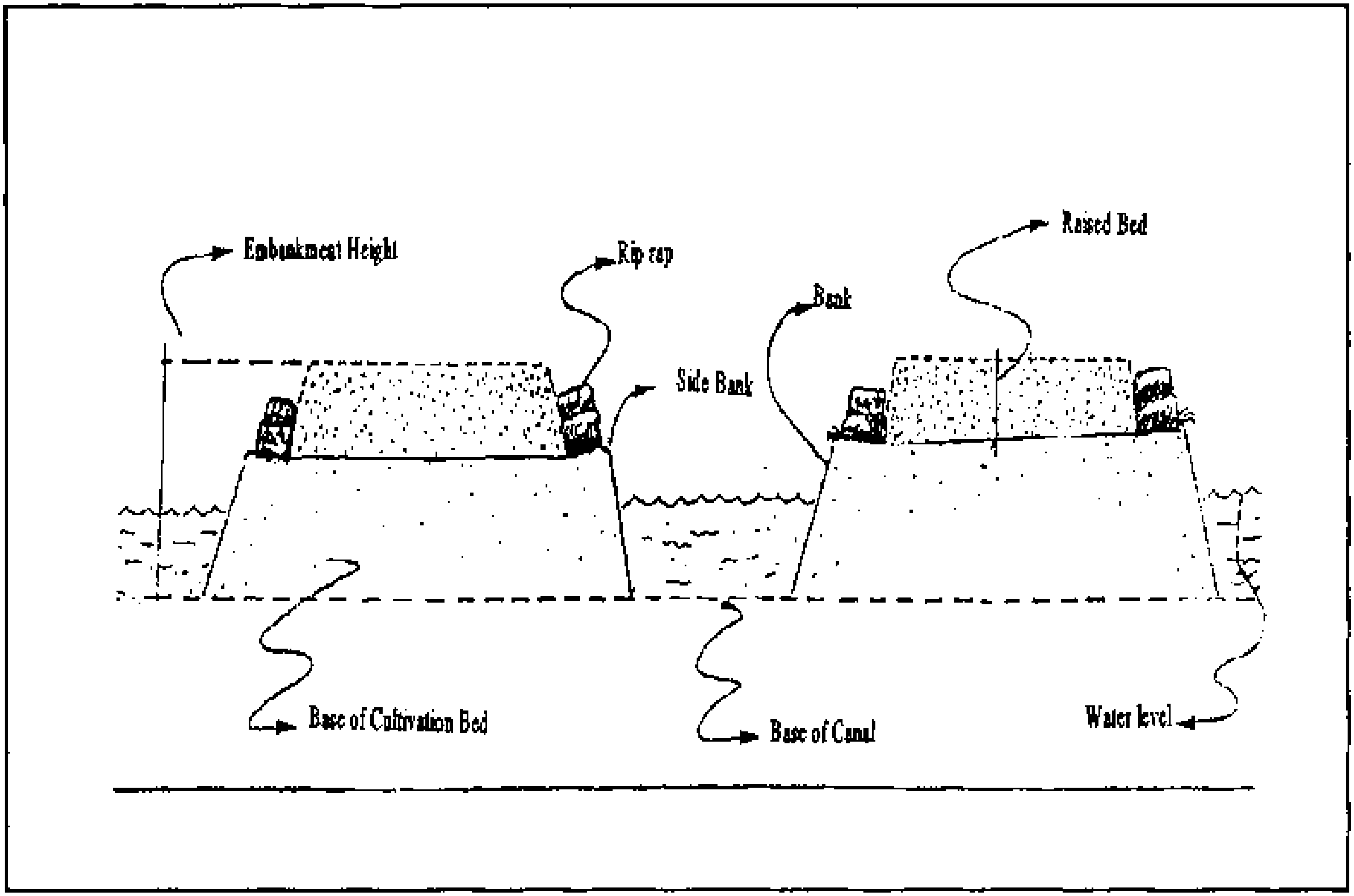

Embankment Height
Rip rap
Raised Bed
Bank
Side Bank
Base of Cultivation Bed
Base of Canal
Water level

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.

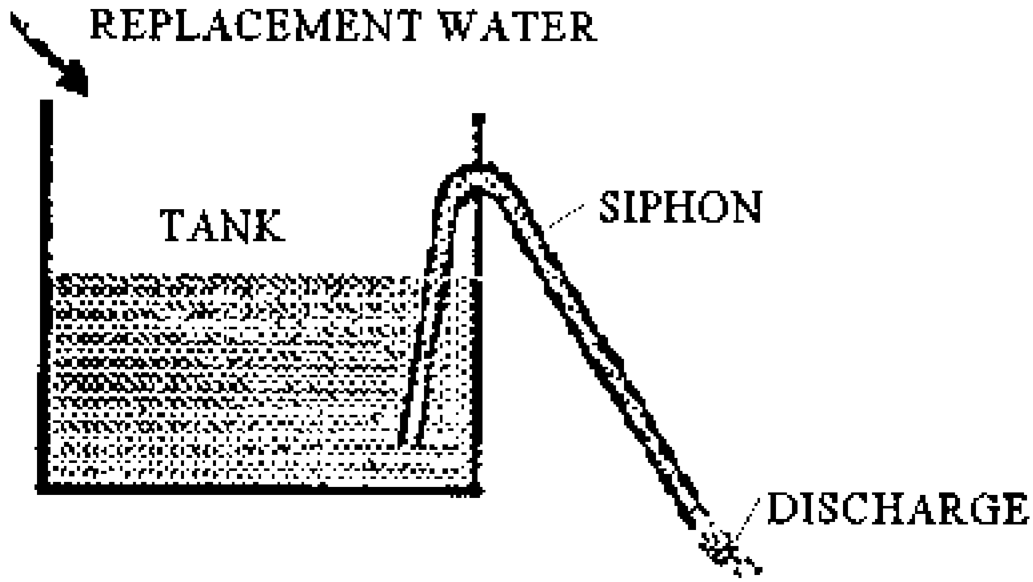
Technical Description

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.

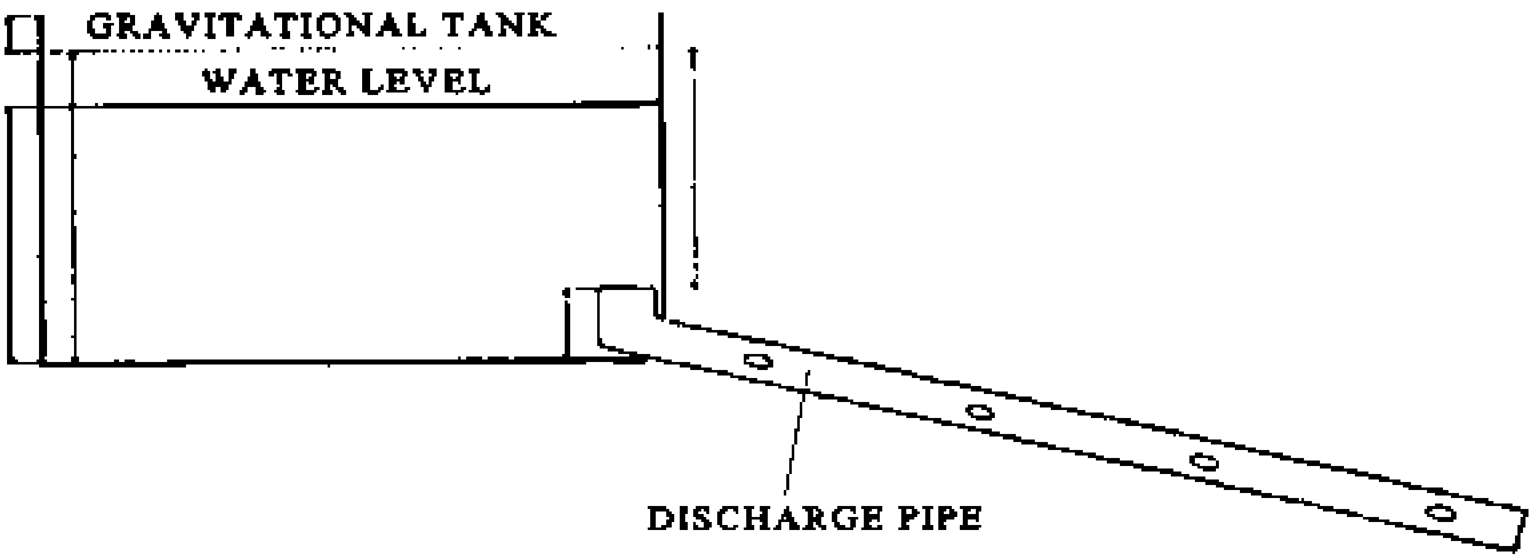
The materials normally used in the construction of the water storage tanks are gravel, cement, and reinforced concrete. The siphons are usually built of a flexible plastic material; PVC is not recommended.

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.

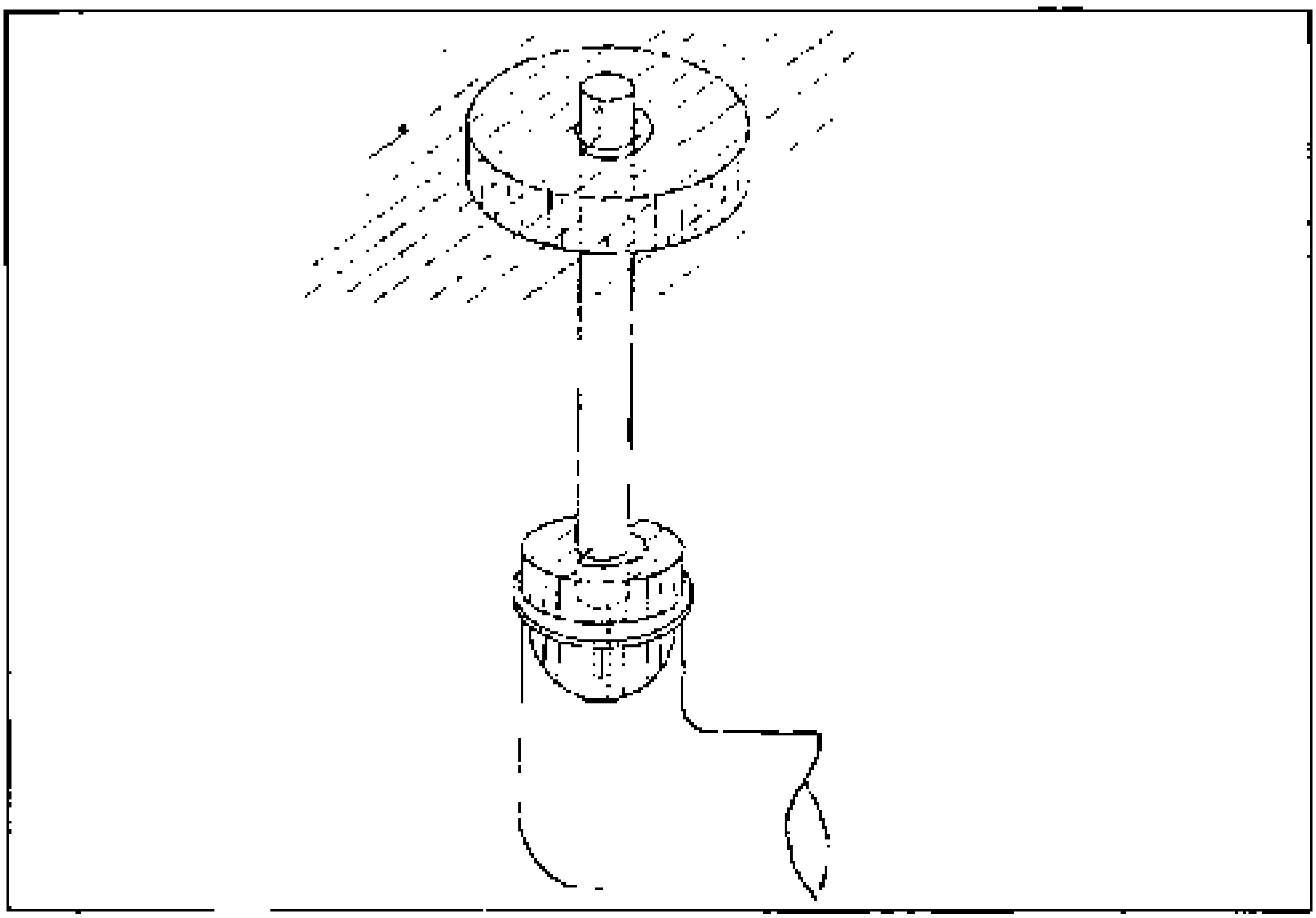
Operation and Maintenance

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

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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

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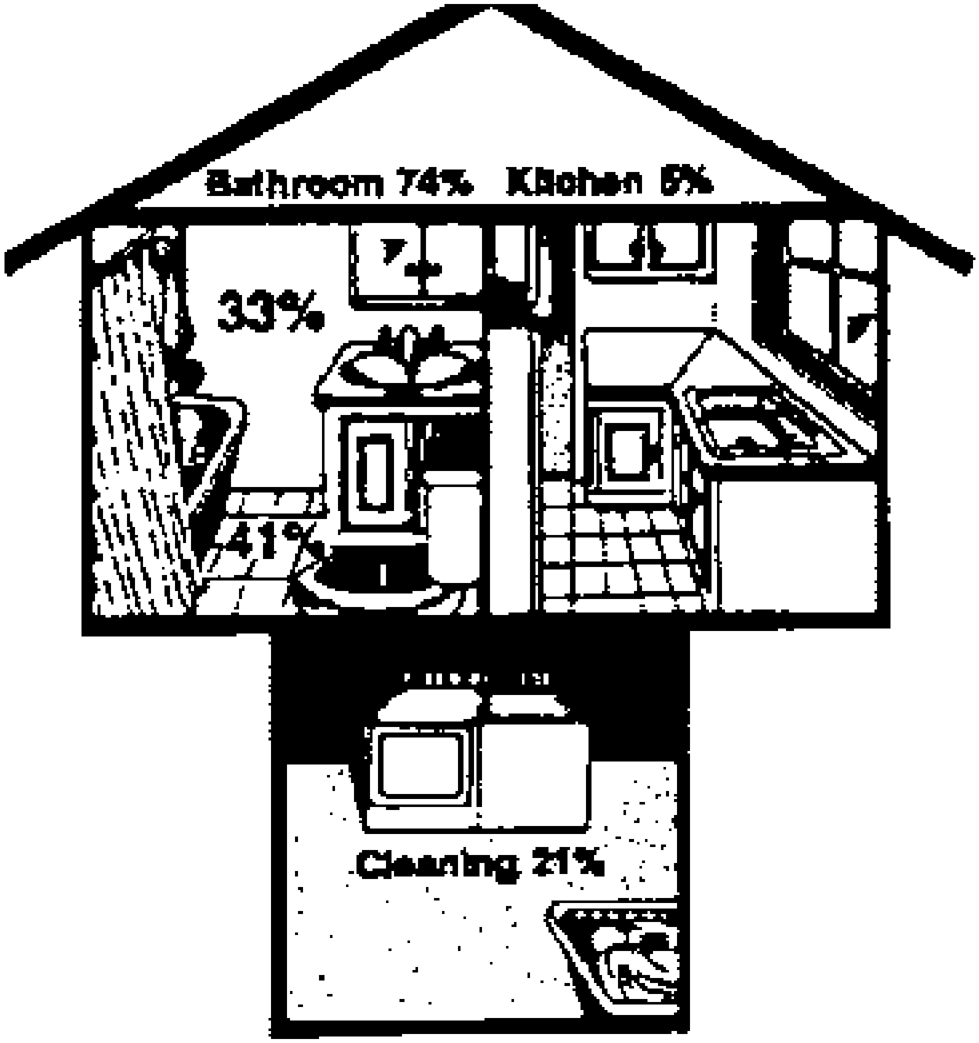
4.5 Other water conservation practices

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.

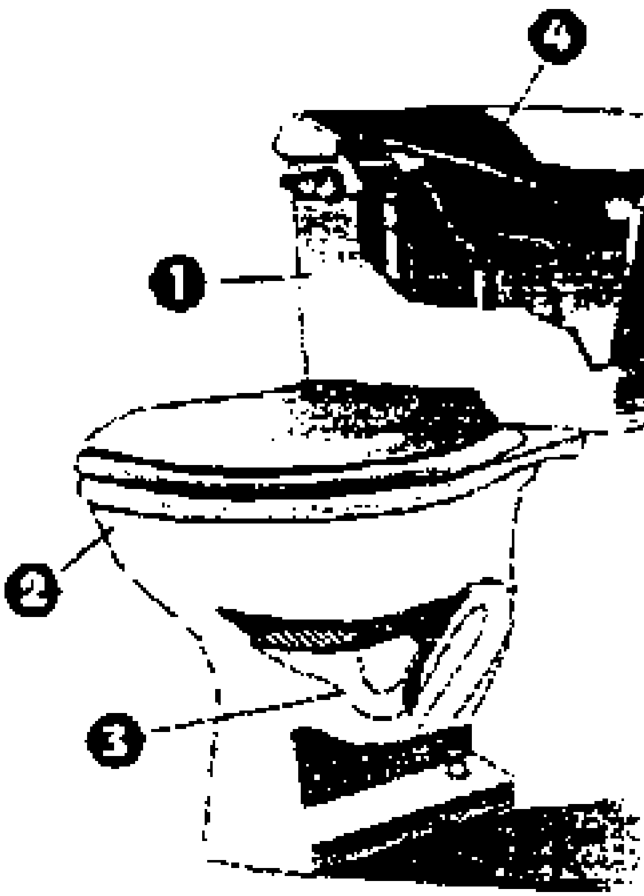
Toilet Displacement Devices. Non-toxic bricks or plastic containers (e.g., milk jugs filled with water or pebbles) can be placed in a toilet tank to reduce the amount of water used per flush. By placing between one and three such containers in the tank, more than 41 of water can be saved per flush. A 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. 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*

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

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Eddy Larios, Coordinador de la Infraestructura, Proyecto de Desarrollo de los Recursos Hídricos del Valle de Nacaome, Dirección de Recursos Hídricos, Tegucigalpa, Honduras.

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

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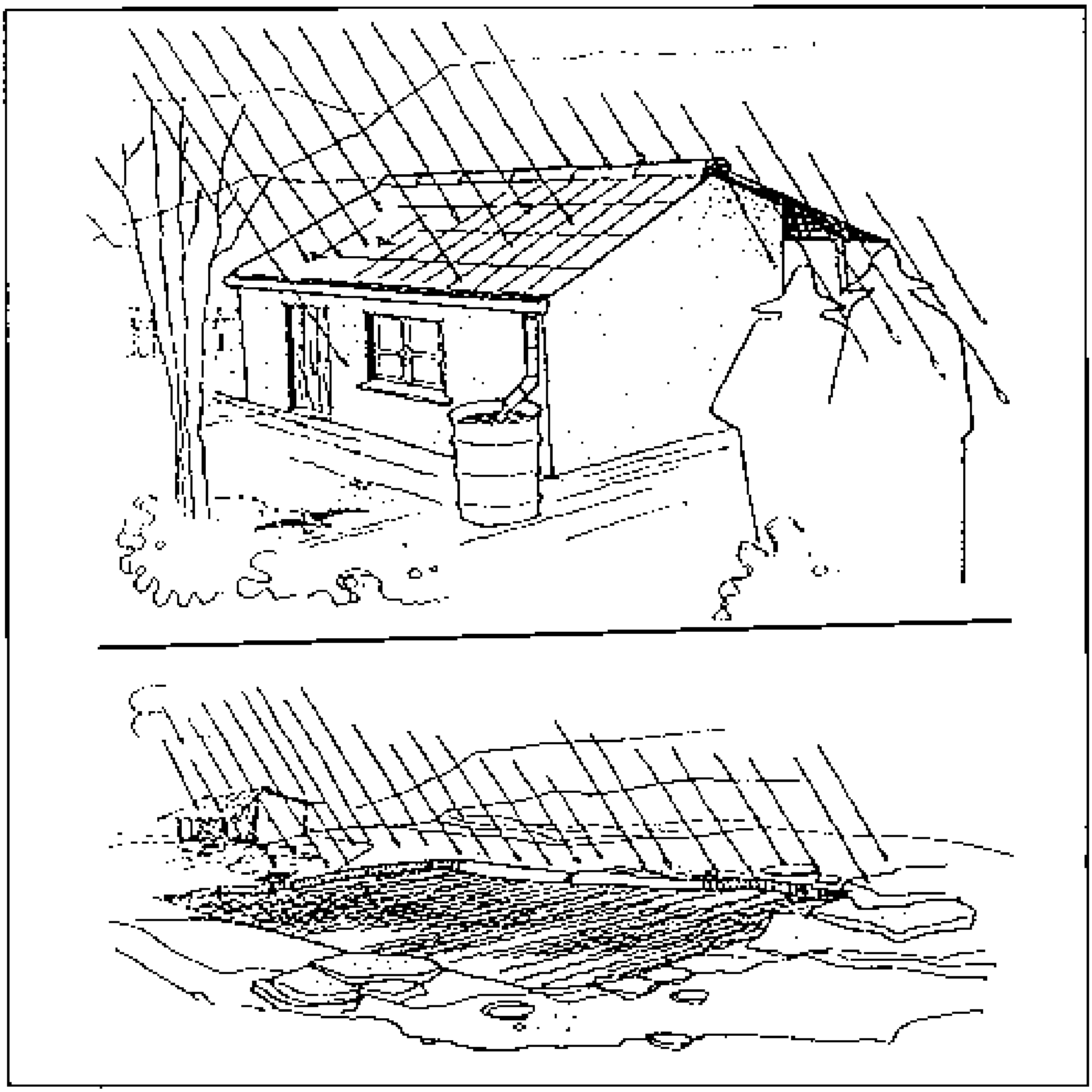
Figure 44: Storage of harvested rainwater in Honduras: in a drum (top) or an impoundment (bottom).



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

Technology	Applications	Extent of Use	Operation and Maintenance	Level of Invovlement	Costs	Effectiveness	Suitability	Advantages	Disadvantages	Cultural Acceptability	Future Development of the Technology
Rainwater Harvesting	Agricultural use; Domestic use	Widespread	Low	Community	Low	High	Widespread, but decreases as other options become available	Simple and easy to construct	Dependant on rainfall	High	Better quality control needed
Fog Harvesting	Agricultural use; Domestic use; Industrial use	Limited to Pacific coastal areas	Low	Community, NGOs and government	Moderate	High under optimal conditions	Limited to areas where heavy fogs occur	Provides good quality water in water-poor areas	Requires a supplementary water source	Experimental	Improved distribution systems needed
Runoff Collection	Primarily agricultural use	Widespread	Low	NGOs and government	Moderate to high	Moderate	Widespread in areas of low relief	Requires little additional labor	Requires low slopes and impermeable soils for best results	High	Incorporation of soil conservation practices needed
Flood Diversion	Agricultural use	Latin America	Moderate to high	Community, NGOs and government (depending on the structures involved)	Moderate to high	High	Widespread in larger river basins where water can be diverted	Provides pollution control as well as water	Structures may fail if design specifications are exceeded	High	Design improvements are needed
Water Conveyance	Primarily domestic use	By tanker in the Caribbean; widespread by pipeline/aqueduct	Moderate	Government	High	High	Primarily as an emergency measure, and ina reas where water is unavailable	Water is delivered to the point of need	Very costly to use on a routine basis	Limited due to costs	Improved distribution infrastructure needed
Artificial Recharge of Aquifers	Agricultural use; Domestic use	Widespread	Low	Community and government	Low to moderate	High	Widespread	Can reduce groundwater salinity	Can introduce pollutants into the groundwater	High	Pollution controls needed
Groundwater Pumping Using Non-conventional Energy Sources	Agricultural use; Domestic use	Widespread	Low to moderate	Community and NGOs	Low to high	Moderate to high	Widespread, especially in areas where conventional energy sources are scarce	Uses renewable energy sources	Replacement parts may not be readily available	High in rural areas	Training in pump maintenance and repair is needed
Desalination	Domestic use	Caribbean	Moderate to high	Government	High	High	Primarily in coastal or island areas where freshwater is not available	Uses an "unlimited" source of water to produce a high quality product water	Energy-intensive and very costly to use on a routine basis	Limited due to cost and technical requirments	More cost-effective and "lower-tech" design improvements are needed
Clarification	Domestic use	Widespread	Low	Community	Low	Moderate	Widespread in areas with suitable plants	It is a natural process	May encourage the spread of undesireable plants (such as water hyacinth)	High	Identification of other suitable plants is needed
Disinfection	Domestic use	Widespread	Low	Community and government	Low	High	Widespread	Effective against most pathogens	Boiling is energy intensive; chlorination presents some safety concerns	High	Improved management methods needed for chlorination systems
Filtration	Domestic use	Widespread	Low	Community, NGOs and government	Low to moderate	Moderate to high	Widespread	Can be applied at scales ranging from household to regional	Filter maintenance is required; media or skilled technicians may not be available	High	Improved filter efficiency is needed
Wastewater Treatment	Agricultural use	Widespread	Moderate	Government	Moderate	High	Widespread	Provides effective pollution control	Large land areas required for facilities and sludge management, etc.	Moderate to high	New, low-cost technologies are needed, especially for small communities
Wastewater Reuse	Agricultural use; Industrial use	Widespread	Moderate	Community; some government	Moderate	High	Widespread, especially for irrigation use	Reduces demands on potable water supplies	Potential for public health impacts exists	Low to moderate	Dual distribution systems need to be incorporated into urban planning
Water Conservation	Domestic use; Some industrial use	Widespread	Low	Community; some government	Low to moderate	High	Widespread	Reduces demands for water from public supplies by up to 50% or more	Initial cost of implementation may be somewhat higher than alternatives	Moderate to high	Public awareness needed

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.

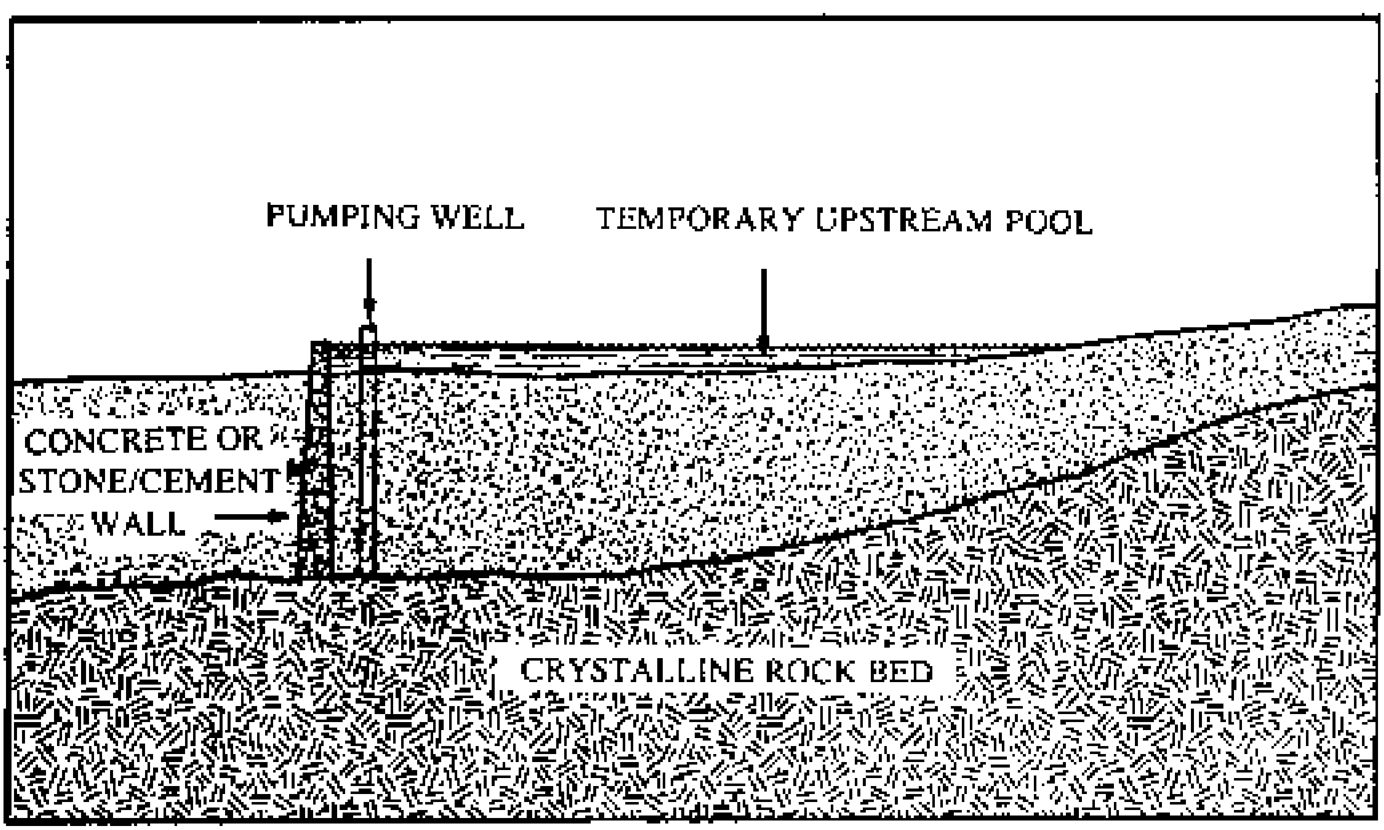
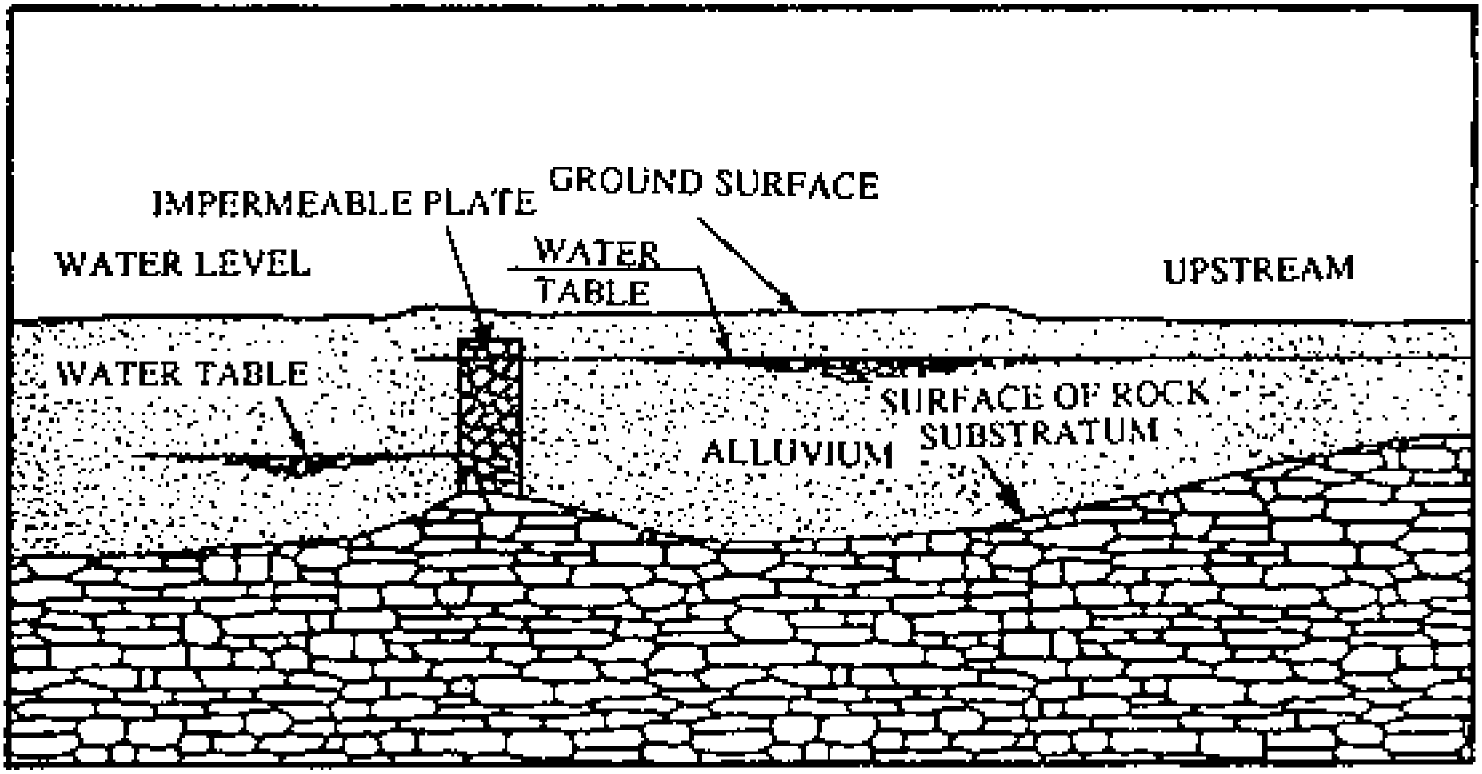


Figure 45 b: Cross-section of a Submerged Dam.



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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5.4 Seawater/brackish water desalination by reverse osmosis in the British Virgin Islands

Technical Description

Desalination by reverse osmosis for public water supply is carried out in the British Virgin Islands on the islands of Tortola and Virgin Gorda. The operations on the island of Tortola may be classified into two different types, based on the source of the feedwater, which is brackish water either from shoreline wells or from alluvial well fields. Of the three plants on the island, the main plant is operated by Ocean Conversion (BVI) Ltd. and obtains its feedwater from wells sunk at the shoreline to a depth of roughly 75 feet. A sanitary seal from ground level to a depth of about 40 feet has been installed. Water is pumped by submersible pumps to the intake of the plant. The two other plants, operated by Aqua Design (BVI) Ltd., obtain their feedwater from either shallow wells dug in the alluvial deposits of the nearby valleys or wells drilled at the shoreline (in the case of the westernmost plant). The two plants operated by Aqua Design (BVI) Ltd. on Virgin Gorda obtain their feedwater from an open-sea intake system. In each case, however, the process of desalination at the plants is generally the same and can be divided into the following stages:

- Pre-filtration of the raw water using disposable 5-10 micron polypropylene cartridge filter elements.
- Pressurization of the raw water to a pressure of about 1 000 psi, utilizing either positive-displacement or multistage centrifugal pumps.
- Separation of the raw water (approximately 40% of the seawater and 73% of the brackish water) into product water and brine, utilizing spiral-wound membrane elements contained in FRP pressure vessels.
- Recovery of the pressure in the brine, by means of a work-exchanger energy recovery system that significantly reduces energy use.
- Disposal of the spent brine.
- Post-treatment of the product water by chlorination, pH adjustment, and corrosion inhibition so that the final water meets the WHO standards for drinking water supply.
- Distribution of the product water, including metering at the exit of the plant and monitoring of the production process through instrumentation and control of automated plant operations.

This technology is described in Part B, Chapter 2, "Water Quality Improvement Technologies."

Extent of Use

All of the public water supply on Tortola, and approximately 90% on Virgin Gorda, is desalinated water. The distribution system covers all areas on the islands below the 300 ft. contour. On Tortola, most of the southern side of the island, from East End, including Beef Island, to Pockwood Pond, is supplied. In the northwest, at Cappoons Bay, desalination plants cover the West End, Carrot Bay, and Cane Garden Bay areas. There are about 4 000 water connections on Tortola, serving a population of 13 500 residents and approximately 256 000 visitors annually. In 1994, the government bought 260.6 million gallons of desalinated water from the two private companies for distribution on Tortola.

On Virgin Gorda, the two plants have open-sea water intakes extending about 1 500 feet from the shoreline: One is in the Valley, and the other is in the North Sound. These plants serve a resident population of 2 500 and a visitor population of 49 000 annually. There are 675 connections to the public water supply system. In 1994, the government purchased 20.8 million gallons of water for distribution in Virgin Gorda.

Operation and Maintenance

On both seawater and brackish water reverse osmosis plants the major maintenance work consists of the following:

- Maintaining and repairing the equipment, which, in the case of the High School Plant located in Road Town, where the wells and well pumps are operated by the Water and Sewerage Department, consists of weekly routine maintenance to ensure a continuous and adequate flow of water to the plant, and general maintenance (e.g., cleaning, painting, leak repair, cleaning around wells).
- Backwashing and flushing of the media filters.
- Replacing cartridge filter elements (approximately every 8 weeks).
- Cleaning the membrane elements (approximately every 4 months).
- Repairing and calibrating instruments.
- Replenishing the pre- and post-treatment chemicals.
- Controlling inventories and ordering spare parts.

The staff required is approximately 1 person for a 200 m^3/day plant, and 3 persons for a 4 000 m^3/day plant.

Level of Involvement

Currently, all plants are operated on a BOOT (build, own, operate, transfer) basis by private (generally foreign) companies which finance, operate, and maintain the plants for a fixed period. The price of the product water is fixed for me period of the agreement, although provision is made for adjustment for inflation, and there are penalties for non-performance. The contracts prescribe a minimum quantity of water which the government is obligated to buy.

At two of the five plants operating on the islands, the government, through the Water and Sewerage Department (WSD), is responsible for the disinfection of the final product water. On Tortola, the WSD is also responsible for the operation and maintenance of the product water pumps at the exit of the plants, and it owns and operates the well fields that serve the westernmost plant. At the Ocean Conversion plant, located close to the Water and Sewerage Department head office, two technicians from the Department have been involved in the operation of the plant from the time of its commissioning. They are paid a monthly stipend as part of the contractual arrangement, and are called in to assist with repair work as and when required. The government also provides the land, tax relief and custom exemptions; buys the bulk water; and monitors the product water quality. The WSD distributes the water.

Costs

The unit cost of production of desalinated water decreases as the plant capacity increases. The turnkey capital cost of a plant of 20 000 gpd is approximately $200 000. For a plant of 1.0 mgd, the cost is approximately $4 500 000. The major operating costs consist of energy (primarily), labor, replacement membranes, and spare parts. Energy consumption ranges from 3 to 6 kWh/m^3 of potable water produced, depending on the size of the plant and the technology employed.

Under the current purchase agreements, the companies maintain and operate the plants at their own cost and sell water in bulk to the government at the following rates per 1 000 gallons:

Tortola

Aqua Design (BVI) Ltd.

- Desalinated seawater = $ 16.50.
- Desalinated brackish water = $9.10

Ocean Conversion (BVI) Ltd.

- Desalinated seawater = $ 15.80

Virgin Gorda

Aqua Design (BVI) Ltd.

- Desalinated seawater = $ 13.10

In 1994, the Government of the BVI bought 260.6 million gallons of water from the desalination companies for distribution on the island of Tortola at a cost of $3 611 000. On Virgin Gorda, after desalinated water became available to the public during February 1994, the Government of the BVI bought 20.8 million gallons at a cost of $485 000.

Effectiveness of the Technology

The seawater/brackish water reverse osmosis technology is very effective at converting Caribbean Sea water to potable water, meeting the WHO standards for drinking water, with a total dissolved solids level of less than 500 mg/l.

Suitability

The technology is suitable for use throughout the Caribbean Basin, provided there is a source of clean raw water, either from boreholes or from open-sea water intakes. The technology is particularly suitable for use in areas where the freshwater resources are inadequate to meet growing demands and the centers of population are concentrated close to the coast. In considering the use of seawater in desalination, the seawater should be free from pollutants, especially from land-based industries, and the intake should be located in an area with little chance of pollution by ocean-going vessels. The disposal of the brine effluent should be carefully considered as this can have adverse effects on sea life.

Advantages

- Desalinated water is a reliable source of water that is not subjected to seasonal changes in, or locally extreme, weather events.
- There is generally minimal usage of chemicals in the process.
- There is minimal environmental impact.
- The plants can be modular in design and easily expanded to meet changing demands.
- Delivery times for modular units and spares are short, typically 3 to 12 months, depending on the location and size of plant.
- If private contractors are used to supply the water, minimal capital investment by the government is required.
- Water price can be fixed and/or linked to inflation for the duration of the agreement.

Disadvantages

- Great care and staff expertise is required to minimize the rate of membrane replacement.
- In the case of open-sea intakes, there is the chance of interruptions during stormy weather.
- The sophistication of plant and the high pressures involved require materials and equipment of a very high standard, not usually available locally, which may result in high importation costs.
- There is usually a need for foreign expertise, with a concomitant commitment of foreign exchange.
- There are many dissimilar components used in the plants, so a highly varied spare parts inventory is required.

Further Development of the Technology

The seawater/brackish water reverse osmosis technology would be further improved by the development of membrane elements that are less prone to fouling, operate at lower pressures, and require less pre-filtration, and by the introduction of highly efficient energy recovery technologies that are simpler to operate than the existing work-exchanger technologies.

Information Sources

Contacts

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William T. Andrews, Managing Director, Ocean Conversion (BVI) Ltd., Post Office Box 122, Road Town, Tortola, British Virgin Islands.

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5.5 Recycling of industrial effluent in Jamaica

Technical description

Recycling of industrial effluent is now being practiced by several industries to reduce the demands on freshwater resources and to reduce pollution of the environment. The recycling of industrial effluent was spearheaded by the bauxite/alumina companies operating in Jamaica, and they are the largest recyclers at the present time. The bauxite/alumina industry produces a waste product known locally as "red mud," which consists of over 70% water, enriched with caustic soda and organics.

The waste is thickened to 28% solids and sprayed on a sloping drying bed in a layer 8 to 10 cm thick. The liquid fraction is collected at the toe of the drying bed and is channeled via pipelines to a sealed holding pond. Pumps move the effluent from the holding pond back to the plant via a pipeline where it is recycled through the process. The system consists of:

- Deep mud thickeners (conical vessels).
- High pressure pumps and pipelines to the drying beds.
- Drying beds, sealed to prevent infiltration of the effluent to the groundwater.
- An effluent holding pond, also sealed to prevent infiltration of the effluent to the groundwater.
- Recycling pumps and pipelines to the plant.

This technology is described in Part B, Chapter 3, "Wastewater Treatment Technologies and Reuse."

Extent of Use

This technology is used at four bauxite/alumina plants in Jamaica. Efforts are under way to encourage other industries to follow suit and recycle process and waste waters.

Operation and Maintenance

Problems encountered in the operation and maintenance of the system include mechanical breakdowns of the pumps; ruptures of the pipelines, necessitating a total shutdown of the system; and heavy rains that overload the system, resulting in spillage to the environment. The bauxite/alumina companies, all being multinational corporations, have few problems in replacing parts or equipment, and generally maintain a large equipment inventory. Each bauxite company has a preventive maintenance program, which also reduces downtime.

The skills needed to operate the system are varied. Overall direction is provided by the senior production engineer. However, skill levels range from laborers, who turn valves on and off, to chemical engineers, who manage the system.

Level of Involvement

The private sector and the government are involved in the implementation of this technology and in certain facets of the operation. The bauxite/alumina companies provide the capital and the engineering designs, and construct the systems. The government, through several specialized agencies, reviews the engineering designs and grant the permits for construction to proceed. Part of the permitting process involves the conduct of an environmental impact assessment. After the permit is granted, construction of the systems is monitored by the government to ensure that design specifications are adhered to. The relationship between the public and private sectors is cooperative and complementary.

Costs

Initial capital costs vary and are dependent on the volume of work to be done in preparing the site, resettling persons living on or near the site, and making the necessary changes in the plant infrastructure. The minimum investment to date in any one system has been $50 million. Operation and maintenance costs are not available as this information is confidential and proprietary to the bauxite companies.

Effectiveness of the Technology

The system, as designed and operated, is very effective in reducing contamination of groundwater resources. Because it is completely sealed, it does not allow infiltration of liquid effluents, and recycling this fraction reduces the risk of contamination of groundwater resources from effluent disposal. The use of this system has reduced groundwater contamination in one area by 44% since 1985, as reported by the Water Resources Authority. Despite some disadvantages, due predominantly to the large land areas consumed by the drying beds and holding ponds, the application of this technology, in all cases, has proved to be advantageous.

Suitability

The technology is suitable for application in areas where large tracts of non-agricultural land - i.e., in excess of 200 ha - are available. In addition, the land should not be steeply sloped, and a supply of nondispersive clay should be available in close proximity to provide impermeable material for sealing the bottom and sides of the drying beds and holding ponds. The technology can be, and is being, adapted for other situations.

Advantages

- Use of this technology reduces the rate of freshwater withdrawal from aquifers; savings of 4 to 5 Mm^3/year of freshwater have been recorded.

- Recycling of process water reduces the volume of caustic soda solution needed, as the caustic soda is recycled with the effluent.

- The use of energy, to pump freshwater from depths greater than 100 m, is reduced, thereby saving on the import bill (foreign exchange) for oil.

- Contamination of groundwater is reduced by removing and recycling the liquid fraction of the waste stream that is a risk to groundwater quality; likewise, the retention of a high percentage of the caustic soda in the thickened mud (solid fraction) and in the recycled process water makes this contaminant less available for migration to the groundwater.

- The bauxite/alumina companies are better able to meet the ISO 9000 and ISO 14000 certifications and thereby gain a competitive advantage in the marketplace.

- The decreased input costs reduce operational costs, resulting in higher profit margins for the companies and more tax revenue for the government, increasing both the level of investment in the country and the GDP.

- Better environmental management by the corporate sector results in fewer governmental regulations; other multinational corporations are likely to see such conditions as favorable and invest in Jamaica.

- The incidence of water pollution is reduced, increasing the availability of freshwater for domestic and irrigation uses and reducing the cost of water to citizens; this increases the standard of living and governmental popularity.

Disadvantages

- There is an increased risk of pollution of surface water resources, due to the large size of the holding ponds and the possibility of spillages.

- Technical problems within the plants may be experienced, reducing the level of production and affecting the volume of recycled effluent; hence, storage volumes can increase to the point where overflows occur, affecting the environment.

- The quality of effluent may vary significantly, affecting the degree of treatment provided by this technology and thus, potentially, the level of production at the plants.

- The technology is capital-intensive, not labor-intensive, and provides few spin-offs for nearby communities where unemployment may be high.

- As a result of the land-intensive nature of this technology, its implementation may result in the relocation of residents, disrupting their lives and causing great inconvenience; for farmers and other small businesspeople, a new location may be less suitable and/or create the need to seek other employment.

- Agricultural land may be lost in some cases, decreasing food production.

Further Development of the Technology

This technology can be more effective if overflows and spills from the system are managed better. Design parameters, especially relating to the effects of rainfall/runoff and the rate at which the plants can accept recycled effluent to prevent negative environmental impacts, need to be better refined.

Information Sources

Contacts

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5.6 Treated wastewater reuse scheme in Barbados

Sam Lord's Castle Hotel is located on the southeastern coast of Barbados, in the parish of St. Philip. It lies within the coral-covered portion of the island, with a coral cap thickness of about 80 ft. With an average annual rainfall of 45 inches, this is one of the driest areas of the island (the average annual rainfall for the whole island is 60 inches). In this area, except for 4 months of the year (August to November), the average evapotranspiration rate, 4.5 inches/month, exceeds the monthly rainfall figures. The groundwater resources in this area consist of a thin freshwater lens floating on top of saline water.

The hotel was formerly supplied with freshwater from a groundwater well, but because of the high water demand, especially for the irrigation of large expanses of lawns and garden plants, saline groundwater intruded into it to the point where the freshwater supply was virtually exhausted. A decision was made then to abandon the use of the well and the hotel sent an application to the Ministry of Health and Environment seeking permission to use the treated effluent from its extended aeration sewage treatment plant for irrigating lawns and garden plants. Permission for wastewater reuse was granted and treated wastewater was diverted to irrigation use from its former disposal site in four deep suckwells.

This technology is described in Part B, Chapter 3, "Wastewater Treatment Technologies and Reuse."

Technical Description

Effluent consisting of kitchen, laundry, and domestic sewage is conveyed to a collection chamber, from which it is pumped through a comminutor to an aeration chamber. No primary sedimentation is provided. The aerated mixed liquor then flows out of the aeration chamber through a rectangular opening at one end into a clarifier for gravity separation of solids. The effluent from the clarifier chamber is then passed through a 16-foot-deep chlorine disinfection chamber and pumped to an automatic sprinkler irrigation system. The irrigated areas are sub-divided into 16 zones with 12 sprinklers each. Some areas also have a drip irrigation system. This process is illustrated in Figure 46.

Sludge with a high water content is pumped from the sludge chamber to the suckwells for disposal without thickening. Previously this sludge was pumped to the Bridgetown Sewage Treatment Plant for further treatment and additional desludging. This pumping incurred additional transportation costs.

The packaged wastewater treatment plant was designed abroad and constructed using local contractors. The drip and sprinkler irrigation systems were designed and installed in part by a local irrigation system consulting company and in part by the hotel's maintenance personnel. The Environmental Engineering Division (EED) of the Ministry of Health and Environment was responsible for approving, monitoring, and controlling the operation of the packaged plant. Thus, despite the absence of effluent standards enacted into law, some conditions were placed on the system before permission was granted for irrigation reuse. The approval process involved consultations with the Town and Country Planning Offices and the

Barbados Water Authority (BWA).

Extent of Use

At present, there are twelve wastewater treatment facilities in use in Barbados, ranging in size from 2 860 gpd to 37 400 gpd for hotel facilities and to 594 000 gpd for the Barbados Water Authority plant. The combined total treatment capacity amounts to 786 280 gpd. Eight of these plants are extended aeration plants, three are rotating biological contactor plants, and one, the Barbados Water Authority plant, is a contact stabilization plant. Two more BWA sewerage systems are planned for the south and west coasts, with the intention of reusing their wastewater effluents.

Reuse of treated wastewater for the irrigation of garden plants and lawn grass is limited at present to Sam Lord's Castle Hotel. Another, the Almond Beach Village Hotel, formerly Heywoods Hotel, in St. Peter on the west coast, is almost ready to start irrigating a 9-hole golf course. Other applications for the reuse of wastewater on golf courses (Westmoreland, Kingsland, and Bushy Park are pending, and a number of major hotels have indicated their interest in applying for permission to reuse their effluent. In addition, plans are in place to reuse some of the treated effluent from the BWA Bridgetown Sewage Treatment Plant for flushing sewer lines.

Operation and Maintenance

According to the report of a survey on the Operational Aspects of Wastewater Treatment Plants in Barbados undertaken by A. Vlugman of PAHO in 1990, the operational status of the Sam Lord's Castle Hotel plant was considered to be moderate. The plant is about twelve years old and the operator reports few problems; those that have occurred are considered minimal (due to grease). There does not seem to be any problem with obtaining spare parts. However, no design or construction drawings are available to help with the operation and maintenance of the plant, and the basic skills required to operate and maintain the plant, such as some knowledge of microbiology, some electrical/mechanical skills to repair the equipment, and some understanding of the treatment process and the impact of poor performance on the whole scheme, are generally lacking.

Considering the small size of most packaged wastewater treatment plants, it may not be cost-effective for each hotel to employ a qualified operator. However, it might be possible for a number of hotels to employ collectively one qualified operator to look after a number of plants. Alternatively, the Barbados Hotels and Tourism Association (BHTA) could employ an environmental officer or sanitary engineer to oversee or advise the various hotels on wastewater treatment and effluent reuse.

The operation and maintenance required consists of turning the pumps that do not run continuously (such as the sludge pumps) on and off, and checking to ensure that all systems are running smoothly without any blockages. There are no flow meters installed and no laboratory facilities of any kind are provided to document the technical performance of the plant. Any operational monitoring of plant and process by the operator is limited to visual inspections. Plant performance is evaluated by the operator on the basis of the color of the mixed liquor in the aeration chamber; a brownish color is an indicator of good performance. Nevertheless, BOD and TSS analyses are done monthly during inspections by the EED.

Level of Involvement

The only government involvement in this program is licensing, monitoring and administrative control, exercised through the EDD, which is charged with the responsibility of approving and monitoring the performance of packaged wastewater treatment plants. The Sam Lord's Castle Hotel plant is entirely privately owned and operated, except for the monthly inspections and sampling for BOD and TSS conducted by the EED.

Costs

As this plant is privately owned and operated, cost figures are not available.

Effectiveness of the Technology

Based on 1989 and 1990 results, BOD and TSS removal efficiencies of 86%, and of 98% and 83%, respectively, are achievable. Data on the microbiological quality of the effluent are not available; two chlorine tablets are put into the chlorination chamber each week, regardless of effluent quality or quantity. Hence there is need to evaluate in detail the effectiveness of the disinfection before the effluent is used for irrigation. However, from an aesthetic point of view, the irrigation of lawns and plants seems to be very successful, as evidenced by the lush greenery surrounding the hotel. This is a great improvement compared to the period before the effluent reuse program was put into place.

Figure 46. Wastewater Treatment Process for Sam Lord's Castle.

> Source: John Bwalya Mwansa, Project Manager, Barbados Water Resources Management & Water Loss Studies, Barbados Water Authority.

Suitability

The applicability of this technology depends on the nature of the land. In Barbados, owing to the karstic nature and topography of the coral rock aquifer system, groundwater contamination by reused wastewater can be avoided only if the wastewater is properly treated. At present, there are very few facilities with a suitable effluent quality. However, the hotels in the belt along the south and west coast, downgradient from the line of public water supply wells, would be obvious candidates for application of this reuse technology, posing the least danger of contamination to the groundwater. The hotel belt also has the advantage of being situated next to the BWA wastewater treatment plants.

Advantages

- The use of the treated effluent results in substantial savings in irrigation water costs and reduces the likelihood of water pollution, assuming that the effluents would otherwise have been disposed of through sea outfalls.

- This technology eliminates the need to use potable water supplied by the BWA public domestic supply system for irrigation and makes it available for other uses.

Disadvantages

- Inadequate operation and maintenance may pose some health risks.

- The WHO criteria on wastewater reuse for recreational purposes with possible human contact may not be fully met in this case. These criteria (effluents should not contain more than 100 coliform organisms/100 ml in 80% of samples, and should not contain chemical contaminants that lead to the irritation of mucous membranes and skin) require primary and secondary treatment and sand filtration, or the equivalent. Provision of such treatment would significantly increase the cost of this technology.

- The potential environmental impacts associated with this technology are contamination of groundwater, human skin irritations caused by bacteria or viruses in inadequately disinfected effluent sprayed on lawns or gardens, and mineral buildup (salination) in the soil, none of which are currently monitored on an adequate and continuous basis. (Because of the proximity of the application area to the coast, there is little risk to the domestic groundwater supply from the Sam Lord's Castle Hotel reuse scheme; however, the flow to the sea could still adversely affect the coastal marine ecosystem. In this case, the irrigation is timed to minimize the health risk to the hotel guests.)

Further Development of the Technology

The technology is well developed; however, local engineers and scientists need to familiarize themselves with it and evaluate its suitability for use elsewhere in Barbados, with any necessary modifications. There is also a need to evaluate the effectiveness of the disinfection process (chlorination by gas or chlorine tablets) in eliminating bacteria and viruses. It is very probable that, in future, more hotels will want to reuse effluent from the packaged treatment plants, especially in the light of proposals to change the domestic water tariff structure. Special training programs, in association with the BWA wastewater treatment facilities, should be developed to improve plant performance and monitoring.

Information Sources

Contacts

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5.7 Clay pot and porous capsule irrigation in Brazil

Subsistence farmers in the tropical, semi-arid parts of Brazil depend on rainfall to provide water for the growth of most of their crops. In years of low rainfall, agricultural production is severely affected. To make matters worse, most agricultural plots in this region cannot be served by conventional systems of irrigation because of the huge volume of water that would be required. To overcome these difficulties, Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA) introduced the use of porous or clay pot irrigation systems in Brazil in 1978. These systems have contributed to ensuring steady or even higher agricultural output owing to the highly efficient and economical use of water. A system of this kind was used centuries ago by the Romans, and initial experience in Brazil suggests that different varieties of plants can thrive in normal, saline, and saline-sodic soils on small amounts of water using the clay pot technology. Water use is roughly equivalent to 17 mm/ha/800 pots over a period of 70 days (Modal, 1978). This technology is described in Part B, Chapter 4, "Water Conservation."

Technical Description

• Clay Pot Irrigation

The clay pot system of irrigation, which consists of individual pots or a series of pots connected with plastic tubing, is easy to install, operate, and maintain. The main components of the system are shown in Figure 37.

A main supply line connects the raw water source (a reservoir, tank, pit, dam, etc.), by way of a storage tank and sand filter, to the series of clay pots, which are joined together with ½″ diameter polyethylene tubing. The water level in the pots is kept steady by a system of float valves. The pots, similar to the tanks used to store drinking water in the home, are generally conical in shape and can hold 10 to 121 of water. They are typically made of clay and baked in home ovens by individual craftsmen. Because each is handmade, they will not all have the same volume. These pots, in turn, may be connected to a row of secondary storage pots which are connected to load pots in the main row. The secondary pots are installed in curved lines and are used to grow different crops.

Before the pots are set up, the soil must be prepared enough to mark out the curved lines where the pots in the secondary line of supply are to be placed. Holes are dug at the desired distance apart to accommodate the pots in the main and secondary lines. Manure from the farm is added at this time, if necessary. Then one pot is placed in each hole and the tubing is attached with an epoxy glue. The tubing is aligned in a small furrow, about 8 cm deep, so that it can be fully covered with soil. It is essential that the pots in the second row be aligned parallel to the gradient so that the water in each pot is kept at the same level.

The clay pot method of irrigation should only be used on small plots of up to one hectare because the pots do not usually release the same volume of water. The system is recommended for home vegetable gardens (10 to 20 pots) and for small orchards in rural communities. The steps involved in setting up a family vegetable garden include:

- Choosing an area with regular to clayey soils to a depth of more than 1 m situated near a water source with a good supply of clean water (without clay particles in suspension).

- Marking out one or two 10 m x 1 m beds in the area selected and digging circular holes 80 cm in diameter and 60 cm deep, about 1 m apart from center point to center point. This will be large enough for 10 clay pots to be placed in each bed. The soil removed should be left beside the hole. Likewise, the soil in the 40 cm strip running from the edge of one hole to the edge of the next and in a 20 cm strip around the borders of the beds should be removed to a depth of 30 cm to take the "wet bulbs" of the clay pots, and left beside the bed.

- Breaking up the soil that has been dug up into pieces of less than 1 cm in diameter, and mixing it with at least 50 kg of manure for each bed.

- Placing the soil-manure mixture in the bottom of each hole to a depth of 30 cm.

- Inserting a porous clay pot 30 cm in diameter and 50 cm high, with a 10 to 12 l capacity, into the center of each hole and filling the rest of the hole with the soil-manure mixture, leaving just the neck of the pot protruding. In the case of heavy clay soils, a fine layer of sand should be placed around the pot.

- Filling the pots with clean water; muddy water or water with clay particles should never be used as the silt particles will interfere with the porosity of the clay vessels.

- Planting vegetable seeds in the bed in the same way as in traditional vegetable gardens. The seeds should be irrigated two or three times a day until germination, which usually takes about 6 days, depending on climatic conditions.

Three days after the pots are initially filled with water, six to eight holes are dug about 2 m to 4 m from the side of each pot for the final planting of the seedlings. The hole should be covered with dry soil and irrigated daily. The pots are refilled with water every day until the seeds or seedlings are able to survive on their own using just the regular release from the clay pots. The same procedure is used for seedlings that are planted directly.

The clay pots should release, on average, at least 3.5 l/day of water each day, although, to start with, as much as 20 l of water may be released. (The important thing is for the pots to be able to release a minimum of 3.5 l/day during the period when the need for water is greatest.) In areas where the clay pots are not baked in closed ovens, sand should be added to the clay mixture to make them more porous.

- Porous Capsule Irrigation

This method is technologically a little more sophisticated than the previous method. It has the advantage of a standard volume for each capsule. Each capsule is also more porous and releases more water. As in the clay pot technology, the capsules are made from a clay mixture. They are reddish brown and conical, with sides about 60 mm thick.

The Center for Research in Tropical Semi-Arid Regions (CPATSA) of Brazil has conducted comparative studies of the capsules used in this technology and has found that Mexican pots have four openings: two at the top and two at the bottom. They are made of pure, nonexpandable clay and are baked in ovens at 850°C. They can hold 600 cm^3 of water and have a porosity of 18% (Santos, 1977). In contrast, the capsules currently in use in Brazil have a 700 cm^3 capacity with a mechanical resistance of 5 kg/cm^2, a porosity of 21%, and two connector spouts at the top. They are commercially made from a mixture of plastic and elastic materials, and baked in closed tunnel ovens at 1120°C. These units can accommodate higher volumes of water and release an average of 5 l/day. They are set in 100 m rows, making them easy to join together. This makes the system economical to install and eliminates the need for a hose (Silva et al., 1981).

The basic components of this system are shown in Figure 38. The storage area of the system consists of a receptacle (a home-made clay pot will do) that can hold 10 to 12 l. A float keeps the water level inside the pot constant. This level then creates the pressure head, which is the difference between the surface level of the water in the reservoir and the average level in each porous pot. The main supply line, consisting of 1" polyethylene tubing, connects the porous pots to this storage reservoir. The porous pots are placed in a series joined together in a curve parallel to the contour, or at a slight incline when the lines exceed 100 m in length, and are connected to the main supply line. This method of irrigation does not require a conventional motor to pump the water; it is distributed automatically and continuously, in direct proportion to the difference in potential between the water level in the pot and the soil surface and inversely proportional to the resistance created by the porosity of the pot.

Extent of Use

Given their limitations in terms of area served and volume of water, irrigation systems of this kind ought to be used mainly on small family farms. The technology is used at present for irrigating small farm plots, small orchards, and small-scale horticultural operations.

Operation and Maintenance

Water is automatically and continuously released owing to the difference in potential (head) between the water level in each unit and the dry soil. As the plants take in water from the soil, the potential between the soil and the irrigation pots increases, causing water to flow directly to the soil and supply the needs of the crop. This system is easy to operate and maintain.

If the required volume of water is not released, this can be corrected by drilling four small (1.5 mm-diameter) drainage holes at regular intervals in the side of the pot, about 10 cm to 15 cm below the soil level. In any case, the pot gradually loses its original capacity to release water after long periods of use. When this occurs, the user has two alternatives: the pot's original capacity to release water can be restored by baking it once more in the oven, or it can be replaced with a new one.

Level of Involvement

The government of the state of Pernambuco recently established a porous pot manufacturing plant, and capsule set up irrigation units on a number of small farms using this system to irrigate the main food crops such as maize and beans. Most clay pot/porous capsule irrigation systems are constructed privately by individual landowners.

Costs

The average cost of an irrigation system is approximately $1 300/ha for an orchard and $1 800/ha for a vegetable garden. Representative costs are shown in Tables 24 and 25 for the two technologies.

Effectiveness of the Technology

Water is released automatically from both the clay pots and porous capsules, as the process of evapotranspiration occurs. As a result, water is not lost through percolation or surface runoff as is the case with conventional irrigation systems. Hence, the system is extremely effective. However, it is limited to small-scale operations at present.

Suitability

This system can be used on agricultural plots that do not have access to water for conventional irrigation methods. It has been well accepted in the semi-arid regions of northeastern Brazil. EMBRAPA reports that the systems have also been well received in other parts of Latin America.

Table 24 Installation Costs of a Clay Pot Irrigation System on a 0.2 ha Plot

Item	Quantity	Total cost ($)
Clay pots	166	73.78
½" diameter plastic tubing	800 m	118.52
Tailpiece	0.8 kg	11.85
Float	7	5.19
Labor (digging)	12 person-days	35.56
Other		22.52
Total		267.42

Table 25 Installation Cost of a Porous Capsule Irrigation System on a 1 ha Plot

Item	Quantity	Total cost ($)
Porous pots	2500	745.00
½" diameter plastic tubing	2500 m	815.00
1" diameter	100 m	23.00
plastic tubing		
Tailpiece	4 kg	60.00
Labor	50 person-days	150.00
Total		1793.00

Advantages

- This technology results in an economical use of water, since losses due to percolation and surface runoff are eliminated.
- Water is distributed evenly through the soil, which is highly conducive to plant growth.

Disadvantages

- With the clay pot system, water may not be released at the same rate from all the pots; since they are handmade by individual craftsmen, there is little control over the proportions of materials used.

- In the case of porous capsules, even though the proportions of materials used can be better monitored, the amount of water released gradually diminishes over time. This problem can be minimized by ensuring that clean water is used at all times, so that water with particles in suspension does not pass through the sides of the pot.

Further Development of the Technology

Research is being carried out to increase the useful life of the system for producers in rural areas, and to develop economical variations of this technology that can be used commercially.

Information Sources

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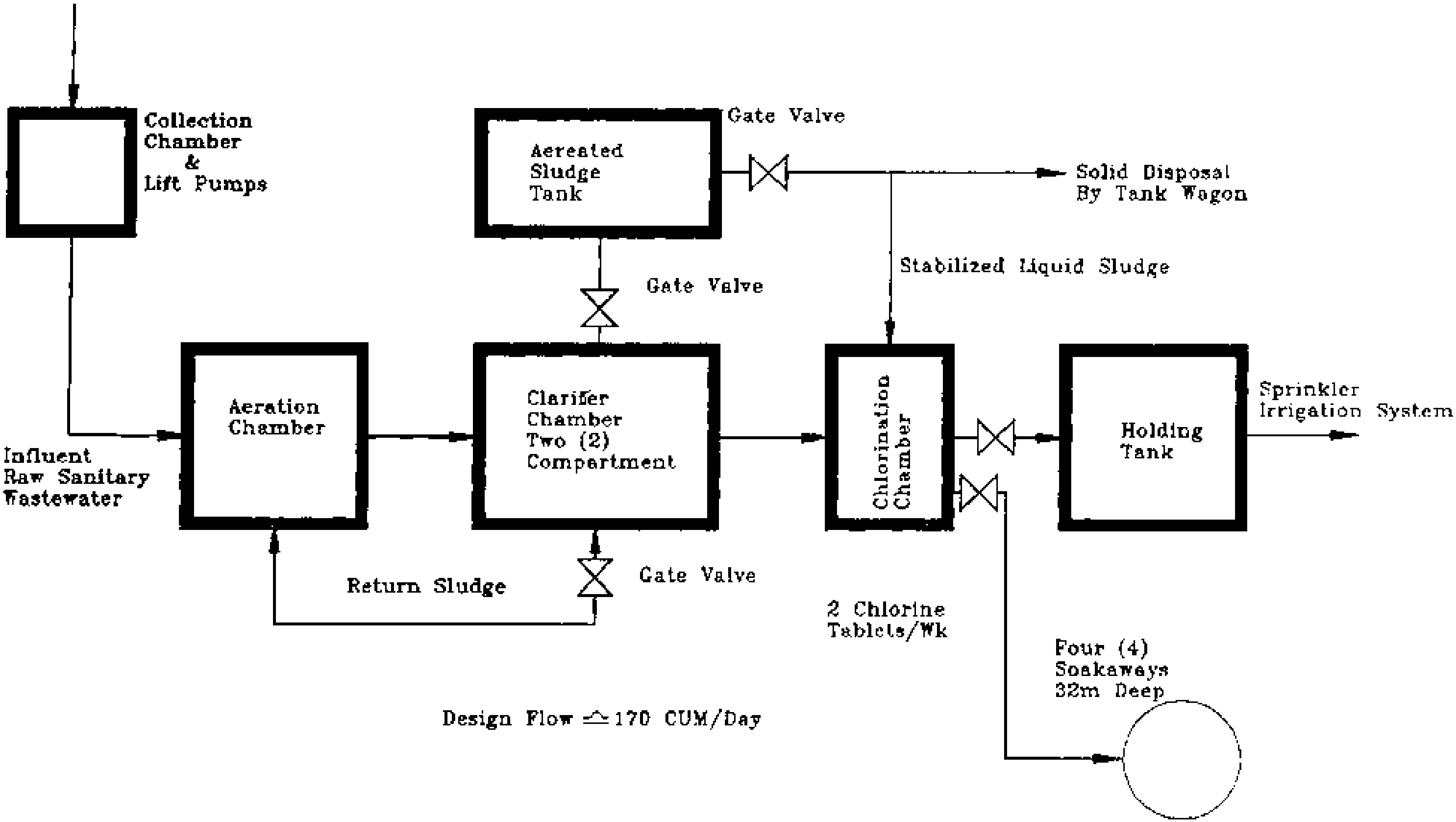
Pesquisa, 3)


Collection Chamber & Lift Pumps
Aereated Sludge Tank
Gate Valve
Solid Disposal By Tank Wagon
Stabilized Liquid Sludge
Gate Valve
Aeration Chamber
Clarifer Chamber Two (2) Compartment
Chlorination Chamber
Holding Tank
Sprinkler Irrigation System
Influent Raw Sanitary Wastewater
Return Sludge
Gate Valve
2 Chlorine Tablets/Wk
Four (4) Soakaways 32m Deep
Design Flow ≃ 170 CUM/Day

Annex 1. Acknowledgments

The national agencies, institutions and organizations listed below provided valuable information or otherwise contributed to the preparation of this *Source Book*. Thanks are due to all of them.

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Proyectos en Sierra y Selva

Asociación para el Desarrollo Rural de Cajamarca (ASPADERUC)
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Inter-American Program OAS/CIDIAT
Caribbean Environmental Health Institute (CEHI)
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Annex 3 Contributions by workshop participants

A. Workshop on alternative technologies for freshwater augmentation in Latin America

Lima, Peru, 19-22 September 1995

CONTRIBUTIONS PRESENTED BY THE PARTICIPANTS

Country	Participant	Technology Profiles	Case Studies
Argentina	Nicolás Ciancaglini	- Artificial recharge of aquifers	Irrigation using clay pots in Mendoza
		- Desalination using reverse osmosis	
		- Irrigation using clay pots	
	Valeria Mendoza	- Artificial recharge of aquifers	Reuse of domestic effluents for irrigation in Mendoza
		- Water management model using conservation	
		- Reuse of domestic effluents for irrigation	
		- Optimization of water resources	
		- Management of potable water systems	
		- Utilization of surface water in dams	
	Eduardo Torres	- Rainwater harvesting roofs/cisterns	Natural and artificial recharge of underground reservoirs in Mendoza
		- Rainwater harvesting (natural low areas)	
		- Use of well buckets in groundwater extraction	
		- Artificial recharge of aquifers	

	Alberto Vich	- Rainwater harvesting (paved roads) - Rainwater harvesting and aquifer recharge	Water traps for runoff diversion, rainwater harvesting, and recharge of aquifers in mountain areas
	Adrián Vargas	- Utilization of river beds	Utilization of river beds in Santiago del Estero
Bolivia	Freddy Camacho V.	- Hand pumps - Use of desalination in irrigation - *Totora* as a water quality treatment agent - Use of native products in clarifying water - Irrigation using clay pots	Use of hand pumps in the high plateau of Bolivia
Brazil	Everaldo R Porto	- Rainwater harvesting (roofs/cisterns) - Rainwater harvesting (paved and unpaved roads) - Irrigation with clay pots and porous capsules	Use of rural cisterns in northeastern Brazil
	Luiza T. de L. Brito	- Rainwater harvesting (in situ) - Runoff collection and storage (dams/dikes) - Underground dams	Underground dams in northeastern Brazil
	Pedro C.S. Mancuso	- Use of continuous vertical reactors for wastewater treatment and reuse	Continuous vertical reactors
	Marco Antonio Palermo	- Runoff collection and storage - Water basin diversion and reuse - Reuse and utilization of saline waters	Optimization of runoff storage and distribution in the state of Sao Paulo
	Claudison Rodrigues	- Desalination using reverse osmosis - Desalination using solar distillation - Desalination using electrodialysis	Desalination of well water in northeastern Brazil using reverse osmosis
	Gertjan B. Beekman	- VLF-WADI method to locate fractures in crystalline rocks	Small systems of dams in river basins of Paraiba
Chile	Roberto Espejo Guasp	- Fog harvesting (Camanchacas) - Desalination using reverse osmosis - Desalination using distillation	Water supply using fog harvesting in Poposo, Chile

		- Treatment and recycling of non-potable water	
	Johannes Wrann	- Fog harvesting (camanchacas)	Rainwater harvesting and utilization of surface water runoff from sloping watersheds for forestation in Chile
		- Rainwater harvesting	
Colombia	Guillermo Sarmiento	- Wastewater treatment technologies	Biological treatment of domestic wastewater using hydroponic cultivation and comparison with other wastewater treatment technologies in Colombia
Costa Rica	Jorge Faustino Manco	- Rainwater harvesting (roofs/cistems)	Runoff storage in irrigation ditches in various regions of Central America
		- Water conservation agricultural practices	
		- Runoff storage in irrigation ditches	
		- Use of lagoons for runoff collection and storage	
	William Murillo Montero	- Comprehensive utilization of water resources (basin transfer)	Comprehensive use of surface water resources in Costa Rica (water transfer from the Arenal to the Tempisque river basin)
		- Sustainable use of aquifers	
		- Efficient use of irrigation methods in small areas (use of pressurized systems)	
Dominican Republic	Milagros Martinez Esquea	- Rainwater harvesting using house roofs	Irrigation with interconnected clay pots in Dominican Republic
		- Irrigation with clay pots	
	José O. Payero	- Artificial lagoons	Home water purification systems in Dominican Republic
		- Rainwater harvesting using collection pipes	
		- Cloud seeding	
		- Water distribution by cistern trucks	
		- Bottling of water	
		- Development of small watersheds	
		- Water storage in homes	
		- Water purification systems	
		- Wastewater treatment technologies	

Ecuador	Felipe Cisneros Espinoza	- Rainwater harvesting - Distribution of potable water - Water transfer by pumping - Disinfection/purification - Use of clay pots in irrigation	Rainwater harvesting through runoff storage in reservoirs in the southern region of Ecuador
El Salvador	Saul Rodríguez	- Cyclic rope pump - Chlorine production *in situ* - Home made artesian filters - Potable water by filtration using slow sand dripping filters	Utilization of cisterns for rainwater harvesting in El Salvador
Guatemala	Luis Alfredo Ochoa	- Rainwater harvesting - Water purification using sodium hypochlorite in rural areas - Stabilization lagoons (Jacintos) - Water quality treatment using seeds *of Monringa oleifera* - Pilot project on the use of pre-filters - Irrigation with treated water	Use of potable water from rainwater harvesting in Guatemala
Honduras	Emesto Bondy Reyes	- Rainwater harvesting (roofs, cisterns, and lagoons) - Rope and bucket homemade wells - Use of mulch to control soil humidity and sediments - Photovoltaic energy for pumping systems - Alternative pumping systems	Rainwater harvesting using roofs, cisterns, and lagoons in Honduras
Mexico	Polioptro F Martinez	- Fog harvesting - Quarry filters - Gravitational tank irrigation system - Device for intermittent irrigation in furrows	Non-conventional devices for use in intermittent irrigation in Mexico
	Carlos Solís Morelos	- Stabilization lagoons	Modified stabilization lagoon system for municipal wastewater treatment in the Lerma River basin in Mexico

Nicaragua	Javier García Romano	- Microbasin management	Microbasin management in Nicaragua
Panama	Icela Márquez de Rojas	- Mini-dams - Irrigation with clay pots - Agriculture and aquaculture water use	Utilization of spring waters for rural aqueducts in Panama
	María Concepción Donoso	- Water recycling in rice cultivation and aquaculture system - Drip irrigation - Use of wind energy for pumping systems - Aqueducts	Utilization of wind energy to augment water supply in the central provinces of Panama
Paraguay	Eugenio Godoy Valdovinos	- Rainwater harvesting using roofs and cisterns - Rainwater harvesting using cultivation - Artificial recharge of groundwater	Artificial recharge ofgroundwater in Central Chaco in Paraguay
Peru	Hugo Rodríguez	- Harvesting use and storage of water with raised beds (Waru Waru) cultivation	The agro-ecosystem of Waru Waru: an alternative technology for agricultural development in the plateau of Puno
	Juan Ocola Salazar	- Wastewater treatment using native plants *(totora)*	Treatment in oxidation lagoons using native plants (Totora) in Puno
	Pablo Sánchez		Poncho Verde project in Cajamarca
	Miguel Hadzich Marín		Pumping systems in Peru
Uruguay	Lourdes Batista	- Utilization and regulation of watersheds	Regulation, water use, and development plan for the region of Rocha in Uruguay
Venezuela	Carmen Fermín Regardiz	- RunotF collection and storage using road dikes - Artificial lagoons - Storage tanks with galvanized plates - *Toroba*	Use of road dikes in the state of Nueva Esparta

	Hernán López Herrera	- River basin rehabilitation	Rehabilitation of the Moron River basin in Venezuela
CEPIS/OPS	Julio Moscoso		Use of effluents from stabilization lagoons in aquaculture and agriculture in San Juan, Peru

B. Workshop on alternative technologies for freshwater augmentation in the Caribbean

Barbados, October 24-27,1995

CONTRIBUTIONS PRESENTED BY THE PARTICIPANTS

Country	Participant	Profiles of Technology	Case Study
Antigua and Barbuda	Vincent Sweeney	- Transportation of water by barges - Desalination: reverse osmosis and distillation	
Aruba	Theofilo Damian	- Desalination: multistage flash evaporation system - Wastewater treatment	Rainwater harvesting in dams for agricultural purposes in Aruba
Bahamas	Cadrington Coleby	- Desalination: reverse osmosis - Trench wells for groundwater extraction - Barging	Barging/tanking water from neighboring islands in the Bahamas
Barbados	John Bwalya Mwansa	- Rainwater harvesting - Surface runoff impoundments - Artificial recharge of groundwater - Wastewater treatment and reuse	Sam Lord's Castle Hotel's treated wastewater reuse scheme, Barbados
British Virgin Islands	Rajkumar Roopchand*	- Rainwater harvesting - Seawater/brackish water desalination by reverse osmosis	Implementation of seawater desalination on the island of Virgin Gorda
Haiti	Bernardine Georges*	- Rainwater harvesting	Rainwater cistern in

		- Hand pumps - Winch	Miragoane, Haiti
	Michael Merisier		Photovoltaic system to pump water in St. Jean du Sud, Haiti
Jamaica	Basil Fernandez	- Rainwater harvesting - Transportation of water by pipeline; interbasin transfer - Artificial recharge of groundwater - Wastewater treatment and reuse - Recycling of industrial effluent	Artificial groundwater recharge of a karstic limestone aquifer using sinkholes as injection points in Jamaica
Montserrat	Margaret Dyer-Howe	- Rainwater harvesting	Floating chlorinator and gas chlorinator in Montserrat
Netherlands Antilles	Martha Pinedo-Medina	- Rainwater harvesting - Artificial recharge of groundwater - Wastewater treatment	Water desalination by distillation in Curaçao (multistage flash evaporation system)
Saint Lucia	Vincent Sweeney	- Rainwater harvesting - Root zone wastewater treatment - Dual distribution system	Root zone wastewater treatment in Saint Lucia
	Martin Satney	- Rainwater harvesting - Runoff harvesting - Wastewater reuse	Transportation of water by canal/pipeline for irrigation in Saint Lucia
Suriname	Moekiran Amatali	- Rainwater harvesting - Storage in natural wetlands - Storage in dammed-up feat lands	The use of the manmade Lake Brokopondo in Suriname
Turks and Caicos Islands	Joseph Williams	- Rainwater harvesting - Desalination; reverse osmosis - Dual distribution systems - Groundwater exploration	Rainwater harvesting in the Turks and Caicos Islands

U.S. Virgin Islands	Henry Smith	- Rainwater harvesting - Dual distribution system - Desalination	Mandatory rainwater harvesting for residential use in the U.S. Virgin Islands

* Mr. Rajkimar Roopchand and Ms. Bernardine Georges were not able to participate in the workshop, but sent their contributions.

Annex 4 Table of conversion factors for metric and english units

This water-quantity equivalents and conversion factor list is for those interested in converting units. The right-hand column includes units expressed in two systems - U.S. Customary and International System (metric). Units, which are written in abbreviated form below, are spelled out in parentheses the first time they appear. To convert from the unit in the left-hand column to that in the right, multiply by the number in the right-hand column. Most of the quantities listed were rounded to five significant figures. However, for many purposes, the first two or three significant figures are adequate for determining many water-quantity relations, such as general comparisons of water availability with water use or calculations in which the accuracy of the original data itself does not justify more than three significant figures. Quantities shown in italics are exact equivalents - no rounding was necessary. Regarding length of time, each calendar year is assumed (for this list) to consist of 365 days.

U.S. Customary	U.S. Customary or Metric
Length	
1 in (inch)	*= 25.4 mm (millimeters)*
1 ft (foot)	*0.3048 m (meter)*
1 mi (mile, statute)	*= 5 280 ft*
	= 1609.344 m
	= 1.609344 km (kilometers)
Area	
1 ft^2 (square foot)	*= 0.09290304 m^2 (square meter)*
1 acre	*= 43 560 ft^2*
	= 0.0015625 mi^2
	= 0.40469 ha (hectare)
1 mi^2	*= 640 acres*
	= 259 ha
	= 2.59 km^2 (square kilometers)
Volume or Capacity (liquid measure)	
1 qt (quart, U.S.)	0.94635 l (liter)
1 gal (gallon, U.S.)	*= 231 in^3 (cubic inches)*
	= 0.13368 ft^3 (cubic foot)

	= 3.78541
	= 0.0037854 m^3 (cubic meter)
1 Mgal (million gallon)	*= 0.13368 Mft^3 (million cubic feet)*
1 Mgal	*= 3.0689 acre-ft (acre-feet)*
	= 3.785.4 m^3
1 ft^3	*= 1.728 in^3*
	= 7.4805 gal
	= 28.317 l
	= 0.028317 m_3
1 Mft^2	*= 28,317 m^3*
1 acre-ft (volume of water, 1 ft deep, covering an area of 1 acre)	*= 43,560 ft^3*
	= 0.32585 Mgal
	= 1,233.5 m^3
1 mi_3 (cubic mile)	*= 1,101.1 billion gal*
	= 147.20 billion ft^3
	= 3.3792 million acre-ft
	= 4.1682 km_3 (cubic kilometers)
Speed (or, when used In a vector sense, velocity)	
1 ft/s (foot per second)	*= 0.3048 m/s (meter per second)*
	= 0.68182 mi/hour (mile per hour)
1 mi/hr	*= 1.4667 ft/s*
	= 0.44704 m/s
Volume per Unit of Time (discharge, water supply, water use, and so forth)	
1 gpm (gallon per minute)	*= 0.00144 mgd (million gallons per day)*
	= 0.0022280 ft^3/s (cubic foot per second)
	= 0.0044192 acre-ft/d (acre-fool per day)
	= 3.7854 l/min (liters per minute)
	= 0.063090 l/s (liters per second)
1 mgd	*= 694.44 gal/min*
	= 1.5472 ft^3/s
	= 3.0689 acre-ft/d
	= 1,120.0 acre-ft/d (acre-feet per year)
	= 0*.043813 m^3/s (cubic meter per second)*

	= 3.785.4 m^3/d (cubic meters per day)
1 billion gal/yr (billion gallons per year)	= 0.0013817 km^3/yr (cubic kilometer per year)
1 ft^3/s	= 2.73 97 mgd
	= 448.83 gal/min
	= 0.6463 2 mgd
	= 1.9835 acre-ft/d
	= 723.97 acre-ft/yr
	= 28.317 l/s
	= 0.028317 m^3/d
	= 2.446.6 m^3/d
	= 0.00089300 km^3/yr
1 acre-ft/yr	= 892.74 gal/d (gallons per day)
	= 0.61996 gal/min
	= 0.0013813 ft^3/s
	= 3.3794 m^3/d
1 acre-ft/d	= 0.50417 ft^3/s
Volume, Discharge, or Use per Unit of Area	
1 in of rain or runoff	= 17.379 Mgal/mi^2
	= 27.154 gal/acre (gallons per acre)
	= 25.400 m^3/km^2 (cubic meters per square kilometer)
1 in/yr	= 047613 (Mgal/d)/mi^2
	= 073668 (ft/s)/mi^2
1 (Mgal/d)mi^2	=21.003 in/yr (inches of rain or runoff per year)
1 (ft^3/s)/mi^2	= 13.574 in/yr
	= 0.010933 (m'/s)/km^2 (cubic meter per second per square kilometer)
Mass (pure water in dry air)	
1 gal at 15° Celsius (59° Fahrenheit)	= 8.3290 lb (pounds avoirdupois)
1 gal at 4° Celsius (39.2° Fahrenheit)	= 8.3359 lb
1 lb	= 0.45359 kg (kilogram)
1 ton, short (2,000 lb)	= 0.90718 Mg (megagram) or ton, metric

Prepared by John C. Krammer, U.S. Geological Survey (National Water Summary 1990-1991).

THE ORGANIZATION OF AMERICAN STATES

The Organization of American States (OAS) is the world's oldest regional organization, dating back to the First International Conference of American States, held in Washington, D.C., on April 14, 1890, This meeting approved the establishment of the International Union of American Republics. The Charter of the OAS was signed in Bogota in 1948 and entered into force on December 13, 1951. The Charter was subsequently amended by the Protocol of Buenos Aires signed in 1967, which entered into force on February 27, 1970, and by the Protocol of Cartagena de Indias, signed in 1985, which entered into force on November 16, 1988. The OAS currently has 35 Member States, In addition, the Organization has granted Permanent Observer status to 25 States in Europe, Africa and Asia, as well as to the Holy See and the European Economic Community.

The basic purposes of the OAS are as follows: to strengthen the peace and security of the continent; to promote and consolidate representative democracy, with due respect for the principle of nonintervention; to prevent possible causes of difficulties and to ensure the pacific settlement of disputes that may arise among the Member Slates, to provide for common action on the pan of those Stales in the event of aggression: to seek the solution of political, juridical and economic problems that may arise among them; to promote, by cooperative action, their economic, social and cultural development, and to achieve an effective limitation of conventional weapons that will make it possible to devote the largest amount of resources to the economic and social development of the Member States.

The OAS accomplishes its purposes through the following organs: the General Assembly; the Meeting of Consultation of Ministers of Foreign Affairs; the Councils (the Permanent Council, the Inter-American Economic and Social Council and the Inter-American Council for Education, Science, and Culture); the Inter-American Juridical Committee; the Inter-American Commission on Human Rights; the General Secretariat; the Specialized Conferences; the Specialized Organizations and other entities established by the General Assembly,

The General Assembly holds regular sessions once a year. Under special circumstances it meets in special session. The Meeting of Consultation is convened to consider urgent matters of common interest and to serve as Organ of Consultation under the Inter-American Treaty of Reciprocal Assistance (Rio Treaty), the main instrument for joint action in the event of aggression. The Permanent Council takes cognizance of such matters as are entrusted by the General Assembly or the Meeting of Consultation and implements the decisions of both organs when their implementation has not been assigned to any other body, it monitors the maintenance of friendly relations among the Member States and the observance of the standards governing General Secretariat operations and also acts provisionally as Organ of Consultation under the Rio Treaty. The purpose of the other two Councils is to promote cooperation among the Member States in their respective areas of competence, These Councils hold one annual meeting and meet in special sessions when convoked in accordance with the procedures provided for in the Charter. The General Secretariat is the central and permanent organ of the OAS. The headquarters of both the Permanent Council and the General Secretariat is in Washington, D.C.

MEMBER STATES: **Antigua and Barbuda, Argentina, The Bahamas (*Commonwealth of*), Barbados, Belize, Bolivia, Brazil, Canada, Chile, Colombia, Costa Rica, Cuba, Dominica (*Commonwealth of*), Dominican Republic, Ecuador, El Salvador, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, St. Kitts and Nevis, Saint Lucia. Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, United States, Uruguay**

and Venezuela.

ISBN# 0-8270-3725-2
