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ENVIRONMENTAL HEALTH PROJECT

WASH Reprint: Field Report No. 400

Prefeasibility Study
for Water Supply, Treatment, and Distribution
for Macala, Ecuador

Elio F. Amiella, P.E.

July 1993

Prepared for the USAID Mission to Ecuador
under WASH Task No. 452

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WASH and EHP

With the launching of the United Nations International Drinking Water Supply and Sanitation Decade in 1979, the United States Agency for International Development (USAID) decided to augment and streamline its technical assistance capability in water and sanitation and, in 1980, funded the Water and Sanitation for Health Project (WASH). The funding mechanism was a multiyear, multimillion-dollar contract, secured through competitive bidding. The first WASH contract was awarded to a consortium of organizations headed by Camp Dresser & McKee International Inc. (CDM), an international consulting firm specializing in environmental engineering services. Through two other bid proceedings, CDM continued as the prime contractor through 1994.

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WASH Field Report No. 400

PREFEASIBILITY STUDY FOR WATER SUPPLY, TREATMENT, AND DISTRIBUTION FOR MACHALA, ECUADOR

Prepared for USAID Mission to Ecuador
under WASH Task No. 452

by

Elio F. Arniella, P.E.

July 1993

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RELATED REPORTS

Water Quality Assesment in Ecuador. Field Report No. 390. Prepared by John Paul Chudy, Elio Arniella, and Enrique Gil.

Machala Integrated Cholera and Prevention Program Preparation Visit, March 22-26,1993. Trip Report under Task 462.

Machala Finance Management and Cost Recovery Technical Assistance. Trip Report under Task 462. (Available in August 1993, in Spanish only).

Machala Cholera Control and Prevention Workshop. Trip Report under Task 448. Prepared by Mercedes Torres Barreiro, Enrique Gil-Bellorin, and Jose Ignacio Mata.

Machala Latrine Design Workshop, Trip report under Task 461. Prepared by Mercedes Torres Barreiro, Enrique Gil-Bellorin, and John Gavin.

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Ing. Wilmer Encalada, Municipality of Machala

Mr. Joffre Vega, Chemist, Municipality of Machala

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ACRONYMS

A.I.D.	U.S. Agency for International Development (Washington)
ASCAM	*Asociación de Consultores Sanitarios y Ambientales* (Association of Sanitary and Environmental Consultants)
CAF	*Corporación Andina de Fomento* (Andean Development Bank)
DI	ductile iron
IDI	Infilco Degremont, Inc.
IEOS	*Instituto Ecuatoriano de Obras Sanitarias* (Ecuadorian Institute of Sanitary Works)
km^2	square kilometers
l/s	liters per second
mg/l	milligrams per liter
MOH	Ministry of Health
O&M	operations and maintenance
PVC	polyvinyl chloride
TDS	total dissolved solids
WHO	World Health Organization
WTP	water treatment plant

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EXECUTIVE SUMMARY

Introduction

This prefeasibility study consists of an evaluation of the current condition, an assessment of the present and future needs, and the development and evaluation of alternatives for meeting those needs. In addition, the prefeasibility study evaluates sources of financing for the project and cost-recovery options for payment of loans for financing the project.

The city of Machala is the largest city in the El Oro Province and is the fourth largest city in Ecuador. The El Oro Province has an area of 5,850 square kilometers (km^2) and the 1990 population was 412,572. The 1990 population recorded in the census for the study area is as follows:

Machala	157,572
El Guabo	28,058
Pasaje	51,406
Total	237,036

Source: CEPAR, Ecuador, September 1992

Evaluation of Existing Systems

Currently, the water supplied to the inhabitants of the city of Machala comes from three principal sources with a capacity of about 490 liters per second (l/s). The only treated water is from La Lucha Water Treatment Plant (WTP), accounting for about 25 percent of the water supplied, or 120 l/s. The water supply losses due to leaks and illegal connections are estimated at about 60 percent.

The regional WTP is part of a water supply project that has been under construction for more than 12 years. Phase 1 of this WTP has a capacity of 1,000 l/s. The plant is built but is not operational. The plant and main aqueducts are undergoing the final testing phase. The entire system is expected to be in full operation by the first quarter of 1994. The total existing storage capacity in the regional system is about 8,500 m^3.

The city of Machala is about 35- to 40-percent covered by the distribution network. In general, the networks are in very poor condition. The existing system does not have individual metering devices for measuring customer water usage. The water demand exceeds the current system capacity, and water losses due to leaks in the pipes significantly reduce the water available to the users.

Water Quality

In order to assess existing water quality in the study area, several bacteriological and physical/chemical water quality parameters were monitored in the regional and municipal systems. All physical/chemical parameters tested were within the suggested guidance of the

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World Health Organization (WHO). Bacteriological characteristics of the surface water sources for Machala, Pasaje, and the regional WTP had fecal coliforms ranging from 46 to 2,300 number/100 ml. The chlorinated finished water from La Lucha WTP had no coliform bacteria count despite registering the highest count in the raw water sample.

Water Quantity

The existing system has significant problems with supplying the demand for water to the population of Machala. The current water deficit is estimated at 305 l/s. Once the regional plant is in full operation in 1994, the deficit is expected to be about 116 l/s escalating gradually to about 750 l/s in 2015. The main contributor to the deficit is the water losses. Therefore, restoring the existing network and installing new water distribution lines are high priorities for meeting Machala's water demand.

Based on the water balance and water quality requirements for Machala, the following is a list of system improvements needed to meet current and future water quality and demand.

- Install a new water distribution network for Machala and Puerto Bolivar by 1996. Add additional 21,600 m^3 of storage capacity.
- Repair the existing water network.
- Disallow and remove illegal or substandard connections by 1996. Pass additional legislation for protection of illegal connections.
- Establish a goal for reducing system losses to less than 20 percent by 1999.
- Install water meters to 50 percent of users by 1996. Install water meters to more than 85 percent of users by 1999.
- Install three to four wells with 200 l/s capacity by 1994.
- Design and build by 1996 a new 500 l/s WTP for removal of iron and manganese and for disinfection of water from wells.
- Provide additional water supply capacity of 250 l/s by 2005 and double this capacity by 2010. This could be achieved through an expansion of the regional system or an expansion of the well fields and treatment systems.

Development and Evaluation of Alternatives

This section evaluates the water supply, storage, and distribution system for the Machala-Puerto Bolivar area. The preliminary construction cost estimate for the Machala Water Distribution System is based on the Asociación de Consultores Sanitarios y Ambientales [Association of Sanitary and Environmental Consultants (ASCAM)] design plus 15 percent extra piping for new development areas and repairs to the existing system. The water balance and distribution components of the design need to be revised based on new population growth

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trends and area developments. Nevertheless, the design is functional and is probably still usable with minor adjustments. The distribution system components include the following:

- 24,700 lineal meters of ductile iron (DI),
- 140,900 lineal meters of polyvinyl chloride (PVC) water distribution pipes,
- 30,000 new water meters,
- 10,000 new home connections,
- 30 water hydrants,
- 30 isolating/controlling valves.

The construction cost estimate for the water distribution system is about $12 million.

Three to four new wells must be installed to supply an additional 200 l/s. The new wells would be installed in the vicinity of the existing well field, about 6 km from Machala. The estimated cost for the new well field is $1.11 million.

Two treatment alternatives were evaluated and discussed in Chapter 3—lime-soda ash softening and pressure filtration using a greensand filter media. The first system provides water softening (to prevent scaling in pipes), filtration, and chlorination. The second process is the usual method for removing iron and manganese from well water without softening treatment.

The estimated construction cost for a 500 l/s softening plant is $2.92 million. The estimated operation and maintenance (O&M) cost for operating such a system is about $0.5 million per year.

The number one priority for Machala is the water distribution system. The only variances in the water distribution system design are the arrangement of the pipes, piping materials used, and construction methods. These are details to be considered during the design of the system.

The immediate water supply for Machala-Puerto Bolivar will come from the regional plant and from new wells. Although this will significantly reduce the existing water deficit, unless the existing plant is repaired and the distribution system installed, more than 40 percent of the water supplied will be lost through leaks.

The well water treatment facility is needed for prevention of scaling in the future distribution system and water meters and for disinfection. Two well water treatment alternatives were evaluated: a softening WTP and a pressure filtration system using greensand media. The second option was the most cost-effective of the two. Its annual capital and O&M costs are estimated at $2.92 and $0.56 million respectively. The following are advantages of the pressure filtration system:

- Allows easy operation,
- Removes iron and manganese,
- Traps sand and other particulates that may interfere with metering,

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- Has lower capital and O&M costs than the softening WTP,
- Does not require a repumping station (although it may require booster pumps), and
- Is easy to expand.

The principal disadvantage of this pressure filtration system is that it does not soften the water, which leaves a potential for scaling in the pipes. This disadvantage can be resolved by blending the treated well water with the water from the regional WTP. The resulting hardness should be less than 100 milligrams per liter (mg/l) as $CaCO_3$.

In addition, to meet the demand, a new 250 l/s source will be needed by 2005, and the same amount of extra capacity will be needed five years later. This additional capacity can be supplied from treated well water or from an expansion to the regional WTP.

Recommendations

Based on the analysis of the system components, the following are recommended:

- Establish a new Municipal Water Enterprise Fund for management of water system improvements.
- Design and install about 120 km of new water distribution for Machala-Puerto Bolivar by 1996. This would include about 10,000 new network connections and 30,000 new water meters.
- Design and install new wells with a 200 l/s capacity.
- Design and install a well water pressure filtration plant to treat 500 l/s. The WTP should be located near the existing well field, or near or at the La Lucha Plant site.
- Delay the decision about additional capacity for 2005 until 2000. Update the feasibility study in the year 2000 based on population growth trends to decide the most cost-effective supplemental water source beyond 2005.

Description of the Proposed Systems

The following proposed water supply systems require immediate action:

- The design and installation of a water distribution network for Machala and Puerto Bolivar,
- The design and installation of four new wells, and
- The pressure filter WTP to be located near or on the site of the La Lucha Plant. The plant will remove iron and manganese from the well water, reduce the sand and particulates that are present in the well water, and chlorinate the effluent. The treated water will be mixed with the water from the regional WTP in the distribution system. This will reduce hardness in the water piped to customers in Machala.

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After the year 2000, a new 500 l/s capacity plant would be required to meet the 20-year water demand. This new plant can be constructed in two phases, with 250 l/s capacity developed in each. According to existing water demand projections, the first phase should be in operation by 2005. Based on the same projections, the next phase should be in operation by 2010. The feasibility and capacity of the future systems should be reevaluated in an updated feasibility study expected in the year 2000.

Prefeasibility Cost Estimates for Design, Construction, and O & M

The estimated costs for designing, constructing, and operating and maintaining the proposed water system improvements for Machala-Puerto Bolivar are summarized in Table 1. This table also presents the annual amortized cost for the loan obtained to implement these facilities.

Table 1
Cost Summary

Water System Component	Design & Administration	Construction Total Cost, $	Annual O&M Cost, $	Annualized Capital Cost, $	Total Annual Cost, $
Water Main & Distribution	962,440	12,030,500	247,590	1,048,870	1,296,460
Storage Tanks 21,600 m^3	150,000	1,800,000	20,000	156,930	176,930
New Well Field & Water Main	88,710	1,108,850	491,290	96,670	587,960
Pressure Filtration Plant	312,510	2,916,740	557,490	254,300	811,790
Total	1,513,660	17,856,100	1,316,370	1,556,770	2,873,140

The total estimated cost for construction of the proposed water system modifications is about $17.86 million. The annualized amortization of the loan for capital improvements is about $2.87 million per year based on 6-percent annual interest for a 20-year period.

Financing Options

Because of the current economic situation in Machala and the escalated cost of the needed facilities, the city is not capable of financing this project. The following are possible external options:

- Loan from the Banco del Estado of Ecuador,
- Loan from international lending institutions through the Banco del Estado,
- Loan from the U.S. Eximbank for equipment and supplies manufactured in the United States (This loan would be managed in Ecuador by the Corporación Andina de Fomento.),
- Private investments,

- Combination of options.

Cost Recovery Options—User Rates

There are two commonly accepted methods for determining system revenue requirements:

- Cash Basis—On an annual basis, this method provides the actual cash necessary to serve existing and expected new customers. This includes O&M expenses as well as annual capital-related cash needs (debt service, pay-as-you-go financing, and reserve accruals).

- Utility Enterprise Basis—The utility enterprise basis for determining revenue requirements applies when there is an identifiable "owner" of the system and user classes that are nonowners. For the municipality of Machala, the users inside the city limits would be expected to share the benefits of ownership; the customers outside the city limits (or marginal areas) served by the municipality could be considered nonowners or "renters" of the system.

Implementation Issues

A municipal water enterprise that is focused on implementation and execution is vital to conducting the project on schedule and within budget. It is the opinion of the author that to try to manage a project of this magnitude with the existing resources or by "adding on" would be a terrible mistake. It is strongly recommended that a new water enterprise be formed with the participation of the municipal government and other appropriate private and public agencies.

Another institutional need for this project is to enforce the existing law regarding illegal connections to the water system. The existing laws must be reviewed and modified to include stricter civil penalties as well as possible criminal penalties.

Phased Approach

The project can be viewed in two characteristic phases. Phase I is the immediate or "urgent" phase that requires building the distribution network now, with about 200 l/s of new water supply. This phase also requires a WTP. Phase II, which is for beyond 2000, involves a feasibility study update and additional water supply sources, currently estimated to be about 500 l/s.

Preliminary O&M Requirements

The proposed new water enterprise would operate and maintain the water supply treatment and distribution system. It is envisioned that the municipality would purchase water supplied to Machala from the regional system at a negotiated fair price. The municipality will sell the water to its customers at a user rate established to recover the cost of investment and to accrue revenues for future improvements. The water enterprise would be responsible for the following activities:

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- Repair water mains and home connections,
- Maintain valves, hydrants, meters, and related items,
- Monitor chlorine in the distribution system,
- Monitor pressure in the system,
- Adjust control valves to balance water flow in the network,
- Maintain and repair the WTP and wells,
- Maintain an inventory of parts and materials needed in daily operations,
- Maintain and order chemicals for water treatment,
- Review drawings and specifications of new requests of installations,
- Conduct billing and collect payment for services.

Chapter 1

ASSESSMENT OF CURRENT SITUATION

1.1 Project Background

In the last quarter of 1992, a multidisciplinary team of professionals from WASH conducted a water quality assessment in Ecuador. The objective of the water quality assessment was to investigate potential sources of cholera in the coastal regions affected by the disease. The study evaluated the water quality, sanitation, and health conditions in three Ecuadorian coastal cities: Machala, Guayaquil, and Esmeraldas. The report from the WASH multidisciplinary team—WASH Field Report 390—listed several recommendations for improving water quality in the region.

The present WASH project is a follow-up assignment to the 1992 assessment and consists of technical assistance to the municipality of Machala for improving water supply, treatment, and distribution in the area. This prefeasibility study consists of an evaluation of the current conditions, an assessment of the present and future needs, and the development and evaluation of alternatives for meeting the needs. In addition, the Prefeasibility Study evaluates sources of financing for the project and a cost-recovery option for payment of loans for financing the project.

1.2 Study Area Description

The city of Machala is the largest city in the El Oro Province and the fourth largest city in Ecuador. The cantón of Machala is comprised by the urban centers of Machala and Puerto Bolivar. The topography is generally flat, and Machala's climate is tropical. The rainy season occurs during the winter months of December through April.

The largest body of water in the area is the Jubones River, which discharges to the Pacific Ocean near Puerto Bolivar. One large tributary of the Jubones River is the Casacay River. An alluvial plain along the banks of the Jubones River provides an abundant groundwater resource. The general soil in the subsurface is sand or silt derived from alluvial deposits. Figure 1 shows a general location map of Machala, with nearby cities and hydrological features.

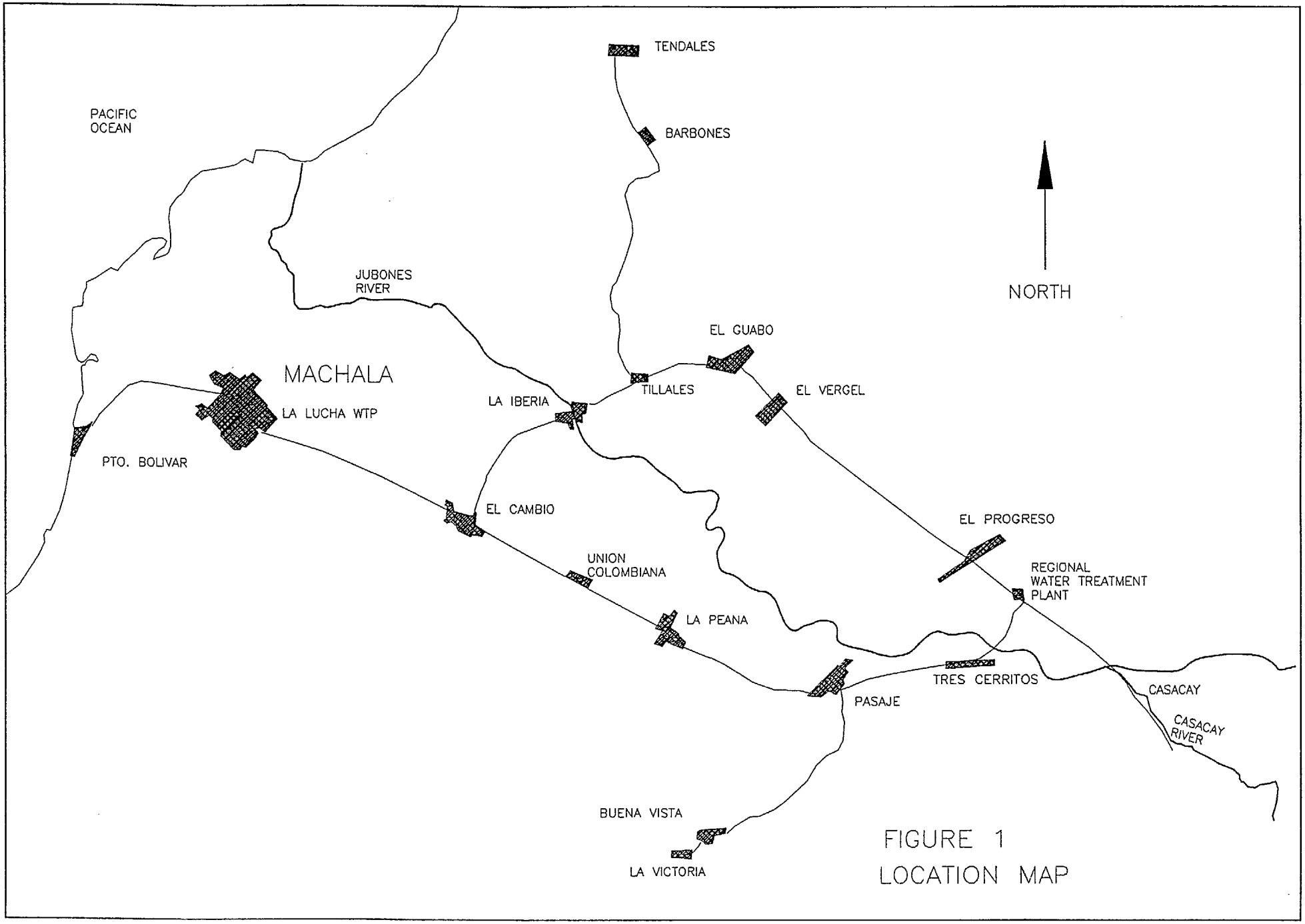


FIGURE 1
LOCATION MAP

1.3 Demographic and Economic Data

1.3.1 Demographic Data

The regional water system serves three cantónes: Machala, El Guabo, and Pasaje. Table 2 shows the population recorded during the 1982 and 1990 census for these areas. The cantón of Machala also includes Puerto Bolivar. The cantónes of El Guabo and Pasaje include smaller population centers in the area.

Table 2
Population Projection for Machala and Other Cantónes
Served by the Regional Water System

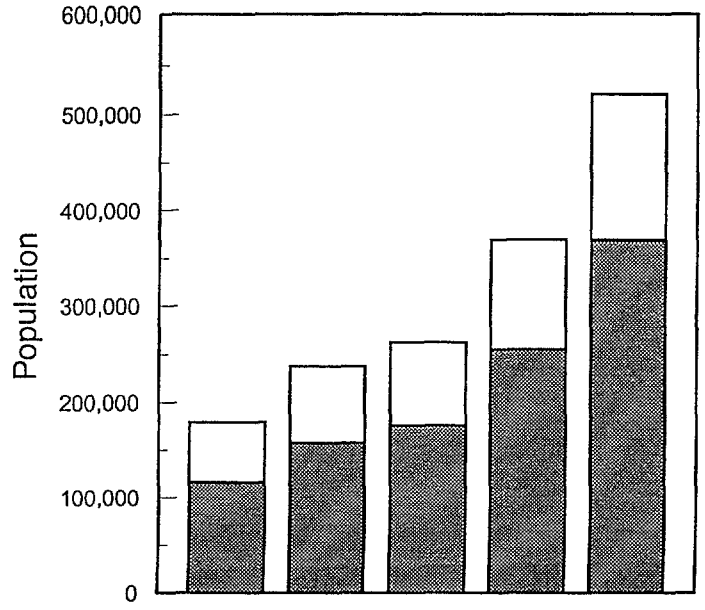
Cantón	1982	1990	Annual Growth Rate, %
Machala	116,091	157,572	3.8
El Guabo	20,801	28,058	3.7
Pasaje	42,675	51,406	2.3
Total	179,567	237,036	3.46

Source: CEPAR, Ecuador, September 1992

The El Oro Province has an area of 5,850 km^2, and the 1990 population was 412,572. The actual and projected population is shown in Figure 2.

1.3.2 Economic Data

The primary sources of economic development in the area include agriculture (banana plantations), silviculture (forestry), and mining. Other secondary sources of employment include manufacturing and construction.



Year	1982	1990	1993	2003	2013
Machala & Pto. Bolivar ▒	116,091	157,572	176,078	254,760	368,604
Other Areas □	63,533	79,464	86,489	114,708	152,135

Other areas include the Catónes of El Guabo and Pasaje

Figure 2
Actual and Projected Population for Machala, Puerto Bolivar, and Other Areas Served by the Regional System

1.4 Evaluation of Existing Systems

1.4.1 Water Supply

Currently, the water supplied to the inhabitants of the city of Machala comes from three principal sources:

- Canal El Macho, which supplies 120 l/s of surface water for treatment at the La Lucha WTP,
- Rio Casacay, which supplies the regional WTP that in turn currently supplies Machala with about 90 l/s of untreated water, and
- Corralitos, Diez de Agosto, La Unión, and Puvenza, wells which provide a combined capacity of about 280 l/s.

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One additional water supply well, El Naranjo, was out of service at the time of the visits. This well has a capacity of 60 l/s. The El Naranjo well has installation or development problems, produces sediment extraction, and is perhaps not reparable. The municipality is contemplating installing a new well adjacent to the El Naranjo that can use the pump and piping from the existing well. In addition, the municipality is locating sites for new wells.

1.4.2 Water Treatment

The only water treatment facility that provides marginal treatment is La Lucha WTP. Other wells and the regional plant supply only raw water that is neither treated nor disinfected. La Lucha WTP uses lime addition for pH adjustment, flocculation with aluminum sulfate, sedimentation in a shallow bed sedimentation basin, and chlorine gas disinfection. The sand filters have been out of operation for more than two years. The plant does not have a laboratory for testing water quality to determine chemical dosages. All chemicals are fed by the operator's estimates. The average chemical additions at this plant include the following:

- Lime = 0.65 mg/l,
- Aluminum sulfate = 15 mg/l,
- Chlorine gas = 2.3 mg/l.

The regional WTP is part of a water supply project that has been under construction for more than 12 years. Phase I of this WTP has a capacity of 1,000 l/s. The plant is built but is not operational. The plant and main aqueducts are undergoing the final testing phase. The entire system is expected to be in full operation by the first quarter of 1994.

1.4.3 Storage

The following are the only functional storage facilities in the system:

- Regional Plant Storage Tank (2,000 m^3)
- El Vergel (5,000 m^3)
- Los Cerritos (1,500 m^3)
- Puerto Bolivar (2,000 m^3)

The La Lucha Plant has an elevated storage tank that has been out of service for more than three years. This tank shows significant corrosion and may be unusable. The tank was taken out of service because it generated a pressure higher than the distribution pipes could tolerate without leaking.

1.4.4 Distribution System

The city of Machala is about 35- to 40-percent covered by the distribution network. In general, the network is in very poor condition. In 1979, the Instituto Ecuatoriano de Obras Sanitarias [Ecuadorian Institute of Sanitary Works (IEOS)] installed about 34 km of water distribution lines. This project has been neither completed nor officially turned over to the municipality. A 1987 evaluation by a consultant pointed out the following deficiencies in the existing system:

- Pipes without connectors (such as Ys, tees, crosses) in many sectors,
- End of pipes without plugs or blind flanges, and
- Illegal connections that used substandard methods of connecting domestic users to the water network.

In 1986-87 a new network for Machala was designed to add about 122 km of distribution pipes; however, this project was never constructed.

1.4.5 Metering

The existing system does not have individual metering devices for measuring customer water usage.

1.4.6 System Losses

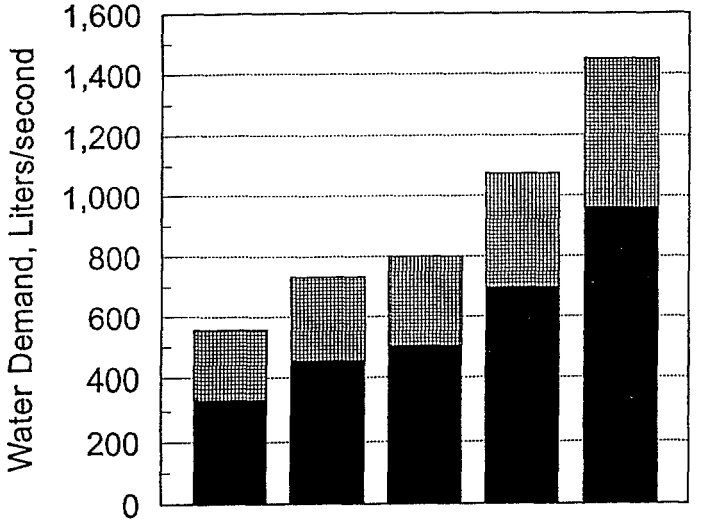
An estimated 60 percent of the water in the Machala system is unaccounted for; about 40 percent of that is assumed to be leaked and the remaining 20 percent is probably lost to illegal connections.

1.5 Water Quantity and Demand

The major water supply for Machala and Puerto Bolivar includes the following sources:

Source	Capacity l/s
La Lucha	120
Wells	280
Regional Plant	90
Total	**490**

As shown in Figure 3, the water demand exceeds the current system capacity. In addition, water losses due to leaks in the pipes significantly reduce the water available to users.



Year	1982	1990	1993	2003	2013
Machala & Pto. Bolivar	336	456	503	695	961
Guabo & Pasaje	221	276	297	381	488

Demand is based on 300 liters/capita per day for Machala & Puerto Bolivar and 250 liters/capita per day for Cantónes El Guabo and Pasaje.

Figure 3
Water Demand for Machala and Puerto Bolivar

1.6 Water Quality

In order to assess existing water quality in the study area, several bacteriological and physical/chemical water quality parameters were monitored in the regional and municipal systems. Table 3 presents a summary of the results. The samples were collected from the following locations:

- Machala municipal wells,
- Rio Casacay—raw water intake for the regional WTP,
- Regional WTP inlet water (untreated),
- City of Pasaje tap water,
- La Lucha WTP raw water, and
- La Lucha WTP treated water.

The following paragraphs describe the principal parameters monitored and briefly discuss their meaning.

Table 3

Drinking Water Characteristics for Machala and the Regional System

Parameters	Expression of Results	Municipal Wells that Supply Machala				Río Casacay Raw Water	Regional Plant Raw Water	Pasaje Tap Water	La Lucha Raw Water	La Lucha Finished Water *
		10 de Agosto	Corralitos	Puvenza	La Unión					
Alkalinity	mg/l CaCO3	230	220	290	244	24	24	36	72	0
Ammonia-nitrogen	mg/l	1	<1	<1	1.5	<1	<1	<1	<1	<1
Chlorides	mg/l	64	48	88	44	12	12	12	12	24
Fecal Coliform bacteria	Number/100 ml	0	0	0	3	50	46	1680	2,300	0
Hydrogen ion concentration	pH units	7.5	7.5	7	7.5	7	7	7.9	7.5	6
Iron **	mg/l	0.1	0.1	0.1	0.4	--	--	--	--	--
Nitrate	mg/l	<0.2	<0.2	<0.2	<0.2	0.1	0.1	<0.2	<0.2	<0.2
Phosphate	mg/l	0.4	0.2	<0.2	0.2	<0.2	<0.2	<0.2	--	<0.2
Silica	mg/l	50	40	50	60	35	20	20	25	25
Total dissolved solids	mg/l	230	220	290	244	20	20	40	100	110
Total hardness	mg/l CaCO3	156	124	172	128	20	20	24	64	44
Calcium hardness	mg/l CaCO3	64	56	124	108	12	12	16	40	28
Manganese hardness	mg/l CaCO3	92	68	48	20	8	8	8	24	16

* The La Lucha Water Treatment Plant effluent sample had 1.19 mg/l of free available chlorine and 1.4 mg/l of total chlorine

** Iron analyses were performed by Ingaoro Softdrinks Co. Laboratories

Alkalinity: Normal conditions of alkalinity in natural waters are associated with the carbon dioxide, bicarbonate, carbonate, and hydroxide components. These factors are characteristic of the source of water and the natural processes taking place at any given time. For particular industrial and domestic uses, it is often desirable to change these characteristics by treatments such as aeration, neutralization, and softening. The particular treatment and the extent to which it is employed depends on the end use of the water.

In general, the well water analyzed for the four existing wells contained a high alkalinity, ranging from 220 to 290 mg/l as $CaCO_3$. In the surface waters analyzed, the alkalinity ranged from 24 to 72 mg/l as $CaCO_3$.

Ammonia nitrogen: Ammonia nitrogen is present in various concentrations in many surface and groundwater supplies; however, any sudden changes in the amount of ammonia in a supply that has been of rather constant composition is cause for suspicion. A product of microbiological activity, ammonia nitrogen is sometimes accepted as chemical evidence of sanitary pollution when encountered in natural waters. Ammonia is rapidly oxidized in natural water systems by special bacterial groups that produce nitrite and nitrate. This oxidation requires that dissolved oxygen be available in the water.

This parameter was relatively low for all samples tested. The highest value detected was 1.5 mg/l at the La Unión well.

Chloride: Chloride is one of the major anions to be found in water. Its presence in large amounts may be due to natural processes, such as the passage of water through natural salt formations in the earth, or it may be an indication of pollution from sea water or industrial and domestic wastes. Any change from the normal chloride content of a natural water should be reason to suspect pollution from one of these sources. U.S. Public Health Service drinking water standards and WHO guidelines recommend a maximum chloride content of 250 mg/l. All samples analyzed were of lesser value.

Fecal Coliform Bacteria: Fecal coliforms provide stronger evidence of the possible presence of fecal pathogens than do total coliforms. Fecal coliforms are a subgroup of the total coliforms, distinguished in the laboratory through elevated temperature tests (43 to 44.5°C, depending on the test). Although the test does determine coliforms of fecal origin, it does not distinguish between human and animal contamination. Fecal coliform numbers can be used as an overall indicator of source water contamination, treatment effectiveness, and posttreatment degradation or contamination.

The guidelines of the U.S. Public Health Service and the World Health Organization indicate that zero coliform bacteria is highly desirable in the water source.

The samples analyzed ranged from 0 to 2,300 number/100 ml. The highest reading was from La Lucha WTP raw water. However, the treated water had no coliform count. The city of Pasaje tap water, which comes partly from the regional system and partly from a raw water intake in the Casacay River, had a very high fecal coliform count of 1,680 number/100 ml. One of the wells (La Unión) had a 3 number/100 ml fecal coliform count. Two samples

collected from the raw water from the regional system had 46 and 50 number/100 ml fecal coliform, respectively. The regional WTP is not providing any treatment at the present time. With the exception of La Lucha WTP, other water sources are not disinfected.

Hydrogen Ion Concentration or pH: The term pH is correctly defined as the negative logarithm of the hydrogen ion concentration. More simply, the term pH can be considered to be an "index" of the amount of hydrogen ions present in a substance. This "index" is important as it can be used to quickly identify the acid, neutral, or alkaline (basic) nature of materials.

Most natural waters will have pH values from pH 5.0 to pH 8.5. The acidic, freshly fallen rain water may have a pH value of 5.5 to 6.0. If it reacts with soils and minerals containing weak alkaline materials, the hydroxyl ion concentrate will decrease. The water may become slightly alkaline with a pH of 8.0 to 8.5. Natural sea water will have a pH value of 8.1; changes from this value indicate that water from an inland source is entering the body of sea water. All waters analyzed had pH values within acceptable limits.

Nitrate: Nitrogen is essential for plant growth, but the presence of excessive amounts in water supplies presents a major pollution problem. Nitrogen compounds may enter water as nitrates or be converted to nitrates from agricultural fertilizers, sewage, industrial and packing house wastes, drainage from livestock areas, farm manures and legumes. Nitrates in large amounts can cause the "blue baby" syndrome or methemoglobinemia in infants less than six months of age. It is an important factor to be considered in livestock production, where, in addition to causing methemoglobinemia, high levels of nitrates in water supplies can cause many other symptoms. Nitrates in conjunction with phosphate stimulate the growth of algae, and can cause all of the related difficulties associated with excessive algae growth.

U.S. Public Health Service drinking water standards and WHO guidelines state that 10 mg/l nitrate nitrogen is a limit that should not be exceeded. All samples analyzed were within this guideline.

Phosphate: Phosphorus is an important nutrient for aquatic plants. The amount found in water is generally not more than 0.1 mg/l unless the water has become polluted from wastewater sources or excessive drainage from agricultural areas. When phosphorus is present in excess of the concentrations required for normal aquatic plant growth, a process called eutrophication takes place. This creates a favorable environment for the increase in algae and weed nuisances. As algae cells die and decompose, oxygen is used, often resulting in fish kills and foul odors.

Silica: Silicon dioxide SiO_2, commonly known as silica, occurs in all natural waters in varying degrees of reactive form. A silica cycle occurs in many bodies of water containing organisms, such as diatoms, that utilize silica in their skeletal structure. The silica removed from the water may be returned slowly to the solution by the decomposition of alumina silicate minerals in the drainage basin from which the waters flow. Values may range from 0 to 75 mg/l. All values observed were within this range.

Total Dissolved Solids: Total dissolved solids (TDS) in natural water are usually composed of sulfate; bicarbonate; and chlorides of calcium, magnesium, and sodium. The U.S. Public Health Service recommends that total solids for potable water be limited to 500 mg/l. If such water is not available, use of water with a total solids content of up to 1,000 mg/l may be permitted. WHO guidelines define 1,000 mg/l as the maximum value of total solids. From the standpoint of irrigation of agricultural crops, total solids of 175 mg/l or less would be considered low; between 175 and 500 medium; 500 to 1,500 high; and above 1,500 very high. The term salinity also is used to describe the solids content of irrigation water. In addition to potable and irrigation uses, a high solids content is undesirable in waters used in industry.

The TDS values for the four municipal wells ranged from 220 to 290 mg/l. The TDS in surface waters ranged from 20 to 100 mg/l.

Total Hardness: Calcium, magnesium, and total hardness factors of water are considered as a group since total hardness generally represents the total concentration of calcium and magnesium ions expressed as calcium carbonate. Other ions may contribute to the hardness of water, but in natural waters all but calcium and magnesium are present in insignificant quantities.

Calcium and magnesium may be added to a natural water system as it passes through soil and rock containing large amounts of these elements in mineral deposits. Waters containing small concentrations are referred to as "soft;" those containing large concentrations as "hard."

A knowledge of the hardness of water is of great importance in industrial uses since it is the chief source of scaling in heat exchange equipment, boilers, and pipelines. From the domestic standpoint, hard water consumes excessive quantities of soap, forming curds and depositing a film on hair, fabric, and glassware.

The U.S. Public Health Service drinking water quality standards set limits of calcium hardness at 200 mg/l and magnesium hardness at 150 mg/l. Water with a total hardness in the range of 0 to 60 mg/l is termed soft; from 60 to 120 mg/l medium hard; from 120 to 180 mg/l hard; and above 180 mg/l very hard. Based on these criteria, the water from the four wells is considered hard, and the water from the regional system soft. The hardness in all well samples analyzed ranged from 124 to 172 mg/l as $CaCO_3$. The surface water sources, particularly the raw water from the Casacay River, were soft.

Iron: Most natural waters contain some iron. Its presence may vary from the smallest tract to very large amounts in water contaminated by acidic mine wastes. For domestic use, the concentration should not exceed 0.2 mg/l, and for some industrial applications, not even a trace of iron can be tolerated. There are many means available for removing or reducing the iron content of water. Water-softening resins are effective for removing small amounts of iron, and special ion exchange materials are selective for iron removal. High concentrations of iron can be removed by such chemical processes as oxidation and lime or lime-soda softening. Because of the many means of removing or reducing the amount of iron in water, the particular method employed will depend largely on the form of iron that is present and the end use of the treated water.

The iron concentration for the Puvenza well was measured at 0.4 mg/l. The other wells all had 0.1 mg/l of iron.

Chapter 2

WATER SYSTEM IMPROVEMENT NEEDS

The existing system has significant problems with supplying the demand for water to the population of Machala. This section addresses the water balance for the "no action" alternative, or what would happen if things remain the way they are now. Also, this section evaluates what is needed to meet the water demand for the present and future. Treatment facilities needed to improve the water quality also are discussed.

2.1 Water Balance Based on the "No Action" Alternative

Figure 4 illustrates an analysis of what would happen if nothing is done to improve the condition of the water system for Machala. The water deficit, as shown in Figure 5 is estimated at 305 l/s. After the regional plant is in full operation in 1994, the deficit is expected to be about 116 l/s, and it would escalate gradually to about 753 l/s in 2015. The main contributor to the deficit is water loss; therefore, restoring the existing network and installing new water distribution lines are high priorities in meeting the water demand for Machala.

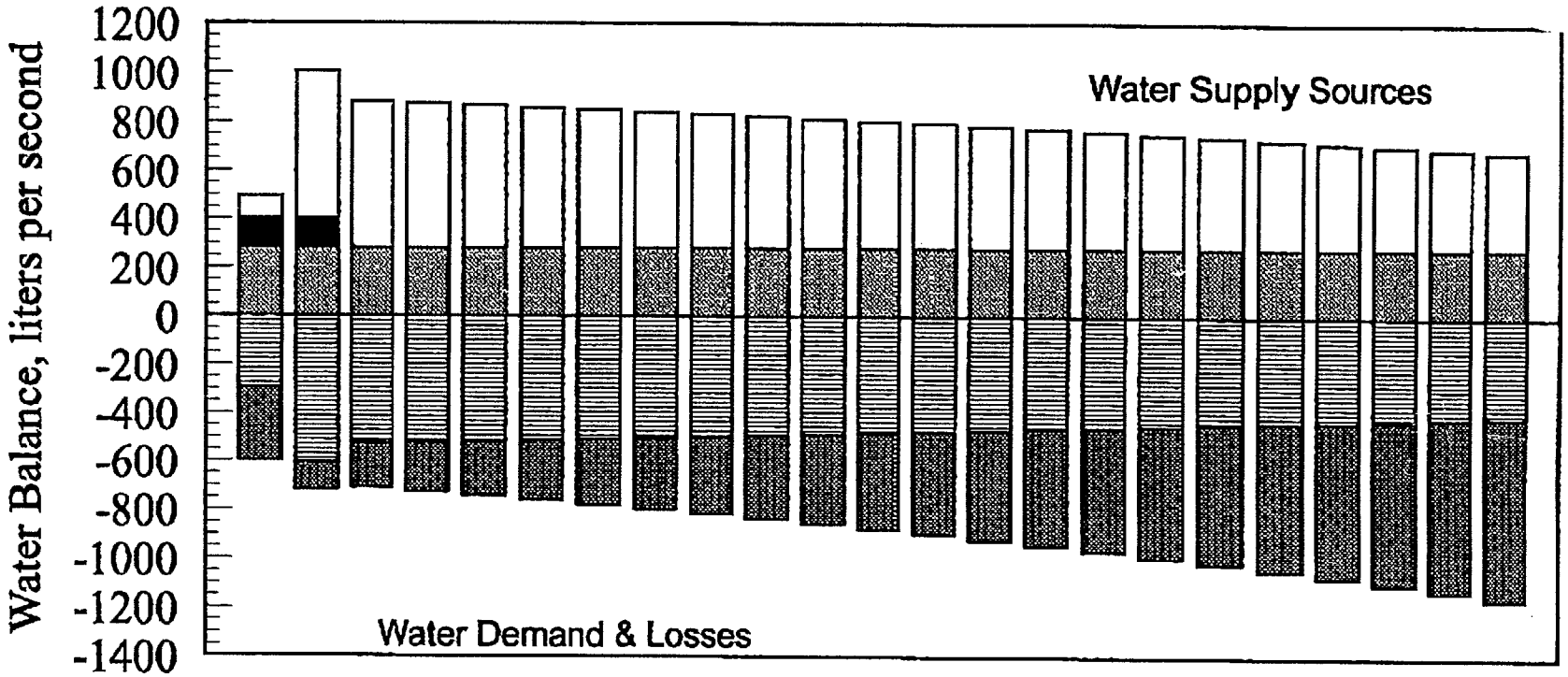
2.2 Water Balance to Meet the Projected Demand

The objective of this analysis is to balance the projected water quantity needs of Machala and Puerto Bolivar. This analysis assumes that the water supply will increase and the system losses will decrease gradually by upgrading the distribution system. The water balance illustration that meets the projected demands is shown in Figure 6. This assumes that water losses in the system are 60 percent now to 20 percent in the year 1999. The analysis also assumes that the losses in the Regional System are 15 percent during the project design period. The assumed system losses are depicted in Figure 7.

2.3 Water System Needs

Based on the water balance and water quality requirements for Machala, the following system improvements are needed to meet current and future water demand and quality:

- Install about 125 km of new water distribution pipes for Machala and Puerto Bolivar by 1996.

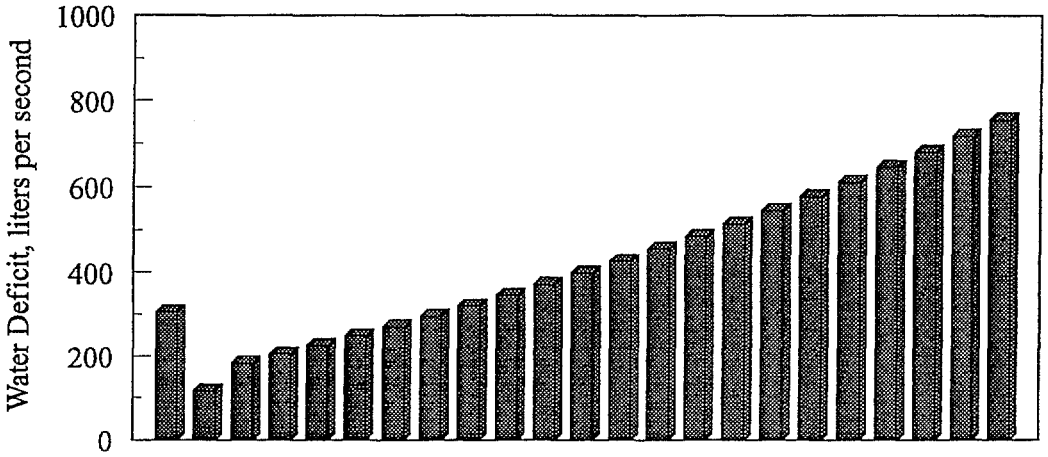


Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Well Water	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280
La Lucha Water	120	120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Regional Plant	90	608	601	593	585	577	568	560	551	542	532	523	513	503	493	482	471	460	449	437	426	413	401
Distribution Losses	(298)	(605)	(528)	(524)	(519)	(514)	(509)	(504)	(498)	(493)	(487)	(482)	(476)	(470)	(464)	(457)	(451)	(444)	(437)	(430)	(429)	(416)	(408)
Water Demand	(305)	(116)	(184)	(205)	(226)	(248)	(271)	(295)	(319)	(344)	(370)	(397)	(424)	(453)	(482)	(512)	(543)	(576)	(609)	(643)	(679)	(715)	(753)

The analysis assumes 300 liters per capita/day
for Machala & Pto. Bolivar and 250 for the rest

Figure 4

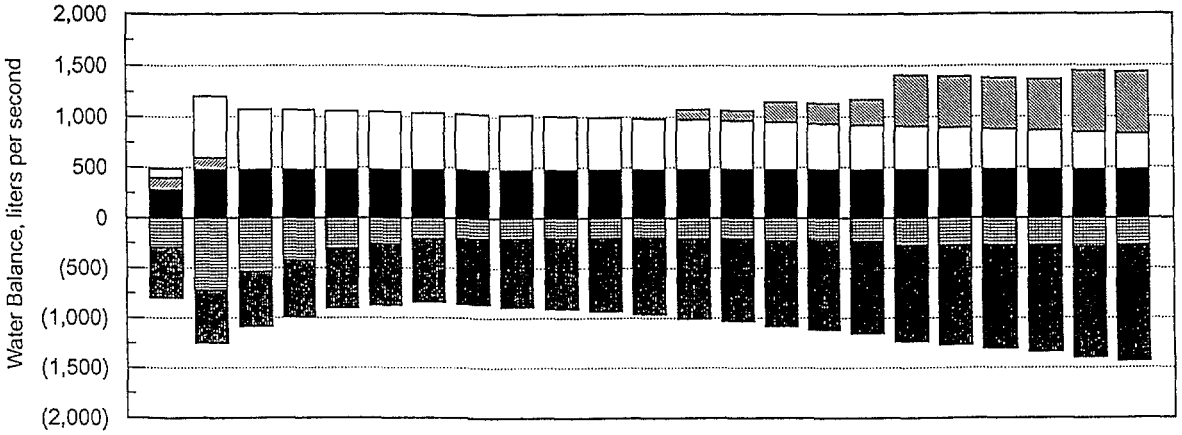
Water Balance for Machala and Pto. Bolivar, Baseline Analysis—No Action



Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Water Deficit, L/sec.	305	116	184	205	226	248	271	295	319	344	370	397	424	453	482	512	543	576	609	643	679	715	753

Figure 5

Projected Water Deficit for Machala and Pto. Bolivar, Baseline Analysis—No Action



Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Well Water	280	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480
La Lucha	120	120																					
Regional Plant	90	604	595	586	577	567	557	547	537	526	515	503	492	480	467	454	441	428	414	400	385	370	354
New Sources	0	0	0	0	0	0	0	0	0	0	0	0	100	100	200	200	250	500	500	500	500	500	501
Loss in System	(295)	(722)	(538)	(425)	(317)	(262)	(207)	(205)	(203)	(201)	(199)	(197)	(214)	(212)	(229)	(227)	(234)	(282)	(279)	(276)	(273)	(290)	(287)
Water Demand	(509)	(529)	(549)	(569)	(591)	(613)	(636)	(660)	(685)	(710)	(737)	(765)	(794)	(824)	(855)	(887)	(920)	(955)	(991)	(1,028)	(1,067)	(1,107)	(1,148)

The analysis assumes 300 liters/per day for Machala and Pto. Bolivar and 250 for the rest.

Figure 6

Water Balance for Machala and Pto. Bolivar,
Network Addition/Modifications and New Sources

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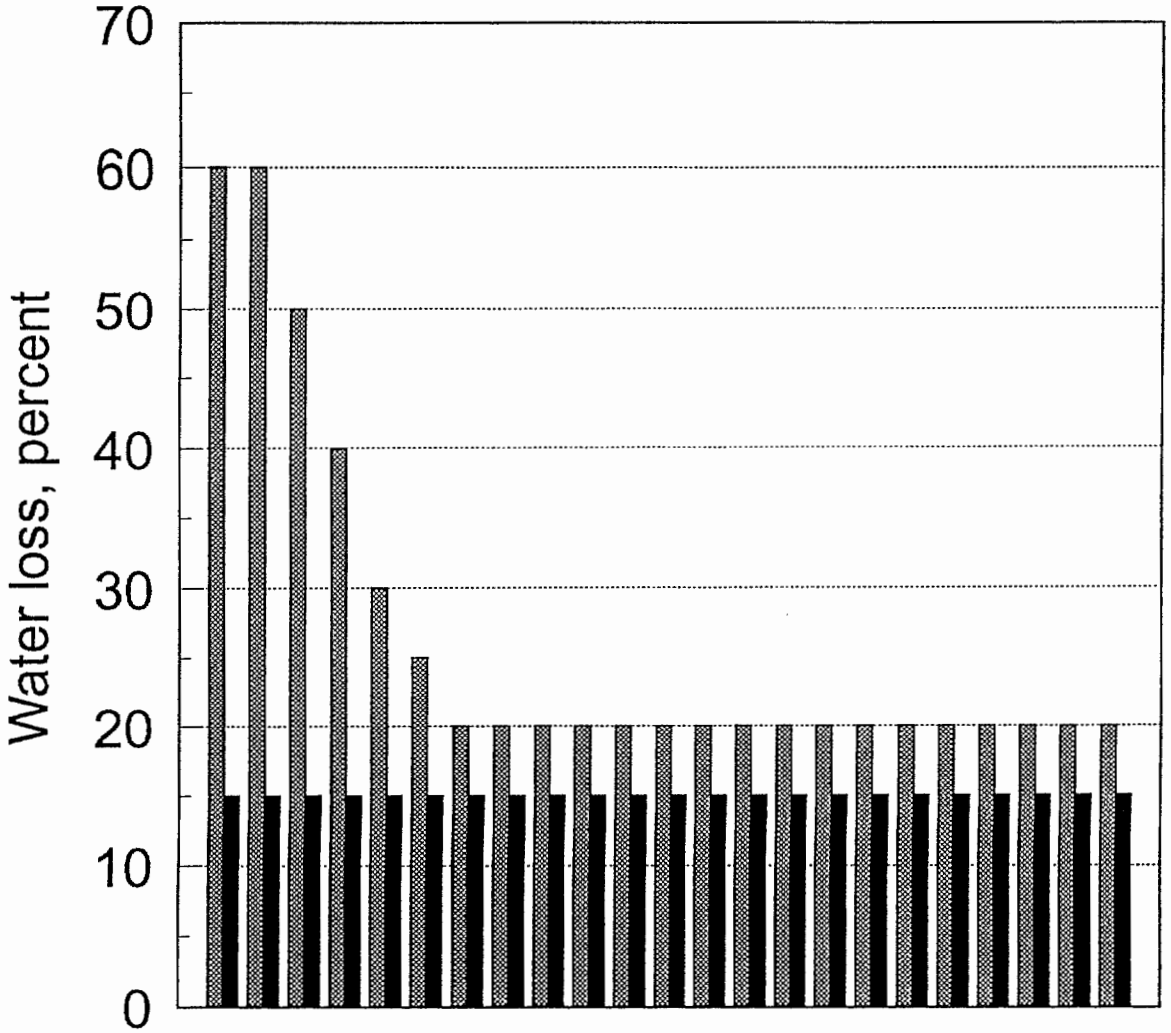

Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Machala & Pto. Bolivar ▨	60	60	50	40	30	25	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Regional System ■	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15

Figure 7
Estimated Water Losses
Assuming Implemetation of a Network Restoration/Expansion Program

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- Repair the existing water network and disallow and remove illegal or substandard connections by 1996.
- Establish a goal for reducing system losses to less than 20 percent by 1999.
- Install water meters to 50 percent of users by 1996; install water meters to more than 85 percent of users by 1999.
- Install three to four wells with 200 l/s capacity by 1994.
- Design and build a new 500 l/s water-softening plant for treatment and disinfection of water from wells by 1996. An alternative to this is to install a central iron and manganese removal plus disinfection system or a similar system at each well. (The cost-effectiveness of these systems is evaluated in Section 3 of this report.)
- Provide additional water supply capacity of 250 l/s by 2005, and double this capacity by 2010. This could be an expansion of the regional system or an expansion of the well fields and treatment systems. (These options are evaluated in the next section of this report.)

Chapter 3

DEVELOPMENT AND EVALUATION OF ALTERNATIVES

3.1 Distribution System for Machala

A new distribution system for the Machala-Puerto Bolivar area was designed in 1987 by ASCAM. The designed system covers a total area of about 2,370 hectares. This area covers four districts divided into a water network with 27 loops. The design was based on a computer program developed by ASCAM that uses a variation of the Hardy Cross method. The program balances the flow and water pressures for all 27 loops.

The system covers 21,490 lineal meters of water mains and 122,510 lineal meters of water distribution pipes. Table 4 summarizes the size and length of the water mains. The size and lengths of the distribution pipes are presented in Appendix A.

Table 4
Size and Length of the Water Mains

Diameter, meters	Length, meters
0.25	260
0.30	2,370
0.40	11,630
0.50	2,660
0.70	2,250
0.90	800
1.00	1,440

Reduced drawings of the water mains and of the network loops are included in Appendix A.

3.1.1 Basic Design Criteria

The existing design (1987) is based on the following parameters:

- Design year: 2010
- Design period: 24 years
- Existing population: 125,000[1]

[1] Population estimate used by ASCAM in 1987.

- Future population: 275,910
- Area served by project: 2,370 hectares
- Future water demand: 300 liters per capita/day
- One hydrant per loop
- New storage for 2010: 29,877 m^3
- Fire flow: 12 or 24 l/s per hydrant
- Maximum water velocity: 1.76 m/s

3.1.2 Water Distribution Construction Costs

The preliminary construction cost estimate for the Machala water distribution system is based on the ASCAM design (1987) plus 15 percent extra piping for new development areas and repairs of existing system. This design needs to be verified based on new population growth trends and area developments. Nevertheless, it is considered a functional design that probably is still usable with minor adjustments. The construction cost components include the following:

- 24,700 lineal meters of DI,
- 140,900 lineal meters of PVC water distribution pipes,
- 30,000 new water meters,
- 10,000 new home connections,
- 30 water hydrants, and
- 30 isolating/controlling valves.

The construction cost estimate for the water distribution system is summarized in Table 5. This construction cost estimate is based on current pipe material costs and current pipe installation costs for Ecuador provided by IEOS.

3.2 New Wells

In order to supply 200 l/s of water, four new wells must be installed. The new wells would be installed in the vicinity of the existing well field, about 6 km from Machala. The most desirable water well quality is from the Corralitos well. The assumed design parameters are as follows:

Table 5
Cost Estimate of the Machala Water Distribution System

Item	Quantity	Unit Cost $	Total Cost $
DI water mains, meters	24,710	*	2,434,724
PVC piping, meters	140,829	*	2,309,824
Water meters, units	30,000	70	2,100,000
New connections, units	10,000	65	650,000
Excavation, backfill & repaving, cubic meters	165,539	8	1,324,312
Hydrants, each	30	1,200	36,000
Valves, each	30	1,200	66,000
Fittings (one per 200 m)	828	850	703,541
Subtotal			9,624,400
Engineering & Administrative @ 15 percent			962,440
Contingencies @ 15 percent			1,443,660
Total Construction Cost			$12,030,500

* For Detailed Unit Cost see Appendix A

- Number = 4
- Depth = 70 meters
- Diameter = 300 mm
- Discharge head = 55 meters
- Pump size = 250 mm
- Motor size = 100 Kw
- Capacity = 65 to 70 l/s each

The new wells will require a new DI water main from the well field to Machala with a capacity of 200 l/s and a pipe diameter of 500 mm. The estimated cost for the new well field is $1.11 million. Table 6 presents a cost breakdown of the new well field.

Table 6
Estimated Cost for New Well Field

Item	Quantity	Unit Cost, $	Total Cost, $
Well installation	4	2,800	11,200
Pump and controls	4	35,000	140,000
Valves and fittings	4	5,000	20,000
Electrical and controls	4	17,120	68,480
Pipe from well to main	1,200	52	62,400
Main water line to Machala	6,500	90	585,000
Subtotal			887,080
Engineering & Administrative			88,710
Contingency			133,060
Total Construction Cost			1,108,850

3.3 Well-Water Treatment Alternatives

Groundwater is an abundant source in the study area and has a relatively good quality, particularly from the bacteriological standpoint. However, several potential problems associated with well waters are summarized below.

- Calcium and magnesium salts present in the water will eventually create scaling. Scaling is defined as a hard, crusty deposit in the walls of pipes, valves, water meters, filters, and heaters. Scaling can reduce the effective area of the pipe or orifices in water meters and make them inefficient or useless.
- The presence of iron and manganese at levels detected in the study area wells would react with chlorination of the water creating a high demand of chlorine and a precipitate.

The removal of calcium and magnesium salts can be achieved with a water-softening process. This type of process also can remove iron and manganese. The effluent from this process can be chlorinated for water distribution. An alternative to water softening is to install a process for removal of iron and manganese without softening. Once these two parameters are reduced, water can be disinfected appropriately. The process used for removal of iron and manganese involves chemical oxidation with potassium permanganate and filtration in a dual media filter (anthracite and greensand). After filtration, treated water can be disinfected with chlorine. The drawback of the second option is that since hardness is not removed, there remains a potential for scaling. However, if the water is blended with the treated water from the regional plant (which is very soft water), the resulting product probably would not cause scaling problems in the system. The two treatment alternatives are discussed in more detail below.

3.3.1 Lime-Soda Ash Softening

Lime-soda ash softening will remove hardness (calcium and magnesium) and will take out iron and manganese as well. This process involves the following:

- Chemical addition,
- Sedimentation,
- Filtration,
- Chlorination, and
- Repumping to the water main.

A process schematic diagram of this system is shown in Figure 8.

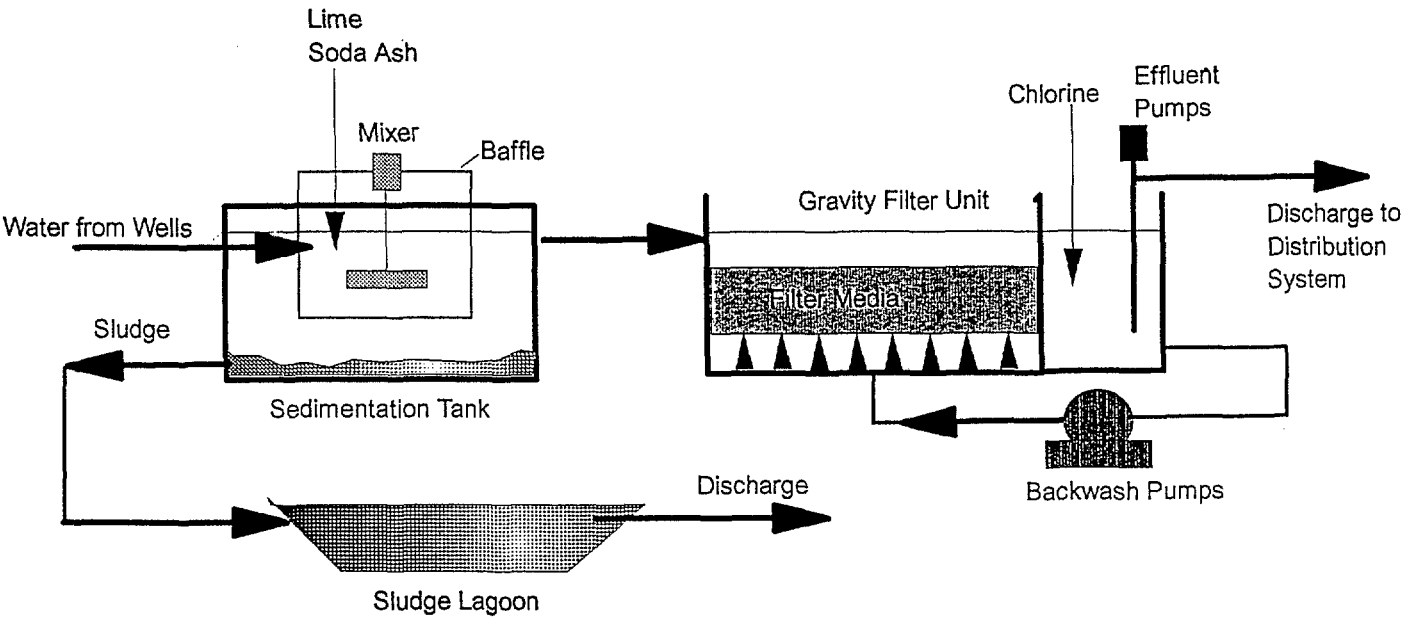

Figure 8
Schematic Diagram of Softening WTP System

The capital costs for such a system are estimated at $4.63 million. Annual O&M costs are estimated at $0.72 million. (See Table 7 for detailed construction and O&M costs for this system.) The system components evaluated include the following:

- Two Infilco Degremont, Inc (IDI) accelerator mechanisms with concrete walls, 18.3m in diameter (This unit can be used for chemical mixing, flocculation, and sedimentation. It includes all mechanisms and controls.)
- One IDI Greenleaf Filter with a filter area of 195 m^2. (The filtration rate used is 0.154 m^3 per minute/m^2.)

3.3.2 Greensand Filter

The process of greensand filter—which involves chemical addition, filtration, and chlorination—is the usual method for removing iron and manganese from well water without softening treatment. Potassium permanganate can chemically oxidize the iron and manganese. Theoretically, one mg/l of potassium permanganate will oxidize 1.06 mg/l of iron or 0.52 mg/l of manganese. In practice, however, the permanganate necessary for oxidation of the soluble manganese is less than the theoretical requirement. One main advantage of potassium permanganate oxidation is the high rate of the reaction. Also, the rate of reaction is relatively independent of the hydrogen ion concentration within a pH range of 5 to 9.

After the water is dosed with the chemical, it is filtered through a manganese zeolite pressure filter. Manganese zeolite is made by coating natural greensand (glauconite) zeolite with manganic oxides. Manganese dioxide removes soluble iron and manganese until it becomes degenerated. The filter is regenerated using potassium permanganate.

Disadvantages of this process are the possibility of soluble manganese leakage when the bed is nearly degenerated and the waste of excess potassium permanganate that is needed to regenerate the greensand. The impact of these two drawbacks has been reduced substantially by continuously supplying a feed of potassium permanganate solution ahead of the dual media filter of anthracite and manganese zeolite. The anthracite filter media removes most insolubles, thereby reducing the problem of plugging the greensand. A continuous feed of permanganate reduces the frequency of greensand regeneration. When the permanganate feed is less than the reduced iron and manganese are the water, excess iron and manganese are oxidized by the greensand. If a surplus is applied, it regenerates the greensand.

Table 7

Construction and O&M Estimates for a Well-Water Softening Plant

1) Construction Costs

Item	Units	Quantity	Unit cost, $	Total Cost, $
Mobilization	ea.	1	50,000	50,000
Excavation & backfill	M3	700	25	17,500
Reinforced concrete				0
Mixing	M3	130	120	15,600
Sedimentation	M3	800	120	96,000
Filters	M3	2,100	120	252,000
Pumping	M3	60	120	7,200
Building	M3	70	120	8,400
Silos & pumps	M3	10	120	1,200
Chlorination	M3	10	120	1,200
Formwork	M2	15,000	25	375,000
Equipment				0
Mixing	ea.	1	20,000	20,000
Sedimentation	ea.	2	230,000	460,000
Filters	ea.	1	650,000	650,000
Pumping	ea.	1	180,000	180,000
Building & Laboratory	ea.	1	86,400	86,400
Silos & pumps	ea.	1	58,000	58,000
Chlorination	ea.	1	35,000	35,000
Backwash Tank	m3	1	150,000	150,000
Piping	Lm	1,200	80	96,000
Valves & fittings	ea.	1	20,000	20,000
Instrumentation	bulk	1	188,900	188,900
Electrical	bulk	1	314,900	314,900
Stand-by generator	bulk	1	150,000	150,000
Roads	Lm	700	52	36,400
Landscaping	m2	400	20	8,000
Painting	m2	350	80	28,000
Subtotal				3,305,700
Engineering & Administration				495,855
Contingencies				826,425
Total construction cost				**$4,627,980**

2) Annual O&M Cost

Item	Units	Quantity	Unit cost, $	Total Cost, $
Labor	hrs.	1.20	10,400	12,480
Energy	Kw-hr	0.08	978,930	78,314
Parts	ea.	1	34,000	34,000
Lime	Kg	3,153,600	0.06	189,216
Soda Ash	Kg	156,950	0.60	94,170
Chlorine	Kg	39,238	7.80	306,053
Supplies	bulk	10,500	1	10,500
Total				**$724,733**

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A schematic diagram of this option is shown in Figure 9.

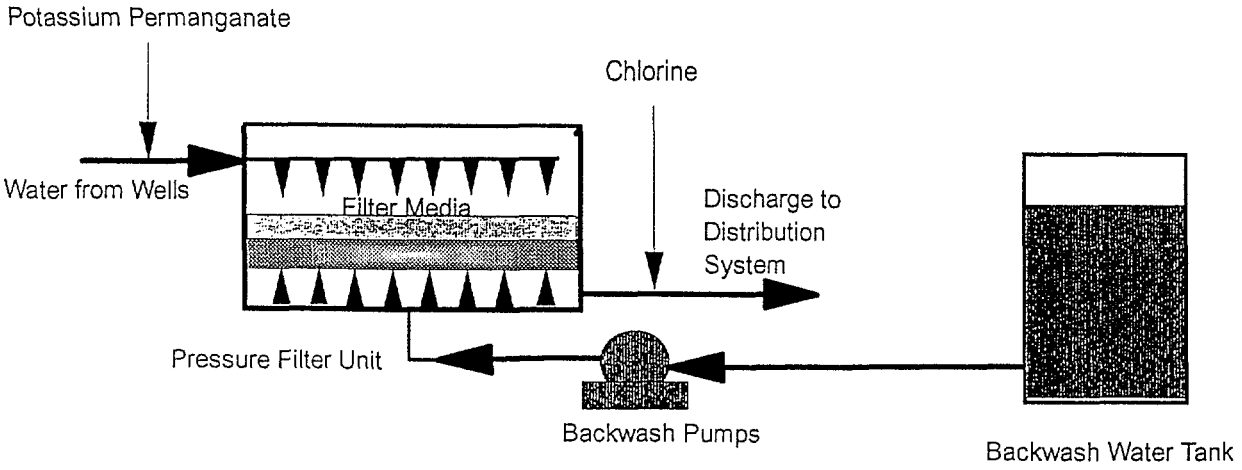

Figure 9
Schematic Diagram of the Pressure Filtration System

The estimated construction costs for a 500 l/s plant is approximately $2.92 million. The estimated O&M costs for operating such a system are about $0.56 million. See Table 8 for a detailed description of construction and O&M costs. The cost estimate is based on four pressure filters with all mechanical components and piping. The filter dimensions are for a horizontal filter with a 3.05m diameter and a 14m length.

3.4 Expanded Regional Water Supply Treatment and Transmission

The Casacay River is the water source for the regional WTP and has a minimum safe yield of about 1,500 l/s, according to local engineers. This information, however, needs to be verified with actual river gauging data, which currently is unmeasured.

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Table 8

Construction and O&M Cost Estimates for a Greensand Filter Plant

1) Construction Costs

Item	Units	Quantity	Unit cost, $	Total Cost, $
Mobilization	ea.	1	35,000	35,000
Excavation & backfill	M3	400	25	10,000
Reinforced concrete				0
Filters	M3	283	120	34,006
Building	M3	34	120	4,081
Permanganate Storage & pumps	M3	30	120	3,600
Chlorination	M3	10	120	1,200
Formwork	M2	1,500	25	37,500
Equipment				0
Pressure filters	ea.	2	562,500	1,125,000
Booster Pumps	ea.	100,000	1	100,000
Building & Laboratory	ea.	86,400	1	86,400
Chlorination	ea.	35,000	1	35,000
Backwash Tank	m3	1	150,000	150,000
Piping	Lm	80	1,200	96,000
Valves & fittings	ea.	75,000	1	75,000
Instrumentation	bulk	33,200	1	33,200
Electrical	bulk	35,000	1	35,000
Stand-by generator	bulk	150,000	1	150,000
Roads	Lm	700	52	36,400
Landscaping	m2	400	20	8,000
Painting	m2	350	80	28,000
Subtotal				2,083,387
Engineering & Administration				312,508
Contingencies				520,847
Total construction cost				**$2,916,742**

2) Annual O&M Cost

Item	Units	Quantity	Unit cost, $	Total Cost, $
Labor	hrs.	8,320	1.20	9,984
Energy	Kw-hr	652,620	0.08	52,210
Parts	ea.	25,000	1	25,000
Potassium Permanganate	Kg	3.25	47,304	153,738
Chlorine	Kg	7.80	39,238	306,053
Supplies	bulk	1	10,500	10,500
Total				**$557,484**

This alternative involves expanding the regional WTP to supply an additional 500 l/s. The process will be identical to the existing process. The treatment process includes alum coagulation, flocculation, sedimentation, gravity filtration (anthracite/sand), and chlorination.

A preliminary evaluation of the regional system hydraulics determined that the 700 mm and 800 mm pipeline of the northern aqueduct (via El Guabo) from the regional WTP has a capacity of 1,350 to 1,500 l/s. Therefore, it is assumed that the regional WTP expansion would not require an expansion of the aqueduct to supply an additional 500 l/s to Machala-Puerto Bolivar.

The estimated construction cost for this expansion is about $3.69 million. The annual O&M cost is estimated at $0.36 million. Table 9 summarizes the construction and O&M costs, respectively.

3.5 Summary of Alternatives

This section provides the cost-effectiveness analysis of alternatives and project needs that were presented previously. Since the number one priority for Machala is the water distribution system, these costs cannot be compromised. The only variances in water distribution system design are the arrangement of the distribution pipes, piping materials, and construction methods.

Immediate water supply for Machala-Puerto Bolivar will come from the regional plant and from new wells. This will significantly reduce the existing water deficit. Unfortunately, unless the regional plant is repaired and the distribution system installed, more than 40 percent of the water supplied will be wasted through leaks.

The well-water treatment facility is needed for disinfection and for prevention of scaling in the future distribution system and water meters. Two well-water treatment alternatives were evaluated: a softening WTP and a pressure filtration system using greensand media. The first option has the following advantages:

- Softens the water to prevent scaling,
- Removes iron and manganese, and
- Produces a better effluent quality.

Its main disadvantage is that it is more expensive than the pressure filtration system.

Table 9

Construction and O&M Cost Estimates for the Regional WTP

1) Construction Costs

Item	Units	Quantity	Unit cost, $	Total Cost, $
Mobilization	ea.	1	50,000	50,000
Excavation & backfill	M3	25	12,500	312,500
Reinforced concrete				
Mixing & flocculation	M3	230	120	27,600
Block masonry	M3	125	120	15,000
Sedimentation	M3	520	120	62,400
Filters	M3	2,100	120	252,000
Building Additions	M3	70	120	8,400
Chlorination	M3	10	120	1,200
Formwork	M2	17,000	25	425,000
Equipment				
Sedimentation plates	ea.	1	230,000	230,000
Filter media	ea.	1	40,000	40,000
Building modifications	ea.	1	15,000	15,000
Miscellaneous equipments & metals	ea.	1	86,400	86,400
Chlorination	ea.	1	35,000	35,000
Piping	Lm	85	800	68,000
Valves & fittings	ea.	1	10,500	10,500
Instrumentation	bulk	1	32,500	32,500
Electrical	bulk	1	40,600	40,600
Stand-by generator	bulk	1	150,000	150,000
Roads	Lm	600	52	31,200
Landscaping	m2	400	20	8,000
Raw water intake piping	Lm	6,550	65	425,750
Raw water intake structure	bulk	1	35,000	35,000
Painting	m2	3,400	80	272,000
Subtotal				2,634,050
Engineering & Administration				395,108
Contingencies				658,513
Total construction cost				**$3,687,670**

2) Annual O&M Cost

Item	Units	Quantity	Unit cost, $	Total Cost, $
Labor	hrs.	1.20	6,240	7,488
Energy	Kw-hr	0.08	65,262	5,221
Parts	ea.	1	10,000	10,000
Alum	Kg	236,520	0.08	17,739
Chlorine	Kg	39,238	7.80	306,053
Supplies	bulk	10,500	1	10,500
Total				**$357,000**

The following are the pressure filtration system's principal advantages:

- Allows ease of operation,
- Removes iron and manganese,
- Traps sand and other particulates that may interfere with metering,
- Has lower capital and O&M costs than the softening WTP,
- Does not require a repumping station (although it may require booster pumps), and
- Is easy to expand.

The principal disadvantage of this pressure filtration system is that because it does not soften the water a potential for scaling remains. This disadvantage can be resolved by blending the treated well water with the water from the regional WTP. The resulting hardness should be less than 100 mg/l as $CaCO_3$.

In addition, as shown in Figure 6, in order to meet demand, a new 250 l/s source is needed by 2005, and the same amount of additional capacity will be needed five years later. This capacity can be supplied from treated well water or from an expansion of the regional WTP. For this period, the pressure filtration using greensand media is not an option because the blended water would have a resulting hardness exceeding 100 mg/l as $CaCO_3$ and probably would cause scaling problems in the system. Therefore, the choice for this later expansion has to be either a softening WTP or an expansion to the regional WTP. Both would need additional capacity of 500 l/s to be built in two phases. The economic analysis for this option slightly favors the regional WTP.

The following are advantages of the regional WTP expansion:

- Produces lower capital and O&M costs,
- Can use available land,
- Uses gravity flow—no pumping,
- Has simple design, and
- Uses existing administrative facilities and other utilities.

The main disadvantages of a regional system are included below.

- The transportation of water 46 km from the regional WTP to Machala implies that losses in the regional system (by leaks or consumption of growing communities) may reduce the effective volume of treated water reaching Machala.
- It is questionable whether the Casacay River can provide the additional 500 l/s for the next 20 years. A gauging station is needed to determine the river's safe yield. Also, future developments in the river's watershed area may degrade water quality, which would require more expensive chemical treatment.

The advantages of a softening WTP would be the following:

- Water is not subject to losses in the regional system.
- Water quality of the source is stable.

Its main disadvantages compared to the regional WTP are as follows:

- Produces higher capital and O&M cost,
- May require neutralization of effluent,
- Needs a slightly more skilled operation,
- Requires more energy consumption, and
- May need to purchase land.

3.6 Recommendations

Based on the analysis of the system components, the following recommendations are made:

- Establish a new Municipal Water Enterprise Fund for management of water system improvements.
- Design and install about 24.7 km of DI water mains and 140 km of new PVC water distribution for Machala-Puerto Bolivar by 1996. Include about 10,000 new connections and 30,000 new water meters.
- Design and locate new water storage tanks that provide 21,600 m^3 of storage. This storage capacity provides four hours of sustained flow at 1,500 l/s. In addition, storage provides for fire protection, meets peak water demand, and helps to control the pressure in the system.
- Design and install new wells with a 200 l/s capacity and a new 500 mm transmission line.
- Design and install a well-water pressure filtration plant to treat 500 l/s. The WTP should be located near the existing well field or near or on the site of the La Lucha Plant. Use the chlorination system from this plant to dose the 1000 mm water main from the regional WTP. This plant should be conveniently located near the 1000 mm water main.
- Delay the decision about additional capacity for 2005 until the year 2000. Update the feasibility study in the year 2000, based on population growth trends, to decide on the most cost-effective supplemental water source beyond 2005.
- Conduct gauging studies of the Casacay River to determine the safe yield of the river. This information would assist the decision-making process regarding future regional WTP expansion.

Chapter 4

PROPOSED OPTIONS AT PREFEASIBILITY LEVEL

4.1 Description of the Proposed Systems

The proposed water supply systems that require immediate action include the following:

- Design and install a water distribution network for Machala and Puerto Bolivar. The new network system requires the following:
  - About 24,700 lineal meters of DI,
  - About 140,900 lineal meters of PVC waste distribution pipes,
  - 30,000 new water meters,
  - 10,000 new water connections,
  - 30 water hydrants,
  - 30 isolating/controlling valves.
- Design and install new storage capacity of 21,600 m^3 in Machala. The location and tank sizes must be based on the final design of the distribution network. The storage is designed to maintain a flow of 1,500 l/s for four hours in the distribution system.
- Design and install four new wells with the following approximate characteristics:
  - Depth = 70 meters
  - Diameter = 300 mm
  - Discharge Acid = 55 meters of the water column
  - Pump size = 250 mm
  - Motor size = 100 Kw
  - Capacity = 65 to 70 l/s each

The discharge from each well will be connected to a new 6,500 m water main that would deliver the raw well water to a new WTP. The new water DI main is 500 mm in diameter.

- Install a pressure filter WTP, which could be located near or on the site of the La Lucha Plant, or near the well field. This process will remove iron and manganese from the well water, reduce the sand and particulates that are present in the well water, and produce a chlorinated effluent. The process consists of four pressure filters, 3.05 m in diameter and 14.6 m long. The filter media consists of anthracite and greensand. Potassium permanganate and chlorine injection facilities also are components of this

system. The treated water will be mixed with the water from the regional WTP in the distribution system. This will reduce hardness in the water being piped to the customers in Machala, and therefore, will reduce the potential for scaling. The chlorination facilities of this new plant should be used to dose the water provided from the regional WTP. One option is to chlorinate the treated well water with a higher dosage and blend it with the water from the regional plant. The actual dosage will be based on the chlorine demand required to maintain 1 mg/l of free available chlorine in the system.

After the year 2000, a new 500 l/s capacity will be required to meet the 20-year water demand. This new plant can be constructed in two phases with 250 l/s capacity each. According to existing water demand projections, the first phase should be in operation by 2005. Based on the same projections, the next phase should be in operation by 2010. The feasibility and capacity of the future systems should be reevaluated in an updated feasibility study expected in the year 2000.

4.2 Prefeasibility Cost Estimates for Design, Construction, and Operation and Maintenance

The cost estimates for designing, constructing, and operating and maintaining the proposed water system improvements for Machala-Puerto Bolivar are summarized in Table 10. This table also presents the annualized amortization cost for the loan obtained for implementing these facilities.

The total estimated cost for construction of the proposed water system modifications is about $17.86 million. The annualized amortization of the loan for capital improvements is about $2.87 million per year based on 6-percent annual interest for a 20-year period.

4.3 Financing and Cost Recovery Options

A detailed evaluation of financing and cost recovery options is beyond the scope of work of this task. Therefore, these options are provided only in a preliminary fashion.

Table 10
Cost Summary

Water System Component	Design & Administration	Construction Total Cost, $	Annual O&M Cost, $	Annualized Capital Cost, $	Total Annual Cost, $
Water Main & Distribution	962,440	12,030,500	247,590	1,048,870	1,296,460
Storage Tanks 21,600 m^3	150,000	1,800,000	20,000	156,930	176,930
New Well Field & Water Main	88,710	1,108,850	491,290	96,670	587,960
Pressure Filtration Plant	312,510	2,916,740	557,490	254,300	811,790
Total	1,513,660	17,856,100	1,316,370	1,556,770	2,873,140

4.3.1 Financing Options

Considering the current economic situation in Machala and the amount needed to implement the proposed facilities, the city is not capable of financing this project. Possible external options include the following:

- Loan from the Banco del Estado of Ecuador,
- Loan from international lending institutions through the Banco del Estado,
- Loan from the U.S. Eximbank for private sector with concurrence of the Government of Ecuador for equipment and supplies manufactured in the United States (The Eximbank supports exports to Ecuador via the Corporación Andina de Fomento.)
- Private investments, and
- Combination of options.

The Banco del Estado has received a loan of $120 million from the Inter-American Development Bank for improvements in Ecuador's infrastructure. This loan will be used primarily for roads and highways and for water supply and sanitation. It is possible that the Banco del Estado can commit the entire cost or a fraction of the cost for the Machala Water System Improvement.

Eximbank supports exports to Ecuador, Peru, Venezuela, Bolivia, and Colombia via the Corporación Andina de Fomento [Andean Development Bank (CAF)], a development bank that primarily is interested in exports related to development projects and supports some commercial projects. Eximbank presently is assisting Bolivia and Ecuador with short-term loans to the private sector.

The above and other options will be evaluated in more detail in an upcoming report on technical assistance from the WASH Project (Wash Task 462).

4.3.2 Cost Recovery Options—User Rates

There are two commonly accepted methods for determining system revenue requirements: the cash basis and the utility enterprise basis.

Cash Basis

The cash basis for determining revenue requirements frequently is used by publicly owned utilities because of its similarity to other elements of the municipal budgeting process. On an annual basis, it provides the actual cash necessary to serve existing and expected new customers. This includes O&M expense as well as annual capital-related cash needs (debt service, pay-as-you-go financing, and reserve accruals). Return on capital is not considered a revenue requirement under this method because the equity capital is contributed initially by all customers within the system. Financial resources for capital expansion are provided by the users as need arises. Revenue requirements include annual O&M expenses, debt service payments (principal and interest payments on outstanding water enterprise debt), accruals to capital reserves to provide future facilities as applicable, and annual contributions to construct facilities (pay-as-you-go financing) as applicable.

Utility Enterprise Basis

The utility enterprise basis for determining revenue requirements is applicable when there is an identifiable "owner" of the system and users who are nonowners. For the municipality of Machala, the users inside the city limits would be expected to share the benefits of ownership; the customers outside the city limits (or marginal areas) served by the municipality could be considered nonowners or "renters" of the system.

The concept behind this approach is that the renters of the system should be charged a rate for service that provides for O&M expenses (plus local taxes where appropriate), depreciation, and a reasonable return on the system's capital investment. Capital recovery (depreciation plus return on investment capital) compensates the owners (inside city residents/rate payers) for obtaining the initial capital and for managing and operating the system. This capital can be provided through debt or equity financing. As managers of the system, the municipality can acquire the necessary capital efficiently, given the limitations on funds generated by the return on invested capital.

Difference Between the Methods

The most significant distinction between the cash basis and the utility basis for determining revenue requirements is the manner in which funds for capital investment are obtained. The components of revenue requirements under each method are listed below:

Cash Basis	Utility Enterprise Basis
O&M expenses	O&M expenses
Taxes on assets	Taxes on assets
Capital investment from current revenues	Depreciation
Current reserve accruals from current revenues	Return on capital (return on equity investment plus interest on debt)
Debt principal payments	
Debt interest payments	

The cash basis, by definition, requires customers and new applicants for service to contribute capital. The utility basis, on the other hand, may be appropriate for determining funding that must be obtained from customers who are not owners of the system; i.e., customers who are not responsible for supplying capital for the construction of the facilities. It therefore follows that the use of system development charges, a front-end contribution of capital from new applicants for service, is an appropriate pricing mechanism under the utility basis.

The user rates usually are calculated by estimating the O&M expenses and the capital-related cash needs for the next five years. The total expenses and cash needs are divided by the number of customers to obtain the user rate.

The following paragraph describes in more detail how the expenses and cash needs are calculated.

O&M Expenses

Cash needs for the water system operation can be divided into two major categories: O&M expenses and capital-related cash needs for operation.

O&M expenses consist of annual systems operation expenses.

O&M expenses are further categorized by function as follows:

- WTP related expenses,
- Distribution system-related expenses (water pipe and meter),
- Administrative and general expenses,

- Variable expenses, e.g. purchased power, potassium permanganate, and other supplies (purchased power is used at the WTP and to operate the well pump; chlorine and other chemicals are used in water treatment at the WTP), and
- Expense of purchasing water from the regional system.

The general approach to forecasting O&M costs through 2001 is to start with the current budget and apply appropriate escalation factors to derive future estimated costs. Each individual O&M expense component should be analyzed to determine an appropriate escalation rate to apply for inflation. In addition, variable costs have to be escalated in proportion to the expected increase in demand for water. Tables 11 and 12 provide examples of annual escalation factors that can be used to forecast O&M expenses.

Table 11
Example O&M Expense—
Escalation Rates for WTP Variable Costs

Item	Annual escalation rate, percent
Water Treatment Plant	
Salaries	8
Motor fuel	12
Uniforms	8
Insurance	10
Maintenance, motor equipment	8
Maintenance, building	8
Maintenance, machinery	8
Dues	8
Telephone	8
Professional services	10
Auto allowance	12
Travel	15
Pension	8
Group insurance	8
Distribution system	8
Administration	8

Capital-Related Cash Needs

Capital-related cash needs for operation of the water system should be forecasted through 2000/2001. Capital-related cash needs refers to the actual cash flow, including O&M expenses, required to sustain the water utility on an enterprise basis.

The components of the capital-related cash needs forecast through 2000/2001 consist of debt service (annual principal and interest payments) of about $2.92 million per year on a proposed $17.86 million loan, plus a capital reserve accrual structured to provide debt coverage of the proposed debt service. Debt coverage usually is required according to specified terms in loan covenants and provides a "safety factor" for the lending institution.

Table 12
Example O&M Expense—
Annual Escalation Rates for General Items

Item	Inflation rate, %	Increase in consumption, %	Escalation rate, %
Utilities	12	0	12
Chlorine	10	2	12
Other supplies	7.4	0	7.4

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Chapter 5

IMPLEMENTATION ISSUES

5.1 Institutional Requirements

A Machala water system improvement project is of such magnitude that it is beyond the existing technical administrative and financial capabilities of the municipality. In addition, since the implementation of a new water distribution system is critical to prevent severe water shortages, the management authority in charge of implementing such programs must have the precise resources (financial, technical, and administrative) and facilities to manage the logistical, financial, administrative, and technical aspects of the project. Therefore, the need for a municipal water enterprise that is focused on the project is seen as vital to conducting the project on schedule and within budget. It is the opinion of the author that to try to manage a project of this magnitude with the existing resources or by "adding on" would be a terrible mistake. It is strongly recommended that a new water enterprise be formed with the participation of the municipal government and other appropriate private and public agencies.

In addition, the existing laws regarding illegal connections to the water system must be enforced. These laws must be reviewed and modified to include stricter civil penalties, as well as possible criminal penalties, for offenders.

5.2 Phased Approach

The project can be implemented in two phases. Phase I is the immediate or "urgent" phase that requires building the distribution network now, with about 200 l/s of new water supply. This phase also requires a WTP. Phase II, to be implemented after the year 2000, includes a feasibility study update and additional water supply sources, currently estimated to be about 500 l/s. It is assumed in this analysis that the construction of the new network will reduce water loss and that incremental demand before construction will be met by recovered water (due to prevention of leaks and illegal connections). A preliminary project schedule is shown in Figure 10.

5.3 Preliminary O&M Requirements

The proposed new water enterprise would operate and maintain the water supply treatment and distribution system. It is envisioned that the municipality would purchase water supplied to Machala from the regional system at a negotiated fair price. This would imply the installation of a water meter at the point of delivery to Machala. The municipality will sell the water to its customers at a user rate established to recover the cost of investment and to accrue

revenues for future improvements. The water enterprise would be responsible for the following O&M activities:

- Provide overall administration of the water system,
- Repair water mains and home connections,
- Maintain valves, hydrants, meters, and related items,
- Monitor chlorine in the distribution system,
- Monitor pressure in the system,
- Adjust control valves to balance water flow in the network,
- Maintain and repair the WTP and wells,
- Maintain an inventory of parts and materials needed in daily operations,
- Maintain and order chemicals for water treatment,
- Review drawings and specifications of new requests of installations, and
- Conduct billing and collect payment for services.

	Time, months from start									
Activity	6	12	18	24	30	36	42	48	54	60
Loan Application										
Network design										
Network Construction										
Ground Water Studies										
Well Design & Construction										
Pressure Filter WTP Design and Construction										
Water Meter Installation										

Phase II starts after the year 2000

Figure 10
Preliminary Schedule for Phase I of the Proposed Project

Appendix A

MACHALA WATER DISTRIBUTION SYSTEM

Table 13

Summary of the Network Piping

Network No.	Diameter meters	Length, m	Unit Cost,$	Cost,$
16.A	0.10	1,080	8.8	9504
10	0.10	2,909	8.8	25599.2
8	0.10	2,370	8.8	20856
17	0.10	524	8.8	4611.2
9	0.10	1,539	8.8	13543.2
19	0.10	4,874	8.8	42891.2
15	0.10	2,724	8.8	23971.2
7	0.10	707	8.8	6221.6
11	0.10	4,031	8.8	35472.8
14	0.10	4,262	8.8	37505.6
12	0.10	2,449	8.8	21551.2
18	0.10	872	8.8	7673.6
2.A	0.10	1,751	8.8	15408.8
20.A	0.10	1,932	8.8	17001.6
3	0.10	2,272	8.8	19993.6
21.A	0.10	2,766	8.8	24340.8
6.B	0.10	2,634	8.8	23179.2
20.B	0.10	782	8.8	6881.6
4	0.10	1,928	8.8	16966.4
13	0.10	2,453	8.8	21586.4
6.A	0.10	1,924	8.8	16931.2
2.B	0.10	2,016	8.8	17740.8
22	0.10	3,119	8.8	27447.2
21.B	0.10	2,390	8.8	21032
14	0.15	1,358	17.71	24050.18
19	0.15	992	17.71	17568.32
15	0.15	1,900	17.71	33649
21.A	0.15	2,334	17.71	41335.14
16.B	0.15	956	17.71	16930.76
17	0.15	1,910	17.71	33826.1
13	0.15	60	17.71	1062.6
18	0.15	3,330	17.71	58974.3
16.A	0.15	2,376	17.71	42078.96

Table 13 (cont.)

Summary of the Network Piping

Network No.	Diameter meters	Length, m Length, m	Unit Cost,$	Cost,$
1	0.15	3,694	17.71	65420.74
8	0.15	2,188	17.71	38749.48
22	0.15	812	17.71	14380.52
2.A	0.15	1,576	17.71	27910.96
3	0.15	2,220	17.71	39316.2
4	0.15	1,324	17.71	23448.04
5	0.15	2,158	17.71	38218.18
6.B	0.15	769	17.71	13618.99
10	0.15	1,784	17.71	31594.64
7	0.15	2,462	17.71	43602.02
11	0.15	2,790	17.71	49410.9
9	0.15	629	17.71	11139.59
New	0.15	18319	17.71	324429.49
19	0.20	565	23.22	13119.3
20.A	0.20	1,695	23.22	39357.9
9	0.20	1,930	23.22	44814.6
20.B	0.20	1,388	23.22	32229.36
5	0.20	656	23.22	15232.32
7	0.20	4,694	23.22	108994.68
6.B	0.20	1,281	23.22	29744.82
16.B	0.20	4,955	23.22	115055.1
18	0.20	1,212	23.22	28142.64
17	0.20	1,532	23.22	35573.04
16.A	0.20	804	23.22	18668.88
8	0.20	396	23.22	9195.12
16.B	0.25	2,800	28.23	79044
8	0.30	669	34.25	22913.25
9	0.30	354	34.25	12124.5
19	0.30	375	34.25	12843.75
6.B	0.30	167	34.25	5719.75
5	0.30	530	34.25	18152.5
20.A	0.35	1,746	42.3	73855.8
20.B	0.35	495	42.3	20938.5
20.B	0.40	1,233	41.35	50984.55
20.A	0.45	1,015	48.4	49126
20.A	0.50	88	61	5368
		140,829		$2,309,824

59

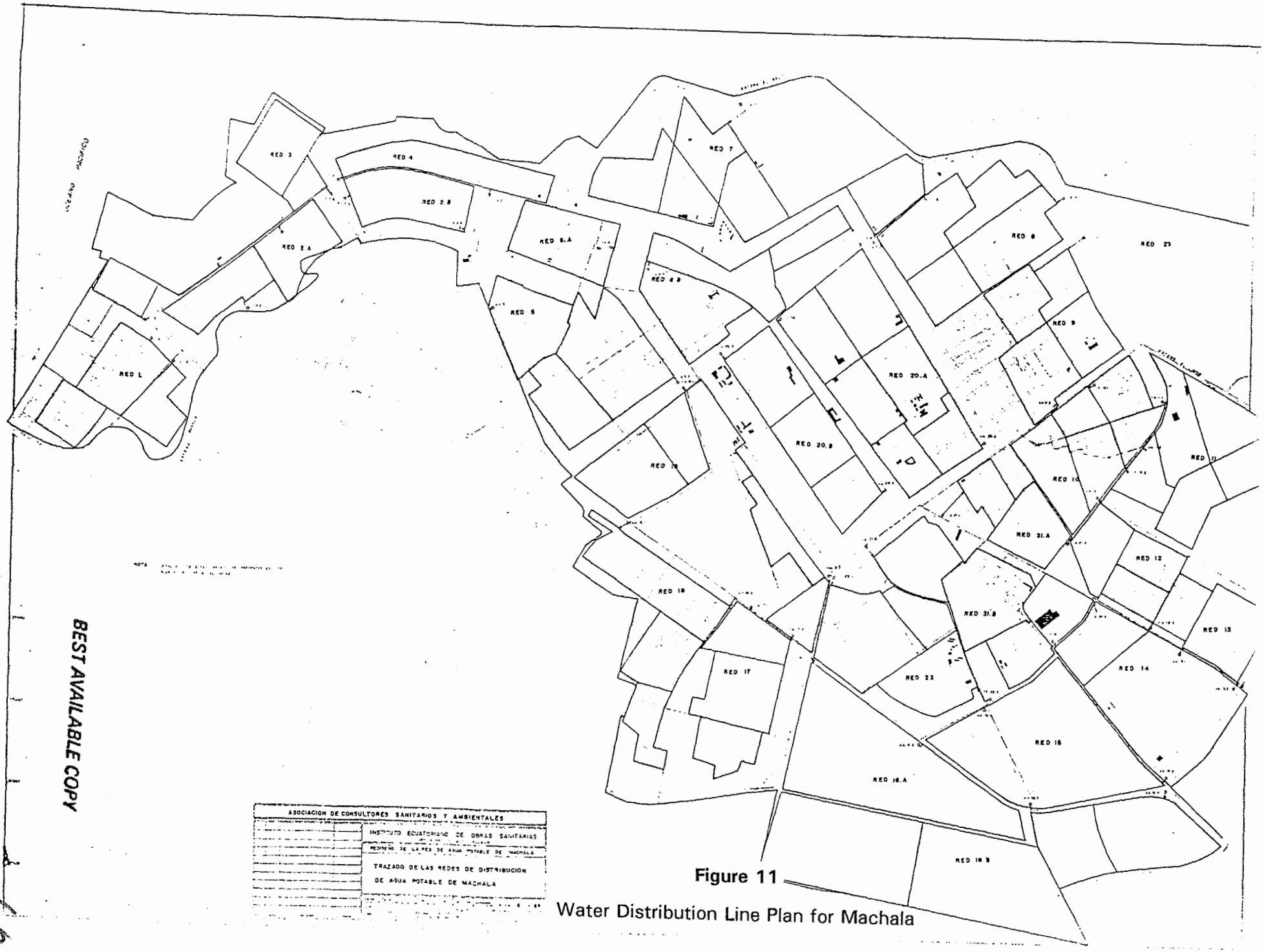

Figure 11

Water Distribution Line Plan for Machala

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SIMBOLOGIA

TUBERIA ALIMENTADORA
CAJA DE CONTROL
REDUCCION
CRUZ
TE
CODO 90°
CODO 45
DIAMETRO 200 (mm)
VALVULA

NOTA DETALLES DE ESTA RED SE PRESENTAN EN LOS PLANOS DEL Nº 8 AL Nº 17

ASOCIACION DE CONSULTORES SANITARIOS Y AMBIENTALES

INSTITUTO ECUATORIANO DE OBRAS SANITARIAS

REDISEÑO DE LA RED DE AGUA POTABLE DE MACHALA

TUBERIAS ALIMENTADORAS
TRAZADO DEFINITIVO

Figure 12

Final Plan for Feeder Lines

Appendix B

PERSONS CONTACTED

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