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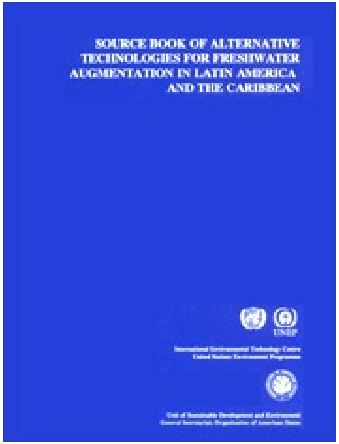
Source Book of Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean



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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

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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.)

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

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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.

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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.

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.

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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.

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".

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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	x			Argentina,

diversion				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,	x	x		Argentina, Brazil, Paraguay, Barbados, Jamaica,

	surface runoff drainage wells, septic tanks, effluent disposal wells, and diversion of excess flow from irrigation canals into sinkholes.				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	*Desalination*				

QUALITY IMPROVEMENT	• 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		x		Bolivia, El

	plant material				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	*Wastewater Treatment*				
	• *oxidation*	x			Aruba,

TREATMENT & REUSE	*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		x		Saint Lucia, U.S. Virgin

	systems				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	**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

cracks in the cistern; regular cleaning of the gutters; and inspection to ensure that the system is free of organic matter.	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:	Disadvantages:
» 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.	» 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 argricultural 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.	**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

» It also provides artificial recharge for aquifers.	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

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

cisterns are free from contamination by cleaning periodically with chlorine and calcium chloride.	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:	Disadvantages:
» 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.	» 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: » Runoff collectors are	**Disadvantages:** » Runoff-based systems may require

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.	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

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

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.

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.	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.	**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

» Pollutants are generally diluted. » Perennial flows may reduce salt water intrusion in coastal areas. » Impoundments provide recreational opportunities.	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:	**Level of Involvement:**

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.	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: » 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.	**Disadvantages:** » 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	**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.

the barge pilot.	
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).	**Disadvantages:** » Weather has a big impact on efficiency.

» It does not require highly skilled personnel. » It is not as expensive as desalination plants.	» 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	**Technology Type:** Freshwater

supply; agriculture; industry and mining	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	**Level of Involvement:** Water distribution projects have a high level of government participation. Planning and design of these systems usually

repairs and cleaning of the system.	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	**Disadvantages:** » Prices of water from water tankers are high. » Water tankers require adequate road infrastructure. » Pipelines involve high capital costs,

transform previously underdeveloped areas into potential areas for agroindustrial enterprise development.	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;	**Technology Type:**

agriculture	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	**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

$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.	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: **»** The techniques are easy to master and easy to operate.	**Disadvantages:** **»** Wells are often not maintained.

» 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.	» 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	**Level of Involvement:** Central governments have had little involvement in supporting non-conventional pumping technologies. The primary

metal surfaces, as well as valve cleaning. Photovoltaic systems may require new parts and frequent checks.	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	**Disadvantages:** » Hydraulic pumps may

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.	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	**Level of Involvement:** Due to the high costs involved, only public water

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.	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	**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

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.	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: » 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	**Disadvantages:** » 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.

"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.	» 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	**Effectiveness of Technology:** The multi-stage flash process (MSF) is generally considered to be more effective than distillation

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.	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	**Disadvantages:** » Some techniques require large energy inputs, regardless of plant size. » Brine disposal may be a problem.

properly, maintenance costs are low. » Low temperature distillation reduces energy requirements and production costs. » High quality water can be produced.	» 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	**Effectiveness of Technology:** Seed

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.	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: **»** This technology has a very low cost, and is easy to implement and use.	**Disadvantages:** **»** Plant seeds may not be readily available.

» 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.	» 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:

Level of Involvement: Boiling is

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.	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	**Cultural Acceptability:** A widely accepted technology, recognized

more sophisticated treatment methods are not available, and/or in case of emergency. Chlorination is considered universally suitable.	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	**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.

optimal performance.	
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	**Cultural Acceptability:** This technology is well accepted as

where water quality is poor.	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	**Disadvantages:** 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	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

resources. » An ability to be incorporated into water reuse schemes.	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	**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.

wastewater as a raw supply.	
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:	Disadvantages:
» 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.	» 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

Level of Involvement: This technology has been promoted, with technical assistance provided, by governmental agencies in Peru. NGOs have

mitigate erosion of soils during torrential downpours. Animals should be excluded from cultivated areas. Use of fungicides and insecticides may be required.	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	**Disadvantages:** » The technology has a

effects of extreme climatic variability. » It has a low cost. » It increases production of selected crops.	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:	**Level of Involvement:**

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.	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.	**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

» It can reduce the use of artificial fertilizers. » It prevents soil erosion. » It has minimal environmental impact.	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	**Level of Involvement:** The Mexican government, through

automatically, using flow control devices, and need no external energy source. Maintenance is simple, requiring periodic cleaning of tanks, siphons, and discharge pipes.	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:	**Level of Involvement:** Installation and maintenance of low-flow household devices

Low-flow water conservation devices require maintenance and repair. Leak detection equipment and meters require periodic calibration and maintenance.	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.	**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

Significant savings have been reported by industrial users adopting water recycling systems.	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:	**Disadvantages:**

» 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.	» 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:

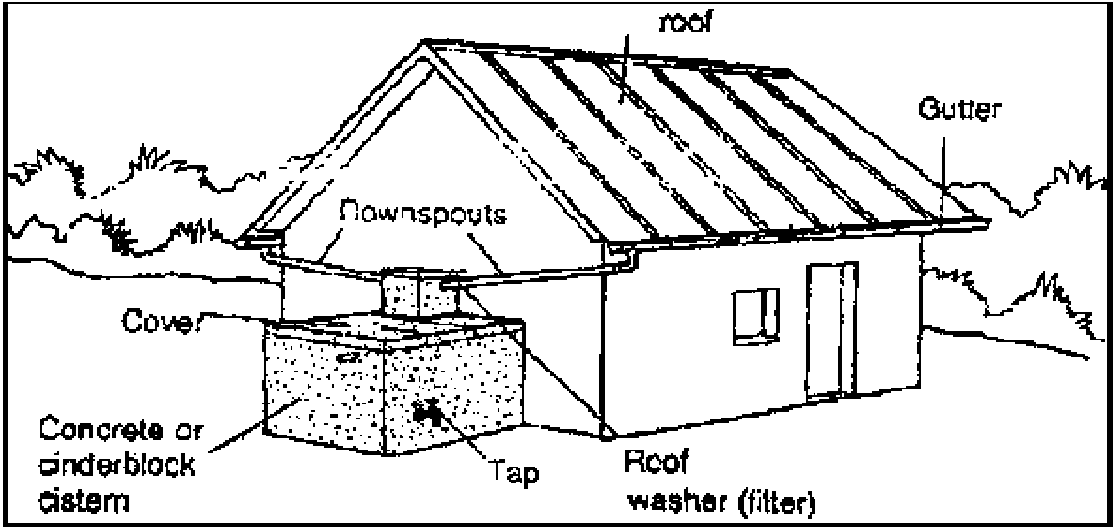
- What alternative water sources are available in the community and how do these compare with the rooftop catchment system?

- 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.

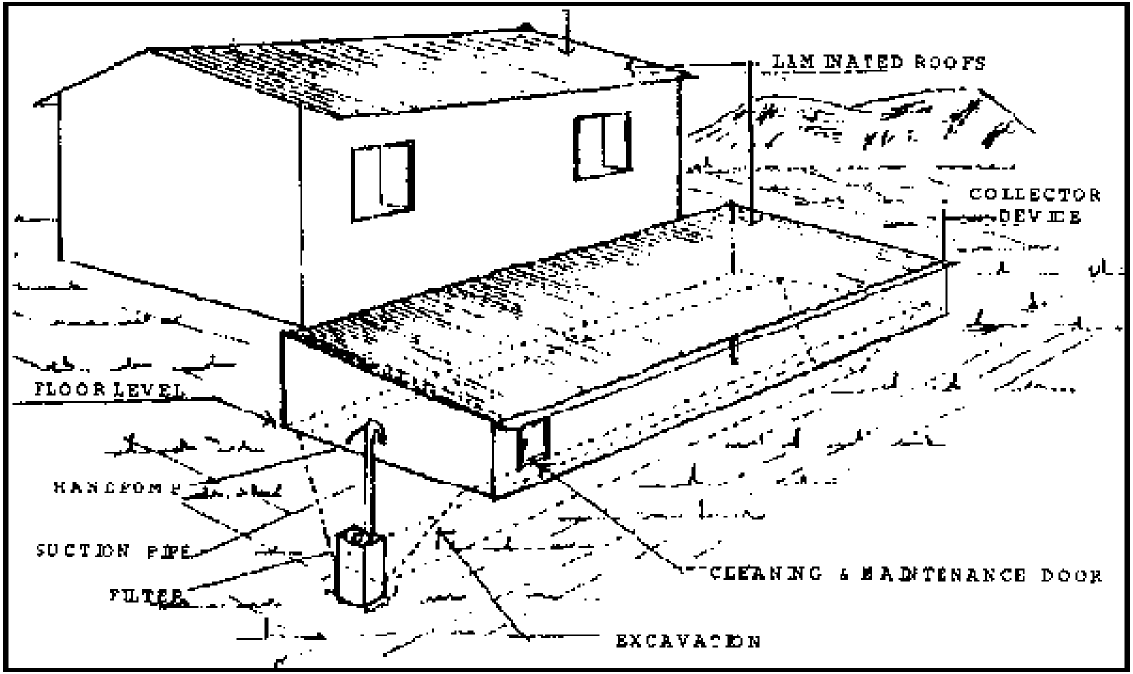
Rooftop and artificially constructed catchments, such as the one at the former United States naval base on Eleuthera, are commonplace in the Bahamas. One settlement (Whale Cay) has a piped distribution system based on water captured from rooftops. On New Providence, most of the older houses collect rainwater 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.

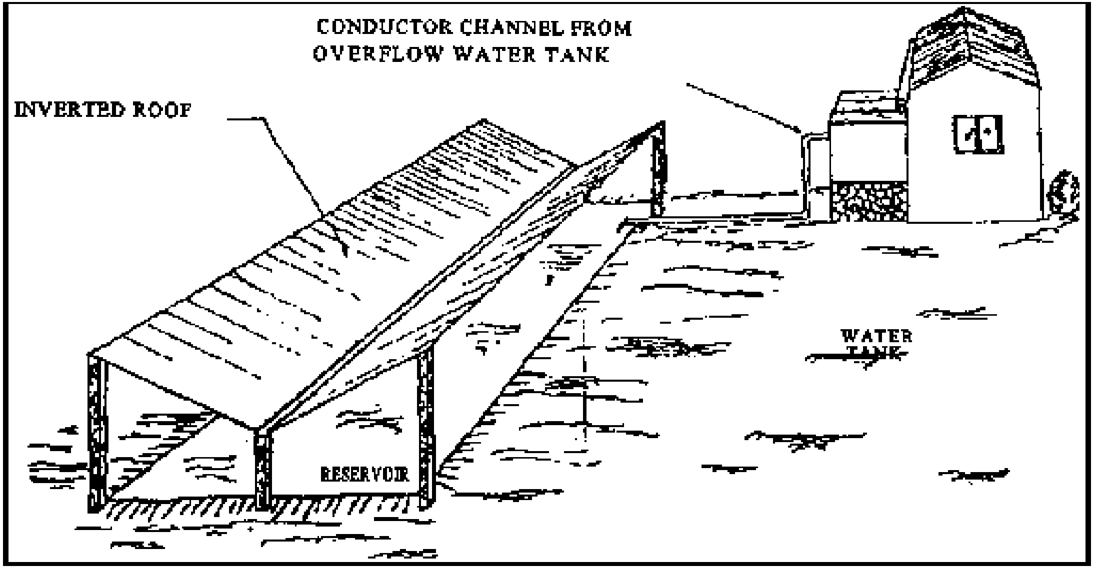
Operation and Maintenance

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

Contacts

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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.

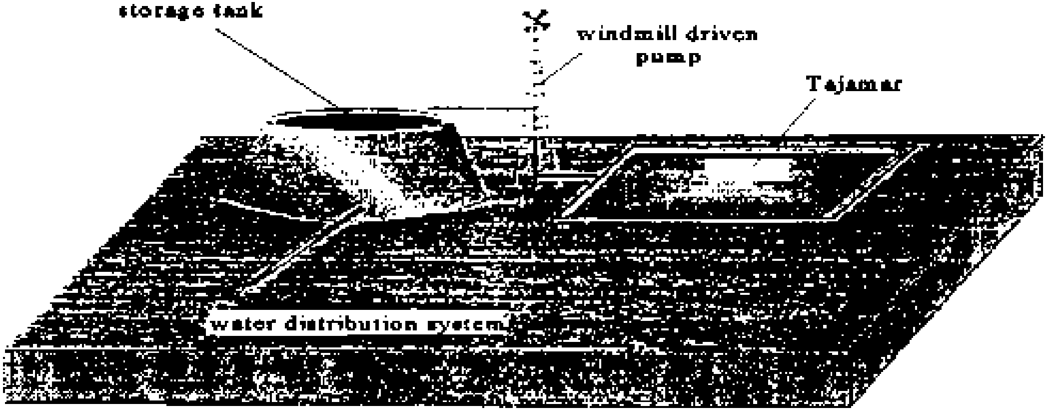
Technical Description

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.

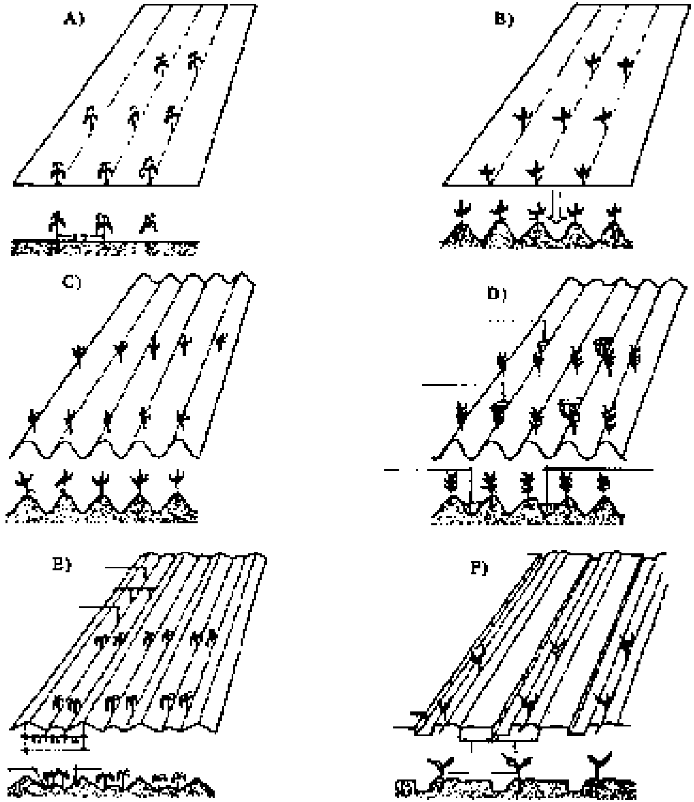
Level of Involvement

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

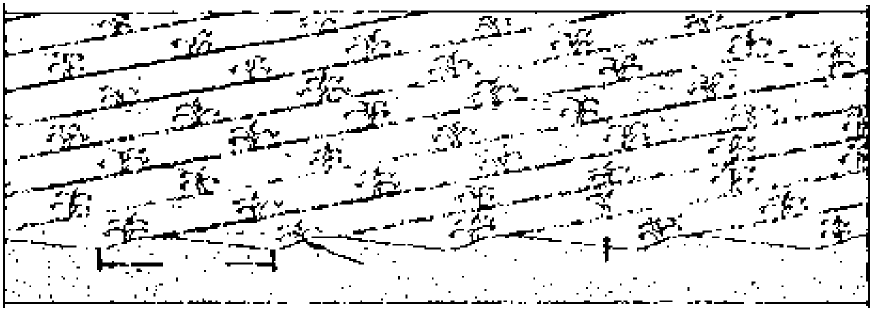
The costs of *in situ* rainwater collection systems are minimal. The main cost of this technology is in the equipment and labor required to build the fences and furrows. Table 1 shows representative costs reported for different methods of site preparation in cultivated areas of Brazil. Further, the construction 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	150.00	300.00	450.00	0.96

trenches				
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.

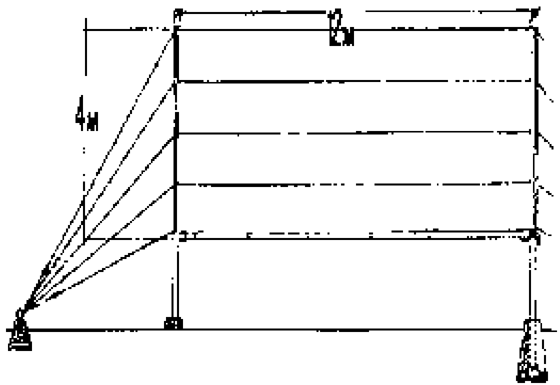
As water collects on the net, the droplets join to form larger drops that fall under the influence of gravity into a trough or gutter at the bottom of the panel, from which it is conveyed to a storage tank or cistern. The collector itself is completely passive, and the water is conveyed to the storage 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.

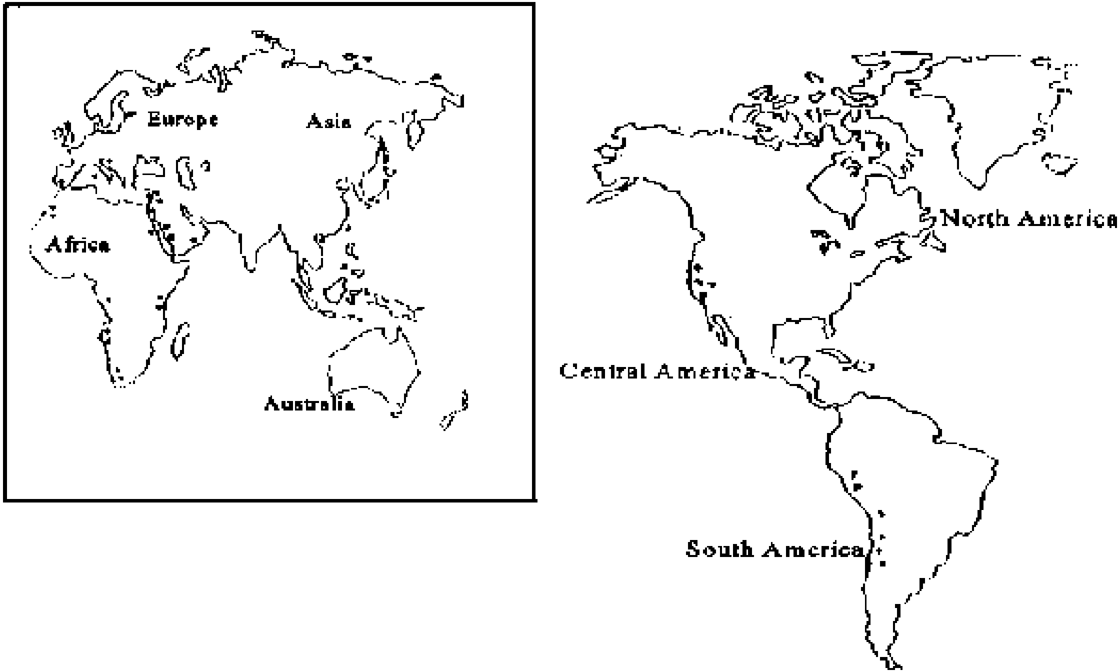
- *Maintenance of collector drains.* A screen should be installed at the end of the receiving trough to trap undesirable materials (insects, plants, and other debris) and prevent contamination of water in the storage tank. This screen should be inspected and cleaned periodically.

- *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.

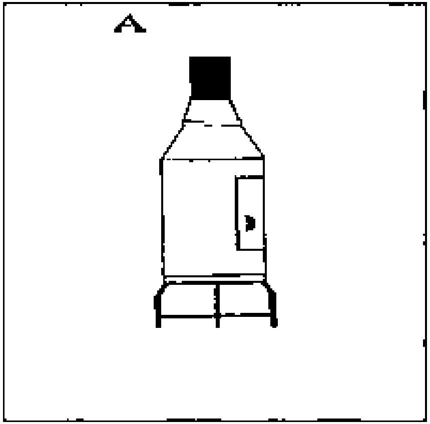
- If the harvesting area is not close to the point of use, the installation of the pipeline needed to deliver the water can be very costly in areas of high topographic relief.

- 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.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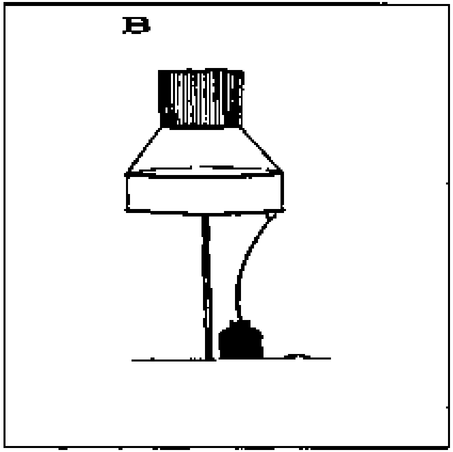
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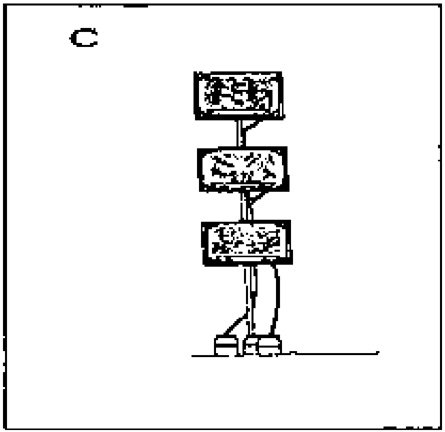
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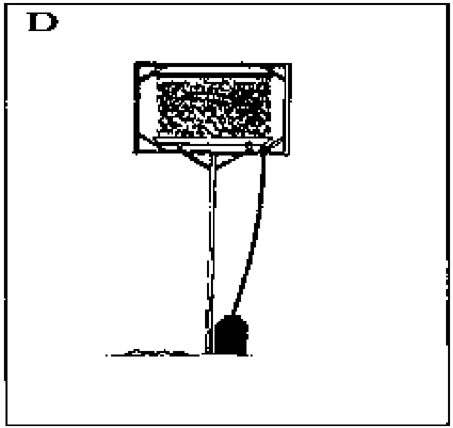
D

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

Contacts

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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.

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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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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	Project	Length of	Diameter of	Capital

Type	Capacity	Pipeline	Pipeline	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 l/day water used for domestic consumption, or approximately 64 million l/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

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