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Urban and industrial growth in developing countries has increased the demand for water and the related need for more information on water and sewage treatment. This project, conducted by the University of Oklahoma, focuses on that need by developing a global network of adaptive and innovative technologies based on economic, social, political and cultural factors. A series of detailed reports have been produced that are designed to assist planners in their selection of suitable water and wastewater treatment processes appropriate to the material and manpower resource capabilities of particular countries at particular times.

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"A Mathematical Model for Predicting Water Demand, Wastewater Disposal and Cost of Water and Wastewater Treatment Systems in Developing Countries," George W. Reid and Michael I. Muiga.
PN-AAD-294

"Treatment Methods for Water Supplies in Rural Areas of Developing Countries," Ir. L. Huisman.
PN-AAD-284
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"Sewage Treatment in Developing Countries," L.W. Canter and J.F. Malina.
PN-AAD-286

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PN-AAD-287

"A Catalog of Water Supply and Waste Disposal Methods for Individual Units," George W. Reid.
PN-AAD-283

"Historic Implication for Developing Countries of Developed Countries' Water and Wastewater Technology," George W. Reid and Kay Coffey.
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"Evaluation of Lower Cost Methods of Water Treatment in Latin America," Odyer A. Sperandio and Jose Perez C.
PN-AAD-289

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PN-AAD-290

"A Water Sterilization Study in the Philippines," Reynaldo M. Lesaca.
PN-AAD-282

"The Study of Microbial Treatment of Nightsoil," Taiwan Institute of Environmental Sanitation.
PN-AAD-281

"Study of an Existing Water Treatment Plant on Simple Design and Operating System for Supplying Drinking Water to Rural Communities in the Lower Mekong Basin Countries," Thailand Ministry of Public Health, Department of Health, Rural Water Supply Division.
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EVALUATION OF LOWER COST METHODS OF WATER TREATMENT IN LATIN AMERICA

FINAL REPORT

SUBMITTED TO:

The Office of Research Administration
The University of Oklahoma
Norman, Oklahoma 73069

BY:

The Pan American Center for Sanitary Engineering
and Environmental Sciences - PAHO/WHO
Casilla 4337
Lima 100, Peru

EVALUATION OF LOWER COST METHODS OF WATER TREATMENT IN LATIN AMERICA

Under Contract With
The University of Oklahoma Project
on
Lower Cost Methods of Water and Waste
Treatment in Developing Countries
(USAID Contract Number: (AID/CM-ta-C-73-13)

F I N A L R E P O R T

Prepared By

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SUMMARY

The evaluation of the water treatment plants designed with new technological criteria in the cities of Cochabamba (Bolivia), Linhares, and Prudentopolis (Brazil) and Cuenca (Ecuador) was carried out with the collaboration of the agencies responsible for the operation and maintenance of the local water supply systems: SEMAPA (Servicio de Agua Potable, Alcantarillado y Desagües Pluviales), FSESP (Fundação Serviços de Saúde Pública), SANEPAR (Companhia de Saneamento do Paraná), and ETAPA (Empresa Pública Municipal de Teléfonos, Agua Potable y Alcantarillado).

Preliminary activities involving the acquisition and installation of equipment, preparation, and adaptation of the treatment plants were completed in 1975. In 1976, basic information was gathered to fulfill the data requirements for the system of matrices being developed to help select the appropriate technology for water treatment projects in developing countries as requested by the University of Oklahoma. This includes data regarding demography, technology, socio-economic conditions, process characterization, and operational and construction costs, which are given in Appendices A, B, C, E, and F of the respective research chapters.

The technical evaluation of the plants was done by conducting special tests during the normal plant operations to determine flow characteristics and the response of the reactors to variations of flow. In addition, laboratory tests were conducted to establish theoretical parameters for comparison purposes.

The results of this research can be summarized as follow:

1. New technological criteria for water treatment plant design can be used successfully to produce very simple easy-to-operate treatment plants with a high level of technical performance that can be built at a very low cost, usually 30% to 40% that of conventional type solutions.

2. Treatment plants capable of good technical performance can be designed without sophisticated equipment and materials, using solutions compatible with the socio-economic realities and the degree of industrial development in the countries.

3. "Low-cost" technology does not imply the adoption of solutions that mean poorer water quality.

4. The use of new technological criteria implies high loadings, smaller areas of construction, and modification of the basic working criteria of the units, all of which facilitate the construction and operation and bring the cost of water treatment plants down to values between US$ 800 and US$ 1 200 per liter/second. This represents a savings of 60 or 70% compared with the cost of conventional treatment plants.

5. The use of simple saturation or suspension feeders in water treatment plants is suitable, because of their low cost and technical efficiency. There are limitations to their use in very small plants serving populations of less than 1 000 inhabitants.

6. The use of hydraulic flow rapid mixing units is suitable because of their low cost and high technical efficiency. The rapid mixing process is influenced by the characteristics of the reactor such as detention time and velocity gradient, as well as water quality.

7. Mechanical and hydraulic flocculation units are equally effective; their efficiency depends on factors other than the source of power. The flocculation process is influenced by the conditions of the reactor such as detention time, velocity gradient and flow conditions, in addition to water quality. The values of G, C and T can be optimized for each case.

8. High velocity gradients are required for rapid mixing and flocculating low turbidity water, while low gradients are needed for turbid waters, when the detention time is kept constant. This factor should be considered when designing and selecting the units.

9. High-rate sedimentation can be used in water treatment plants with efficiencies greater than 90% at a cost which is 30% lower than with conventional units. High-rate sedimentation is influenced mainly by water quality characteristics such as suspended solids and temperature, by the previous mixing and flocculation processes, and by the characteristics of the reactor such as the type and shape of the module, length of time in operation, and flow conditions, and by the inlet and outlet structures. It is possible to optimize the geometry of the reactor to produce optimum solutions.

10. Good technical performance can be obtained with high-rate filtration using multi-media beds and declining filtration rates. This process can be controlled hydraulically with an effluent weir. Three typical stages of filtration are observed.

11. Any one filter may be properly washed with the flow of the other units. This process can be used with a minimum of four filters, providing a good washing process in terms of the existing hydraulic conditions as well as the wash velocities. Each time a unit is washed the water quality decreases by 0.10 JTU. The washing process is characterized by three distinct stages.

12. Contact units with deep-bed upflow filtration have a high performance rate of 99.7% with water containing less than 50 units of turbidity and/or color. With color and turbidity between 50 and 100 units, the efficiencies are greater than 96%. Contact units are more economical than any other conventional system when treating this type of water.

13. By optimizing the mixing and flocculation processes, greater efficiency and lower operating costs can be obtained. These costs range between US$ 3.91 and US$ 16.29 per 1 000 m^3.

1. PROJECT DESCRIPTION

1.1 BACKGROUND

A large number of water treatment plants in Latin American countries are the product of technical know-how and standards adopted by industrialized countries. Often these solutions are incompatible with the resources or the industrial development of the country or region. Technological problems arise which result in the wasting of local resources, the reduction of local economic potential and the disruption of efficient public services. This situation has been brought about by the importation of foreign technology, the technical and commercial promotion of products and solutions from industrialized countries, and the use of a "manual technique" based on pre-established standards in the absence of local basic and applied research.

These factors have led to the selection of water treatment processes without giving due consideration to the socio-economic conditions of the area or to the existing level of industrial development. This problem has been recognized both at the national and international levels by professionals who have abandoned the conventional canons in favor of solutions that are compatible with the characteristics of the area involved.

The University of Oklahoma, under the auspices of the U.S. Agency for International Development (AID), has undertaken the development of a methodology that would make it possible to select appropriate water treatment processes for sites ranging from non-nucleated areas to medium-size cities in developing countries.

The main objective of the studies being carried out by the University of Oklahoma is to develop a system of matrices dealing with process characteristics and in-country resources in order to select the optimal treatment methods for the existing conditions. The processes will not necessarily be either high or low technology, but rather will use a level of technology which is compatible with the resources available in the country to build, operate and maintain them properly.

Once the matrices have been developed, the second step is to conduct a global study of water treatment projects that are successful examples of this concept, both from the point of view of technical efficiency and of their suitability to the conditions in the areas in which they are located.

Because of the broad professional experience of the Pan American Center for Sanitary Engineering and Environmental Sciences (CEPIS) in this area, its extensive knowledge of the current water treatment situation in the Region, as well as the Center's work in promoting the use of advanced technology in projects and solutions compatible with the socio-economic and technological characteristics in the area, the University of Oklahoma signed a contract with the Pan American Health Organization (PAHO) for CEPIS to conduct a research study and evaluation of lower cost water treatment methods being used in Latin America.

1.2 RESEARCH OBJECTIVES

A. Identification of the new water treatment methods.

B. Identification of the projects in Latin America which use new technological criteria in the design of water treatment plants.

C. Selection of the most outstanding projects in this area and definition of their technical characteristics.

D. Identification of the demographic, socio-economic and technical development characteristics required by the University of Oklahoma to apply the system of matrices which is the basic objective of the study.

E. The principal objective of the research conducted by CEPIS will be the evaluation of the technical, operational and economic efficiency of the selected treatment projects.

1.3 GENERAL PROGRAM OF ACTIVITIES

The general program of activities and their sequence is described in figure 1-1. The program is divided into the following stages:

A. Preliminary activities including the signing of contracts, acquisition of laboratory equipment, modification and adaptation of the treatment plants.

B. Gathering of basic demographic, socio-economic and technolcgical development data.

C. Technical research to determine the ideal theoretical conditions by laboratory and/or pilot plant tests, collection of normal operational data in the plant regarding raw, settled and filtered water quality, and the study of the characteristics of the reactors, flow conditions, and response capacity with variations in loadings and water quality.

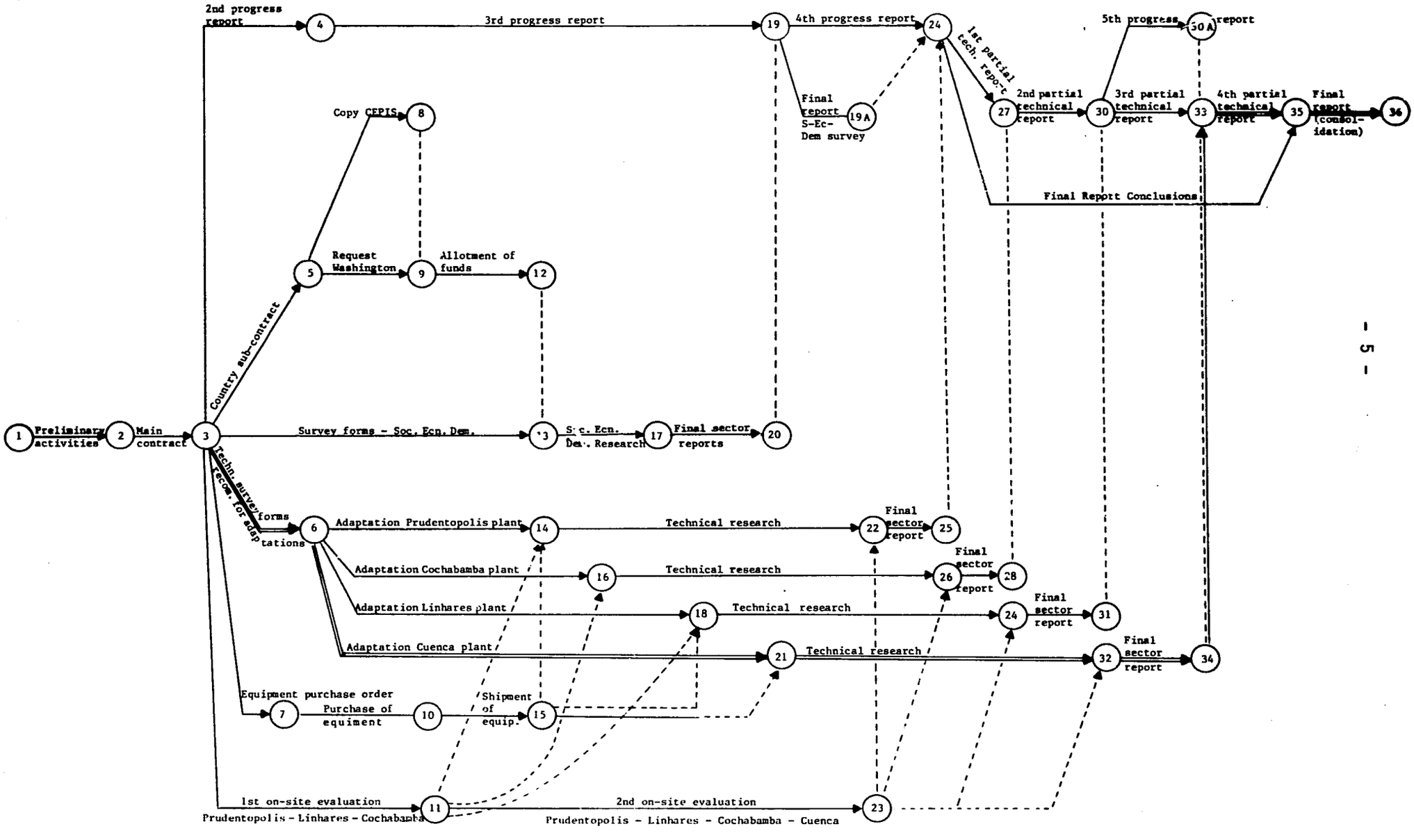
D. Economic evaluation including general construction, operating and maintenance costs, as well as economic data required to determine the fiscal soundness of the community.

The detailed results of this research are presented in Chapters 3 through 6 of this report.

Figure 1-1

CEPIS-OU RESEARCH PROJECT ON LOWER COST METHODS OF WATER TREATMENT IN LATIN AMERICA

GENERAL PROGRAM OF ACTIVITIES



2. DEVELOPMENT OF THE RESEARCH

2.1 IDENTIFICATION OF NEW DESIGN CRITERIA FOR WATER TREATMENT PROCESSES*

Water treatment processes can be divided into four groups:

Clarification processes
Disinfection processes
Chemical conditioning
Organoleptic conditioning

Figure 2-1 presents a schematic description of these processes.

It is in the first of these processes that the most technological advances have been made recently. Therefore, this research study is dedicated exclusively to clarification processes.

There are three basic clarification processes: coagulation, flocculation and particle removal. The first two are merely preparatory processes for the third, which can be accomplished by sedimentation or filtration. More commonly, these two processes are used consecutively (figure 2-2).

2.1.1 Advances in coagulation and flocculation

Intense research has been carried out recently on the theory of water coagulation. La Mer, O'Melia, Stumm, Black, Fair, Kaufman, Riddick, Langelier, MacKrle, Hudson, Singley, Vrale, Jordan, Letterman, to mention only a few, have published studies in which they try to explain what happens when a coagulant is added to water.

Better knowledge of the technology of coagulation has led to the introduction of some changes in the conventional processes:

A. By taking into account the speed of chemical reaction, considerable savings have been obtained in the use of coagulants.

B. For the same reason, in-line blenders and diffusers were introduced.

C. Turbine flocculators have been applied successfully.

D. Studies of the average residence time in the reactors served to further emphasize the importance of compartmentalizing the flocculation tanks.

E. The efficiency of hydraulic mixing units has been proven.

F. The factors influencing the coagulation and chemical feeding processes have been quantified.

G. Velocity gradients and detention times have been optimized to obtain the best coagulation conditions.

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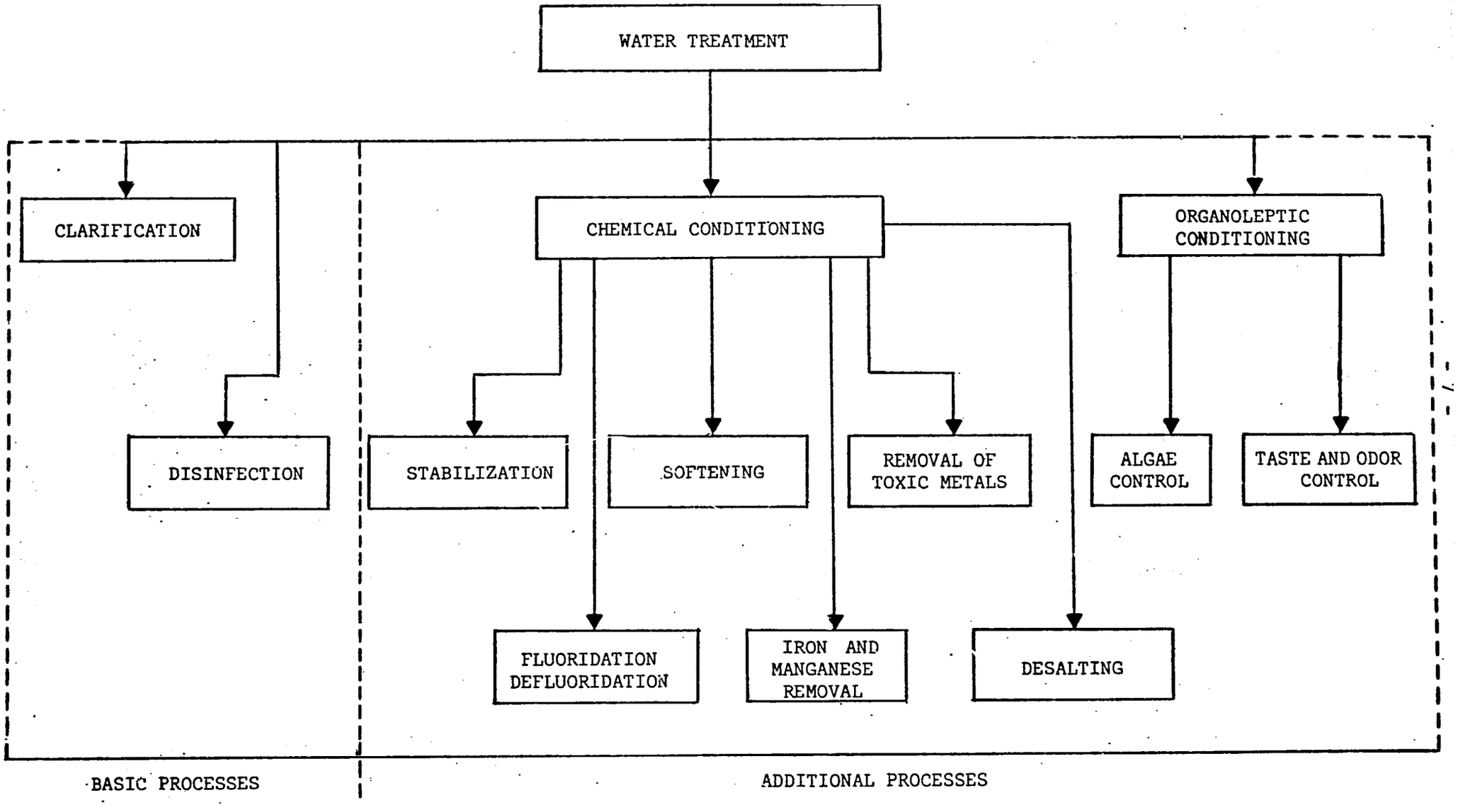
* Based on: PAHO/CEPIS. Teoría, Diseño y Control de los Procesos de Clarificación del Agua. EH Technical Series 13, Lima, 1973

Figure 2-1



Source: PAHO/CEPIS. Teoría, Diseño y Control de los Procesos de Clarificación del Agua. EH Technical Series 13, Lima, 1973

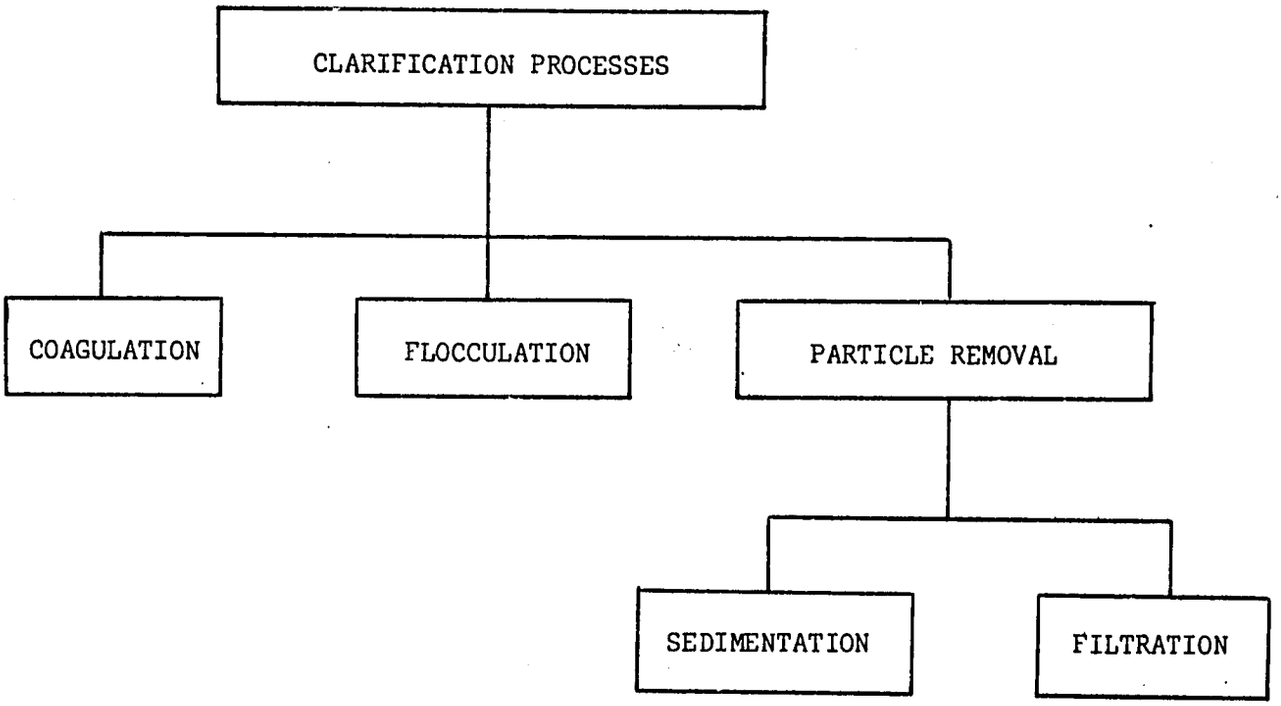


Figure 2-2

Source: PAHO/CEPIS. Teoría, Diseño y Control de los Procesos de Clarificación del Agua. EH Technical Series 13, 1973

2.1.2 Advances in sedimentation

The theory of sedimentation has been enriched by the studies of Rebhun and Argaman, Wolf and Resnick, and others, who analyzed the distribution of detention time in settling units, and by the work of Bond, Tesarik, Miller, Ives and Brown, who investigated the behavior of sludge blanket clarifiers and formulated equations to describe them.

The most significant change was brought about by putting into practice the old theory of Hazen and Camp. This gave rise to tube settlers or inclined cells, capable of working at rates four to six times greater than horizontal settlers.

This solution, proposed by Hanzen and Culp, was based on earlier work done by Thomas and Camp and developed in its theoretical aspects by Yao. It has proven to be applicable in new treatment facilities as well as in expanding existing plants, with notable cost reductions.

Additionally, the characterization of flow in high-rate settling units has been studied, especially by El Baroudi.

2.1.3 Advances in filtration

Few processes have been as intensely analyzed in recent years as this one. Filtration mechanisms have been studied by an infinite number of authors, including Camp, Stein, Fair, Stanley, MacKrle, Mintz, Smith, Ling, Hudson, O'Melia, Gregory, etc. Work has been done on the formulation of a mathematical model to describe the process. The equations of Ives, based initially on those of Iwasaki, have been the object of careful verification and have become an interesting analytical tool.

Although further clarifications are still needed, these studies have provided a much broader knowledge of what happens inside a filter bed and have made it possible to propose significant changes in existing practices.

A. Extensive work has been done on the use of high filtration rates, beginning with Baylis in Chicago and Brown in Durham. Conley's publications on his experiences with sand and anthracite in Hanford opened up a new field of study to which many authors have contributed, including Robeck, Dostal, Culbreath, Ives, Mohanka, and Rimer. This practice makes it possible to use filtration rates three times greater than those used traditionally, thereby facilitating the expansion of existing filter systems at minimum cost by changing only the filter beds, and reducing notably the capital investment required for new plants.

B. The studies of Cleasby and Hudson on methods of controlling rapid filters has led to filter batteries without flow regulators which operate with declining rates, thereby simplifying the construction of pipe galleries and their operation and maintenance.

C. Greenleaf and others have demonstrated the feasibility of washing one filter with the flow from the other units in the battery, which introduces

a new simplification and reduces costs even further.

D. Mintz and others demonstrated the advisability of inverting the direction of the flow (upflow filtration).

E. Grinplastch, Spink, Hutchison, Sweeny and others demonstrated the efficiency of using filtration as the only treatment process after rapid mixing (contact units).

2.1.4 Simplification of treatment plants

When all of these modifications are combined in a single design, it is possible to arrive at an extraordinarily simple and economical treatment plant. Arboleda synthesizes and adapts this new technology to suggest designs without pipes, with very few valves and using only equipment manufactured in-country, without violating any of the basic principles of water technology. These projects are very easy to build and operate, essentially all materials and labor are available locally, they have high technical efficiency and low costs, and are compatible with the industrial development and the existing conditions in developing countries.

This new generation of treatment plants could help to solve the problems mentioned in Chapter 1. The cost of building water treatment facilities would be reduced by 50%, maintenance would be simplified, and the operation of the plant would be better understood by those who run it.

In this way, the operation of treatment plants could be notably simplified as indicated in figure 2-3. The entire operation would be based on the industrial development of the country and communications problems would be alleviated.

2.2 IDENTIFICATION OF WATER TREATMENT PROJECTS THAT USE NEW TECHNOLOGY

Table 2-1 summarizes the main water treatment projects in various stages of execution in the different countries of Latin America, with a description of the treatment processes used and the state of each of the projects.

2.3 SELECTION OF PROJECTS TO BE EVALUATED

From among the projects listed in table 2-1, the following were selected:

1. The water treatment plant of the city of Cuenca, Ecuador - an expansion project utilizing flocculation processes with optimization of velocity gradients and detention times in baffled units with horizontal flow, high-rate settling with parallel flat plates, dual-media filtration with sand and anthracite with declining filtration rates. The city of Cuenca has 100 000 inhabitants and is representative of average conditions existing in Latin America. The plant is managed by the Empresa de Teléfonos, Agua Potable y Alcantarillado (ETAPA).

2. The water treatment plant of Cochabamba, Bolivia - an expansion and modification project utilizing hydraulic flocculators with adjustable asbestos-cement plates, high-rate settlers with parallel flat plates, dual-media filters with

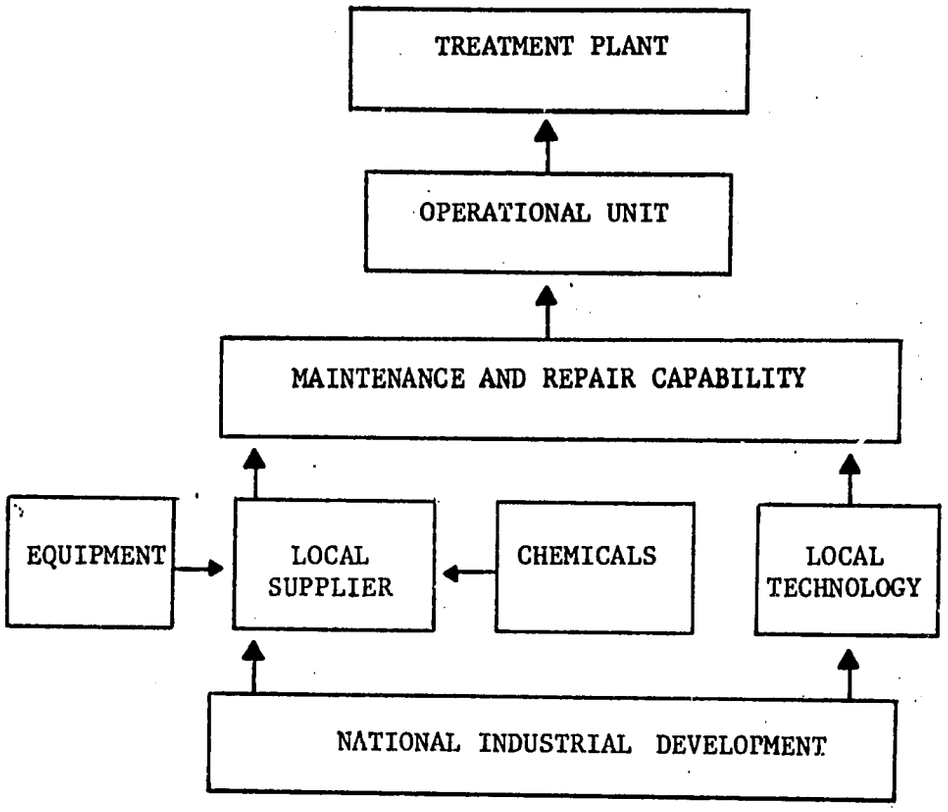


Figure 2-3

Source: PAHO/CEPIS. Teoría, Diseño y Control de los Procesos de Clarificación del Agua. EH Technical Series 13, Lima, 1973

Table 2-1

STATE OF DEVELOPMENT OF NEW WATER TREATMENT METHODS IN LATIN AMERICA

City	Country	Plant	Flow (l/s)	Population served (thousands)	Methods used	State of works development
				A. Expansion		
Caracas	Venezuela	La Mariposa	1680	500	Short settling, mixed media, polyelectrolites, coagulation monitoring	In operation since 1965
Rio de Janeiro	Brazil	Guandu	12000	4000	Mixture improvements, short settling, mixed media, declining rate	Under construction
Barramansa	Brazil	Barramansa	180	60	Tube settlers	In operation since 1971
Sao Paulo	Brazil	ABC	2000	1000	Mixing with multiple-orifice grid, tube settlers, dual media	Under construction
Santiago	Chile	Las Vizcachas	9000	3000	Tube settlers, dual media, solution feeders	Under construction
Santiago	Chile	Lo Castillo	200	70	Tube settlers, dual media, split flow	In operation since 1973
Cucuta	Colombia	El Portico	800	200	Dual media	In project
Bogota	Colombia	Tibitoc	8000	2000	Dual media, turbidity monitoring	Under construction
Bogota	Colombia	El Sapo	--	--	Contact unit	In project
Medellin	Colombia	La Ayura	2000	7000	Dual media, direct filtration	In project
Medellin	Colombia	Villa Hermosa	1600	500	Declining rate	In operation
Cali	Colombia	Rio Cali	1000	350	Compartamentalization of flocculation chambers, dual media	In operation
Cali	Colombia	Rio Cauca	2500	850	Dual media	Under construction
Cuenca	Ecuador	Cuenca	500	150	Plate settlers, dual media, declining rate	In operation since 1975
Asuncion	Paraguay	Viñas Cue	500	800	Tube settlers, mixed media, coagulation monitoring	In operation since 1972
Curitiba	Brazil	Curitiba	2000	800	Compartamentalization of flocculation chambers, dual media, declining rate	Under construction
Arequipa	Peru	Arequipa	1600	500	Dual media	In project
Chiclayo	Peru	Chiclayo	--	--	Tube settling, dual media	Under construction
Lima	Peru	La Atarjea	9000	3000	Declining rate, dual media,	In operation
				B. New Designs		
Cañete	Peru	El Imperial	40	10	Plate settling, dual media, declining rate, mutual filter washing	In operation 1975
Curitiba	Brazil	--	11.5	2000	Plate settling, dual media, declining rate, mutual filter washing	Under construction
Prudentopolis	Brazil	Prudentopolis	20	5	Plate settling, dual media, declining rate, mutual filter washing	In operation 1975
Cochabamba	Bolivia	Cala-Cala	230	100	Plate settling, dual media, declining rate, mutual filter washing	In operation 1975
Botucatu	Brazil	Botucatu	300	100	Tube settlers	Under construction
Sao Paulo	Brazil	Guarau	33000	6000	Dual media	Under construction
Cali	Colombia	Puerto Mallarino	4000	1000	Dual media, declining rate	In project
Guarico	Venezuela	--	6	1	Small angle tube settler	In operation since 1972
				C. Upflow Filters		
Colatina	Brazil	Colatina	30	10	Contact coagulation, declining rate	In operation since 1970
Linhares	Brazil	Linhares	70	6	Contact coagulation, declining rate	In operation since 1972
Ponta Grosa	Brazil	--	--	--	--	--
Caracas	Venezuela	Experimental plant	--	--	--	In operation

declining rates and backwashing system using the flow from the other units. Cochabamba is an average size city and representative of prevailing conditions in Latin America. The plant is managed by the Servicio de Agua Potable, Alcantarillado y Desagües Pluviales (SEMAPA).

3. The water treatment plant of Linhares, Espirito Santo, Brazil - an expansion project utilizing direct filtration in upflow filters. Linhares is a small city. The plant is run by the Fundação Serviços de Saúde Pública (FSESP)

4. The water treatment plant of Prudentopolis, Parana, Brazil - a new and very advanced design utilizing mechanical flocculation, sedimentation with a sledge blanket unit and high-rate settlers with parallel flat plates, dual-media sand and anthracite filters, declining filtration rates and backwashing system using the flow from other units. Prudentopolis is a small rural town in southern Brazil. The plant is run by the Companhia de Saneamento do Paraná (SANEPAR).

2.4 COLLECTION AND ANALYSIS OF DATA

CEPIS sub-contracted the execution of the research to the agencies in charge of each plant as indicated in table 2-2. CEPIS technical staff supervised and collaborated on at least two occasions in the execution of the research at each site. The research was conducted according to the schedule of activities shown in figure 2-4. Data analysis and the preparation of the final report was done at CEPIS.

2.5 LIMITATIONS

The main limitation was the raw water quality, since at all four project sites the water was relatively clear, with low turbidity, color and alkalinity. Unfortunately, during the research period there were no heavy rains to produce substantial changes in water quality.

The conclusions are based on the operational data from the plants and on the results of laboratory and pilot plant studies. The observed phenomena are defined, not for the purpose of establishing ranges of use and application, but solely for the purpose of evaluating the water treatment processes used and determining the characteristics and influences of the main parameters. The results can be used as a guide to orient design work, but should not be used as specific design criteria.

Although the water quality, as well as the unit cost of the coagulants and salaries are similar in all four projects, the values corresponding to operating costs showed a great disparity. The average value was US$ 10.64 per 1 000 m^3 with a standard error of US$ 3.86. Since the standard error is greater than the lowest of the observed values, these results are questionable.

Table 2-2

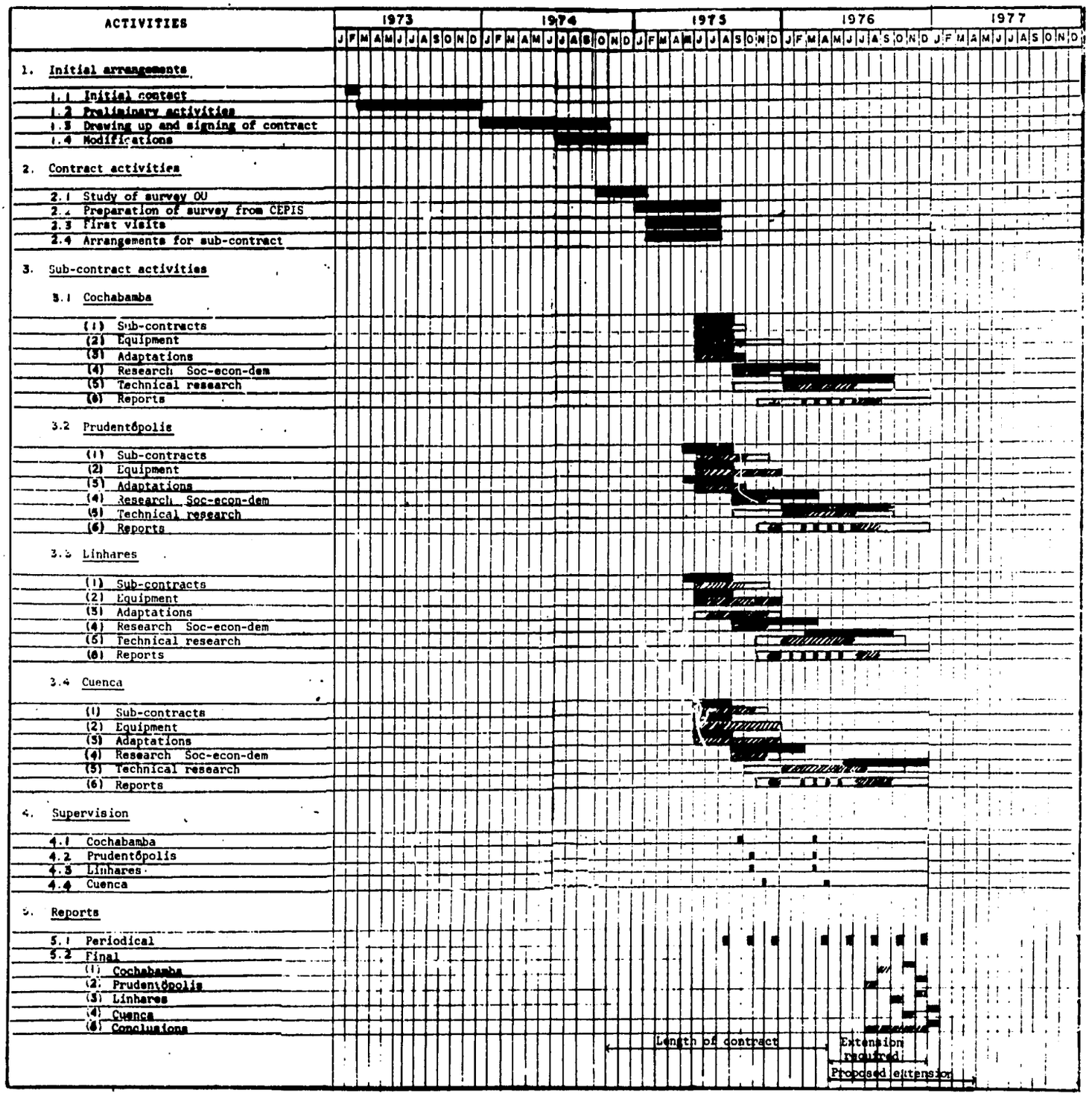
DETAILS OF RESEARCH STUDIES

Project No.	Name	Responsible agency	RESEARCH STUDIES					
			Normal operations (hourly data required)					Special tests
			General	Raw water	Chemical dosage	Settled water	Filtered water	
1	Water Treatment Plant Cochabamba, Bolivia	SEMAPA	Date Hour Flow	Turbidity Color pH Alkalinity	Alum Lime Chlorine	Overflow rate Turbidity Color pH Alkalinity Residual alum	Turbidity Color Residual alum Filtration rate Water level Loss of head Length of filter run Backwashing time	Adaptation of the plant Determination of optimum coagulation conditions (laboratory) Tracer tests in rapid mixing, flocculation and settling units Parameters influencing settling units Parameters influencing filtration processes
2	Water Treatment Plant Linhares, Brazil	FSESP	Date Hour Flow	Turbidity Color pH Alkalinity	Alum Lime Chlorine	———	Turbidity Color Residual alum Filtration rate Water level Loss of head Length of filter run Backwashing time	Determination of optimum coagulant dosage (laboratory) Filtration and filter washing characteristics
3	Water Treatment Plant Prudentopolis, Brazil	SANEPAR	Date Hour Flow	Turbidity Color pH Alkalinity	Alum Lime Chlorine	Overflow rate Turbidity Color pH Alkalinity Residual alum	Turbidity Color Residual alum Filtration rate Water level Loss of head Length of filter run Backwashing time	Operator training Determination of optimum coagulation conditions (laboratory) Tracer tests in flocculation and sedimentation units Parameters influencing sedimentation Filtration and backwashing characteristics
4	Water Treatment Plant Cuenca, Ecuador	ETAPA	Date Hour Flow	Turbidity Color pH Alkalinity	Alum Lime Chlorine	Overflow rate Turbidity Color pH Alkalinity Residual alum	Turbidity Color Residual alum Filtration rate Water level Loss of head Length of filter run Backwashing time	Adaptation of the plant Determination of optimum coagulation conditions (laboratory) Tracer tests in settling units Parameters influencing sedimentation Comparative study of settler efficiency Comparative study of constant-rate and declining rate filters

Figure 2-4

SCHEDULE OF ACTIVITIES FOR RESEARCH ON LOWER COST METHODS OF WATER TREATMENT IN LATIN AMERICA

PAHO/CEPIS - THE UNIVERSITY OF OKLAHOMA



Expected duration
Possible extension
Actual duration

3. EVALUATION OF THE CALA-CALA WATER TREATMENT PLANT IN COCHABAMBA, BOLIVIA (RESEARCH PROJECT No. 1)

3.1 INTRODUCTION

CEPIS agreed to collaborate with the University of Oklahoma in the execution of a research project for the purpose of optimizing the criteria for selecting processes and techniques for water treatment, not only from the point of view of the characteristics and quality of the water itself, but also as a function of socio-economic factors, technical and industrial development of the community, and at the same time evaluate the efficiency of the new technologies utilized in the design and operation of the water treatment plants.

The Cala-Cala water treatment plant in the city of Cochabamba, operated by the Servicio de Agua Potable, Alcantarillado y Desagües Pluviales (SEMAPA), was selected as one of the research sites because of the relatively new technology used in designing the plant, especially in the sedimentation and filtration processes; the characteristics of the city of Cochabamba, which is of medium size and is representative of the socio-economic and technical conditions prevalent in Latin America; and because the construction of the plant was completed and its performance could be easily evaluated by making only minor modifications.

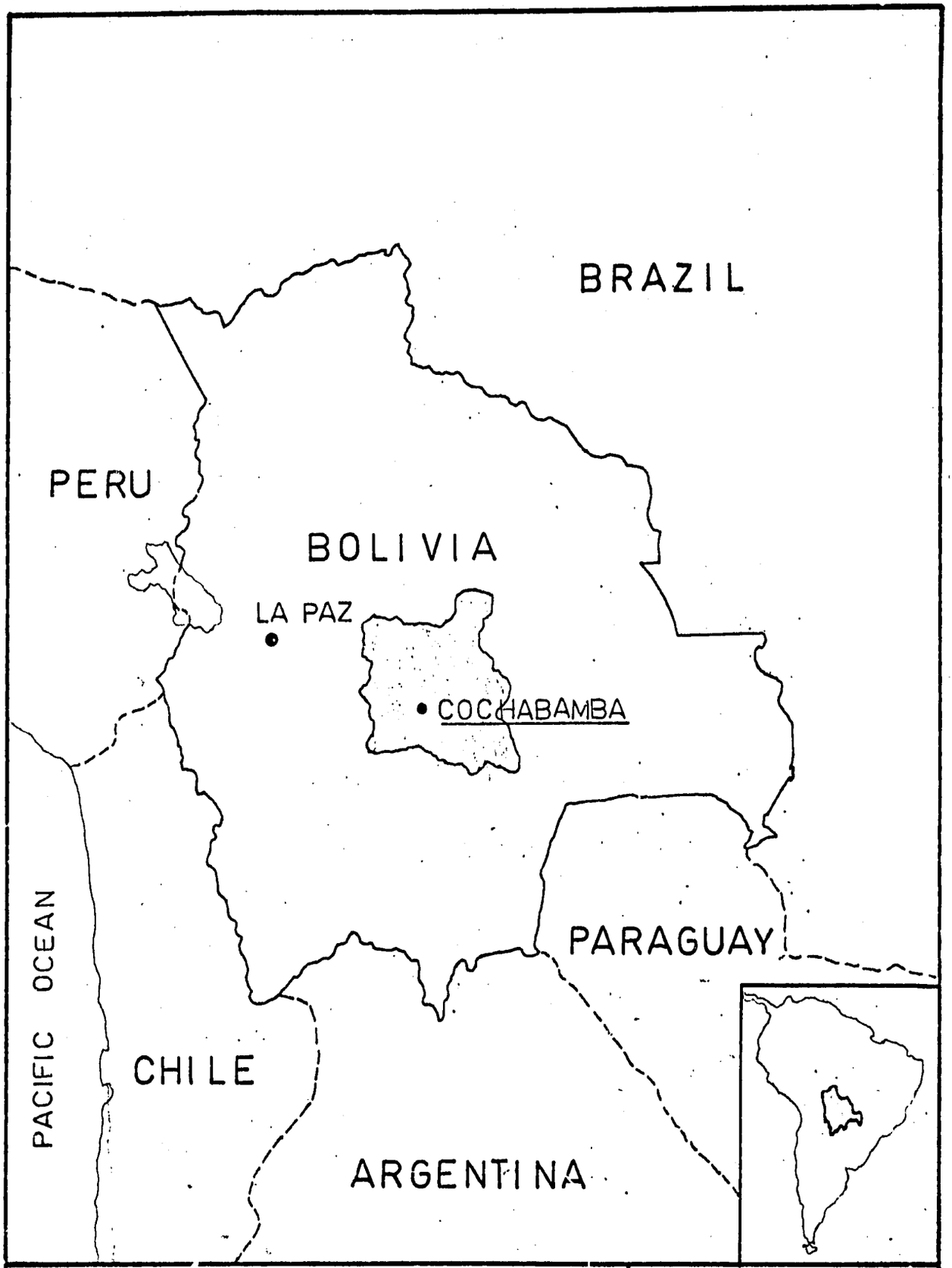
An agreement was signed with SEMAPA to conduct a research program including the following components:

- Study of the general demographic and socio-economic conditions of the city.
- Overall technical evaluation of the plant and of each of the unit processes used.
- Economic study of the capital investments and the maintenance and operating costs of the plant.

GENERAL INFORMATION ABOUT THE CITY

The city of Cochabamba is located in the center of the Republic of Bolivia. Its geographical position is: 66°10' longitude west and 17°83' latitude south (figure 3-1). The average annual temperature is 18°C; the maximum recorded temperature was 33.5°C and the minimum was 3°C.

The average relative humidity is 55% during the rainy season and 40% in the dry season. The average altitude is 2 550 meters above sea level. The average annual precipitation is around 480 mm. This precipitation occurs mostly between November and March of each year.



LOCATION OF COCHABAMBA
BOLIVIA

FIGURE 3-1

The city of Cochabamba covers an area of approximately 3 000 hectares and its population in 1972 was about 155 000 inhabitants.

Because of its favorable climate and location, the city has grown rapidly. In 1945 its population was 78 000 inhabitants; its current population is double that amount.

Studies indicate the following demographic growth:

Table 3-1

POPULATION GROWTH FOR THE CITY OF COCHABAMBA

Year	Population
1972	155 000
1982	205 000
1992	256 000

3.3 GENERAL DESCRIPTION OF THE WATER SUPPLY SYSTEM

The construction, operation and maintenance of the city water supply system facilities is the responsibility of SEMAPA.

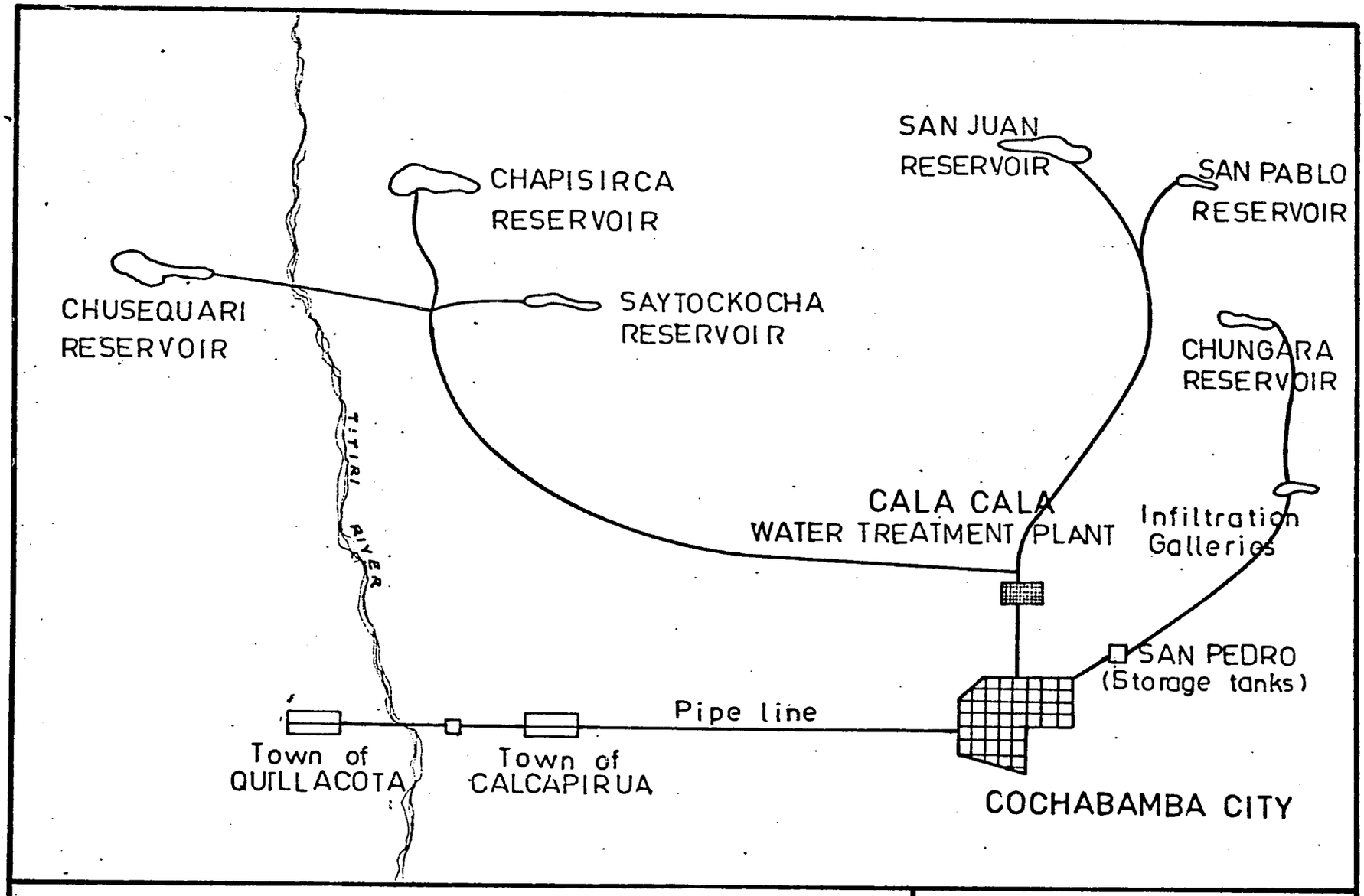
The water supply system consists of the following:

3.3.1 Collection works

The principal source of water supply for the city of Cochabamba is surface water from the Chapisirca, Chusequari and Saytockocha Reservoirs. The city purchases 600 000 cubic meters per year from the owners of the Saytockocha Reservoir. The total area of the Chapisirca and Chusequari Reservoirs is 6.42 km^2 and their storage capacity is 1 920 000 m^3. The capacity of this system is 160 l/s.

Ground water from the semi-artesian wells of Arocagua and from the Chungara filtration galleries is also used.

The main characteristics of these waters which were used in designing the treatment plants are given in tables 3-2 and 3-3.



WATER SUPPLY SYSTEM OF COCHABAMBA

BOLIVIA

FIGURE 3-2

Table 3-2

CHARACTERISTICS OF SURFACE WATERS

Characteristics	Value		Unit
	Minimum	Maximum	
Temperature	8	20	°C
Color	5	20	CU
Turbidity	2	650	JTU
pH	6.7	9.1	p.p.m.
Alkalinity	10	25	p.p.m.
Hardness	12.5	139	p.p.m.
Total iron	0	0,3	p.p.m.
Total solids	60	260	p.p.m.

Source: Memoria Técnica. Planta de Tratamiento de Agua Potable Cala-Cala. Ing. Severo Vega, 1972

3.3.2 Transmission works

A. Canal - Chapisirca Rapids

The water is transported from the dams to the edge of the mountain range through an unlined canal of irregular sections, which is 15.3 km long and has a 6 ‰ grade.

From the edge of the mountains to the valley of Cochabamba it falls 1 300 m for a distance of 6.5 km, through a rapids that follows the course of a natural gorge.

B. Tolapujru Intake - Treatment Plant

At a place called Tolapujru the water is diverted to the grit chambers from these units it is transported to the treatment plant through two pipelines:

1) An old pipeline that for the first two kilometers is made of 10 inch steel pipe with a relatively steep grade; the remaining 10 kilometers is made up of concrete conduits 18 inches in diameter with a slope of 2%; it has a capacity of 130 l/s.

2) A new concrete conduit, 24 inches in diameter, for the entire distance with a 2% gradient.

3.3.3 Treatment plant

The Cala-Cala Treatment Plant has a design flow of 235 l/s and is made up of the following units:

A. Intake conduit

The intake conduit is 75 meters long with a gradient of 1.15‰ and a diameter of 24".

B. Mixing and measurement system

A 0.30 meter (1 foot) Parshall flume has been constructed in the canal followed by a hydraulic jump (the nominal head is 0.49 meters) and a water velocity of more than 3.0 m/s, producing a critical regimen. This hydraulic jump is used to obtain efficient coagulant dispersion in the mass of water.

The Parshall flume is used both for efficient mixing and for measuring the incoming flow. The application limits of the 30 cm Parshall meter, with free flow, measure a minimum flow of 3.11 liters per second and a maximum of 455.6 liters per second.

The coagulant is injected at the critical flow point of the flume.

C. Coagulation

Aluminum sulfate is used as the coagulant and lime to adjust the alkalinity.

Aluminum sulfate and lime are added using saturated solution feeders and suspension feeders respectively. Rapid mixing is done in the Parshall flume.

D. Flocculation

This process takes place in a hydraulic flocculator with horizontal flow. Adjustable baffles are used to modify the width of the channel, velocities and velocity gradients. There are 3 sections with decreasing velocities of 0.28, 0.22 and 0.18 m/s, and velocity gradients of 100, 68 and 51 s^{-1}, and a total detention time of 20 min.

E. Sedimentation

Three high-rate settling units are used. Asbestos-cement plates (0.01 x 1.20 x 2.40 m) are supported in slots in the concrete wall. They are set at an angle of 60° with 5.25 cm between plates.

The inlet is a perforated baffle through which the water passes at a velocity of 0.10 m/s. The outlet system consists of peripheral troughs located throughout the settling area. The high-rate unit, with a relative length of 19.18, has a overflow rate of 120 m^3/m^2/day and a Reynolds number of 74.

F. Filters

Six dual media sand and anthracite filters with declining rate and a common flow-control weir are used. Each unit has an area of 11.22 m^2 (2.55 x 4.40 m) with a maximum filter rate of 300 m^3/m^2/day.

Table 3-3

WATER QUALITY

SUMMARY OF BACTERIOLOGICAL AND PHYSICAL-CHEMICAL ANALYSES

Samples		BACT. ANALYSIS		Turbidity Sample Jackson units	Optimum Aluminum Demand	pH	Langelier Index	Color	Odor	Total	Dissolved	$CaCO_3$	CO_3	HCO_3	$CaCO_3$	Ca	Mg	Na	K	SO_4	Cl	NO_3	F	Fe	Mn	Lab	Remarks
Nº	Date Taken	Colonies per ml at 35 °C	MPN Coli per 100 ml																								
CALA-CALA SYSTEM																											
1	30/ 7/47	-	-	5	-	7.4	-1.7	20	-	90	80	-	0	20	37	12.7	7.7	0	-	-	1	1	-	0.1	-	LCC	
2	25/ 9/49	-	-	15	-	6.7	-2.2	15	-	60	50	-	0	25	50	13.0	5.2	-	-	5	1	0.3	-	0.3	-	LCC	
3	19/11/51	-	-	180	-	6.9	-	10	-	100	80	-	-	12	40	13.0	4.2	-	-	6	1	0.04	-	0.2	-	LCC	
4	21/ 3/52	-	-	5	-	7.3	-0.20	15	-	70	56	-	-	12	44	12.0	3.5	-	-	2	2	0.05	-	0.1	-	LCC	
5	21/ 3/52	-	-	5	10	9.1	+0.3	5	-	100	80	-	-	10	139	50.0	3.5	-	-	5	2	0.02	-	0.1	-	LCC(1)	
6	3/ 4/52	-	-	35	-	7.3	-1.4	10	-	90	72	-	-	25	74	22.0	4.3	-	-	2	-	0.02	-	0.2	-	LCC	
7	3/ 4/52	-	-	-	18	9.2	+0.2	-	-	60	48	-	20	-	37	12.0	1.7	-	-	3	-	-	-	-	-	LCC(2)	
8	12/12/66	3 200	9.1	-	-	7.1	-2.1	-	-	133	90	-	-	18	42	11.0	3.5	-	-	24	2	-	-	0	0	INSO(3)	
9	12/12/66	3 500	23.0	-	-	7.5	-1.6	-	-	38	32	-	-	16	81	5.6	12.5	-	-	9	2	-	-	0	0	INSO	
AROGAGUA SYSTEM																											
10	10/ 8/63	-	-	30	-	6.0	-3.1	30	-	150	-	-	-	15	6	19.0	4.2	-	-	35	100	-	-	0.1	-	LCC	
11	12/12/66	300	3.0	<5	-	8.1	-0.6	-	-	103	70	-	-	44	83	15.0	11.0	-	-	16	2	-	-	0	-	INSO	
12	27/12/66	-	-	<5	-	7.3	-1.9	-	-	65	45	-	0	22	61	9.0	9.0	-	-	16	3	-	-	0	-	INSO	

Laboratory where analysis was done: I.N.S.O. (Instituto de Salud Ocupacional, La Paz) - L.C.C. (Laboratorio Central Cochabamba).

Note
(1) With purification and calcination
(2) With purification and calcination
(3) Raw
(4) Network

Source: Sistema de Abastecimiento Público de Agua Potable de Cochabamba. Planta de Agua Potable. Memorias del Proyecto. March 1972

The media characteristics are:

Sand

Øe = 0.50
Cu = 1.65

Anthracite

Øe = 1.00
Cu = 1.10

Supporting gravel bed

Ø = 1/8" to 2"

The underdrainage system consists of a prefabricated false bottom in the form of an inverted "V" with Ø 1/2" orifices every 12.5 cm. The filters are backwashed using the flow from other units; the backwash rate is 600 $l/min/m^2$.

G. Disinfection

Chlorine gas is applied using Wallace and Tiernan equipment with a maximum capacity of 100 lb/day. Lime is used to correct the pH, in a dosage of 10 mg/l.

Figures 3-3 to 3-6 show the main characteristics of the treatment plant.

3.3.4 Storage

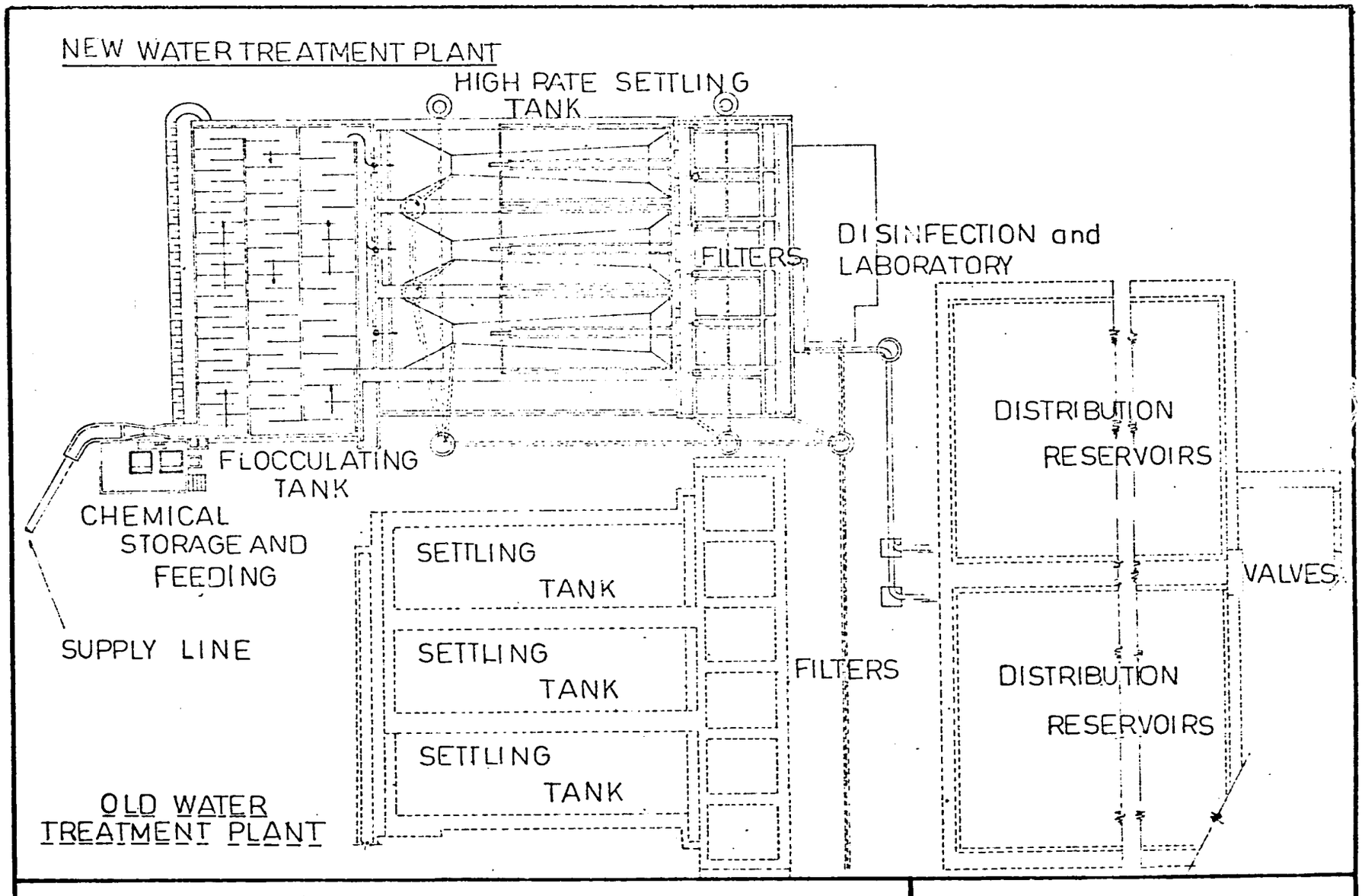
The water from the filters enters two clear water tanks. Each one has a capacity of 2 500 m^3. In the valve chamber there are two outlet pipelines and two drainage pipes, plus two 14-inch overflow conduits with their respective valves. The flow meter and the two chlorinators are out of use.

3.3.5 Distribution system

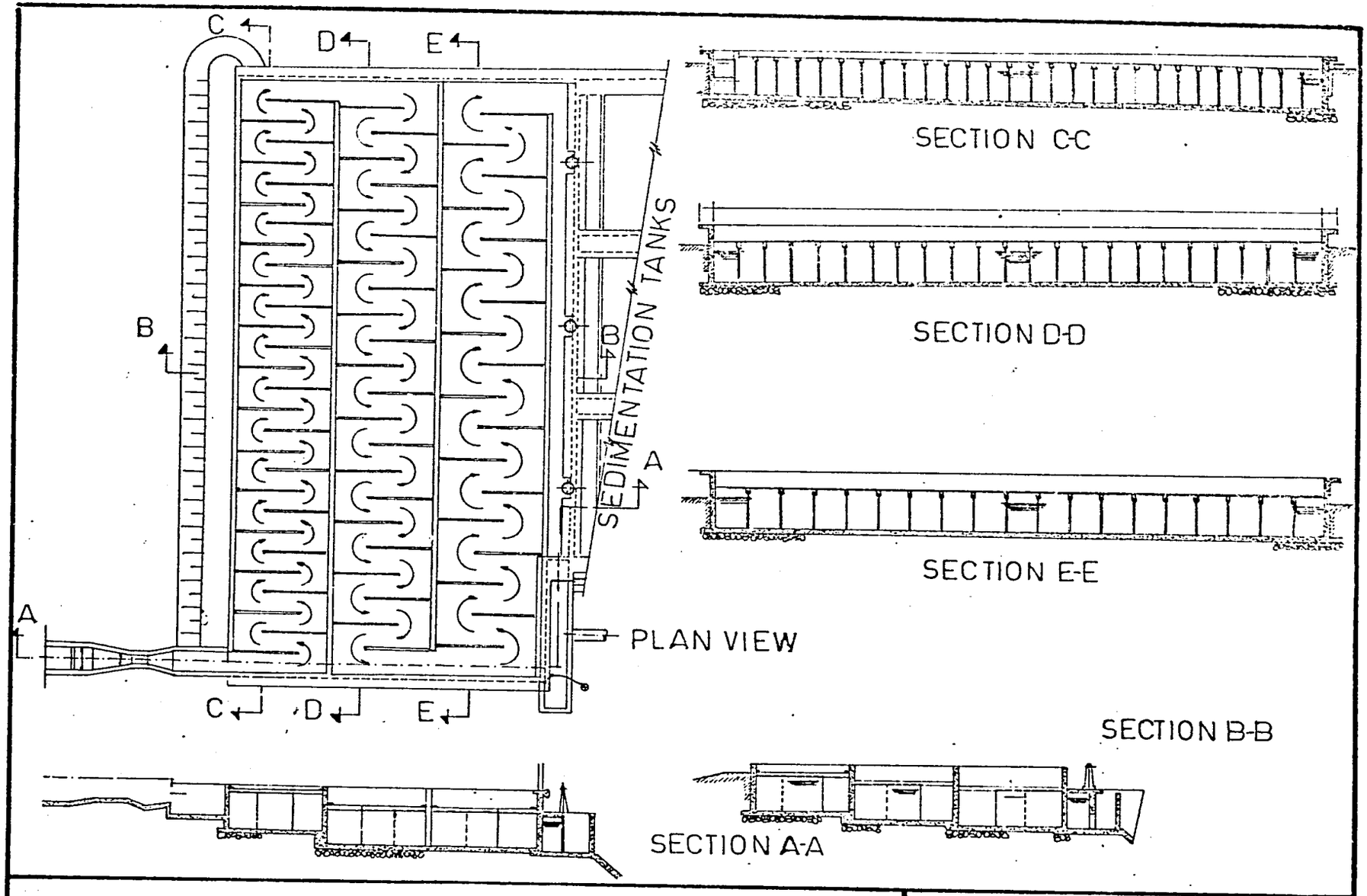
The system which serves the oldest zone of the city was installed between 1929 and 1930 with an approximate length of 30 km. The present system has a total of approximately 78.5 km. According to the aforementioned reports, 55.3% of the pipelines larger than 8 inches and 36.5 of those less than 7 inches are in poor condition.

3.4 RESEARCH STUDIES

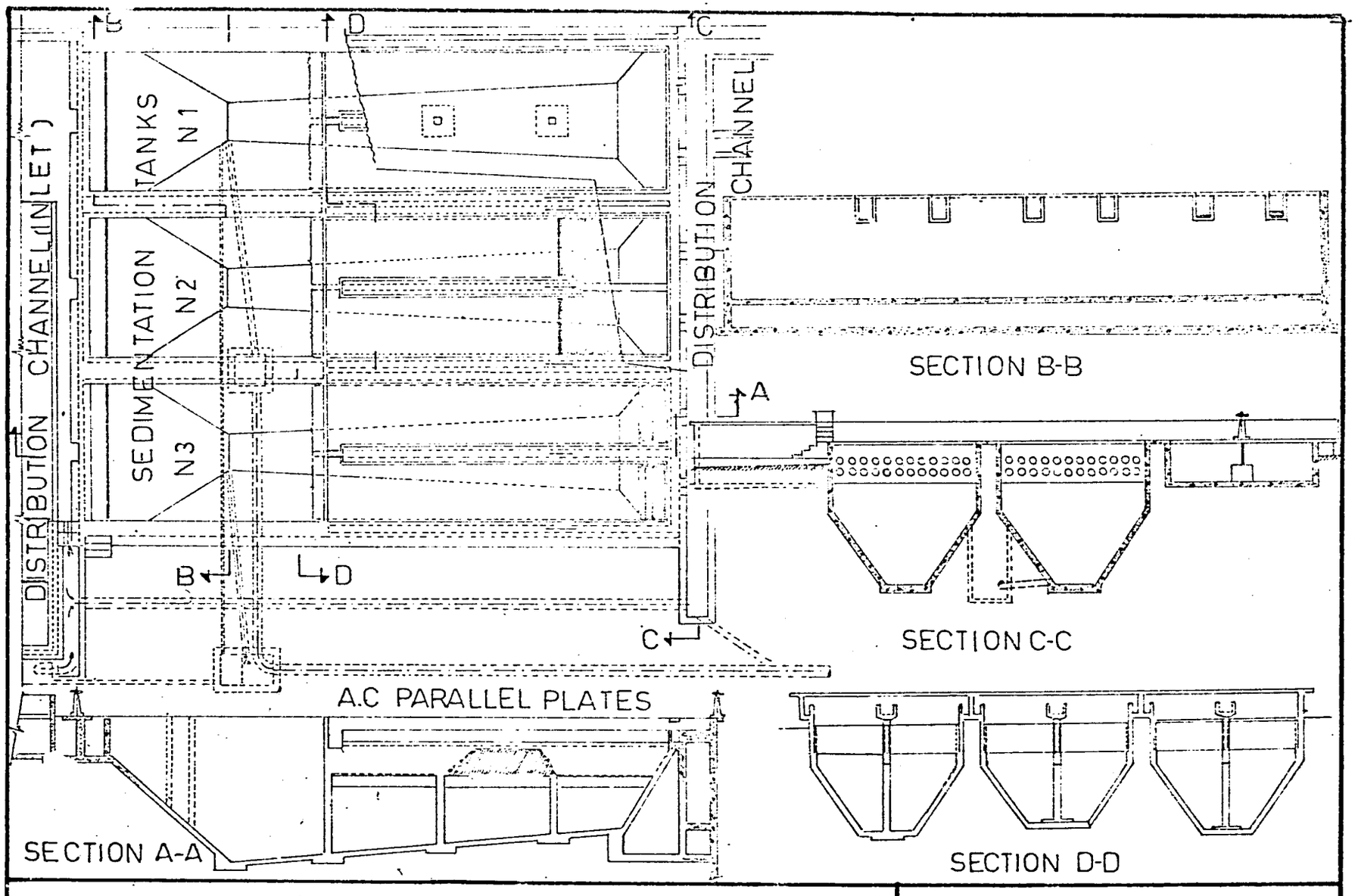
Research was carried out on the following aspects: determination of the general characteristics of the city, technical evaluation of the treatment plant and economic evaluation of plant construction, operation and maintenance costs.



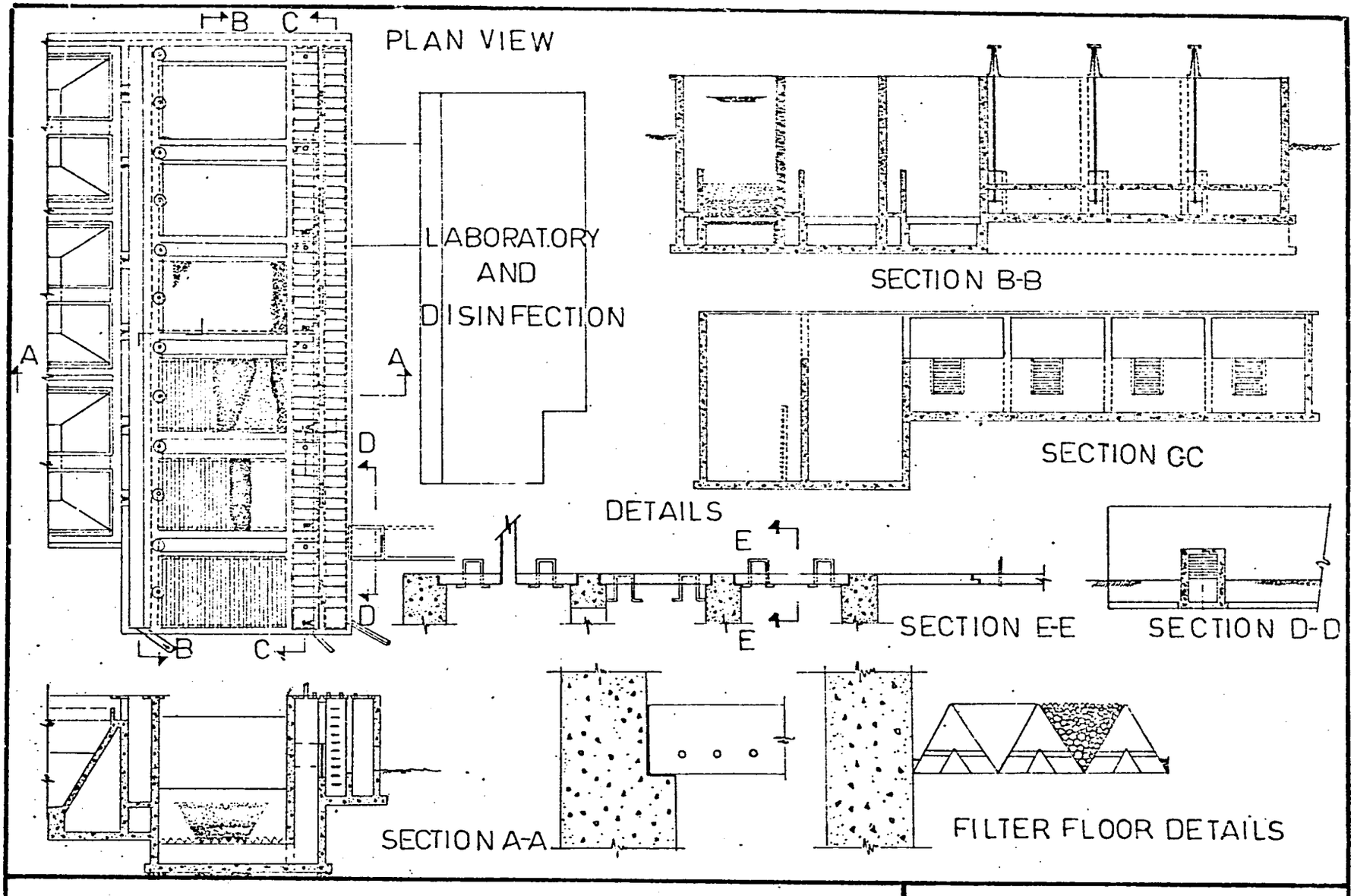
GENERAL PLAN	FIGURE 3-3
COCHABAMBA WATER TREATMENT PLANT	



FLOCCULATOR	FIGURE 3-4
COCHABAMBA WATER TREATMENT PLANT	



HIGH RATE SETTLING TANKS	FIGURE 3-5
COCHABAMBA WATER TREATMENT PLANT	



HIGH RATE FILTERS	FIGURE 3-6
COCHABAMBA WATER TREATMENT PLANT	

3.4.1 General characteristics of the city

In order to fulfill the principal research objective of the University of Oklahoma, information on the following topics was gathered using a survey questionnaire:

A. Identification of the city and institution responsible for water supply services;

B. Technological and demographic data;

C. Basic socio-economic data.

The results are included in Appendices 3-A and 3-B.

3.4.2 Technical evaluation

The immediate objective of this research was to study the efficiency of the Cala-Cala treatment plant under actual operating conditions and determine the factors that influence its performance and the operation and maintenance problems derived from typical local conditions. In particular, the response of the plant to variations in flow and water quality were studied.

A. Raw water quality

During the period under study, which corresponded to the dry season, the raw water quality was satisfactory. Raw water turbidity during the period between March and November varied from a minimum of 4 JTU to a maximum of 100 JTU, with an average value of 9.04 JTU. During 84% of the time the turbidity was less than 13 JTU; 95% of the time it was less than 19 JTU.

Raw water color during the period under study ranged from a minimum of 0 to a maximum of 50 CU, with an average value of 11.4 CU. During 84% of the time the color values were less than 15 CU; 95% of the time they were below 19 CU.

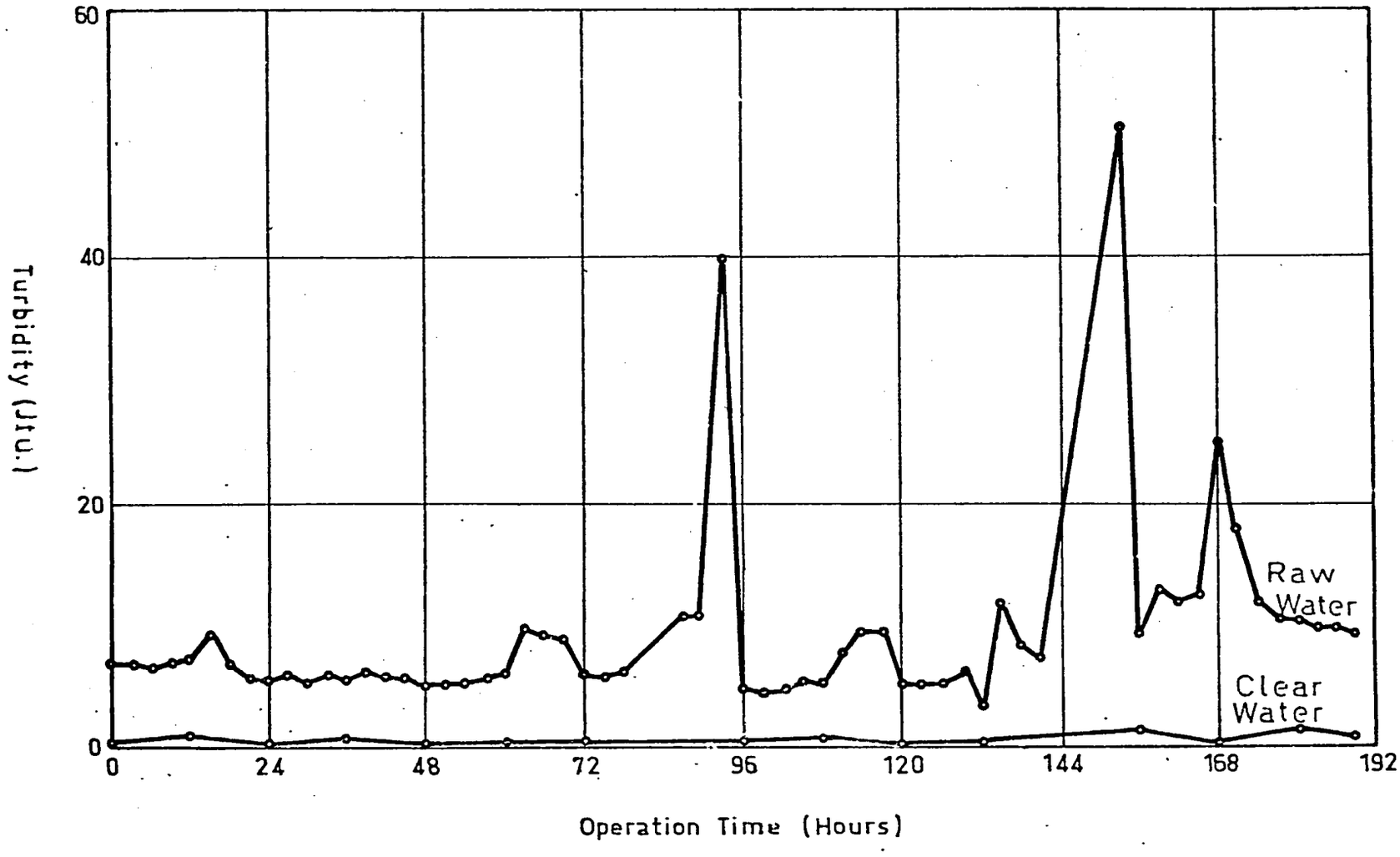
The pH varied from a minimum of 6.0 to a maximum of 8.9, with an average of 7.23.

The water generally had very low alkalinity, with a minimum of 8 mg/l and a maximum of 28 mg/l, and an average of 14.17 mg/l. During 84% of the time the alkalinity was less than 17 mg/l and 95% of the time it was below 20 mg/l.

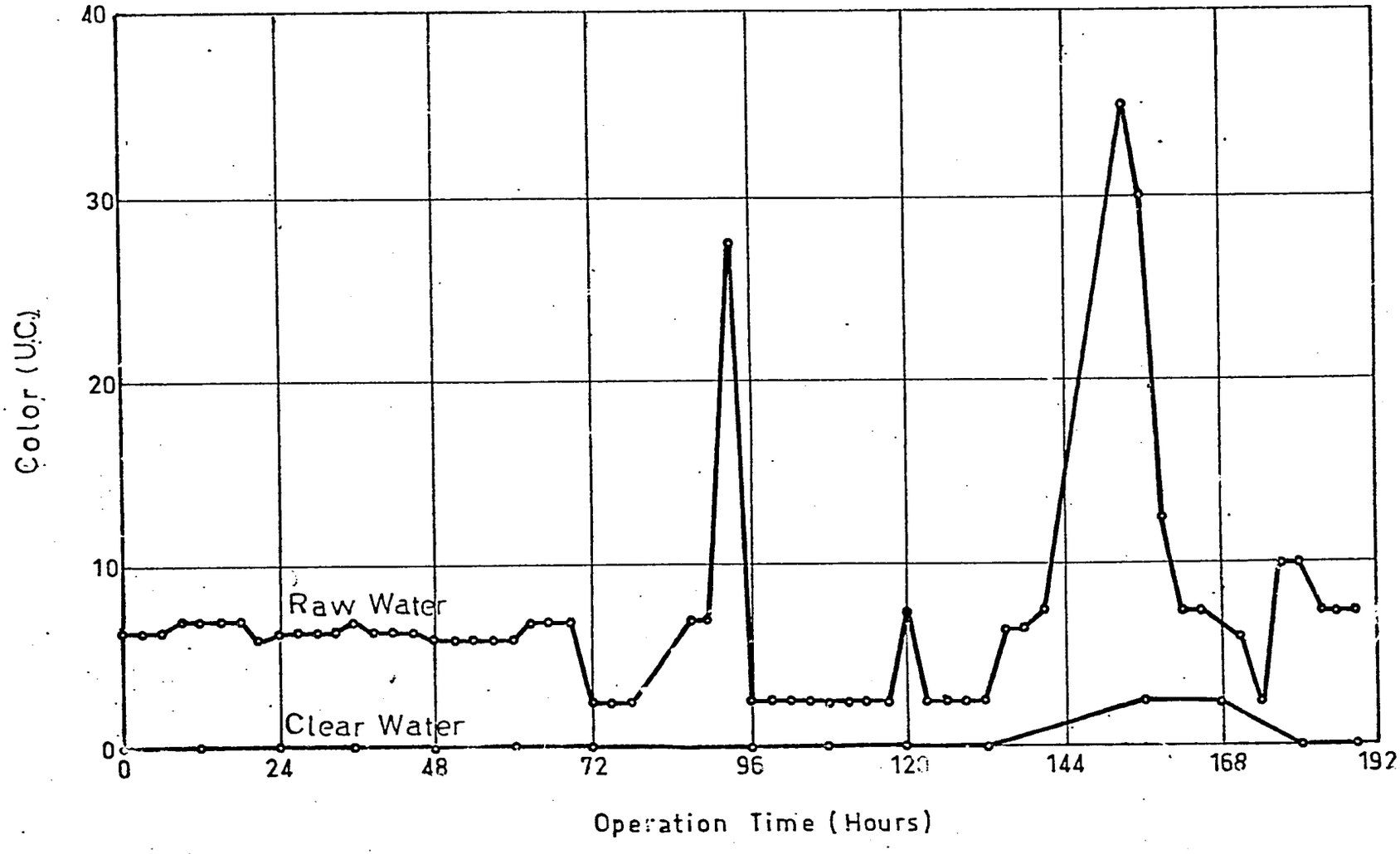
These values were obtained from hourly samples during the period between March and November.

B. Process data

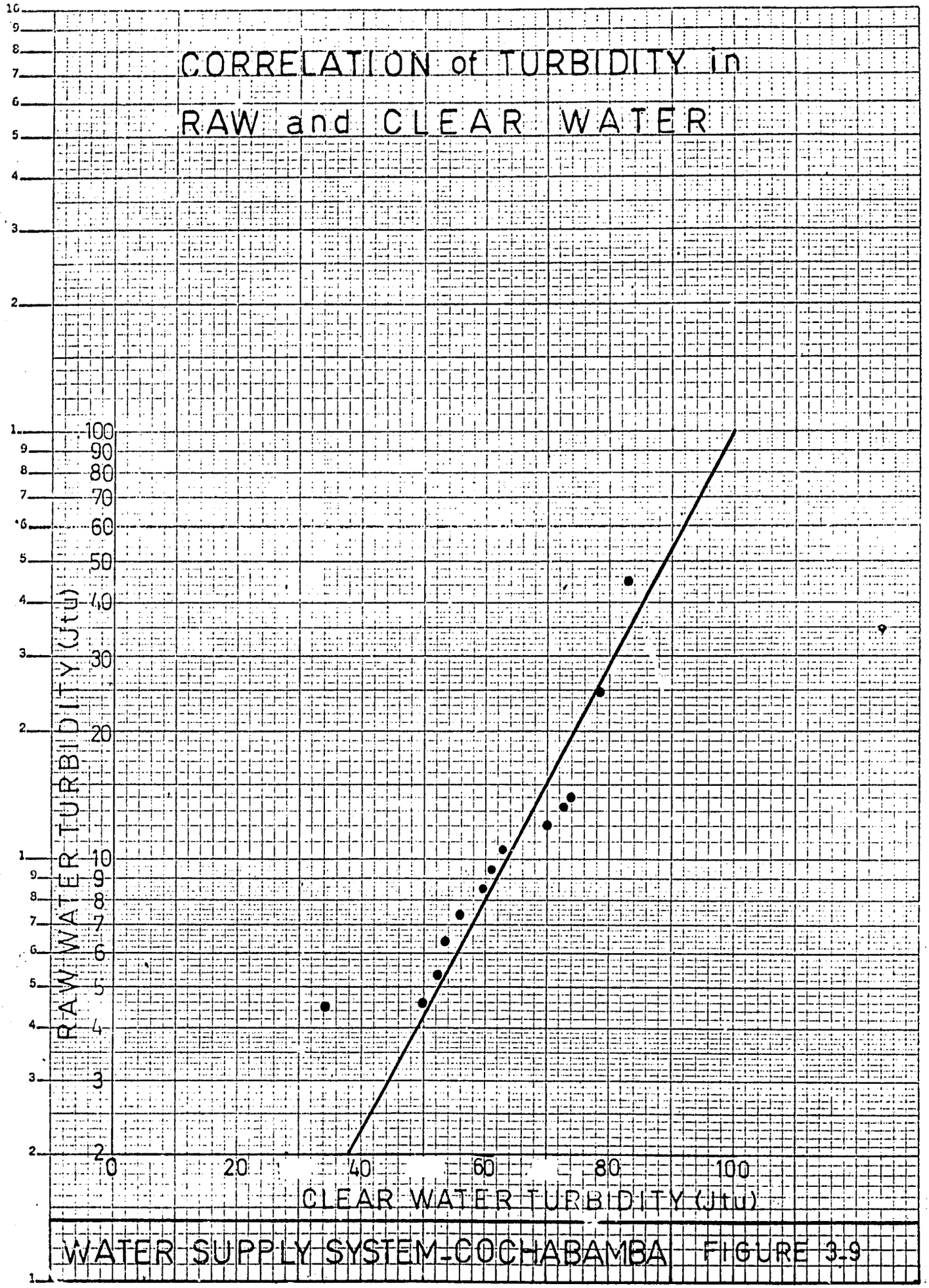
Data required by the University of Oklahoma regarding the technical characteristics of the processes used in the water treatment plant are included in Appendices 3-C and 3-E.



EFFICIENCY of TURBIDITY REMOVAL	FIGURE 3-7
WATER SUPPLY SYSTEM – COCHABAMBA	



EFFICIENCY of COLOR REMOVAL	FIGURE 3-8
WATER SUPPLY SYSTEM — COCHABAMBA	



WATER SUPPLY SYSTEM-COCHABAMBA FIGURE 3.9

Semi-Logarithmic
3 Cycles x 10 to the inch

C. General plant performance

Although advanced technological criteria were used in the design of the settling units and the filters, as well as in the overall conception of the plant, the design incorporated many factors, forms and dimensions of the existing conventional rapid filtration plant. The result is an extremely simple solution as far as the overall conception is concerned, as well as for operation and maintenance with a technical performance superior to that normally obtained in Latin America. Mechanized equipment and imported materials and appurtenances have been completely eliminated. The water itself is difficult to treat, because the precipitates must be formed by means of sweep floc which requires high dosages of coagulants and generally the addition of alkalinity in order to adjust the pH and/or the addition of a flocculant aid. During the period under study additional problems were encountered due to hourly flow variations which reached a maximum of 260% with normal values of 50%, caused by the constant variations in the amount of flow diverted from the canal for irrigation purposes. These flow variations made the chemical feeding and normal operation of the plant more difficult.

Treated water quality, as far as the physical and chemical parameters are concerned, was within the desirable limits recommended by the World Health Organization in "International Drinking Water Standards." On the other hand, the bacteriological standards were not met because the water was not disinfected.

The turbidity of the effluent water ranged between 0.13 JTU and 2.5 JTU, with an average value of 0.59 JTU. During 84% of the time the turbidity was less than 0.79 JTU; 95% of the time it was less than 1 JTU.

The efficiency of the plant was greater as far as color is concerned, producing effluents with a total absence of color during 95% of the time. The maximum color value was 5 units. The magnitude of this phenomenon may have been influenced by the accuracy of the equipment used for the determination of color, which had a sensitivity of 5 CU. The pH of the water ranged from a minimum of 6.0 to a maximum of 7.9 with an average value of 7.02. The use of lime alone was not sufficient to stabilize the water which normally showed corrosive conditions since the alkalinity values were only between 2 and 16 mg/l with an average of 10.67 mg/l.

Figures 3-7 and 3-8 show the turbidity and color of the raw water and treated water during a period in which there were appreciable variations in water quality.

Since it had been determined during preliminary start-up and operational tests that the efficiency of the treatment depended on the water quality, random data was taken as representative of plant efficiency. For raw water with 4 to 5 JTU, the average turbidity of the treated water was 0.34 JTU, and for raw water with 60 to 100 JTU, the treated water had a maximum turbidity of 1 JTU. Table 3-4 indicates the treatment efficiency for different turbidity ranges and figure 3-9 shows the correlation between the raw water and treated water turbidities.

The analysis of the results of the study leads to the general conclusion that advanced technology can be applied successfully to simple projects,

producing a highly efficient plant which is easy to operate and compatible with the existing socio-economic conditions and to the state of development of the country.

Table 3-4

CORRELATION BETWEEN RAW WATER AND TREATED WATER TURBIDITIES

N° of samples	Turbidity (JTU)		Standard deviation (JTU)
	Raw Water	Treated water Average	
10	4 - 5	0.34	0.09
60	5 - 6	0.53	0.12
80	6 - 7	0.54	0.13
90	7 - 8	0.56	0.14
60	8 - 9	0.60	0.14
30	9 - 10	0.61	0.16
20	10 - 11	0.63	0.16
10	11 - 12	0.64	0.15
10	12 - 13	0.70	0.17
10	13 - 14	0.73	0.17
8	14 - 15	0.74	0.17
6	15 - 20	0.76	0.12
5	20 - 30	0.78	).16
5	30 - 60	0.83	).16
1	60 - 100	1.00	-

D. Chemical feeding

To form a satisfactory precipitate and obtain a sweep floc for turbidity and color removal (100 JTU and 50 CU) relatively high dosages of coagulant (aluminum sulfate, 15 mg/l) are required, plus the use of pH adjusting compounds to correct the low alkalinity (average 14.17 mg/l). In this case lime is used for economic reasons (although from a technical point of view sodium carbonate or some other base would be preferible).

Table 3-5 shows the results of 680 jar tests, from which it was found that the dosage varies between 8.8 mg/l for low turbidities and 13.9 mg/l for medium turbidities. Figure 3-10 shows the correlation between the coagulant dosage and raw water turbidity; the linear regression equation is $y=3.34 + 0.57x$ with a goodness of fit of $r^2 = 0.90$, where x is the raw water turbidity and y is the coagulant dosage. This criterion is useful only for turbidities between 7.5 and 100 JTU.

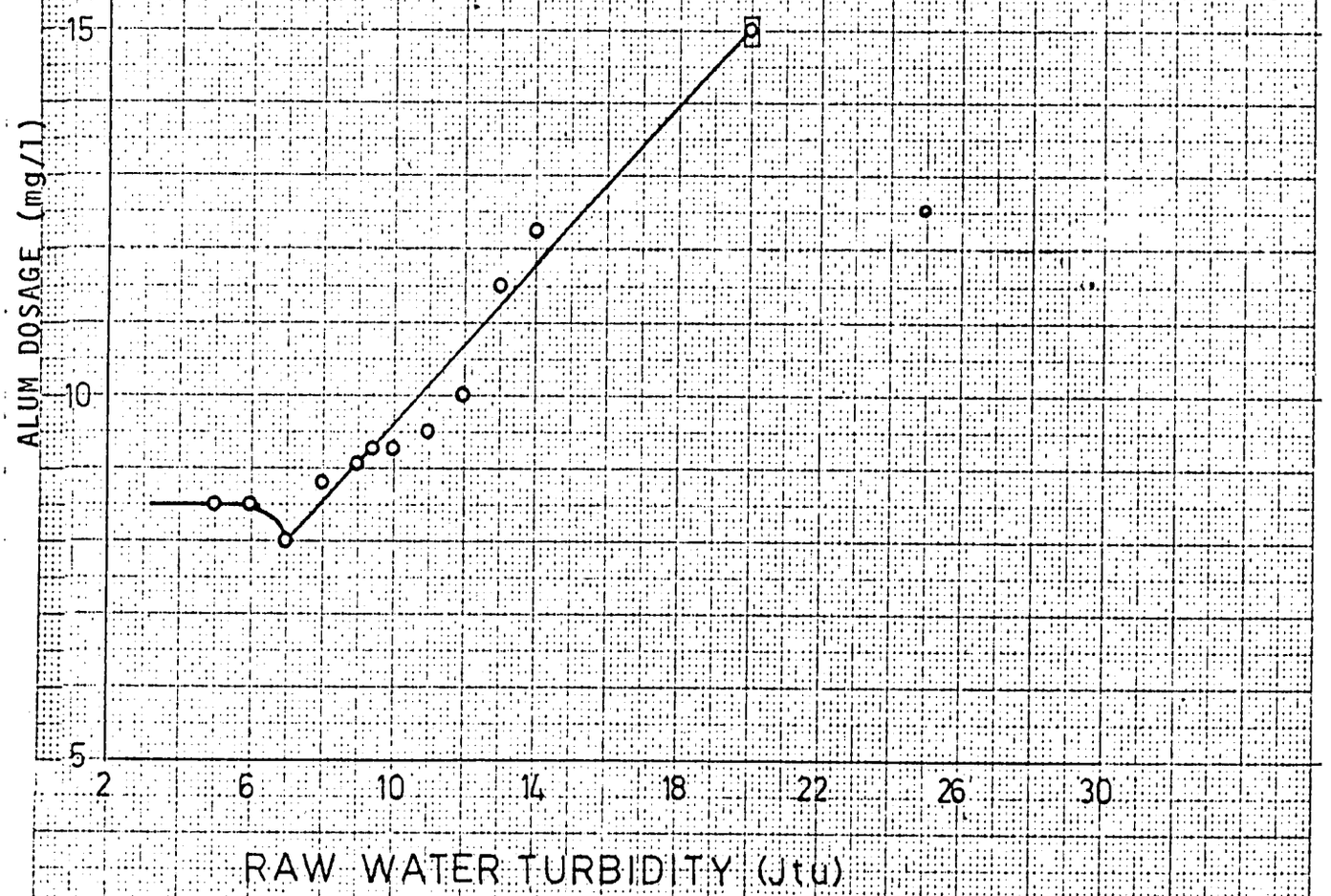
When the flow is low, small amounts of alum had to be added and problems were encountered in obtaining the correct dosage when using saturated solutions; therefore, solutions with concentrations up to 5% were used.

Another problem was the variation of the concentration of the lime suspension in relation to the time elapsed between its preparation and use, due to a slow carbonation process when the suspension is in contact with the air.

CORRELATION of RAW WATER TURBIDITY and COAGULANT DOSAGE

REGRESSION EQUATION: $y = 3.74 + 0.57x$

r^2 : 0.90



WATER SUPPLY SYSTEM-COCHABAMBA | FIGURE 3-10

Table 3-5

CORRELATION OF TURBIDITIES AND COAGULANT DOSAGES

No. of tests	Turbidity (JTU)	Dosage of aluminum sulfate (mg/l)	Remarks
120	5 - 6	8.8	
120	6 - 7	8.8	
100	7 - 8	8.10	*
100	8 - 9	8.90	*
90	9 - 10	9.35	*
70	10 - 11	9.45	*
30	11 - 12	9.70	*
20	12 - 13	10.15	*
10	13 - 14	11.75	*
10	14 - 15	12.50	*
5	20 - 30	12.60	
5	40 - 50	13.90	

(*) Data considered in the linear regression equation

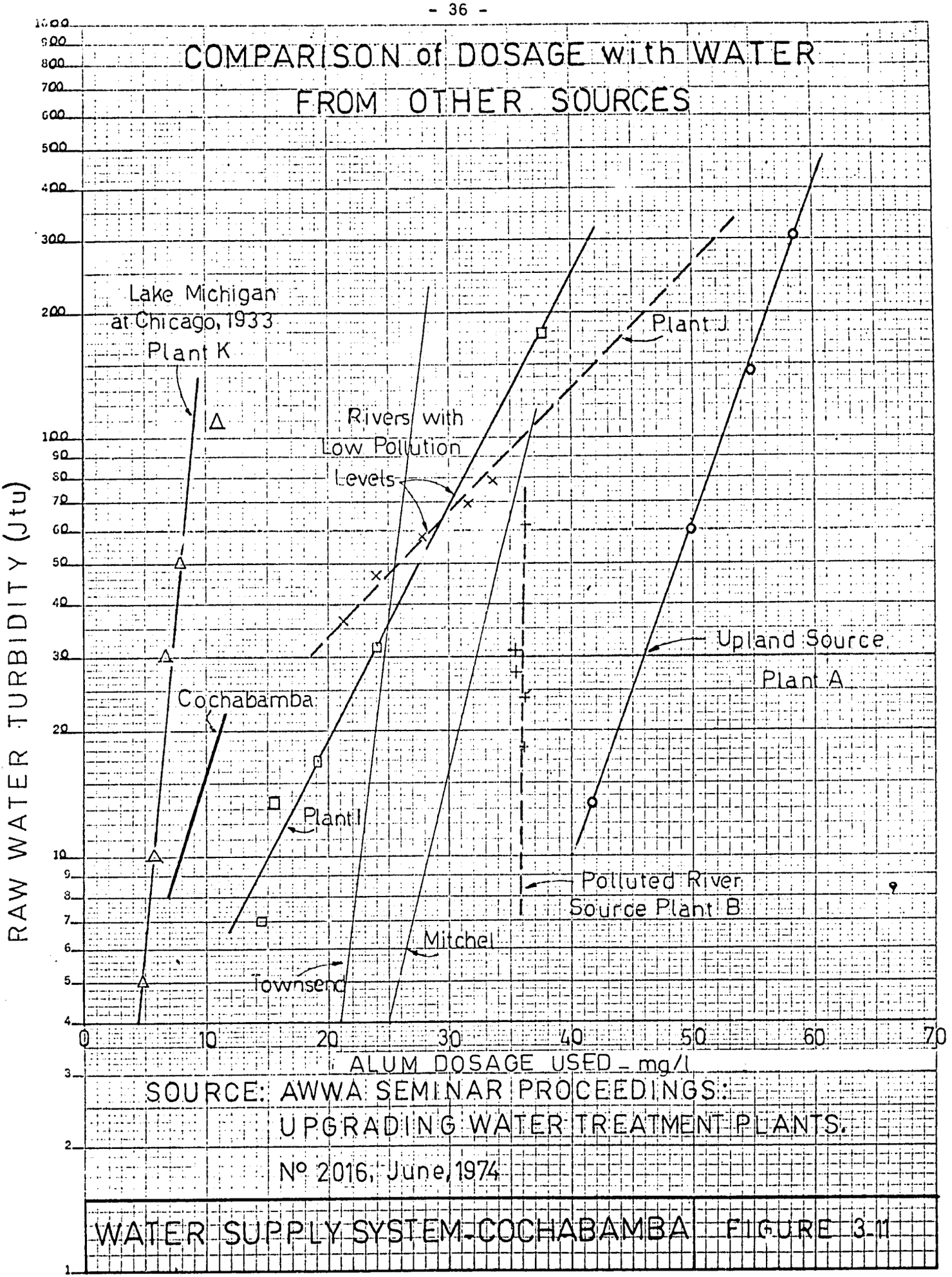
Since it was determined that large amounts of coagulant are necessary to begin precipitation when there is low turbidity, smaller dosages are required as the turbidity increases, until a critical point is reached beyond which there is, as indicated previously, a clear stoichiometric relation between water turbidity and the coagulant dosage applied; for turbidities between 7.5 and 100 JTU, as in the case under study, this is a straight line. The apparent reason for this behavior would seem to be that when there is low turbidity coagulation is produced by the precipitation of the metal hydroxides resulting from the reaction of the coagulant with the alkalinity which drag down the colloidal particles. This process requires high coagulant dosages. On the other hand, with greater turbidity, coagulation is produced by the adsorption of the products of hydrolisis or polymers with the turbidity particles and there is a clear correlation between the surface area of the colloidal particles and the amount of coagulant added to the water.

Figure 3-11 shows comparative data from other treatment plants.

E. Mixing unit

When the plant was operating normally it was found experimentally that by modifying the turbulence or velocity gradients upstream of the metering and rapid mixing unit effluents of different quality were obtained with the same chemical dosages and the same water quality.

Although the problem was not analyzed completely, it was found that low turbidities required higher velocity gradients and greater turbidities needed lower velocity gradients, with a constant detention time. It was also found that the performance of the plant could be modified by altering the velocity gradients above and below the rapid mixing unit; decreasing the



SOURCE: AWWA SEMINAR PROCEEDINGS:
UPGRADING WATER TREATMENT PLANTS.
Nº 2016, June, 1974

WATER SUPPLY SYSTEM-COCHABAMBA FIGURE 3-11

Semi-Logarithmic
3 Cycles x 10 to the inch

velocity gradients, especially downstream, yield better water quality since high velocity gradients (>4 000 s^{-1}) have a negative influence, delaying the appearance of the floc by more than 10 minutes.

Figure 3-12 shows the results of the tests conducted. It should be kept in mind that the number of analysis is insufficient to obtain definite conclusions on the matter.

Figure 3-13 presents the results of evaluative tests of the rapid mixing unit, which has 82% mixed flow and 18% pure piston flow.

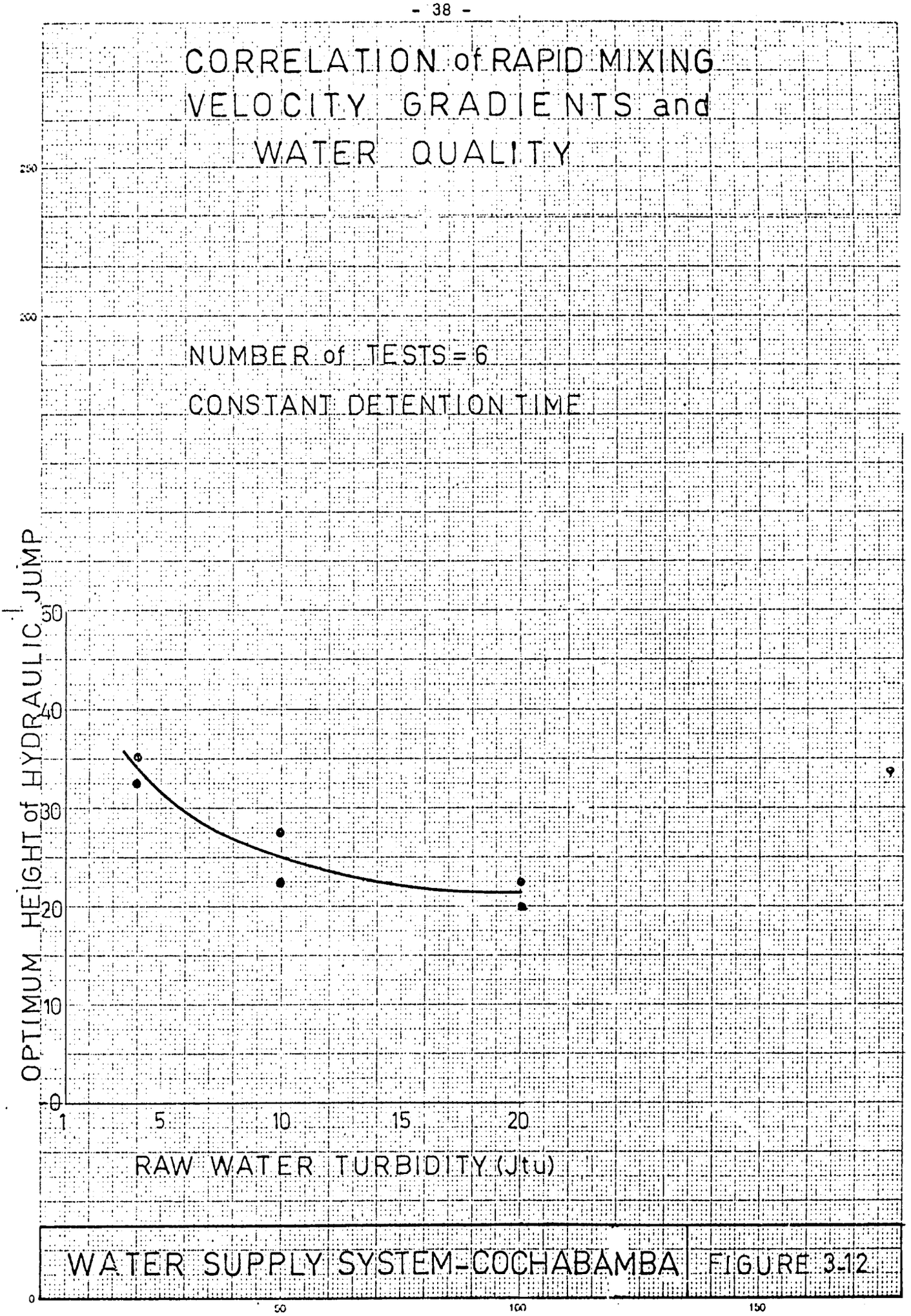
F. Flocculation unit

Without a doubt, the factor which has the greatest influence on the efficiency of a water clarification plant of the type existing in Cochabamba is the flocculation process. This process defines the characteristics of the floc which are then used to establish the parameters and loads for the settling units and filters.

1) Determination of the optimum flocculation conditions

Considering the velocity gradient, detention time, water quality, and hydraulic conditions as the main intrinsic factors influencing the efficiency of the flocculators, a series of jar tests were conducted to determine the optimum values of the velocity gradients and detention times, as well as the appropriate sequence of velocity gradients keeping the raw water characteristics constant. With constant velocity gradients throughout the tests, the most efficient removal was obtained with lower velocity gradients. Shorter detention times were obtained with higher gradients: 20 minutes for velocity gradients of 35 s^{-1} and 25 minutes for gradients of 20 s^{-1}. The performance curves for these parameters are parabolic (curves a and b of figure 3-14). Greater efficiencies were obtained when the jar tests were carried out with variable velocity gradients. This phenomenon is represented by curves c and d of the same figure which correspond to the true velocity gradient variation in the flocculator under study and the ideal limit curve.

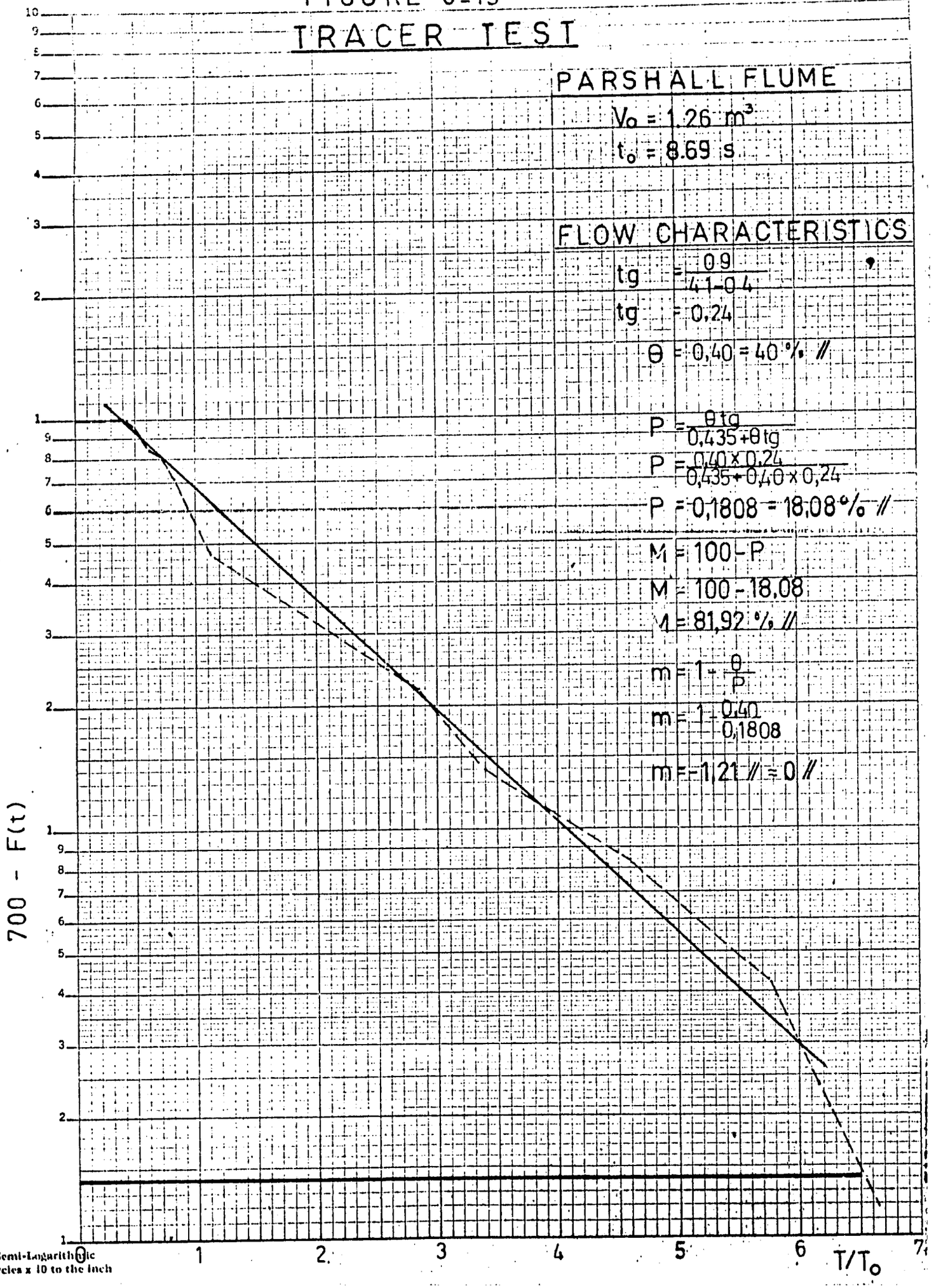
There was a disparity between the results of the jar tests and the normal performance of the plant, since higher efficiencies were obtained when the plant was operating with slightly higher velocity gradients. When lower gradients were used larger floc was formed but it was weaker and broke down during filtration. On the other hand, greater velocity gradients yielded smaller and more compact floc which was better able to resist the high velocity gradients produced in the filters. This gave better quality water but reduced the filter runs. The ideal velocity gradient or sequence of gradients which would produce the highest plant efficiency by achieving an equilibrium in the functioning of the filters to produce a filter effluent of acceptable quality while at the same time using all the available head loss and producing the minimum possible filter flow were not determined.



WATER SUPPLY SYSTEM-COCHABAMBA | FIGURE 3-12

FIGURE 3-13

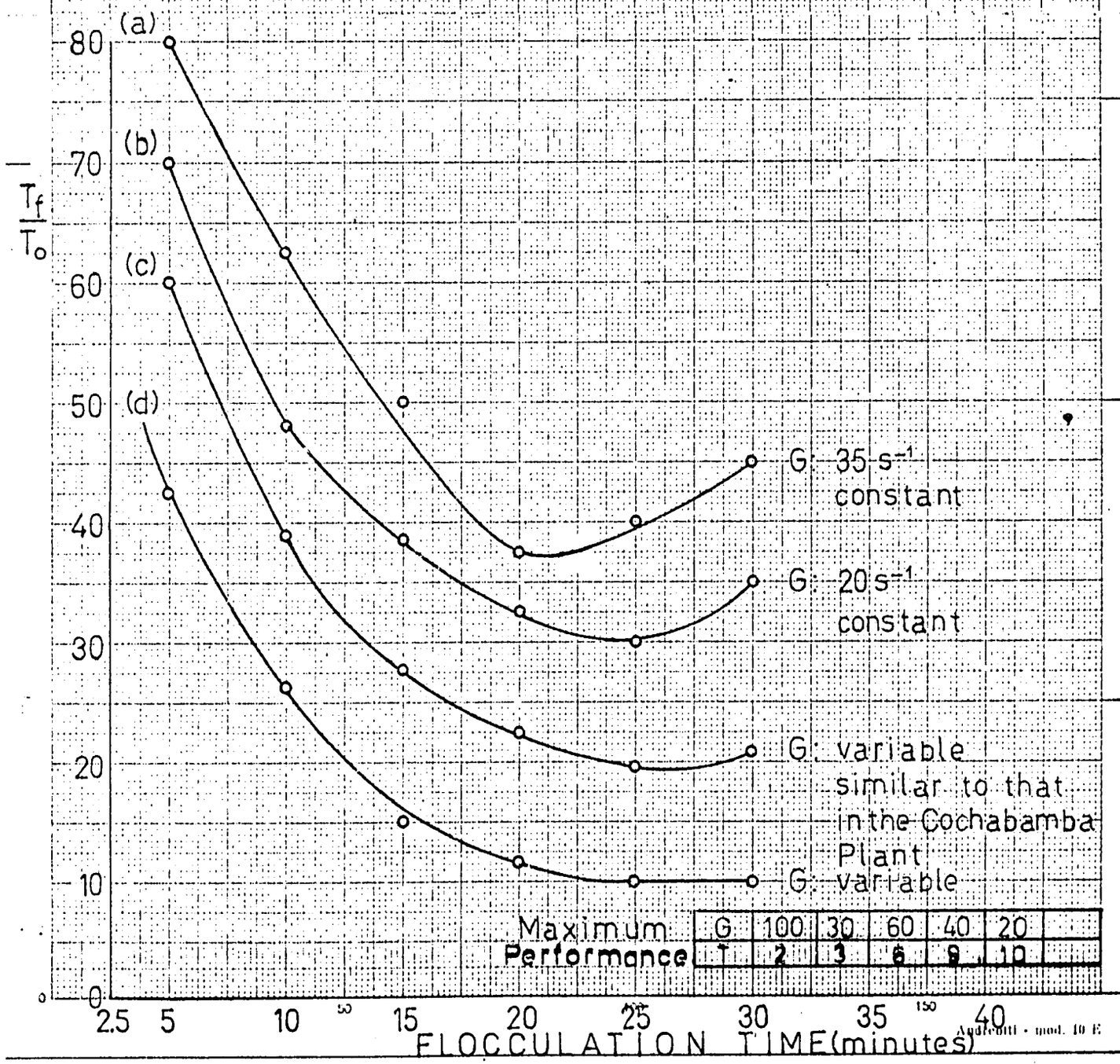
TRACER TEST



WATER SUPPLY SYSTEM_COCHABAMBA FIGURE 3_14

INFLUENCE of FLOCCULATOR CHARACTERISTICS on WATER QUALITY (JAR TEST)

SETTLING TIME: 15 minutes
INITIAL TURBIDITY: 10 JTU
TEMPERATURE : 10°C



2) Hydraulic characteristics

As indicated in section 3.3, the flocculator is hydraulic with horizontal flow. Adjustable vertical baffles made of asbestos-cement are used to modify the velocity gradients in the three flocculator compartments by varying the width of the channels. Besides the gathering of normal operational and start-up data, different tests were carried out both in the laboratory (jar tests) and in the treatment plant itself to determine the optimum flocculation conditions and obtain the highest possible plant efficiency and performance. The hydraulic conditions of the flocculator were evaluated by instantaneous tracer tests using the formulas of Wolf and Resnick to define the different kinds of flow values. These tests indicated a high level of hydraulic efficiency for the flocculation units. The results of the tests are given in table 3-6.

Table 3-6

RESULTS OF TRACER TESTS IN THE FLOCCULATION UNIT

Test No.	Piston flow	Mixed flow	Dead space
1	80	20	6
2	80	20	6
3	75	25	4
4	95	5	5
Average	82.5	17.5	5.25

It should be pointed out that the results varied depending on the sequence followed in carrying out the test. Although the difference is small with flocculators of this type, in the case of conventional settling units it could be much greater. Therefore, it is recommended that small amounts of the tracer be added continually for at least an hour before the test to obtain the most accurate results possible.

In general, no operational problems were encountered in the flocculator during the test period. This type of flocculator has both its advantages and disadvantages.

Among the points in its favor are the production of pure piston flow, the absence of short circuiting, the lack of moving parts, and the elimination of manual operations and outside energy requirement. The detention time and velocity gradients can be modified, giving it a certain flexibility.

One of its disadvantages is the rigid hydraulic conditions. Although the space between the asbestos-cement baffles can be changed to adjust velocities and velocity gradients, a considerable amount of effort is required to do so. Additionally, since the efficiency of the flocculation process depends on the number of units, the only way to increase the efficiency is to build more units, which requires a much larger capital investment.

Based on the results obtained in the jar tests, a combination of high velocity gradients and short detention times should be used when flocculation begins and lower velocity gradients with longer detention times (as the process continues). In other words, although the efficiency of the flocculator is improved by dividing it into three compartments each with 1/3 of the total detention time, the optimum flocculation conditions have still not been met.

Since the performance of the settling units and filters depends on the characteristics of the floc which in turn depend on the flocculation conditions, the optimum flocculation conditions should be established jointly with the selection of design parameters or overflow rates for sedimentation and filtration when designing a water clarification plant. The correlations between water quality, coagulant dosage, combinations of velocity gradients and optimum detention times should be established initially in order to optimize the efficiency of each process. This type of hydraulic flocculating unit with horizontal flow appears to be recommendable when there are no large fluctuations in water quality which would require a wide range of velocity gradients.

G. Settling units

Taking into consideration the inestability of the flow in the settling units and the fact that its efficiency and behavior depend on many factors, an attempt was made to determine the influence of the following parameters of settler performance: raw water quality, overflow rate, and water temperature.

In addition, a comparison of theoretical efficiency (jar tests) and the actual efficiency of the settling units was made and the hydraulic conditions were determined.

1) Influence of raw water quality on the efficiency of the settling units

Since the ability of a settler to remove turbidity depends on the weight of the particles suspended in the water, greater efficiency is obtained with higher raw water turbidities. Thus, with raw water turbidities that vary between 30 and 40 JTU, the settler efficiency was 95% and with turbidities ranging from 5 to 10 JTU, the removal efficiency was 86%.

Table 3-7 gives the performance of the high-rate settling units during the test period. A clear correlation can be observed which is defined by equations of the type $x/y = a+b\ x,y$. For the case under study, $a = 1.37$ and $b = 1.02$, with x = raw water turbidity and y = % turbidity removal (% performance).

Table 3-7

COMPARISON OF INFLUENT AND SETTLED WATER TURBIDITIES

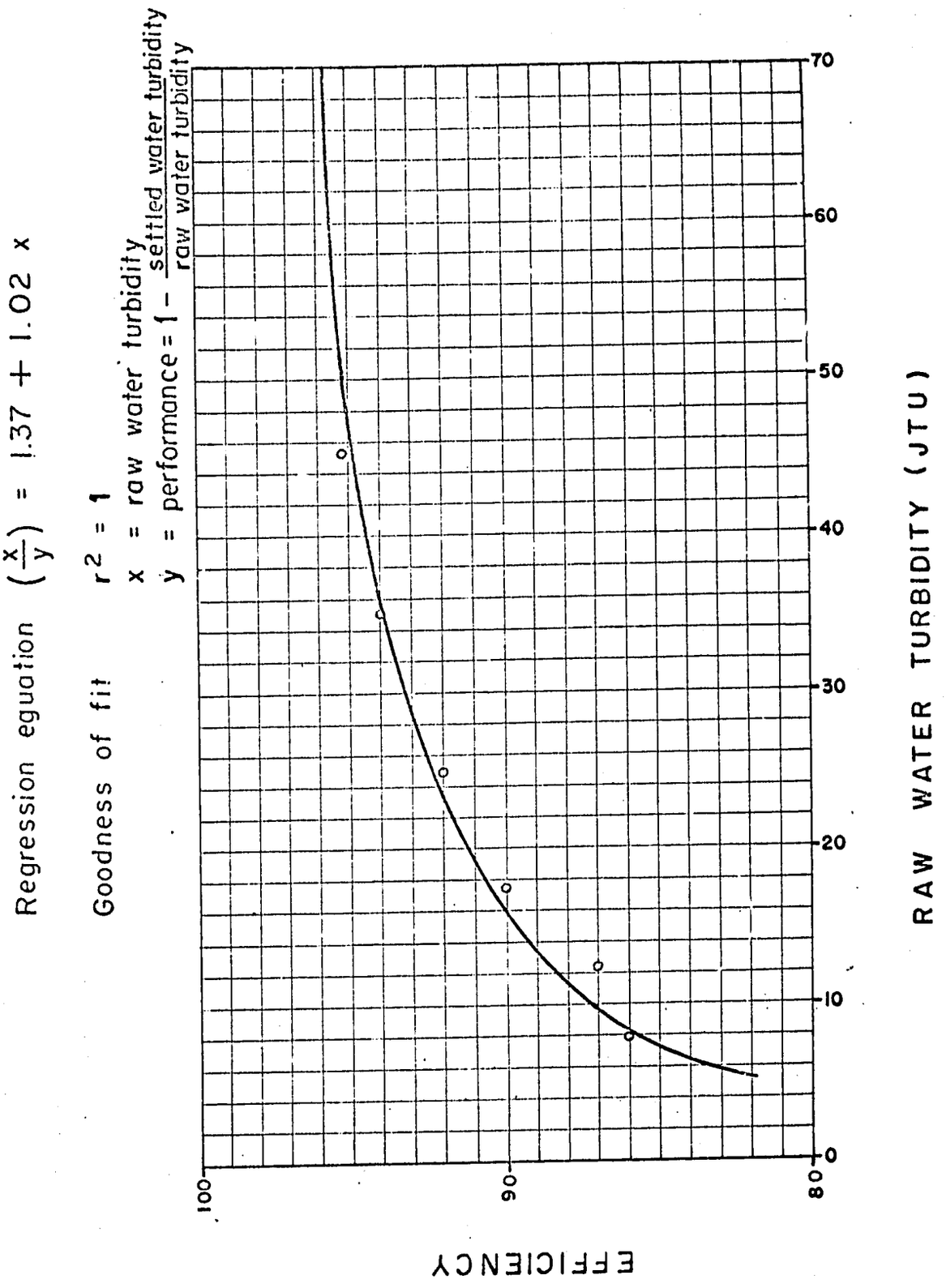
No.	Influent Turbidity JTU	Settled water turbidities JTU		
		Minimum	Average	Maximum
20	4.00 - 4.99	0.5	1.05	1.8
20	5.00 - 5.99	0.5	1.13	2.0
70	6.00 - 6.99	0.6	1.23	2.0
140	7.00 - 7.99	0.6	1.25	2.5
110	8.00 - 8.99	0.6	1.29	2.9
80	9.00 - 9.99	0.8	1.41	3.0
70	10 -10.99	0.8	1.46	3.0
50	11 -11.99	0.9	1.55	3.0
50	12 -12.99	0.9	1.58	3.4
30	13 -14.99	0.9	1.64	4.2
5	15 -20.00	1.0	2.12	4.5

A perfect fit is obtained since r^2 is equal to 1.00. The corresponding curve is shown in figure 3-15. In figure 3-16 the efficiency of the Cochabamba settling units is compared with results obtained in sedimentation processes in other treatment plants. The efficiency of this type of settling unit is shown to be superior to that of conventional settlers.

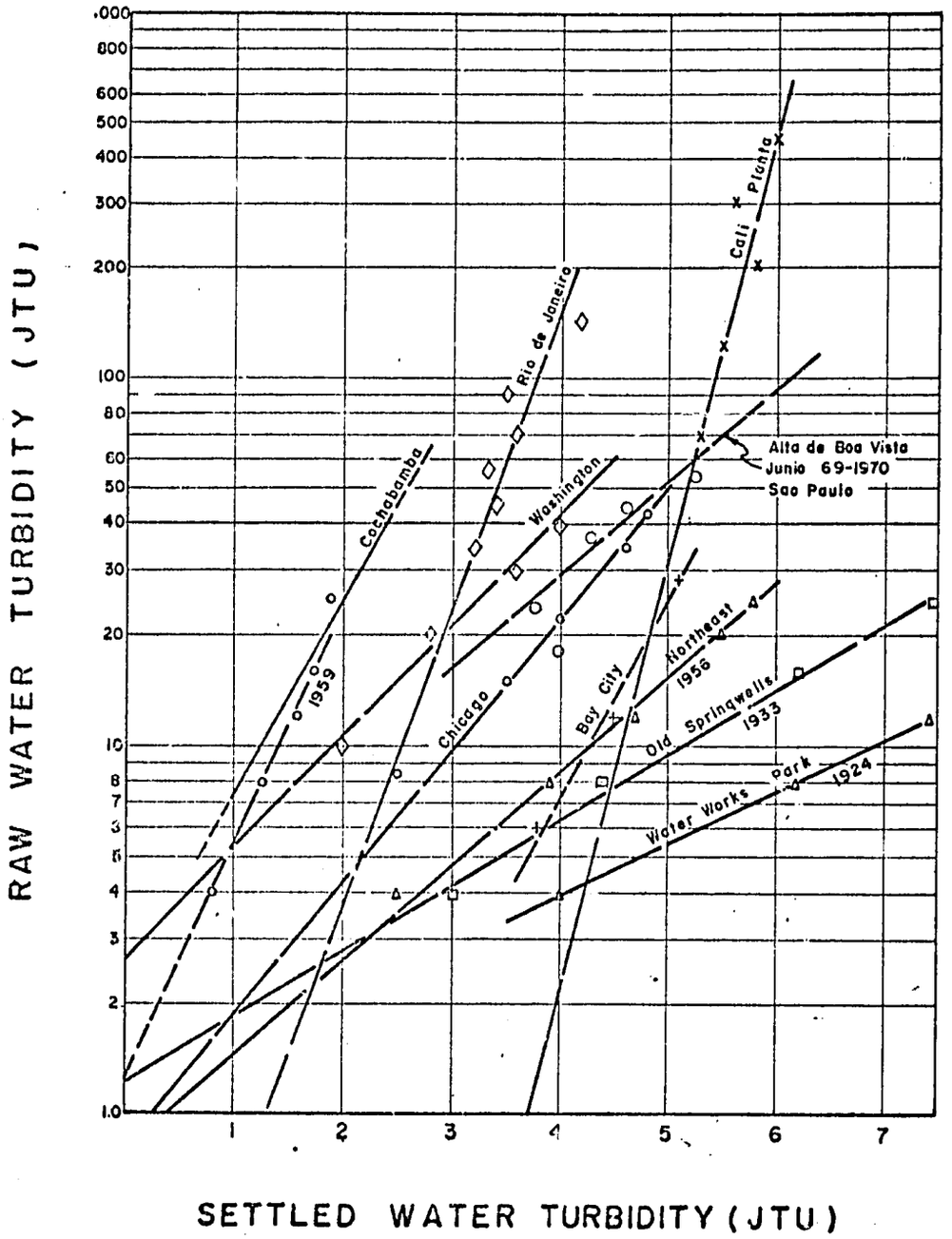
2) Comparative study of actual and theoretical efficiency

The classic theory of the performance of an ideal settling tank is based on the postulates of Hazen and Camp, which state that in the ideal settling unit the flow is horizontal, direction and velocity are the same in all parts of the tank, the concentration of suspended particles of each size is the same at all points in a vertical plane and particles settle without interference. In practice, however, there are appreciable differences between the theoretical and real values for various reasons (unequal distribution of incoming flow, production of kinetic and density currents). Therefore, the principal parameters, especially the "settling velocity" (overflow rate) and "performance", are determined by laboratory tests or by using pilot units.

For the case under study, to establish an order of comparison of the actual efficiency of the sedimentation process, the jar test containers were used. The results of 150 laboratory tests indicate that for overflow rates of 10 m^3/m^2/day it is possible to obtain 92.5% performance (with $R_t = [1 - (C_o - C_f)] + a/V_{sc}$) and for loads of 120 m^3/m^2/day the theoretical performance is 66%. Figure 3-17 and table 3-8 illustrate the results of these tests. It can be



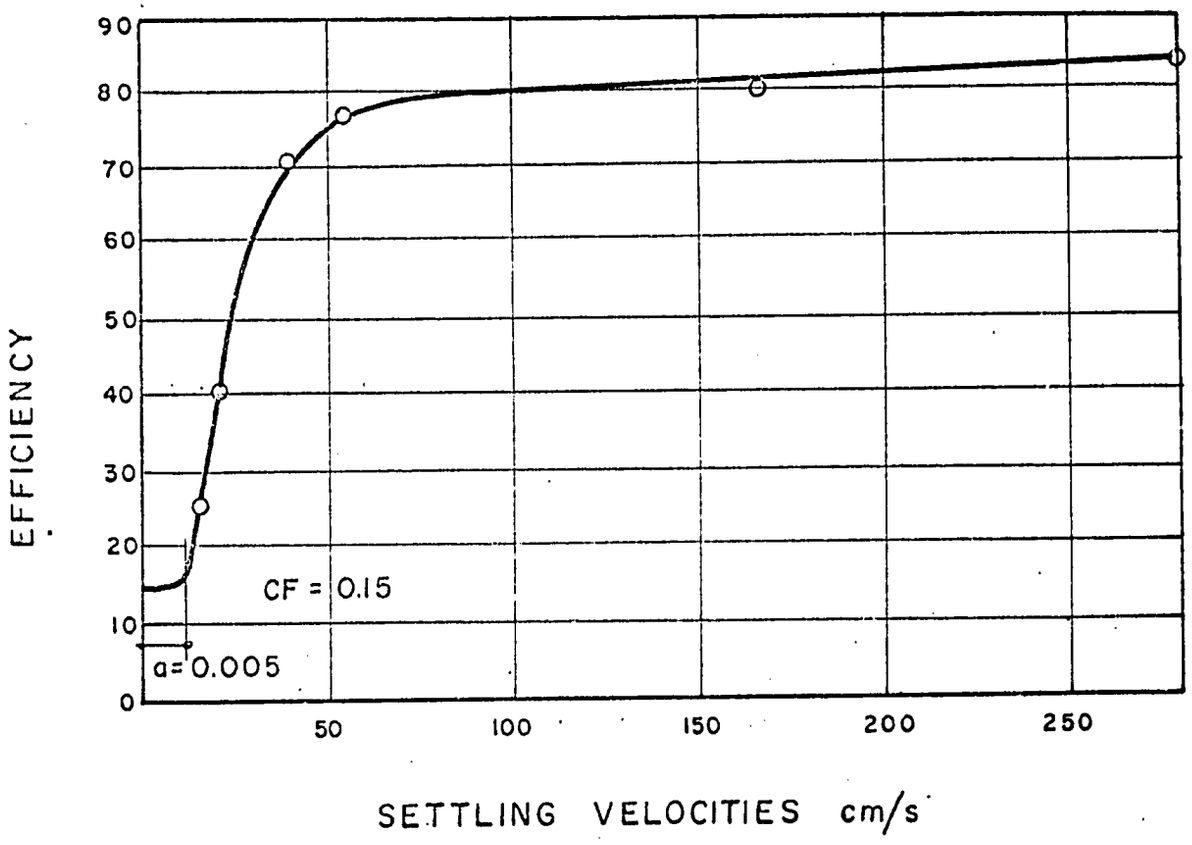
EFFICIENCY OF SETTLING UNITS AS A FUNCTION OF WATER QUALITY	FIGURE 3 - 15
WATER SUPPLY SYSTEM- COCHABAMBA	



COMPARATIVE STUDY OF SETTLING UNIT EFFICIENCY

WATER SUPPLY SYSTEM - COCHABAMBA

FIGURE 3-16



THEORETICAL SETTLING EFFICIENCY (JAR TEST)	FIGURE 3-17
WATER SUPPLY SYSTEM - COCHABAMBA	

Table 3-8

THEORETICAL PERFORMANCE OF SETTLING UNITS (JAR TESTS)
INITIAL TURBIDITY No. = 7.81
NUMBER OF TESTS = 150
LENGTH OF SEDIMENTATION = 5 cm

a) Results of tests

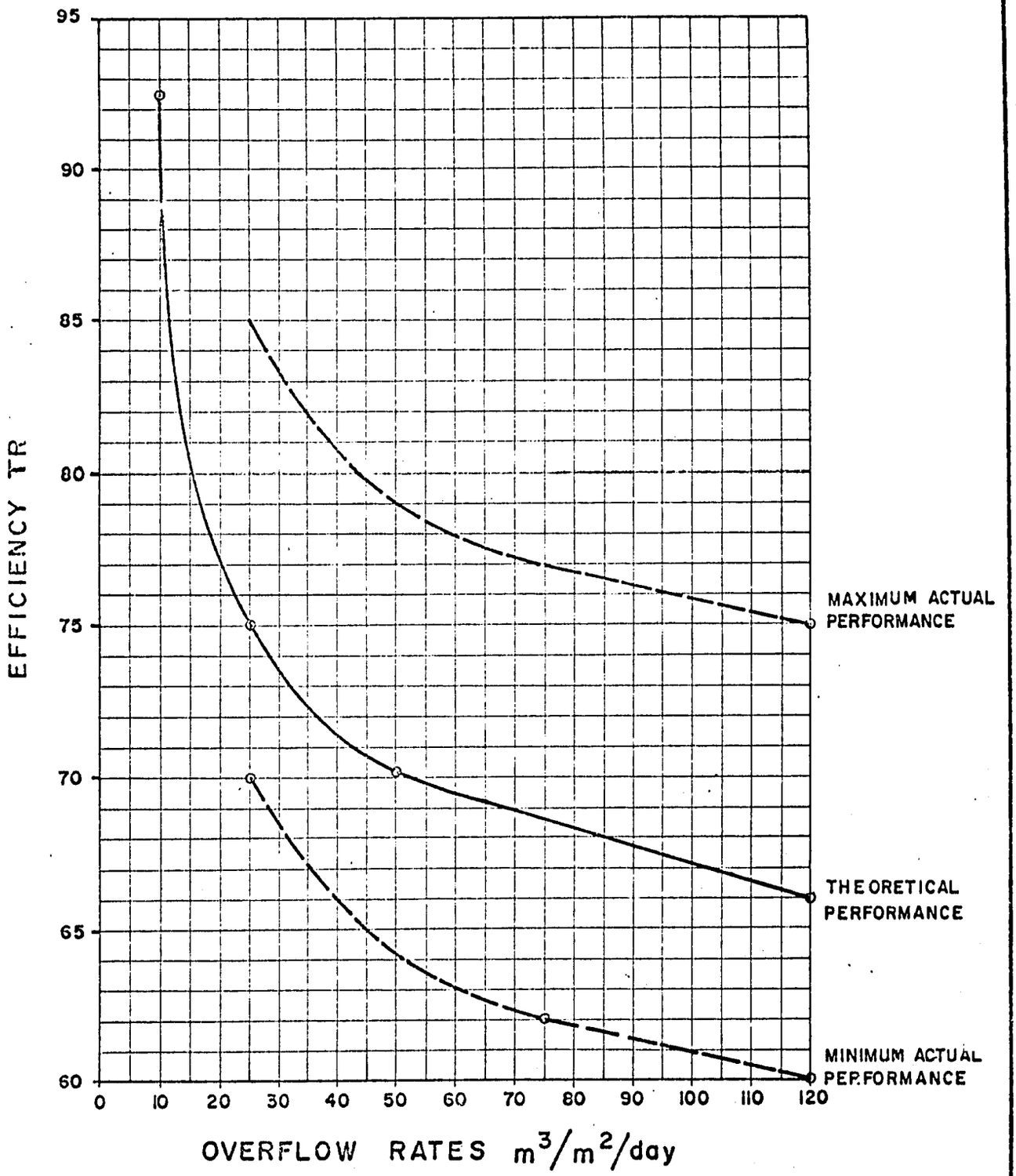
Time min	Settling velocity V_s cm/s	Final turbidity N_T (JTU)	N_T/NO
0	-	7.81	1.000
0.5	0.167	6.56	0.840
1	0.083	6.30	0.807
3	0.028	6.05	0.775
4	0.021	5.56	0.712
8	0.010	3.21	0.411
12	0.007	2.03	0.260
16	0.005	1.26	0.161

b) Correlation between Overflow Rate and Performance

Overflow Rate q $m^3/m^2/day$	Critical settling velocity V_{sc} (cm/s)	Theoretical concentration C_o	Performance
10	0.011	0.425	0.925
25	0.029	0.750	0.75
50	0.057	0.805	0.701
75	0.086	0.815	0.687
100	0.114	0.830	0.670
120	0.132	0.840	0.660

seen that during 42% of the time the efficiency of the settling unit was greater than that obtained in the jar tests. (Figure 3-18). This is an unusual situation since normally the jar test results are theoretical values which are difficult to achieve in practice.

In figure 3-19 the results obtained at the Cochabamba plant are compared with results obtained by Hudson in different water treatment plants in the United States. The performance of the Cochabamba plant is superior to the average of the plants which are rated as efficient.

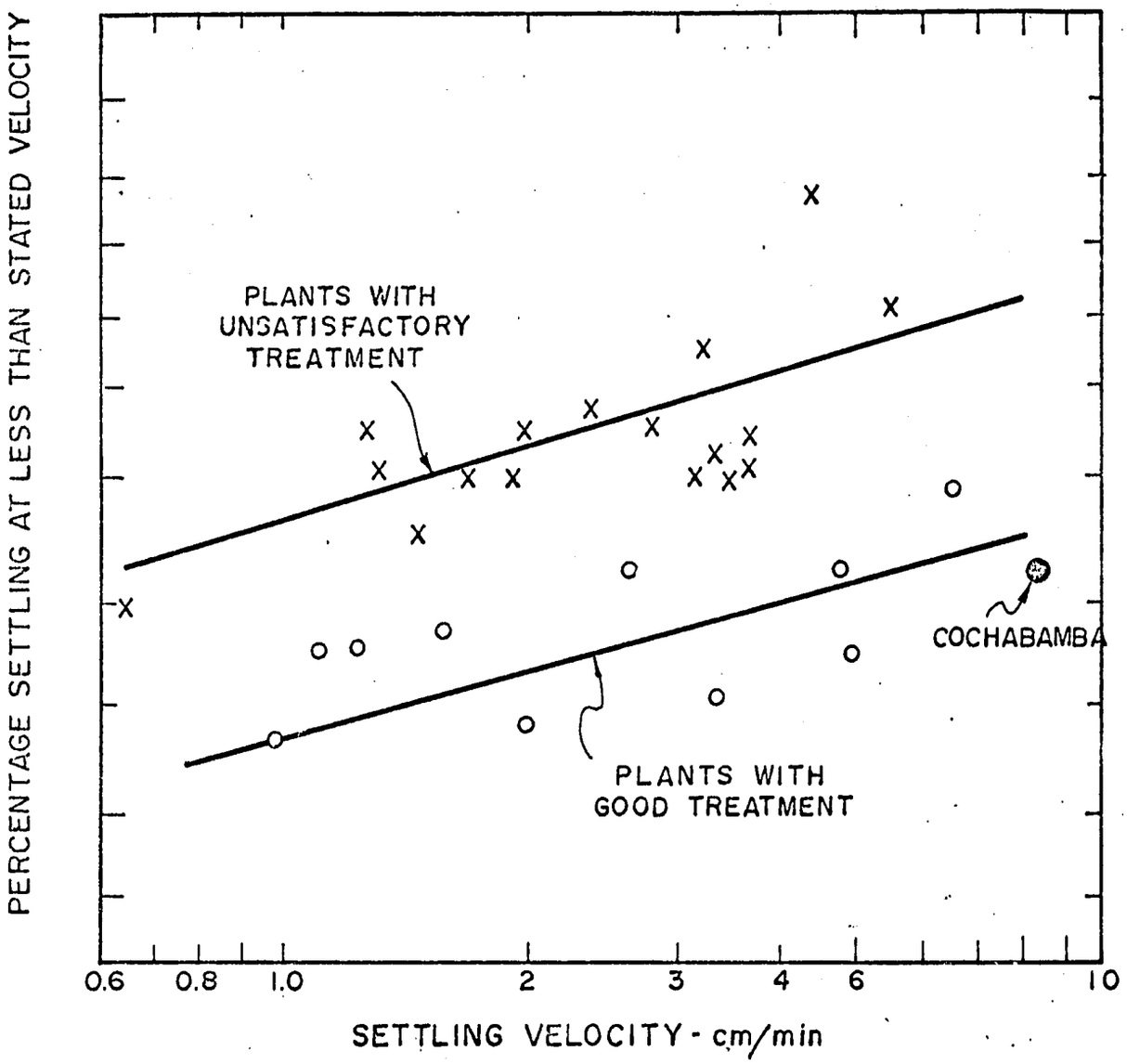


COMPARATIVE STUDY OF THEORETICAL AND ACTUAL SETTLING EFFICIENCIES

PERIOD OF LISTING: OCTOBER 1976

FIGURE 3-18

WATER SUPPLY SYSTEM - COCHABAMBA



AVERAGE SETTLING EFFICIENCY	FIGURE
WATER SUPPLY SYSTEM - COCHABAMBA	3-19

3) The influence of temperature

Water temperature is an important parameter in the sedimentation process because of its influence on the viscosity of the water and consequently on the determination of the flow conditions (Reynolds number), on the drag coefficient (which in turn influences the settling velocity) and on the performance of the settling units.

Temperature also has an appreciable influence by modifying the density of water masses, producing thermal density currents which have a notable effect on settler performance.

When conducting the routine tests to determine the characteristics of the raw and settled waters, a cyclical water quality tendency was found - depending on the temperature of the water. Efficiencies as high as 91% were observed with low temperatures (4°C); as the temperature rose, especially around noon when it reached 11°C, the settler efficiency dropped to 82%. Table 3-9 gives the values obtained in 250 tests which show a clear linear correlation between settler efficiency and water temperature (figure 3-20).

Table 3-9

INFLUENCE OF WATER TEMPERATURE ON THE PERFORMANCE OF HIGH-RATE SETTLING UNITS
NUMBER OF TESTS: 250
RAW WATER TURBIDITY: 3-10 JTU
WATER TEMPERATURE: 4-11°C

Temperature range °C	Settler unit efficiency
4 - 5	0.91
5 - 6	0.89
6 - 7	0.88
7 - 8	0.85
8 - 9	0.84
9 - 10	0.83
10 - 11	0.82

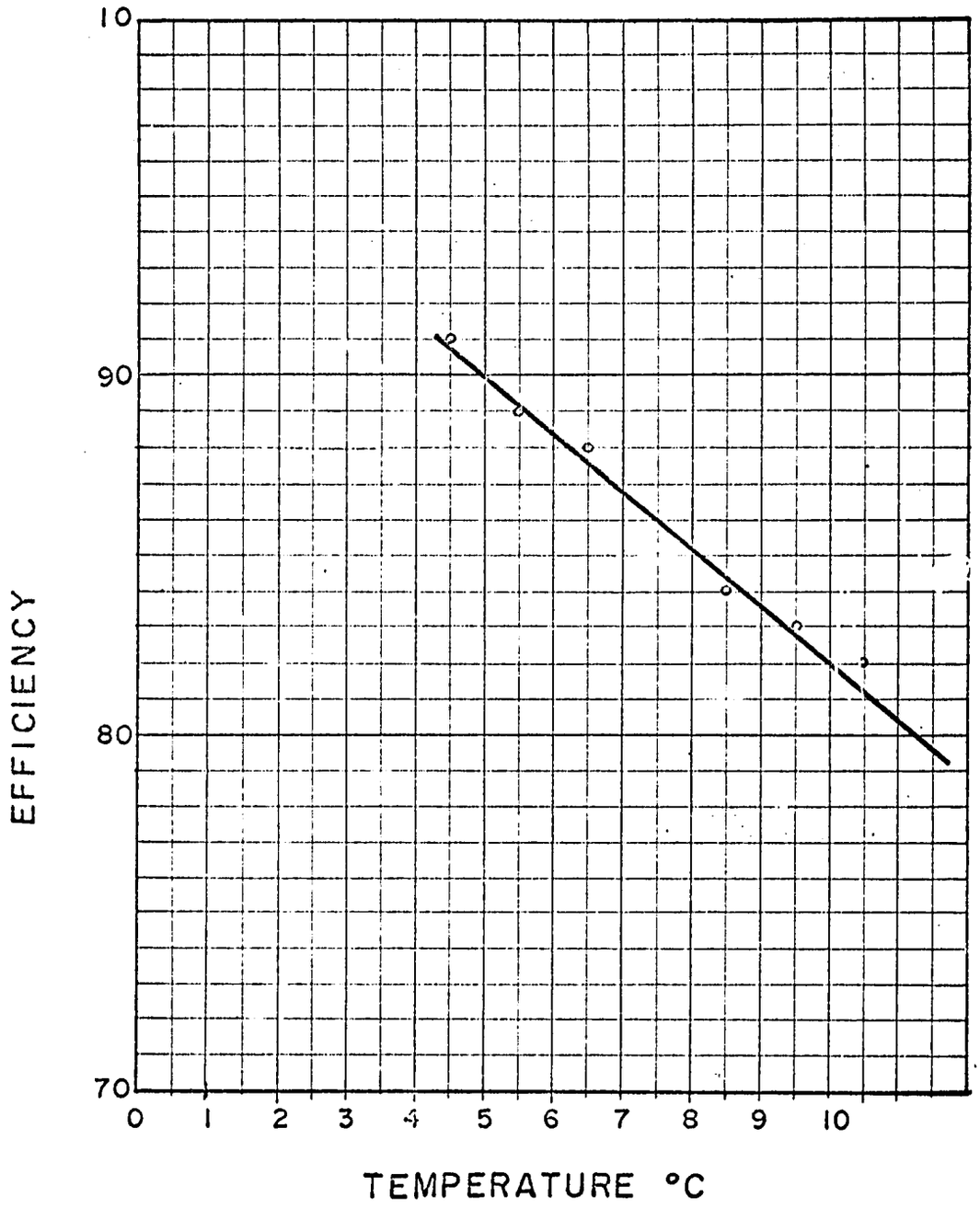
$$\text{Efficiency} = 1 - \frac{\text{settled water turbidity}}{\text{raw water turbidity}}$$

REGRESSION EQUATION CORRELATION $y = 0.98 - 0.02\ x$

GOODNESS OF FIT $r^2 = 0.92$

$$y = 1 - \frac{\text{SETTLED WATER TURBIDITY}}{\text{RAW WATER TURBIDITY}}$$

x = WATER TEMPERATURE (°C



INFLUENCE OF WATER TEMPERATURE ON THE EFFICIENCY OF THE HIGH-RATE SETTLERS	FIGURE 3-20
WATER SUPPLY SYSTEM - COCHABAMBA	

4) Determination of the hydraulic characteristics of the settling units

In order to evaluate and define the hydraulic characteristics of the settling units, tracer tests were carried out using the flow evaluation criteria of Wolf and Resnick in their original form:

$$\frac{c}{C_o} = e^{-\frac{1}{(1-p)(1-m)}\left[\frac{t}{to} - p(1-m)\right]}$$

$$F(t) = 1 - \frac{C}{C_o}$$

or expressed in its simplified form:

$$\log\left[1 - F(t)\right] = -\,\mathrm{Tag}\alpha\left[t/to - \theta\right]$$

when

Piston flow: $p = \dfrac{\theta\ \mathrm{Tag}\alpha}{0.435 + \theta\ \mathrm{Tag}\alpha}$

Mixed flow: $M = 100 - p$

Dead space: $M = 1 - \dfrac{\theta}{p}$

The following average values were obtained in the six tests:

Piston flow = 28 %
Mixed flow = 72 %
Dead spaces = 45 %

Table 3-10

FLOW CONDITIONS IN HIGH-RATE SETTLING UNITS - 6 TESTS

Condition	Value		
	Maximum	Minimum	Average
Piston flow	37	14	28
Mixed flow	86	63	72
Dead Spaces	73	19	45

Table 3-10 gives the results of the tests, which are somewhat incompatible with the theoretical principles of high-rate settler design which consider the existence of an absolutely laminar flow with low Reynolds numbers. This leads to the deduction that the general Wolf - Resnick equation is not suitable for determining the hydraulic conditions in high-rate settlers. On the other hand, the equations developed by Hassan M. El Baroudi, which are given below, yielded better results:

$$\frac{C}{C_o} = \frac{e^{-\left(\frac{1}{\beta}\right)\left[t/t_o-\gamma\right]} - e^{-(1/\alpha)\left[t/t_o-\gamma\right]}}{\beta-\alpha}$$

where α = Mixed flow
β = Varied flow
γ = Piston flow

$m - 1-(\alpha+\beta+\gamma)$ = Dead spaces

The following average conditions were obtained

Piston flow = 37%
Mixed flow = 5%
Dead spaces = 40%

These values are quite different from those obtained with the Wolf-Resnick formula.

5) Conclusions

a) It is feasible to use an accelerated sedimentation process in water treatment plants and obtain high efficiency (above 90%), even higher than the theoretical performance determined by laboratory tests.

b) The use of high-rate sedimentation with parallel plates makes it possible to surpass the efficiency determined theoretically by jar tests and others. This success seems to be due to a phenomenon of self-interference, similar to that produced in sludge blanket units. Based on data from other plants, it is supposed that the performance of this type of settling units improves with the period of operation.

c) From the results of the special tests as well as the normal operation of the high-rate settlers, the following can be summarized:

The efficiency of high-rate settlers depends mainly on the water quality, coagulation conditions, the overflow rates or settling velocities used, and the water temperature.

It was not possible to establish a clear correlation between the hydraulic conditions, geometrical forms and the efficiency of the settling units. These factors have a clear influence on the conception of the project and the cost of the settling units.

. When dealing with the sedimentation of agglomerable particles, it is preferable to set the overflow rates of the settling units (settling velocity) on the basis of experimental criteria rather than use arbitrary figures.

. The use of tracers with any theory of evaluation defines the distribution and classification of the flows, but not the trajectories.

- To avoid discrepancies in the tracer test results, it is advisable to add small amounts of tracer prior to the injection of the instanteous dosage test for a period equal to at least 1/60 of the theoretical detention time.

d) The flow characterization equations developed by El Baroudi give results which reflect the actual flow conditions produced in high-rate settlers.

H. Filters

During the research period the declining-rate filters were evaluated both under normal operating conditions and by means of special tests, the results of which are given below.

1) Filter efficiency

Due to the efficient pretreatment, the turbidity of the water entering the filters was almost always below 3 JTU. The filtered water was of excellent quality, since except for very short periods of time, the turbidity of the filter effluent was less than 1.0 JTU (95% of the time).

The maximum turbidity values produced were 2.5 JTU due to operator problems, and the average turbidity was 0.59 JTU. Table 3-11 illustrates the average efficiency of the filters.

Table 3-11

FILTER INFLUENT AND EFFLUENT TURBIDITIES

Influent turbidity JTU	Frequency	Effluent turbidities (JTU)		
		Minimum	Average	Maximum
0.5 - 1	70	0.13	0.43	0.8
1 - 1.5	100	0.30	0.54	0.9
1.5 - 2	35	0.40	0.63	0.9
2.0 - 2.5	10	0.50	0.73	0.9
2.5 - 3.0	10	0.60	0.80	1.0

Since there were no periods of poor water quality, it was not possible to study the efficiency of the filters with high turbidity and color loads. The normal color removal capacity was 5 CU; 95% of the time there was a total absence of color.

a) Filtration rates

Although it was difficult to find an exact correlation between the period of operation of the filter and the flow rate, tests

indicated that after backwashing the filter takes a loading of 325 $m^3/m^2/day$ (the design flow being 300 $m^3/m^2/day$). Loadings as high as 375 $m^3/m^2/day$ were observed for the first two hours of the run. The flow rate decreases gradually until after 30 hours the filter is accepting a loading of between 30 and 50 $m^3/m^2/day$. The average filtration rate was 186 $m^3/m^3/day$ for the entire filter run. The curves for the flow rate variation are shown in figure 3-21, in which three operational stages can be seen. The first stage corresponds to an increasing flow rate, the second to a decreasing rate with a linear tendency, and the third stage to a relatively constant flow rate.

b) Loss of head
The head loss variation had a linear tendency during the first and second stages of filter operation, followed by an exponential increase and then a simultaneous stabilization of the head loss and flow rate in the third stage.

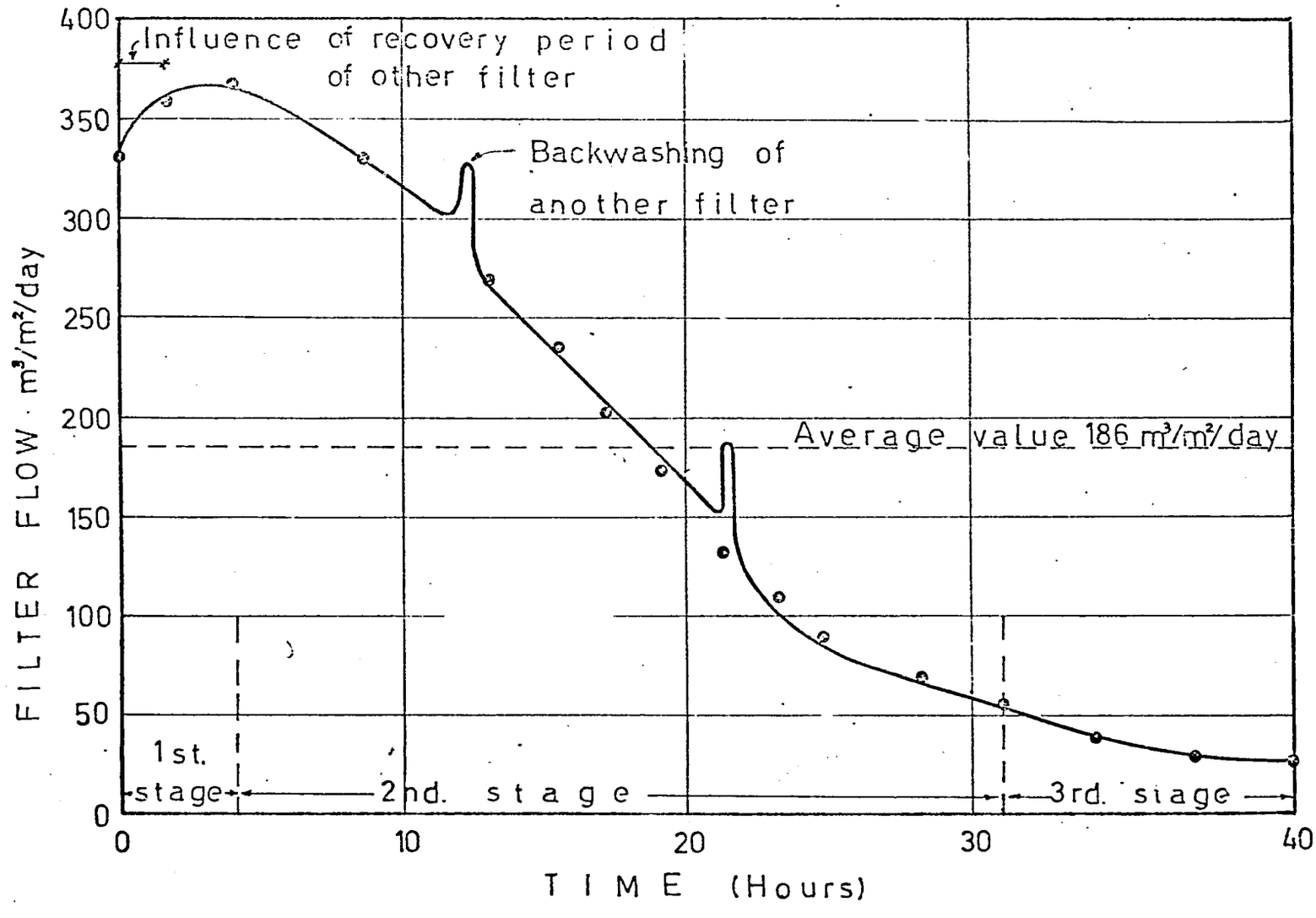
Figure 3-22 shows the curves of the variation in head loss in Filter No. 1.

c) Variation of water level in the filters
At the beginning of the filter run the resistence is minimum and the filter takes a high load without greatly affecting the water level in the other filters (stage 1): in the second operational stage the water level increases with a linear tendency which is a product of the linear variation in head loss. However, at the end of the second stage the filter loses its hydraulic capacity, with high head loss, so that in order to continue functioning the water level begins to increase exponentially (figure 3-23).

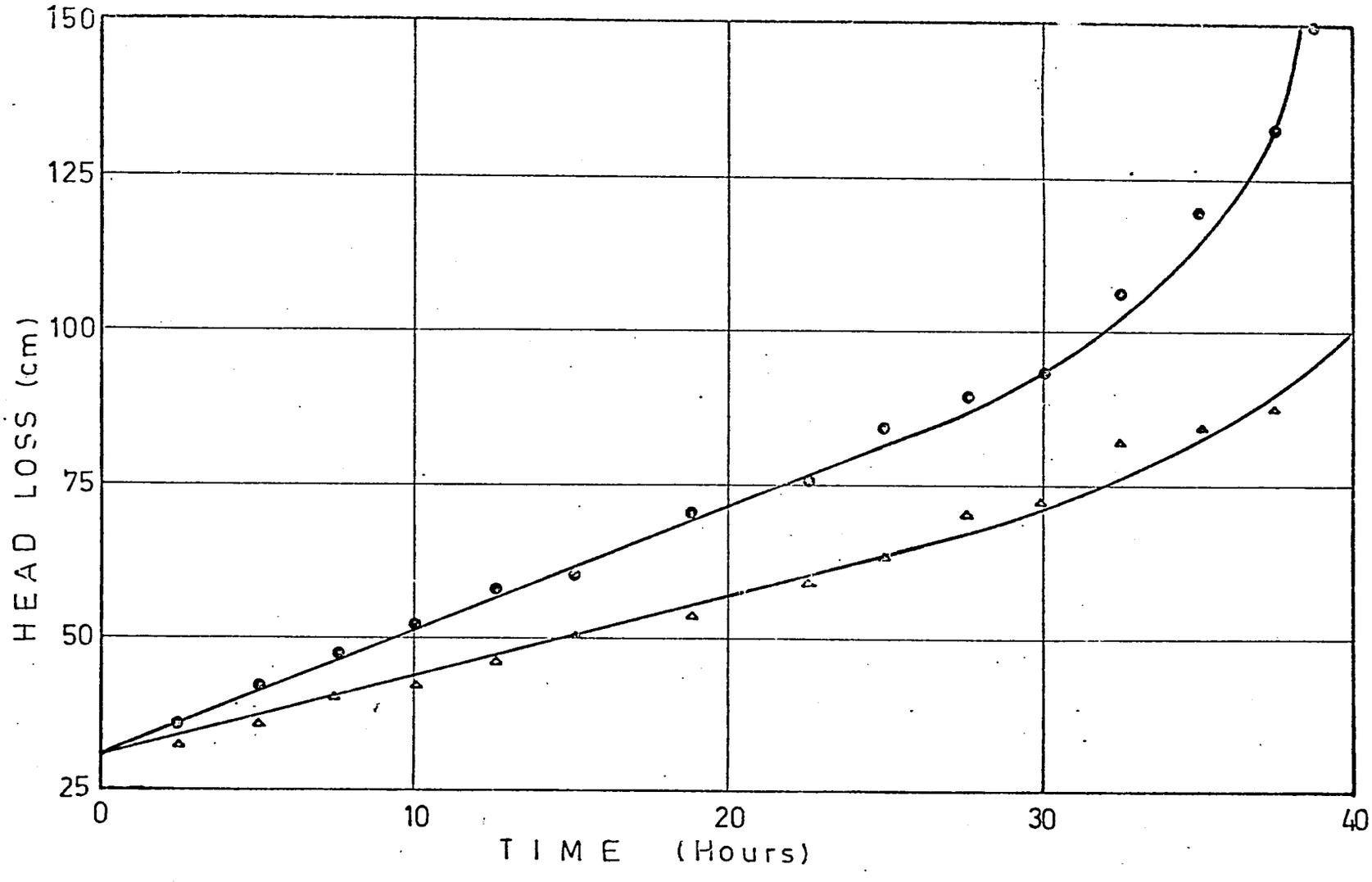
d) Variation in water quality
Although the quality of the filter effluent in general is superior to that recommended in the WHO International Drinking Water Standards, there is a progressive deterioration of water quality (segment a-b, figure 3-24) during the initial and middle stages of the filter run with a tendency toward a linear correlation, but in the third stage there is an exponential deterioration as a function of time which rapidly reaches the point of filter breakthrough (segment b-c, figure 3-24). The influence of the backwashing of other units on the effluent water quality of the filter under study will be analyzed later on.

e) Filter runs
The runs of the filter being studied varied from a minimum of 21 hours to a maximum of 98 hours; normally the values were between 40 and 80 hours and the average value was 64.6 hours. The first and second stages combined averaged between 30 and 50 hours.

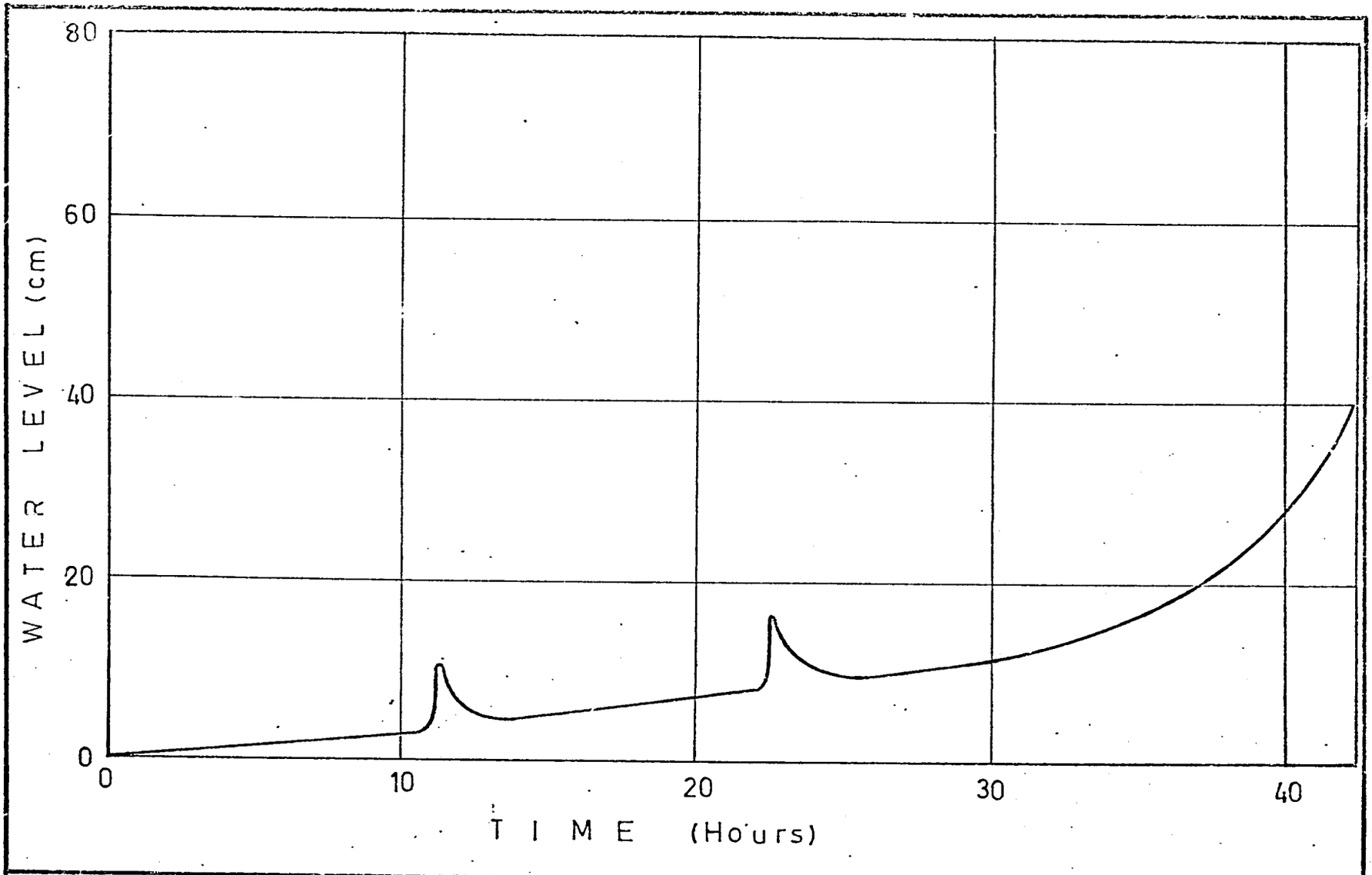
Analyzing the data given above as a whole, the limiting factors for the filter run are: loss of capacity (filtration rate), available water head (loss of head), water level above the



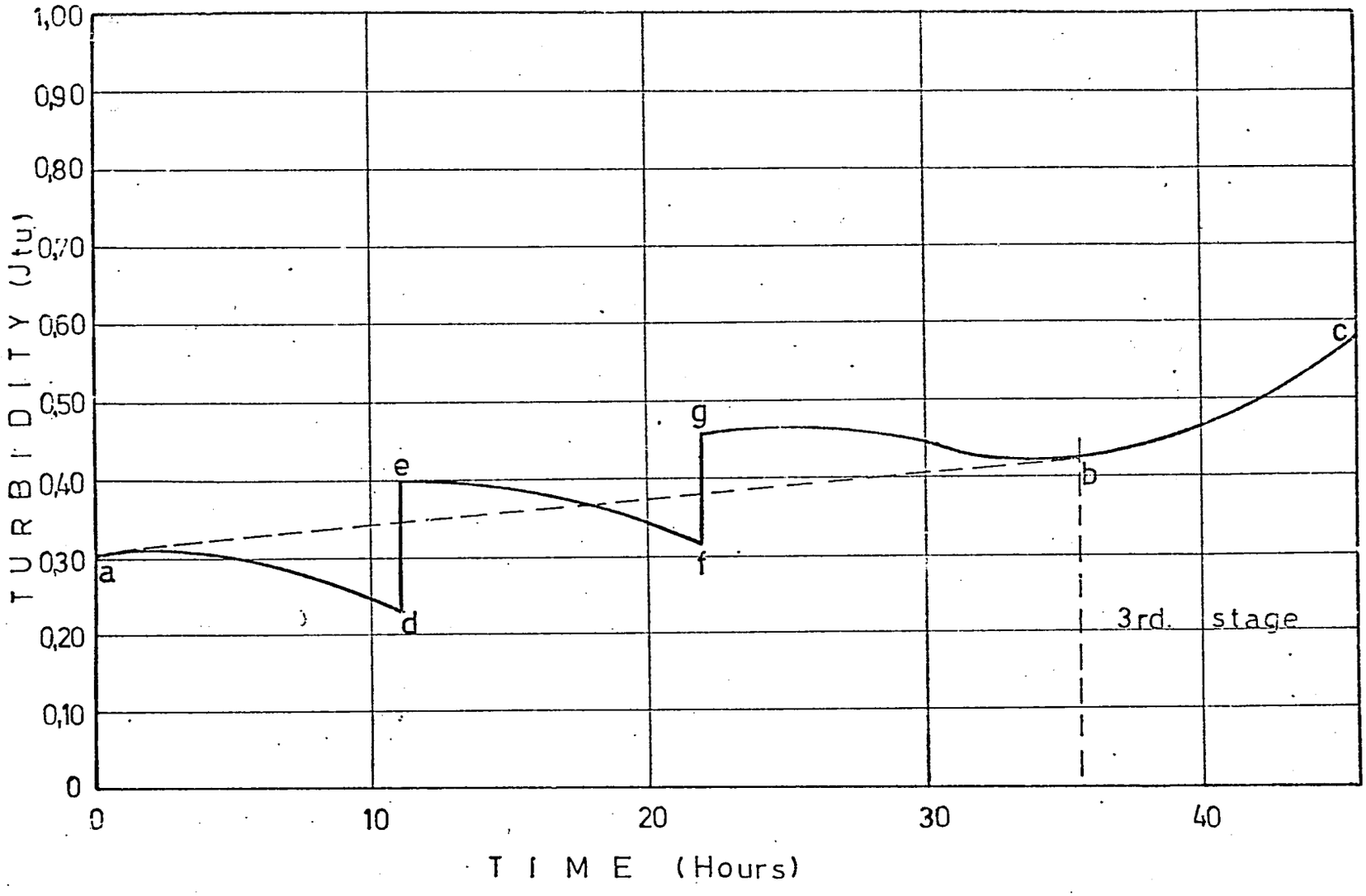
FLOW RATE	FIGURE 3-21
WATER SUPPLY SYSTEM - COCHABAMBA	



HEAD LOSS in DECLINING-RATE FILTERS	FIGURE 3-22
WATER SUPPLY SYSTEM - COCHABAMBA	



VARIATION of WATER LEVEL	FIGURE 3-23
WATER SUPPLY SYSTEM _ COCHABAMBA	



FILTERED WATER QUALITY	FIGURE 3_24
WATER SUPPLY SYSTEM _ COCHABAMBA	

filter bed (water loading) and effluent water quality, all of which should be analyzed in relation to the filter run. In the ideal run, the maximum flow rate, the maximum permissible turbidity and the maximum head loss will be reached simultaneously. These factors can be regulated by pretreatment to obtain the most suitable floc.

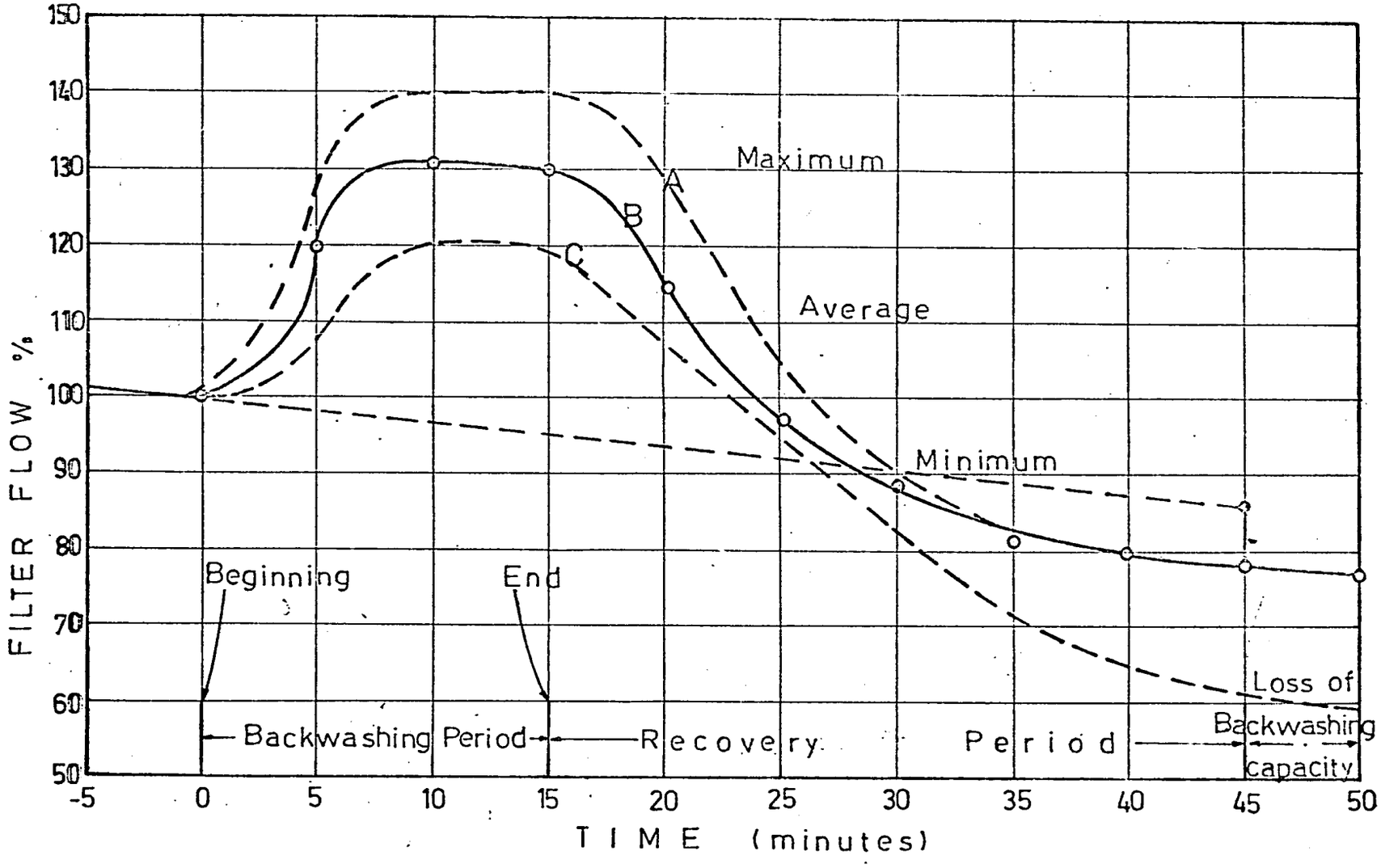
2) Filter backwashing

a) Influence of backwashing on the filtration rate
As it can been seen in figures 3-21 and 3-25, when one filter is backwashed with the flow from the other units, the flow rate in the other units increases in an inverse proportion to the number of units, in this case up to 30% of the filter flow (curve B of figure 3-25 which shows the results of one test). The distribution of flow during backwashing is not equal in all the filters. Apparently the cleanest filter tends to take the highest loading, as indicated in curve A of figure 3-25 and the dirtiest unit takes a lesser loading (curve C of the same figure).

Three distinct stages of flow rate in the other units are also observed during the backwashing of one of the filters. The first stage has a duration of up to five minutes during which the filters take a progressively higher loading until a maximum value is reached. In the second stage, this maximum value remains constant throughout the rest of the washing period. The third stage begins when washing has been completed and represents the recuperation period of the filter which is approximately three times the backwash time. It should be mentioned that each time one filter is washed, the others lose an average of 10% of their normal filtration capacity (value "a" in figure 3-25).

b) Influence of backwashing on the quality of the effluent of the other filters
In addition to what has been indicated in the discussion of filtered water quality, it should be noted that the relatively rapid increase in flow rate due to the backwashing of any of the filters almost instantly produces a deterioration in effluent water quality of an average magnitude of 0.20 JTU (segments d-e and f-g, figure 3-24). When the backwashing is done during the first or second stage of filter operation there is an average recuperation of 0.10 JTU in each cycle, which is maintained until another unit is washed. If the backwashing is done in the third stage of the filter run, no recuperation is observed and the quality continues to deteriorate.

c) Backwash characteristics
The studies conducted indicate that the filter backwashing is adequate for the following reasons:



VARIATION of FLOW DURING BACK-WASHING of ANOTHER FILTER	FIGURE 3-25
WATER SUPPLY SYSTEM - COCHABAMBA	

The backwash velocities during the second stage reached 0.78 m/min, with average values of 0,70 m/min, which are above the minimum design requirements (0,60 m/min).

The backwashing time varied between 6 and 14 minutes with an average of 10 minutes (figure 3-26); 95% of the time backwashing took less than 12 minutes. The backwashing time was determined by analyzing the turbidity of the wash water, which varied from a minimum of 3,5 JTU to a maximum of 10 JTU with average values of 5,38 JTU; 95% of the time the turbidity was less than 7.96 JTU.

There was no loss of filter media nor excessive mixing of sand and anthracite.

After one year of operation, a study of the topography of the supporting gravel bed showed a maximum variation of 5 cm, with the greatest values being those occurring opposite the wash water inlet. The filter bed topography, as illustrated in figure 3-27, indicates a fairly uniform distribution of flow and the absence of problems due to jetting.

3) Conclusions

The tests and normal plant operation demonstrate not only the viability of the theory of declining-rate filtration and the possibility of backwashing a filter with the flow from the other units, but also that it is possible to apply these principles in the design of simple and economic treatment plants capable of achieving high levels of efficiency and performance, superior to those normally obtained in conventional plants.

3.4.3 ECONOMIC ANALYSIS

A. Construction costs

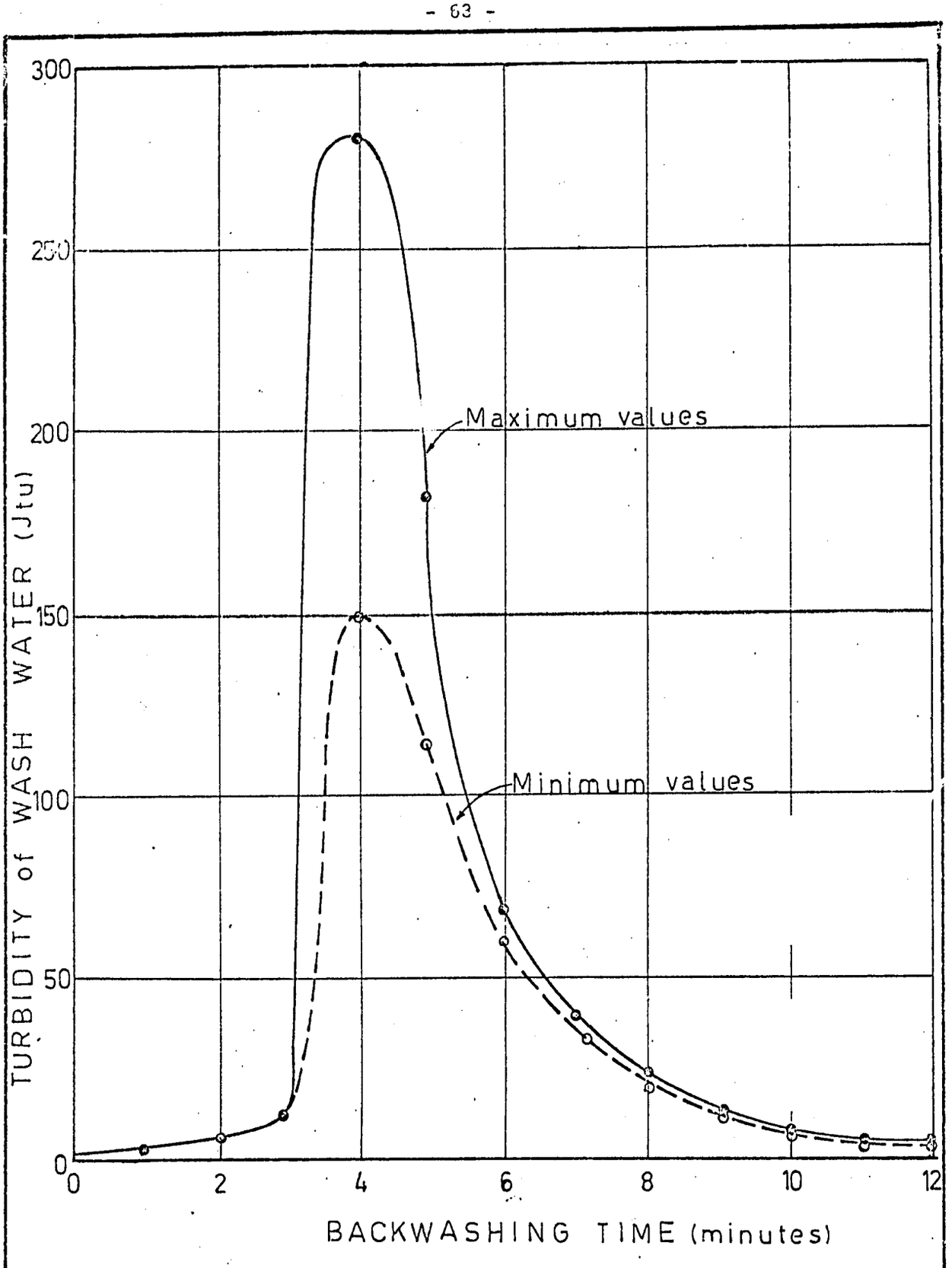
The total plant construction cost was US$ 262 380, which for its design capacity of 235 l/s gives a unit cost of US$ 1 111 per l/s.

A comparative study of the construction costs of the Pampahasi water treatment plant, which supplies water to part of the city of La Paz and consists of conventional rapid mixing and rapid filtration units, shows an approximate construction cost of US$ 1 000 000 and a unit cost of US$ 3 367 per l/s.

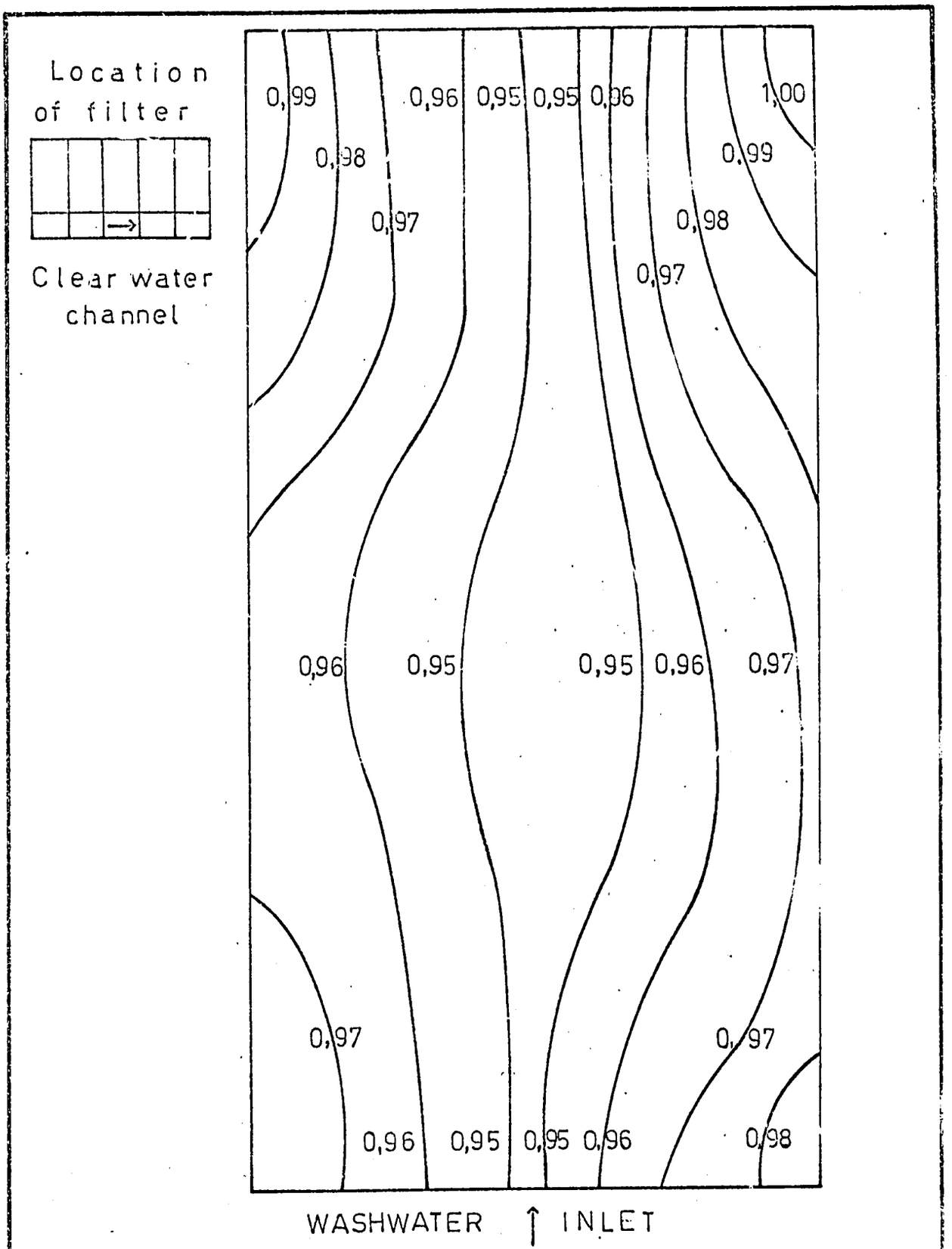
Although both plants were built at the same time and under relatively similar conditions, the cost of the Cochabamba plant was 33% of that of the Pampahasi plant.

The construction costs are divided as follows:

Labor	= 33,37%
Materials	= 60,63%
Supervision and administration	= 6.00%



BACKWASHING TIME	FIGURE 3-26
WATER SUPPLY SYSTEM-COCHABAMBA	



TOPOGRAPHY of SUPPORTING BED	FIGURE 3-27
WATER SUPPLY SYSTEM-COCHABAMBA	

Only 8% was spent on skilled labor and 8% for imported equipment and materials.

These amounts are of great significance and are very favorable for the project.

B. Operating costs

During the research period, no expenses were incurred for maintenance or repairs. Therefore, only the operational costs are considered here, with unit costs of:

Alum	US$ 140.00 US ton
Lime	US$ 47.50 US ton
Operators wages	US$ 300.00 man/month

The operating costs varied between US$ 3.50 and 4.38, with an average cost of US$ 3.91 per 1000 m^3 of treated water; 63% corresponds to personnel and the remaining 37% to chemicals and other supplies.

C. Research data

The results of the economic survey carried out for the University of Oklahoma are included in Appendices 3-E and 3-F.

4. EVALUATION OF THE WATER TREATMENT PLANT OF LINHARES, ESPIRITO SANTO, BRAZIL (RESEARCH PROJECT No. 2)

4.1 INTRODUCTION

The first stage of the treatment plant for the city of Linhares was designed and built with rapid filters and conventional treatment methods. The Fundação de Serviço Especial de Saúde Pública (FSESP), the agency responsible for the construction, operation and maintenance of the water supply systems in the State, decided to expand the capacity of the treatment plant by building two contact clarifiers with a capacity of 60 l/s. The new units were designed based on experiences in Russia and The Netherlands as well as work done by Miller and Boddy in England, McKinney in the United States and Grinplastch in Brazil.

CEFIS was contracted by the University of Oklahoma to carry out an evaluation of water treatment plants designed using new technological concepts to determine the technical efficiency of the processes involved and the degree of adaptability of this technology to the conditions prevailing in developing countries. The Linhares treatment plant was selected as one of the project sites because it is an example of advanced technology and because the city of Linhares is representative of conditions in developing countries. An agreement was signed with FSESP for the execution of studies and field research including the following components:

- Study of the general demographic and socio-economic conditions.
- Technical evaluation of the characteristics and efficiency of the new treatment units.
- Economic study of the initial investments and operation and maintenance costs.

The main results of these studies are described in this chapter.

4.2 GENERAL INFORMATION ABOUT THE CITY

The geographical coordinates of the city of Linhares are 19°24'20" latitude south and 40°04'05" longitude west. It is the capital of the Municipality of Linhares in the State of Espirito Santo, Brazil (figure 4-1), located in a large fertile plain between the Doce and Pequeno Rivers and Juparana and Aviso Lakes, with an average elevation of 28 m above sea level. The average annual precipitation is 1516 mm and the temperature varies between 17° and 38°C.

Linhares is the fourth largest municipality in the state in terms of population, 86.6% of which is rural. In 1968 when the water supply system was designed, the municipality had 13 700 inhabitants. Table 4-1 gives the population estimates.

LOCATION OF LINHARES BRAZIL	FIGURE 4.1

Table 4-1

POPULATION GROWTH FOR THE CITY OF LINHARES

Year	Population
1950	2 939
1960	5 751
1964	9 625
1968	13 700
1998	35 000

4.3 GENERAL DESCRIPTION OF THE WATER SUPPLY SYSTEM

Figure 4-2 shows the general plan of the water supply system for the city of Linhares, which has the following characteristics:

4.3.1 Demand

The unit consumption is 150 l/capita/day. The average daily consumption at the beginning and end of the design period is 23.78 l/s and 60.76 l/s. A coefficient of 1.31 for the maximum daily consumption at the end of the design period yields a flow of 79.30 l/s.

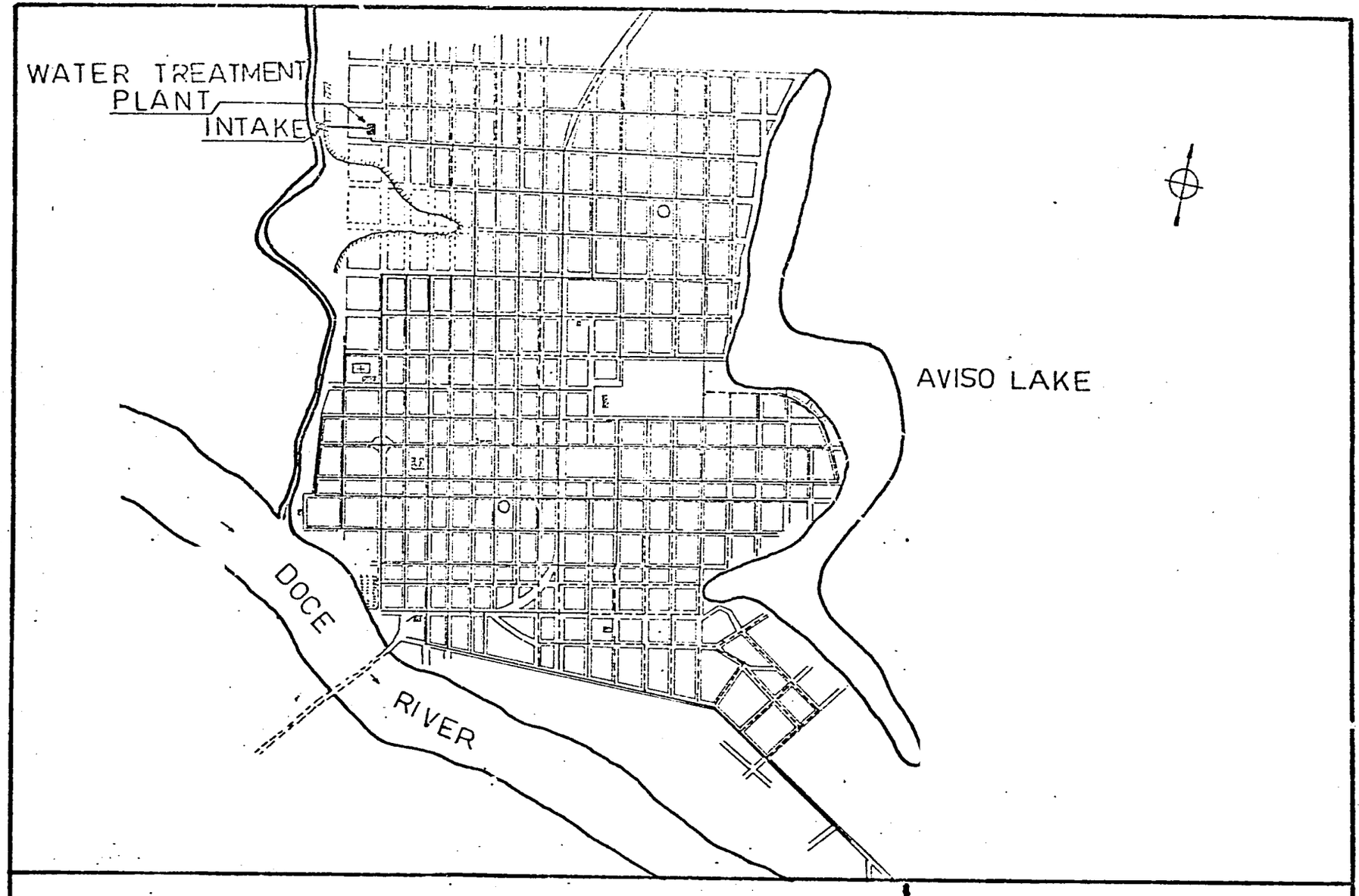
4.3.2 Source of supply

The water is taken from the Pequeno River, which is a channel connecti the Doce River and Juparana Lake. During the summer (rainy season) the waters flow from the Doce River to the lake and during the winter (dry season) from the lake to the river. The minimum flow in the river is 8 m^3/s.

The water quality of the Pequeno River varies according to the seasons, as indicated above. As a general reference, the results of physical-chemical and bacteriological analyses are given in Table 4-2. The principal problems are turbidity during the summer and high color with low alkalinity during the winter.

4.3.3 Collection works

These consist basically of a 250 mm screen connected to an asbestos-cement pipe with the same diameter, and gradients of 1.5% which transport the water to a suction well. The screen is located 0.60 m below the low-water level. The suction well is made of reinforced concrete with a section of 1.20 x 3.50 and a depth of 4.50 m.



WATER TREATMENT PLANT	FIGURE 4-2
WATER SUPPLY SYSTEM - LINHARES	

Table 4-2

GENERAL CHARACTERISTICS OF THE WATER

Temperature	23°C
Color	38 CU
Turbidity	17 JTU
pH	6.9
Total solids	147 mg/l
Dissolved solids	147 mg/l
Alkalinity	16 mg/l
Total hardness	22 mg/l
Calcium hardness	10 mg/l
Magnesium hardness	12 mg/l
Chlorides	13 mg/l
Iron	0.03 mg/l
Free CO_2	3.8
Total coliforms/100 ml	35 000
MPN/100 ml	23

4.3.4 Pumping station and supply line

There are three 25 HP pumping units with capacities of 36.45 l/s each, and a head of 27 m.

The supply line consists of a 350 mm asbestos-cement pipe about 250 m long.

4.3.5 Treatment plant

The original treatment plant was designed with an initial treatment capacity of 36.45 l which was expanded to 50 l/s by constructing two additional rapid filters. Two new contact units have increased the capacity by another 60 l/s (Figure 4-3). The plant includes the following units:

A. Chemical feeders

Aluminum sulfate in solution and lime in suspension are added using a dosing tower.

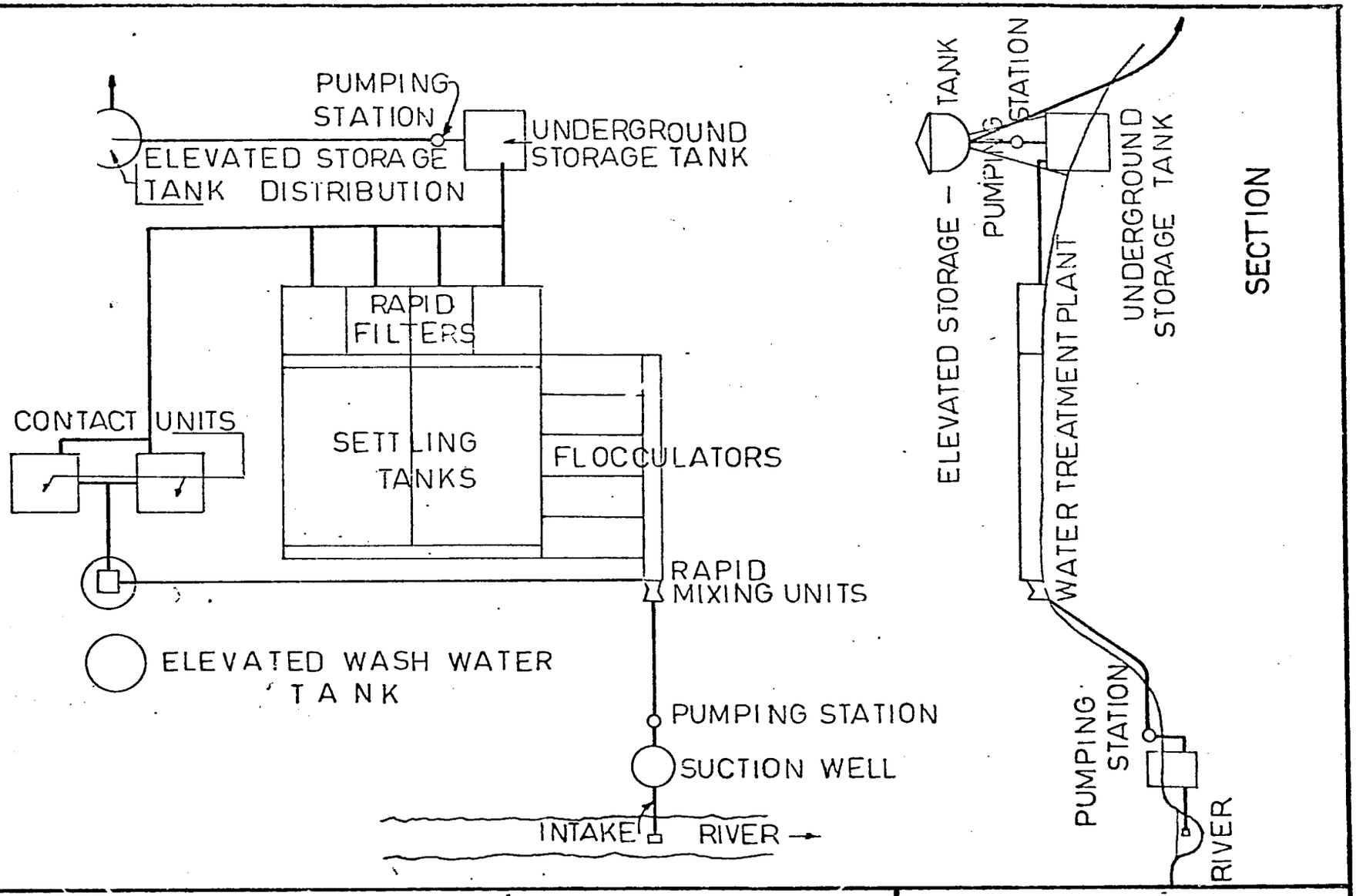
B. Mixing system

Mixing is done in a Parshall flume with a 15 cm throat and a head loss of 25 cm with maximum flow, producing velocity gradients between 1 200 and 1 600 s^{-1}.

C. Clarification

1) Original plant

a) *Flocculation units.* Flocculation takes place in a vertical flow hydraulic flocculator with five square chambers, with a section of 2.00 x 2.00 m, and an average depth of 3.55 m. With the



GENERAL PLAN

FIGURE 4-3

WATER TREATMENT PLANT LINHARES

original flows the detention time is 30 minutes and the estimated average velocity gradient is 26 s^{-1}. The chambers are joined by orifices located in the floor and by weirs in the upper part, in order to produce helicoidal flow. The total head loss in the flocculator is 11 cm.

b) *Sedimentation units.* Settling takes place in two conventional horizontal flow settling units with the following characteristics:

Width - 5.00 m
Length - 17.00 m
Average depth - 3.15 m
Overflow rate - 18 $m^3/m^2/day$
Horizontal velocity - 0.11 cm/s

The flocculators are connected with the settling tanks by a canal with two gates for each settler, maintaining a maximum velocity of 0.14 m/s. The water is distributed in the settling tanks through a canal with a perforated floor; the water velocity is 0.18 m/s, and 0.15 m/s in the diffusion wall. The water is collected at the outlet of the settling tank by a channel located at the far end which has a flow of 3.78 l/s per meter of channel.

c) *Filtration.* Filtering was done in two conventional rapid filters with the following characteristics:

Area of each unit - 12.90 m^2
Filtration rate - 122 $m^3/m^2/day$
Filter media - sand with an effective size of 0.50 mm and a uniformity coefficient of 1.92

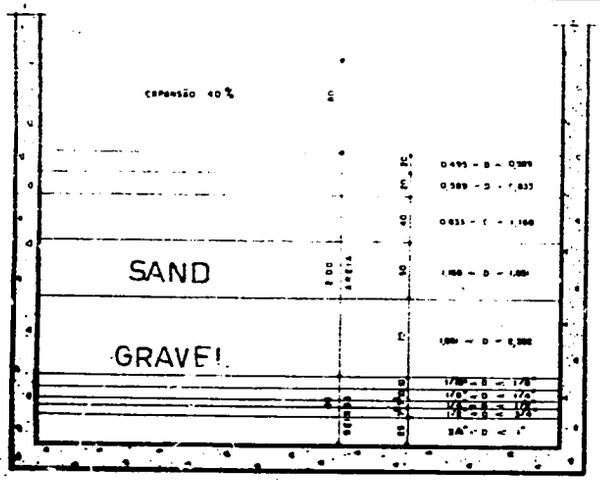
The filter has a false bottom with 25 porcelain nozzles per square meter. The filters are backwashed using conventional methods. The bottom of the wash water storage tank is 3.50 m above the surface of the filter sand, producing upflow backwash velocities of 0.73 m/s.

This original design was expanded by adding two more conventional rapid filters and modifying the flocculation and sedimentation units to produce a flow of 50 l/s.

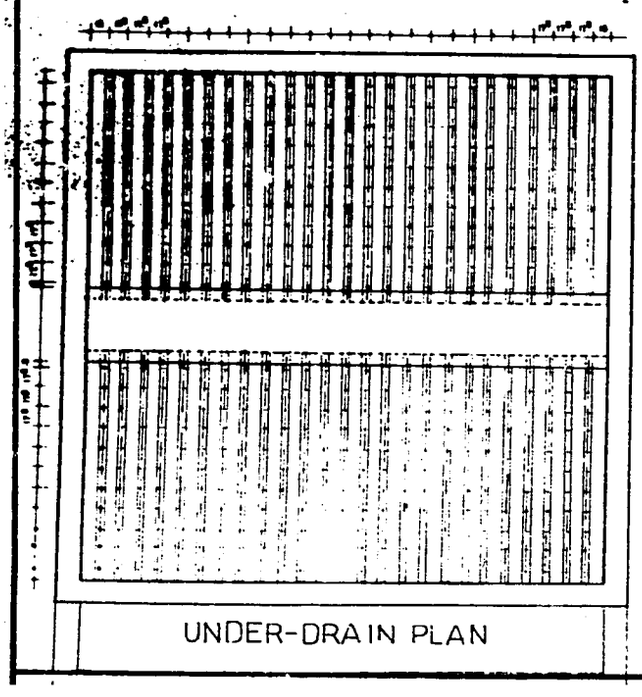
2) Contact clarifier

The treatment plant described above was later modified by the construction of two contact clarifiers (figures 4-4 and 4-5) with the following characteristics:

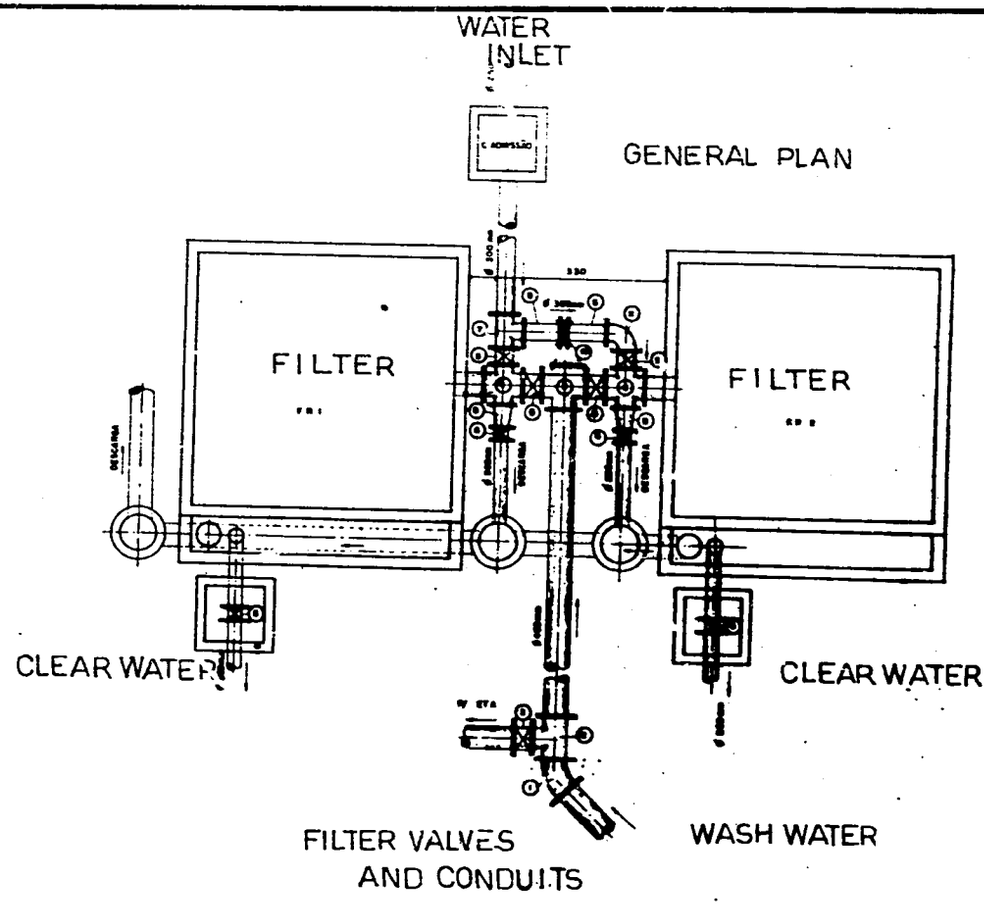
Number of units - 2
Average capacity per unit - 30 l/s
Average filtration rate - 130 $m^3/m^2/day$
Maximum filtration rate - 175 $m^3/m^2/day$



FILTER BED



UNDER-DRAIN PLAN



CONTACT UNITS	FIGURE 4-4
WATER TREATMENT PLANT LINHARES	

Dimensions of the filter box:

Section - 4.50 x 4.50 m

Height of supporting bed	- 0.60 m
Height of filter bed	- 2.00
Water head	- 1.40
Freeboard	- 0.40
Total height	4.40 m

The filter bed is made up of quartziferous sand with an effective size of 0.60 mm and a uniformity coefficient of 2.5. The height of the filter bed is 2.00 m, with the sand graded as follows:

Height	Diameter (mm)
0.20	0.495 - 0.598
0.20	0.598 - 0.833
0.40	0.833 - 1.168
0.50	1.160 - 1.661
0.70	1.661 - 2.362

The supporting bed is made up of gravel with the following characteristics:

Ø (mm)	Height of the layer (m)
2.36 - 3.20	0.10
3.20 - 6.35	0.10
6.35 -12.7	0.075
12.70 -19	0.075
19 -25.4	0.250
	0.60

The filter underdrain system consists of perforated pipes connected to a central reinforced concrete canal. The system has the following characteristics:

Diameter of the laterals - 75 mm
Number of laterals - 50
Length of laterals - 1.90 m
Separation between pipes - 0.15 m
Orifices - 2 rows of Ø 3/8" with separations of 17.5 cm

The backwash conditions are as follows:

Backwash rate - 840 l/min/m^2
Backwash velocity - 0.84 m/min
Sand expansion - 40%

There are three wash water troughs 0.35 m wide and 0.50 m high, with 1.40 m of freeboard above the surface of the sand.

A storage tank with a capacity of 147 m^3 for filter backwashing has been designed to complement the tank which has already been built, yielding a total volume of 204 m^3 which is enough to wash the filters with a flow of 17 m^3/min for 10 minutes.

D. Disinfection

Disinfection is accomplished using chlorine gas.

E. Clear water tank

After filtering, the water goes to an underground reservoir with a storage capacity of 400 m^3.

4.3.6 Storage and pumping

The system has a pumping station with three 20 HP centrifugal pumps which lift the water to an elevated storage tank with a capacity of 378 m^3.

4.3.7 Distribution system

Class 15 asbestos-cement pipes with diameters between 50 and 150 mm are used in the distribution system. The secondary and main networks have 200 to 300 mm pipes. The total length of the system is 58 700 m. Presently there are about 3 000 household connections.

4.4 RESEARCH STUDIES

Research was carried out on the following aspects: determination of the general characteristics of the city, technical evaluation of the treatment plant and economic evaluation of plant construction, operation and maintenance costs.

4.4.1 General characteristics of the city

In order to fulfill the principal research objective of the University of Oklahoma, information on the following topics was gathered using a survey questionnaire:

A. Identification of the city and institution responsible for water supply services;

B. Technological and demographic data;

C. Basic socio-economic data.

The results are included in Appendices 4-A and 4-B.

4.4.2 Technical evaluation

When water with low turbidity is treated using the conventional processes of coagulation, flocculation, sedimentation and rapid filtration, large amounts of coagulant are needed for the precipitate to drag down the

particles in its path. The high cost of this form of treatment led investigators to consider the possibility of treating the water by coagulation and contact filtration, where the addition of the coagulant produces a microfloc which is filtered before it increases in size through hydration. Furthermore, upflow filters have proven to be efficient since they use deep-bed filtration.

Engineer Grinplastch applied these criteria in designing the expansion of the Linhares Treatment Plant. The object of this research study was to evaluate the performance of the contact unit and its limits of use and applicability under normal operating conditions.

A. Raw water quality

Since the research was done during months of low precipitation, the water quality characteristics were good and treatment problems were due almost exclusively to color. The turbidity ranged between 4 and 87 JTU, with an average value of 10.82 JTU; 90% of the time the turbidity was less than 14 JTU. Figure 4-6 shows the turbidity frequency curve. Color ranged from 10 to 220 CU with an average value of 22.66 CU; 90% of the time the color was less than 40 CU and 95% of the time it was below 90 CU. The cumulative color frequency is indicated by the curve in figure 4-7.

The pH of the water ranged between 6.9 and 7.2, with an average value of 6.98. The alkalinity was low, with minimum values of 12 mg/l, maximum values of 31 mg/l and an average of 25.74 mg/l.

B. Process data

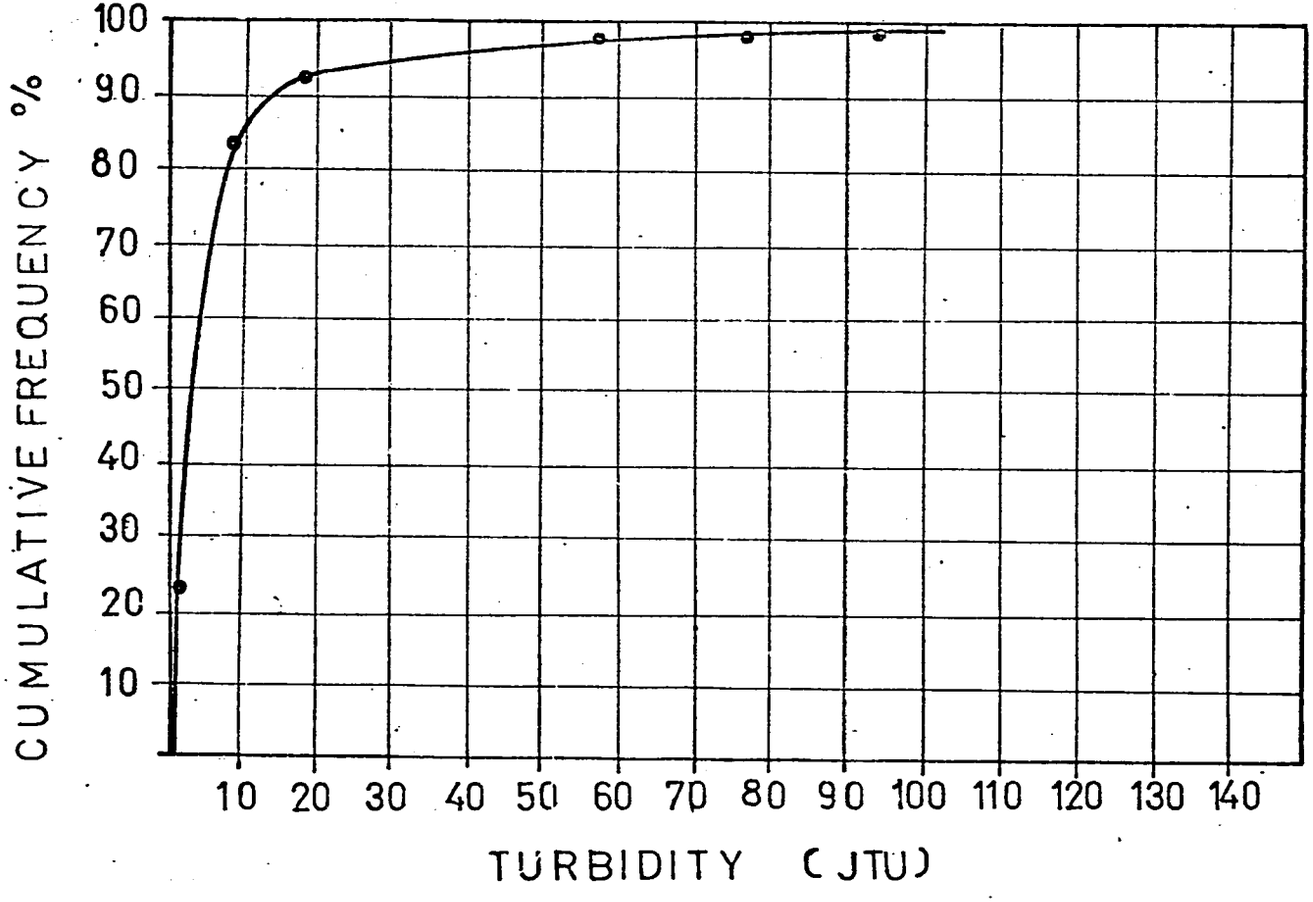
Data required by the University of Oklahoma regarding the technical characteristics of the processes used in the water treatment plant are included in Appendices 4-C and 4-E.

C. General plant performance

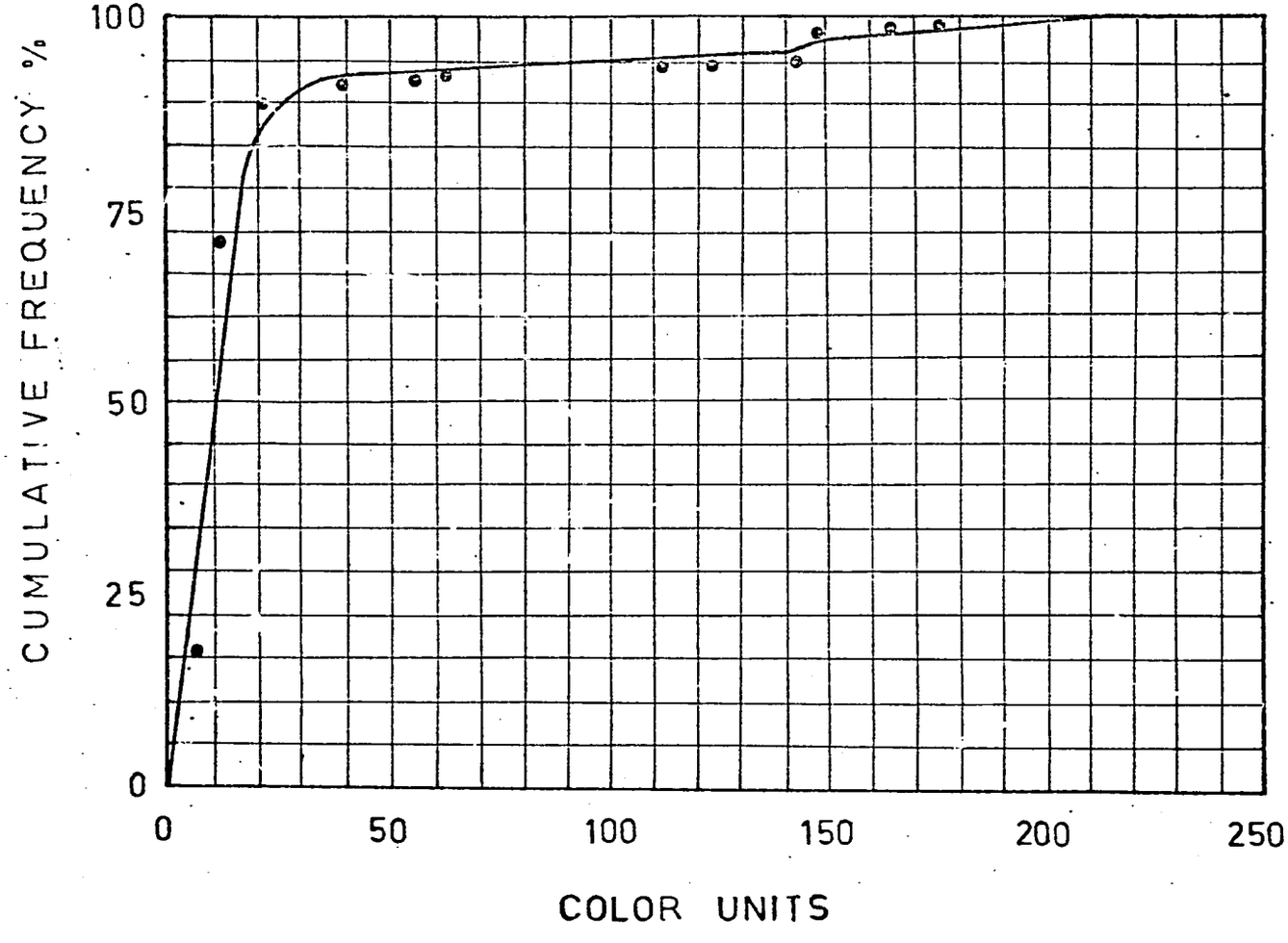
In general the plant was found to be highly efficient when treating clear waters (less than 50 color and turbidity units). Color removal efficiencies greater than 99.7% and turbidity removal efficiencies above 99.5% were achieved (figure 4-8). With higher color and turbidity values, there was a rapid decrease in efficiency, although with 100 units of turbidity or color, the efficiencies were 96 and 97.5% respectively. Figures 4-9 and 4-10 show the turbidity and color of the raw water and the treated water. The quality of the treated water remained relatively constant even though the plant has only two filter units.

D. Comparative efficiency

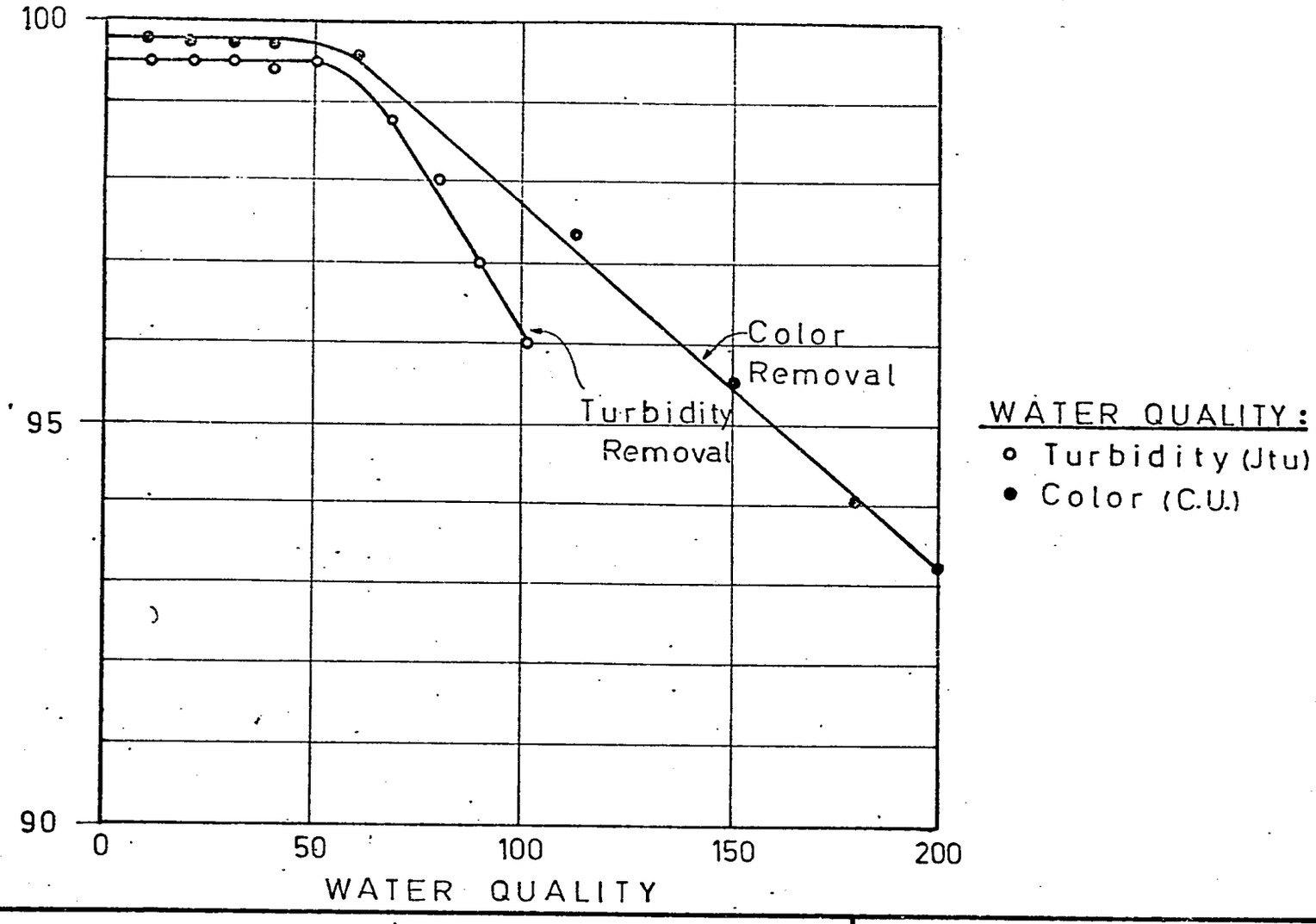
Since the plant has a single rapid mixing unit and two different treatment processes (contact units and conventional rapid filters) brief comparative studies of the efficiencies of the two processes were carried out while operating both systems at normal design rates. In general, the contact units showed greater efficiency. With normal filter runs of up to 40 hours, the effluent water turbidity remained constant, with values between 0.2 and 0.9 JTU; the average turbidity of the water filtered by the conventional filters was greater and the quality of the effluent deteriorated steadily.



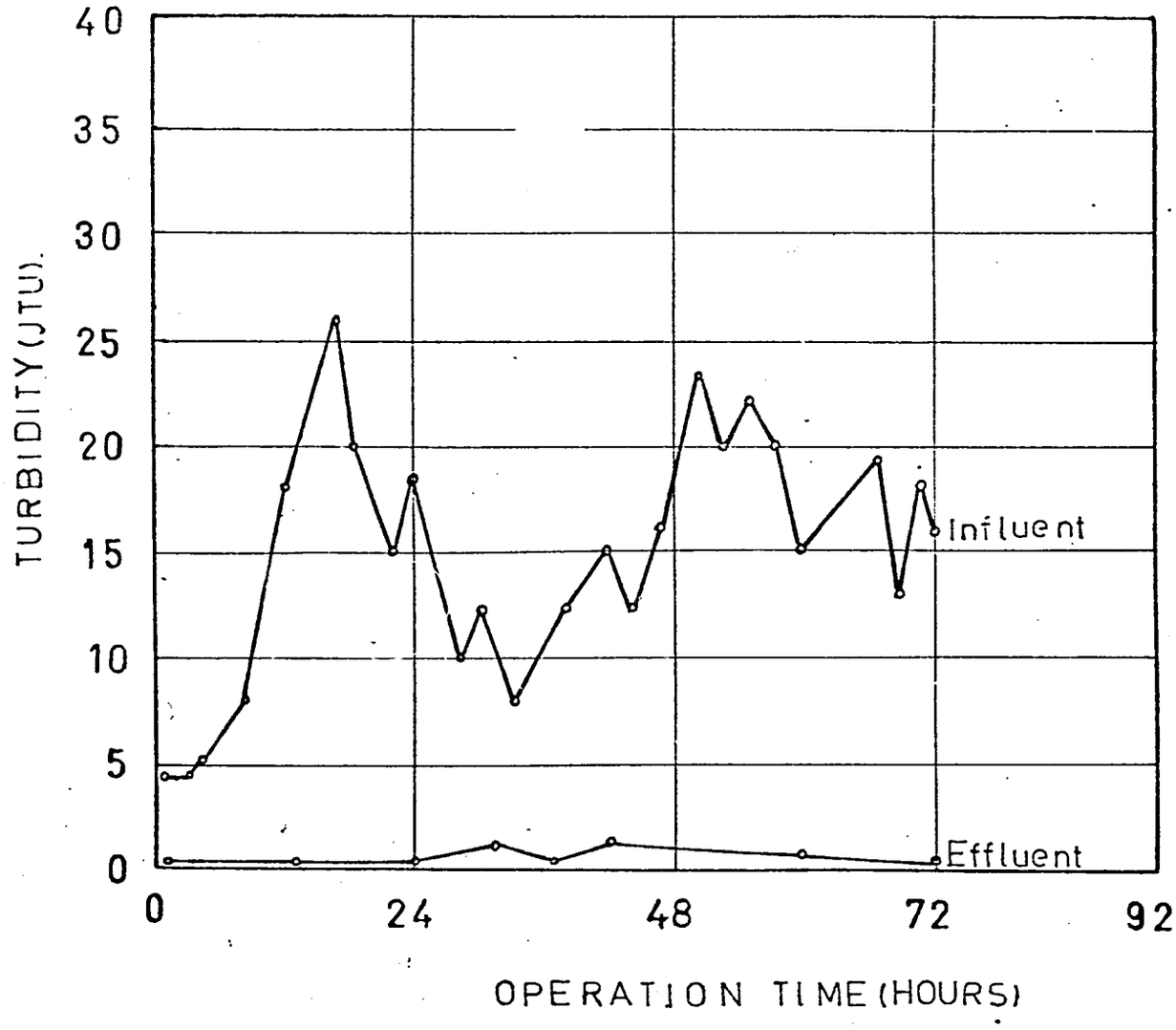
TURBIDITY FREQUENCY IN RAW WATER	FIGURE 4 - 6
WATER SUPPLY SYSTEM_LINHARES	



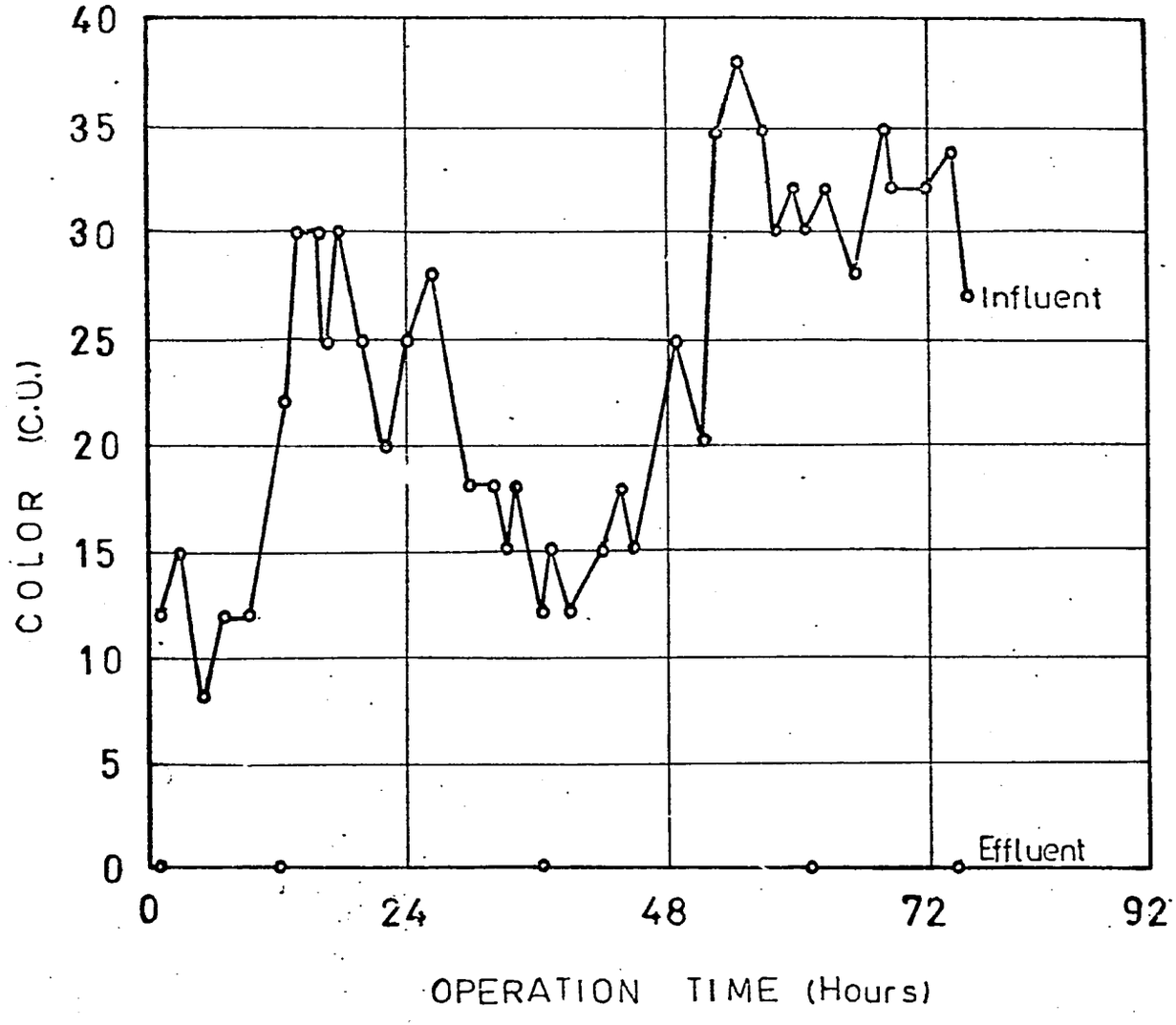
COLOR FREQUENCY IN RAW WATER	FIGURE 4-7
WATER SUPPLY SYSTEM – LINHARES	



TREATMENT EFFICIENCY	FIGURE 4_8
WATER SUPPLY SYSTEM_ LINHARES	



EFFICIENCY OF TURBIDITY REMOVAL	FIGURE 4 – 9
WATER SUPPLY SYSTEM – LINHARES	



EFFICIENCY OF COLOR REMOVAL	FIGURE 4-10
WATER SUPPLY SYSTEM – LINHARES	

The contact units showed the additional advantage of longer filter runs with better water quality.

Figure 4-11 illustrates the comparative efficiency of the two processes.

1) Influence of filtration rate on the efficiency of the contact units

In a brief test an effort was made to determine the effect of the variation of the flow rate by increasing the flow gradually (from 130 m^3/m^2/day up to two times that amount). The filtered water quality remained constant at 0.5 JTU using a raw water turbidity of 15 JTU. Higher turbidity was observed when the flow was increased suddenly, but the turbidity was less than 1.0 JTU throughout the test.

2) Influence of the filter run

The filter run varied between 16 and 48 hours, with an average of 30 hours.

Representative samples of the operational water quality data indicate that in general the turbidity was constantly lower than 0.50 JTU in normal runs of up to 30 hours.

On the other hand, the head loss showed a tendency to increase exponentially as a function of time.

The initial head loss ranged between 0.50 and 1.75 m with an average of 0.90 m which is less than the design value (1.30 m). The filter loses capacity because of clogging (head loss) rather than because of media breakthrough. The results of these tests are illustrated in figure 4-12.

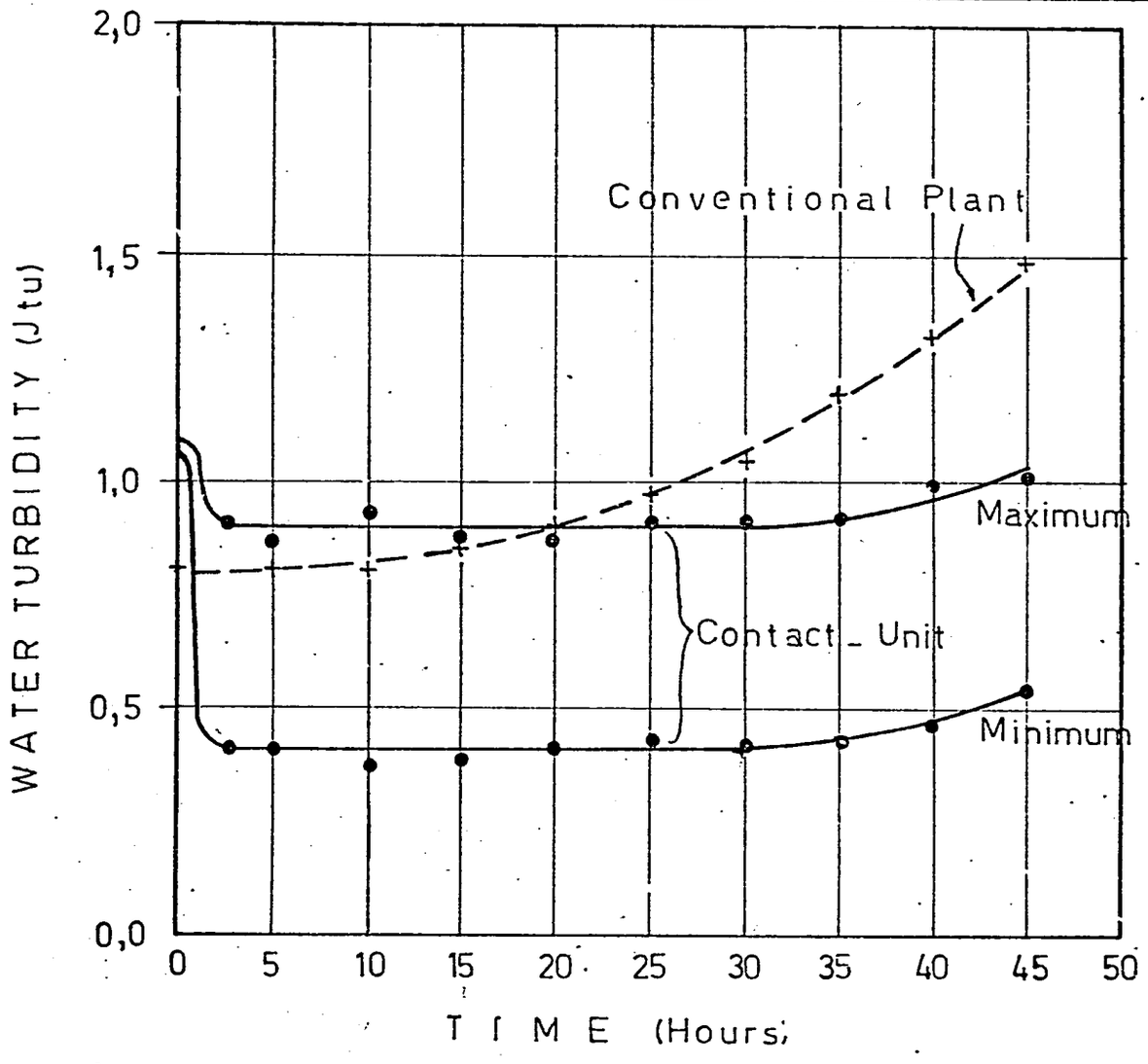
3) Coagulant dosage

From the data obtained during normal plant operation, a clear correlation can be found between the coagulant dosage and water turbidity. As indicated previously, larger coagulant dosages are required with lower turbidities (7.5 JTU) beyond which a linear correlation is established between the required dosages and the solid content (figure 4-13).

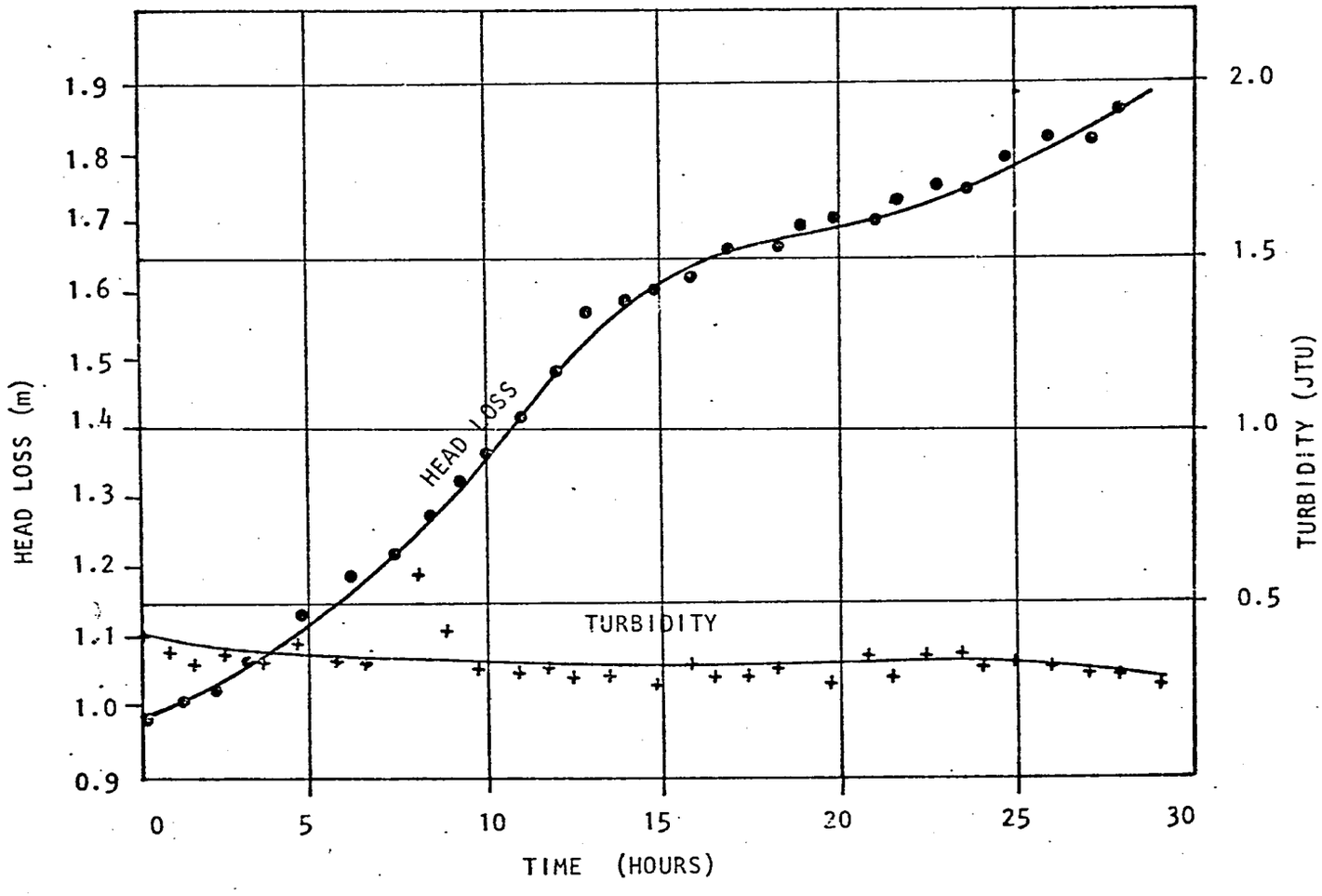
On the other hand, no correlation could be established for water with less than 50 color units, which is to be expected since the coagulant dosage is determined by analyzing the turbidity parameter (figure 4-14).

4) Filter backwashing

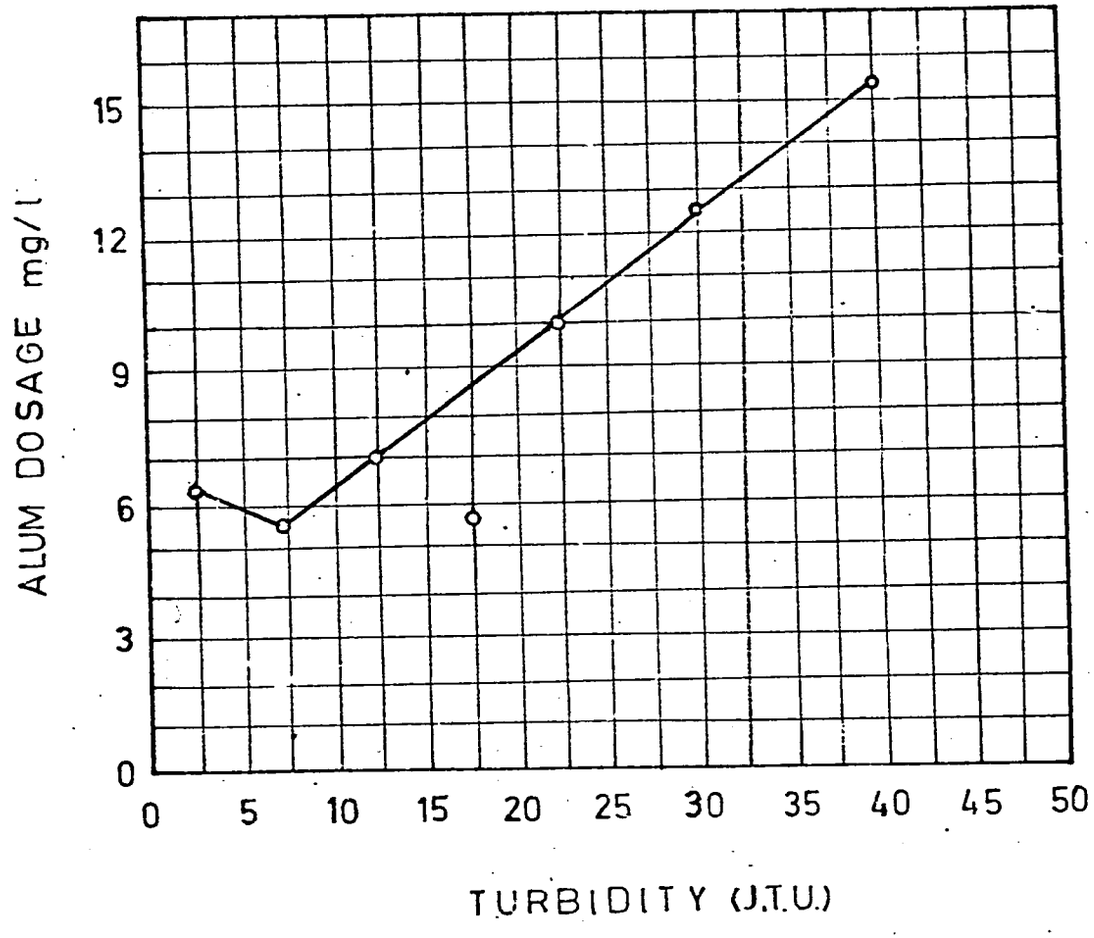
Two types of filter wash are used. The first consists of reversing the flow (downflow) every 10 hours or so, with flow rates of 0.15 m/min (the plant design does not include any special means of



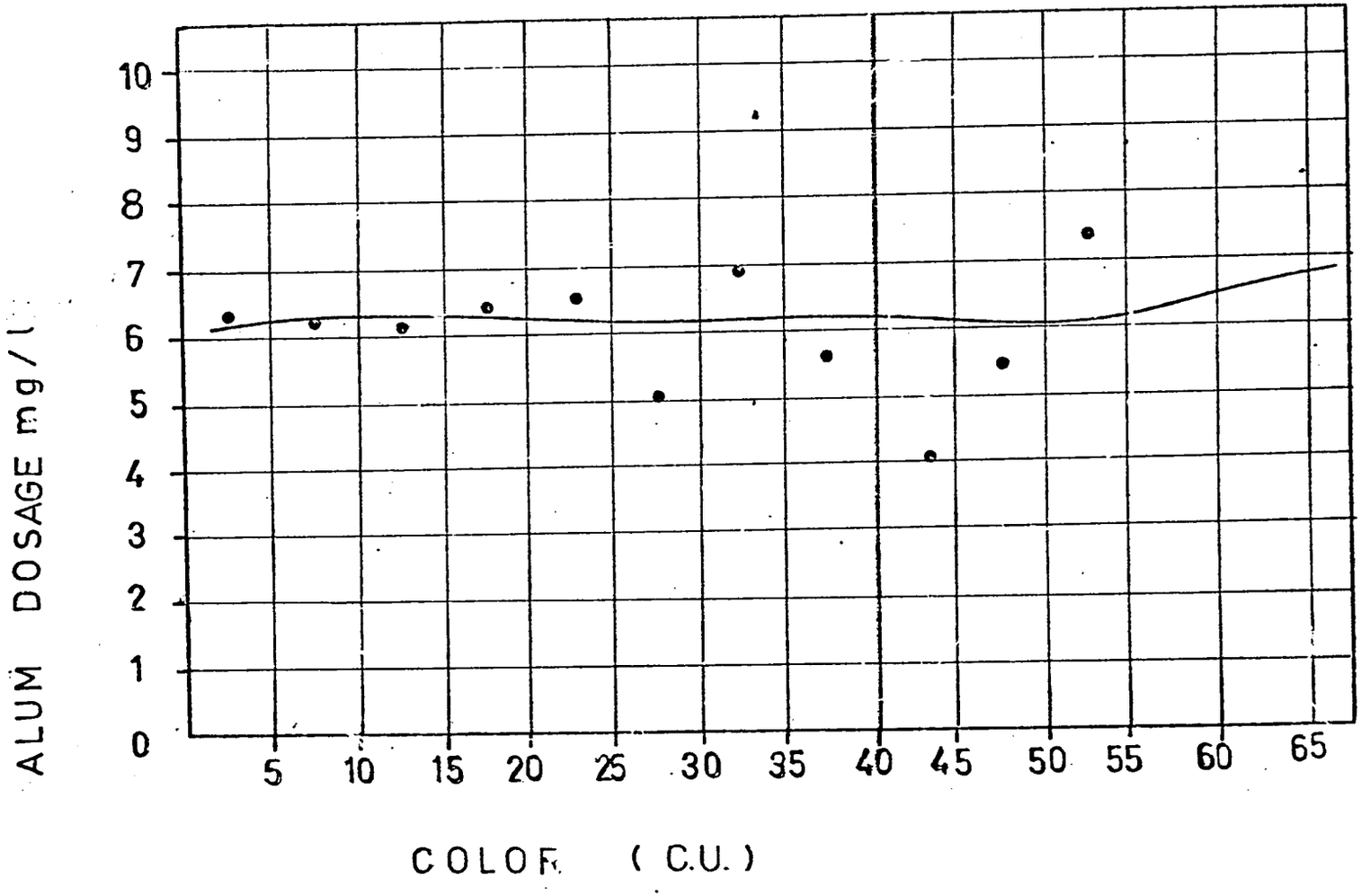
COMPARATIVE EFFICIENCIES of THE CONVENTIONAL PLANT and CONTACT UNIT	FIGURE 4_11
WATER SUPPLY SYSTEM_ LINHARES	



VARIATION OF HEAD LOSS AND FILTERED WATER QUALITY	FIGURE 4-12
WATER SUPPLY SYSTEM - LINHARES	



TURBIDITY – COAGULANT DOSAGE	FIGURE 4-13
WATER SUPPLY SYSTEM – LINHARES	



COLOR - COAGULANT DOSAGE	FIGURE 4-14
WATER SUPPLY SYSTEM_LINHARES	

preventing the fluidization of the filter bed). The second is the normal washing process for this type filter, using upflow velocities between 0.55 and 0.84 m/min with an average value of 0.60 m/min. A relatively large amount of water (200 m^3) is required to wash each unit, which produces a 40% expansion of the filter bed.

In general, the time needed to complete the washing of the filter is longer (20 minutes) than that normally recommended for this typ filter (7 to 8 minutes).

Figure 4-15 shows the turbidities observed with different wash times.

5) Conclusions

a) Upflow filters can be used efficiently as contact clarifiers, with flow rates of 130 $m^3/m^2/day$.

b) With good quality water (less than 50 units of color or turbidity) performance is above 99.7%.

c) With raw water turbidity and color ranging between 50 and 100 units, the efficiency is above 95% with normal loadings of up to 130 $m^3/m^2/day$.

d) No deterioration of water quality was observed with loadings up to twice the normal flow rate.

e) This type filter produces water of better quality and possibly has a higher biological efficiency than the conventional processes of coagulation, flocculation, sedimentation, and rapid filtration.

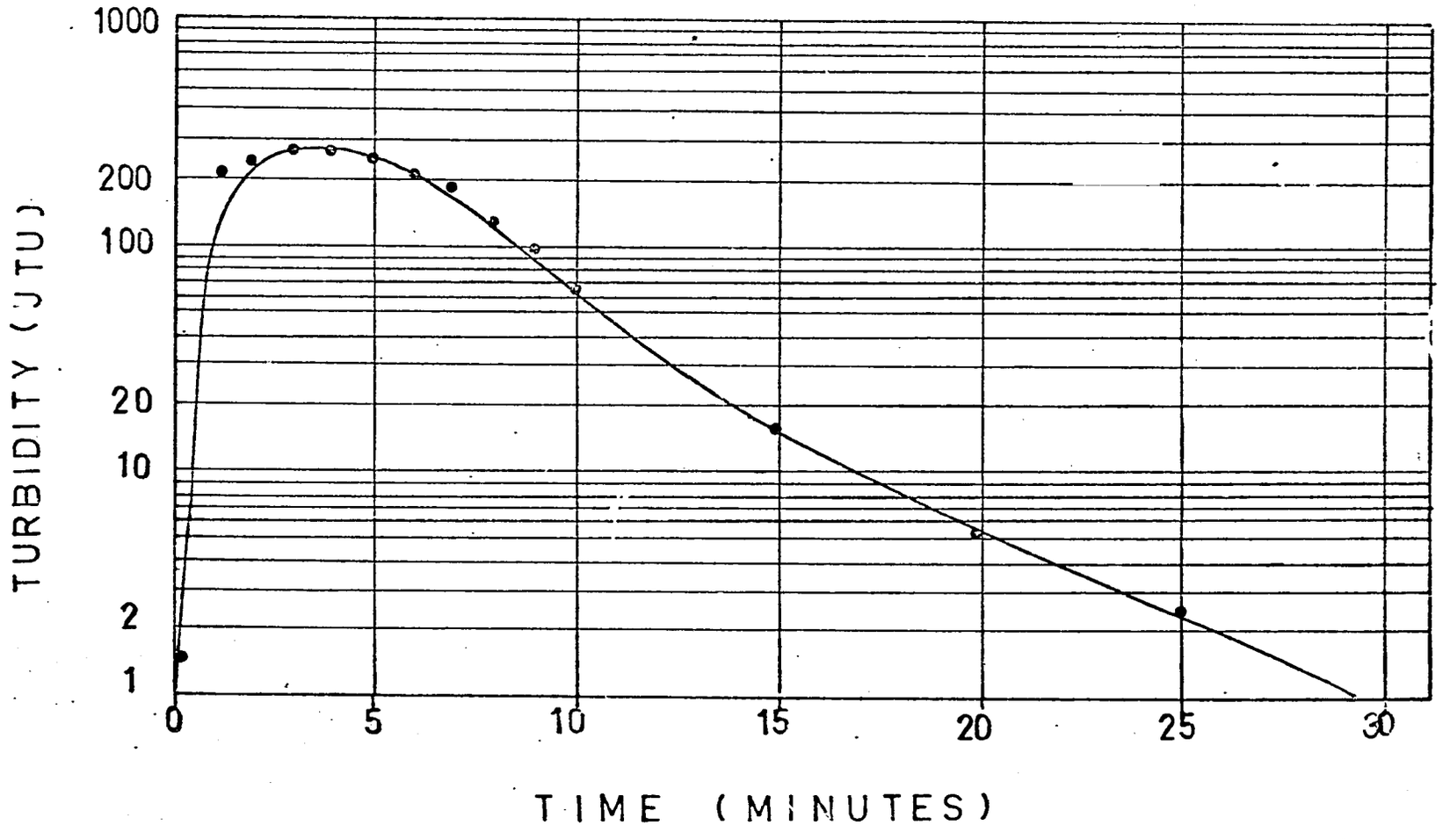
f) To avoid problems of fluidization of the filter bed, the flow can be reversed periodically (downflow) to partially backwash the unit, which gives longer filter runs, improves the water quality and eliminates the need for screens on the top of the bed, or other such devices.

g) In general longer washing times are required, in proportion to the depth of the filter bed. Since the depth of the filter bed is twice that of conventional filters, it takes twice as long to obtain an efficient washing.

h) During the research period there were no operational problems or deficiencies due to the design of the plant or the use of contact units and upflow filtration.

i) Apparently, the coagulant dosages required are lower than with conventional processes.

j) The plant is more compact than conventional installations.



FILTER WASHING TIME	FIGURE 4_15
WATER SUPPLY SYSTEM_LINHARES	

k) There is a greater potential for removing and storing suspended matter, since the entire depth of the filter bed is utilized rather than just the surface layers as occurs in downflow filters.

l) The following disadvantages of the process can be mentioned:

The efficiency decreases as a function of the deterioration of raw water quality, making it possible to use contact units only with relatively clear waters (up to 50 units of color and/or turbidity).

There is a possibility of fluidization of the filter bed which could produce a sudden and appreciable deterioration in the effluent water quality. For this reason, careful operation is required.

Wash water could be mixed with the clear filtered water if errors occur on the part of the operators.

4.4.3 Economic evaluation

A. Construction costs

The original design of the water supply system to be executed in two stages had an estimated cost in 1968 of US$ 88 400. Of this amount, US$ 14 100 (16%) corresponded to the treatment plant.

Table 4-3 gives the cost estimates for the different parts of the Linhares water supply system.

Table 4-3

CONSTRUCTION COST ESTIMATES FOR THE LINHARES WATER SUPPLY SYSTEM

Work	Cost US$	% of total cost
Collection, pumping and supply line	3 100	4
Treatment	14 100	16
Storage	6 300	7
Second pumping system	2 700	3
Distribution network	42 500	48
Household connections	1 600	2
Miscellaneous and unforeseen expenses	6 800	8
Administration	11 300	12
Total	88 100	100

In 1973, after a technical and economic feasibility study, it was decided to expand the plant by building contact units, since it was the most economical solution (40% of the cost of expanding the conventional plant).

The contact clarifiers were built between 1973 and 1975 at a total cost of US$ 68 600 with a unit cost of US$ 923 per l/s, of which 30% was spent for wages, 60% for materials and 10% for engineering and administration costs. Only 10% was used for skilled labor and less than 10% for the purchase of imported materials.

B. Operating and maintenance costs

Using the unit costs given in table 4-4, operation and maintenance costs ranging from US$ 14.29 to 18.32 per 1 000 m^3 are obtained, with an average of US$ 16.29. The amount corresponding to operation and chemicals was only US$ 3.85 which is equal to 24% of the total costs. The majority of the costs were incurred in the maintenance of the plant in general; it was not possible to separate the disbursements for the new and old plant. Table 4-5 gives details of these expenses.

Table 4-4

UNIT PRICES

Item	Price US$	Unit
Alum	94.00	ton
Lime	49.30	ton
Chlorine	0.30	kg
Personnel (operators)	170.00	man/month

Table 4-5

ANALYSIS OF OPERATING AND MAINTENANCE COSTS PER 1 000 m^3

Item	Maximum	Average	Minimum
Alum	1.27	1.13	1.06
Lime	0.42	0.39	0.36
Chlorine	0.33	0.30	0.27
Operation	2.66	2.03	1.70
Repairs	1.66	1.66	1.66
Maintenance	11.98	10.78	9.24
Total cost	18.32	16.29	14.29

C. General economic data

The results of the survey done in order to provide the economic data requested by the University of Oklahoma are included in Appendices 4-E and 4-F.

D. Conclusions

1) The results of the research indicate that contact units are more economical than the conventional coagulation, flocculation, sedimentation, and filtration processes, or even the newer high-rate settling and filtration processes, when treating good quality water with an average turbidity and color of less than 50 units.

2) Apparently contact units are more economical to operate, especially since they require smaller coagulant dosages.

5. EVALUATION OF THE WATER TREATMENT PLANT OF PRUDENTOPOLIS, CURITIBA, PARANA, BRAZIL (RESEARCH PROJECT No. 3)

5.1 INTRODUCTION

The Companhia de Saneamento do Paraná (SANEPAR), the agency responsible for constructing and administering the water supply and sewerage services in the State of Parana, Brazil, signed an agreement with the National Housing Bank in 1972 for the execution of a sanitation program which required the preparation of a large number of projects in a relatively short period. For this purpose, research was undertaken on pilot filters and at the same time four basic module projects for water clarification were designed with CEPIS collaboration, based on the results of the research.

The University of Oklahoma signed an agreement with CEPIS under which the latter would conduct research at water treatment plants in Latin America designed with new technological concepts, including an evaluation of the degree of adaption of these projects to the socio-economic and technical conditions existing in the countries.

Because the water treatment plant of the city of Prudentopolis is an example of new treatment technology and the city is representative of prevailing conditions in Latin America, it was chosen as one of the research sites.

An agreement was signed with SANEPAR for the execution of a research program which included the following components:

- A study of the general demographic and socio-economic conditions of the city.

- Overall technical evaluation of the plant and of each of the unit processes involved.

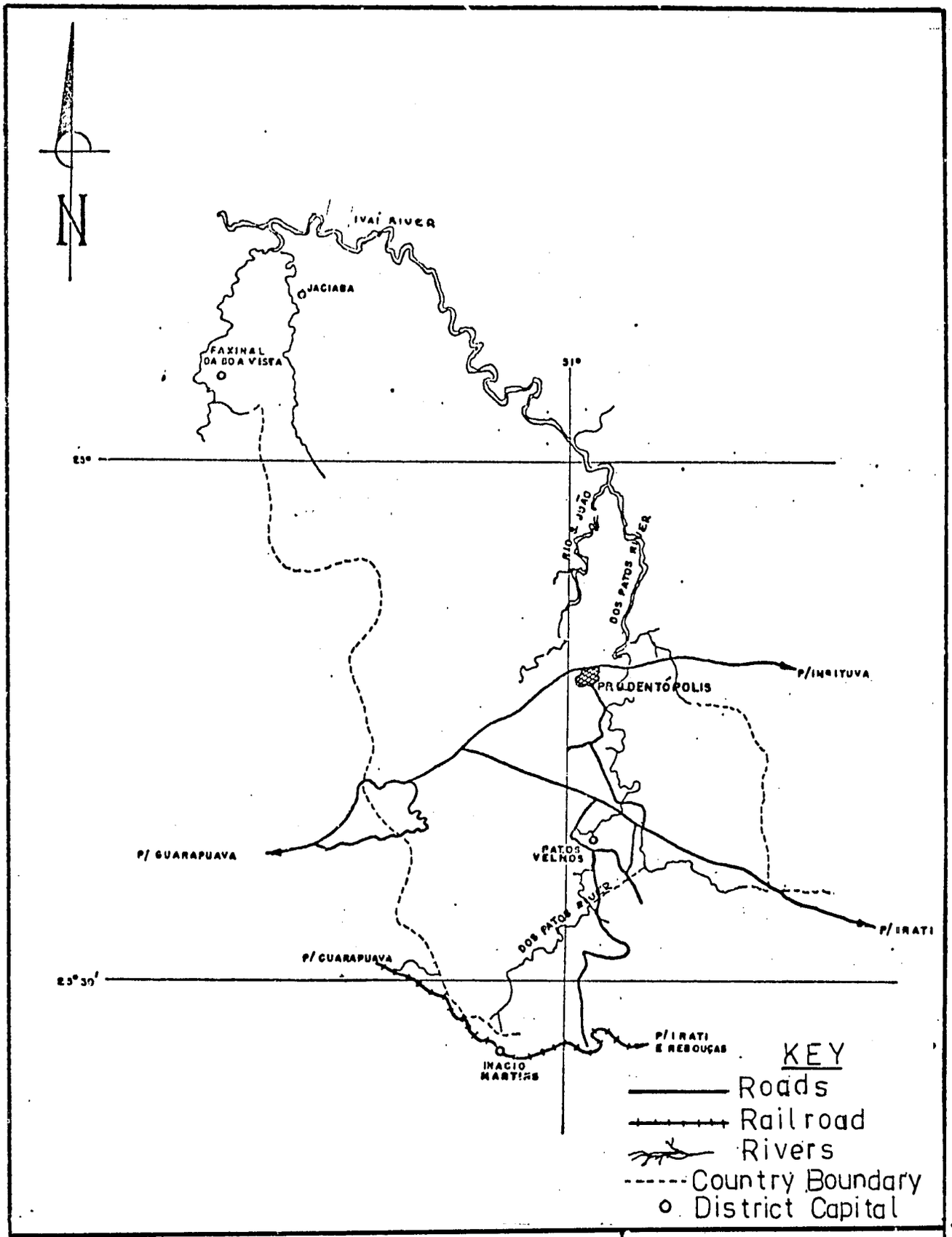
- Economic study of the capital investments and operation and maintenance costs.

A description of the general characteristics of the city and the treatment plant, and a summary of the research program and the conclusions reached are presented in this chapter.

5.2 GENERAL INFORMATION ABOUT THE CITY

The city of Prudentopolis is located in the west central region of the State of Parana, Brazil; its geographical position is 51° longitude west and 25°13' latitude south (figures 5-1 and 5-2) and it is connected with Curitiba by an asphalt highway.

LOCATION OF PRUDENTOPOLIS -BRAZIL	FIGURE 5-1
WATER TREATMENT PLANT-PRUDENTOPOLIS	



LOCATION of PRUDENTOPOLIS – BRAZIL (Detail)	FIGURE 5-2
WATER SUPPLY SYSTEM-PRUDENTOPOLIS	

It has a temperate climate and an average annual precipitation of 1 654 mm.

The current population of Prudentopolis is approximately 7 500 inhabitants, and it is expected to grow to about 12 500 inhabitants by 1992. Table 5-1 gives the estimated population and water consumption data.

Table 5-1

POPULATION AND WATER CONSUMPTION - PRUDENTOPOLIS

Year	Population	Population served	Flow l/s		
			Daily average	Maximum daily	Maximum hourly
1973	6 895	-	-	-	-
1974	7 190	-	-	-	-
1975	7 485	3 742	6.7	8.1	12.1
1976	7 780	4 668	8.4	10.1	10.1
1977	8 075	5 652	10.2	12.2	18.3
1978	8 370	6 277	11.3	13.6	20.4
1979	8 665	6 932	12.5	15.0	22.5
1980	8 960	7 168	12.9	15.5	23.2
1981	9 255	7 404	13.3	16.0	24.0
1982	9 550	7 640	13.7	16.5	24.8
1983	9 845	7 876	14.2	17.0	25.5
1984	10 140	8 112	14.6	17.5	26.3
1985	10 435	8 348	15.0	18.0	27.1
1986	10 730	8 584	15.4	18.5	27.8
1987	11 025	8 820	15.9	19.1	28.6
1988	11 320	9 056	16.3	19.6	29.4
1989	11 615	9 292	16.7	20.1	30.1
1990	11 910	9 528	17.2	20.6	30.9
1991	12 205	9 764	17.6	21.1	31.7
1992	12 500	10 000	18.0	21.6	32.4

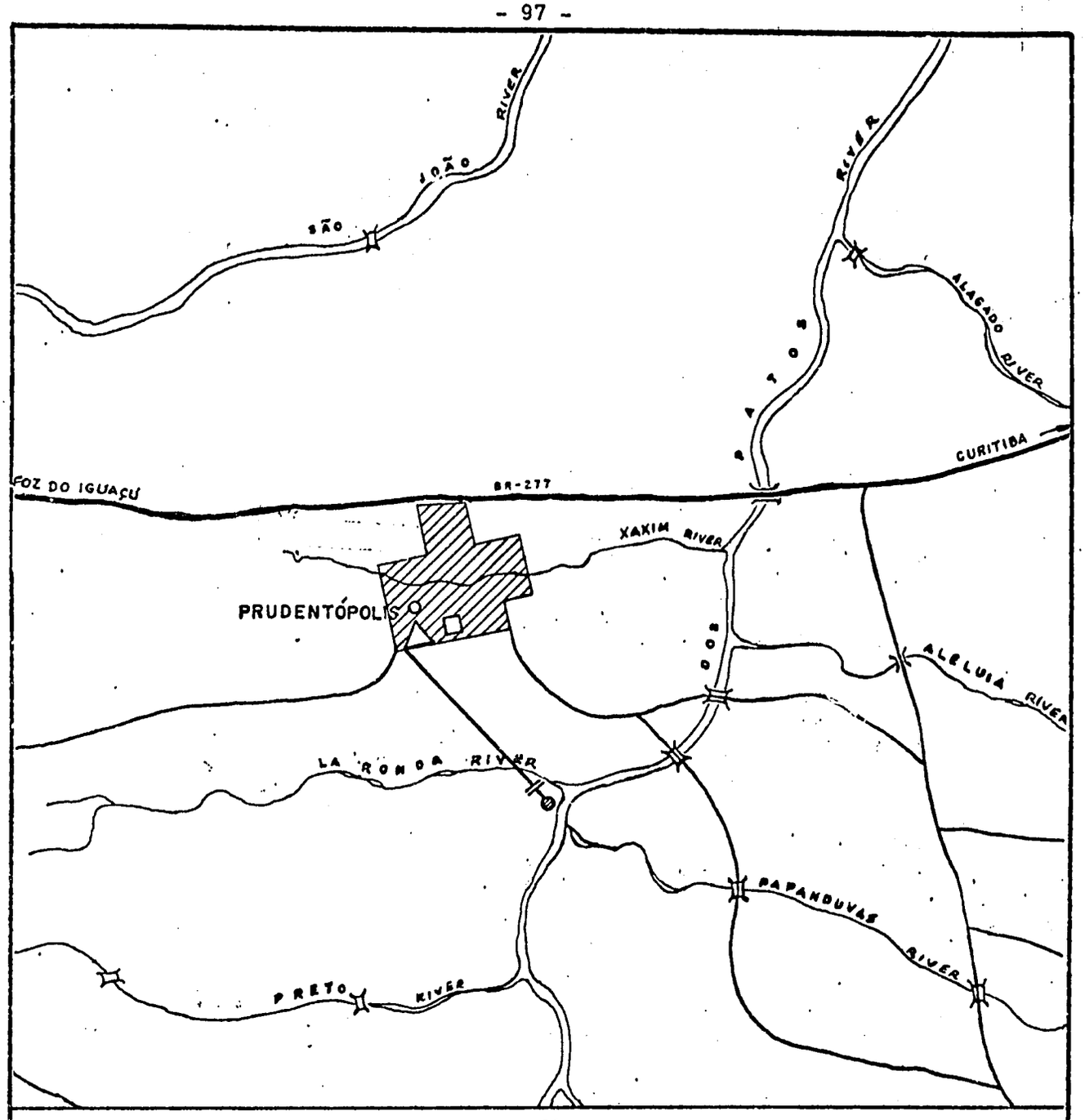
Source: Preliminary Report on the Prudentopolis water supply system, SANEPAR

5.3 GENERAL DESCRIPTION OF THE WATER SUPPLY SYSTEM

SANEPAR is responsible for the design, operation and maintenance of the water supply system for the city of Prudentopolis. Figures 5-3 and 5-4 illustrate the general layout of the system which has the following characteristics:

5.3.1 Demand

The unit consumption is 120 l/cap/day with a coefficient of 1.40 for the maximum daily consumption.

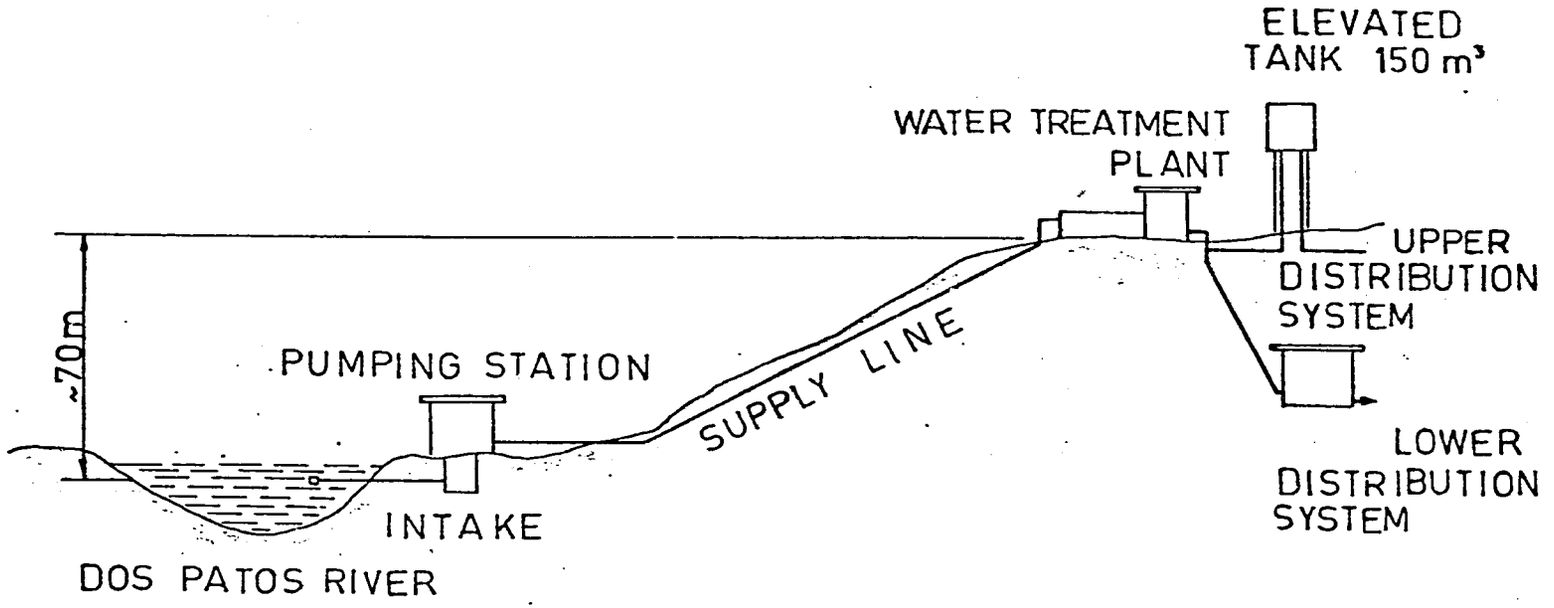


KEY

- Supply Conduit
- Intake
- Pumping Station
- Water Treatment Plant
- Ground Storage
- Elevated Storage
- Federal Roads
- State Roads
- Rivers

FIGURE 5-3

WATER SUPPLY SYSTEM-PRUDENTOPOLIS



WATER SUPPLY SYSTEM PRUDENTOPOLIS | FIGURE 5-4

5.3.2 Sources

The water is taken from the Dos Patos River which has a drainage area of 780 km^2 and a minimum recorded flow of 2.00 m^3/s.

The waters have medium turbidity (56 JU), medium color (58 U), low alkalinity (19 mg/l), slightly acid characteristics (pH=6.7), low hardness (17 mg/l), high iron content (1.25 mg/l).

The turbidity of the water varies from 17 JU to 370 JU, with an average value of 56 JU. Table 5-2 and figure 5-5a summarize the distribution of turbidity frequencies.

The color of the raw water varies from 30 to 700 CU with an average value of 115 CU. Table 5-3 and figure 5-5b summarize the distribution of color frequencies.

5.3.3 Collection works

The water is taken directly from the Dos Patos River by means of a 250 mm screened pipe connected to a suction well. Above the well are two turbine pumps with a capacity of 11 l/s against a head of 120 m (figure 5-4).

5.3.4 Supply line

The supply line is made of iron with an inner lining of cement. It has a diameter of 150 mm and a length of about 3 000 m.

5.3.5 Treatment plant

Two "I" modules of the SANEPAR-CEPIS plant have been constructed which can treat 22 l/s. The treatment unit or module (figures 5-6 to 5-12) consists of a tank in the form of an inverted truncated pyramid, in the center of which the coagulation process takes place. Sedimentation takes place in four lateral compartments and the filters are located at each corner. The result is a very compact plant which is easy to operate and easy to build.

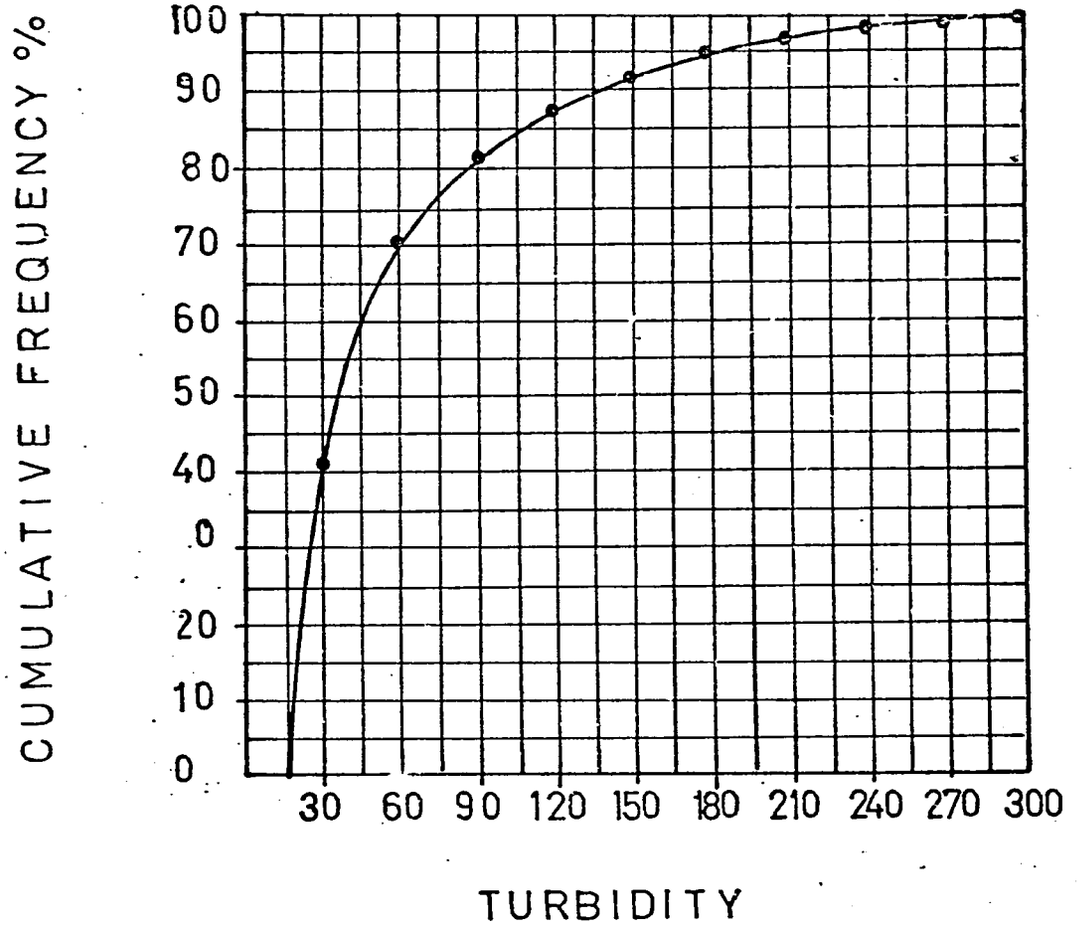
The raw water enters a chamber by means of a circular weir with a vertical wall, creating the hydraulic conditions necessary for a perfect diffusion of the coagulants.

A. Reagents

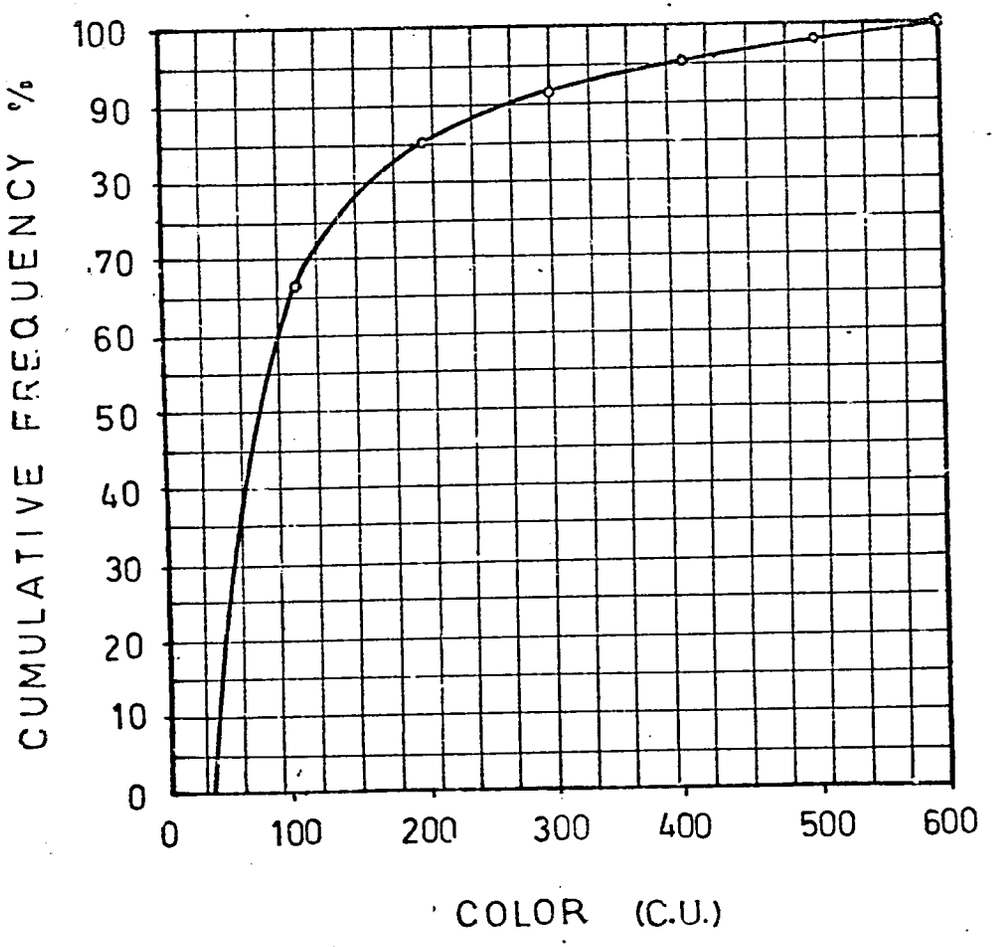
Aluminum sulfate in solution is used, in concentrations of 2 - 5%. Lime is used as a coagulant aid in order to provide the alkalinity required to reach the optimum pH for coagulation. Lime is also added to correct the pH of the filtered water. Hydrated lime in suspension is used.

B. Chemical feeders

The aluminum sulfate is prepared in two reinforced concrete tanks (duly protected against the action of aluminum sulfate) with an effective volume that allows a consumption of 30 mg/l of alum with a concentration of 5% during 12 hours. Alum cake is used because of its low cost. The solution is mixed by means of an inclined axle agitator powered by a 1/3 HP electric motor. There are two constant level feeders with adjustable orifices and 12-litre boxes; they have a feeding capacity of 250 litres per hour. The inlet and outlet pipes are 1 1/2" in diameter.



TURBIDITY FREQUENCY IN RAW WATER	FIGURE 5 - 5a
WATER TREATMENT PLANT_PRUDENTOPOLIS	



COLOR FREQUENCY IN RAW WATER	FIGURE 5-5b
WATER SUPPLY SYSTEM-PRUDENTOPOLIS	

Table 5-2

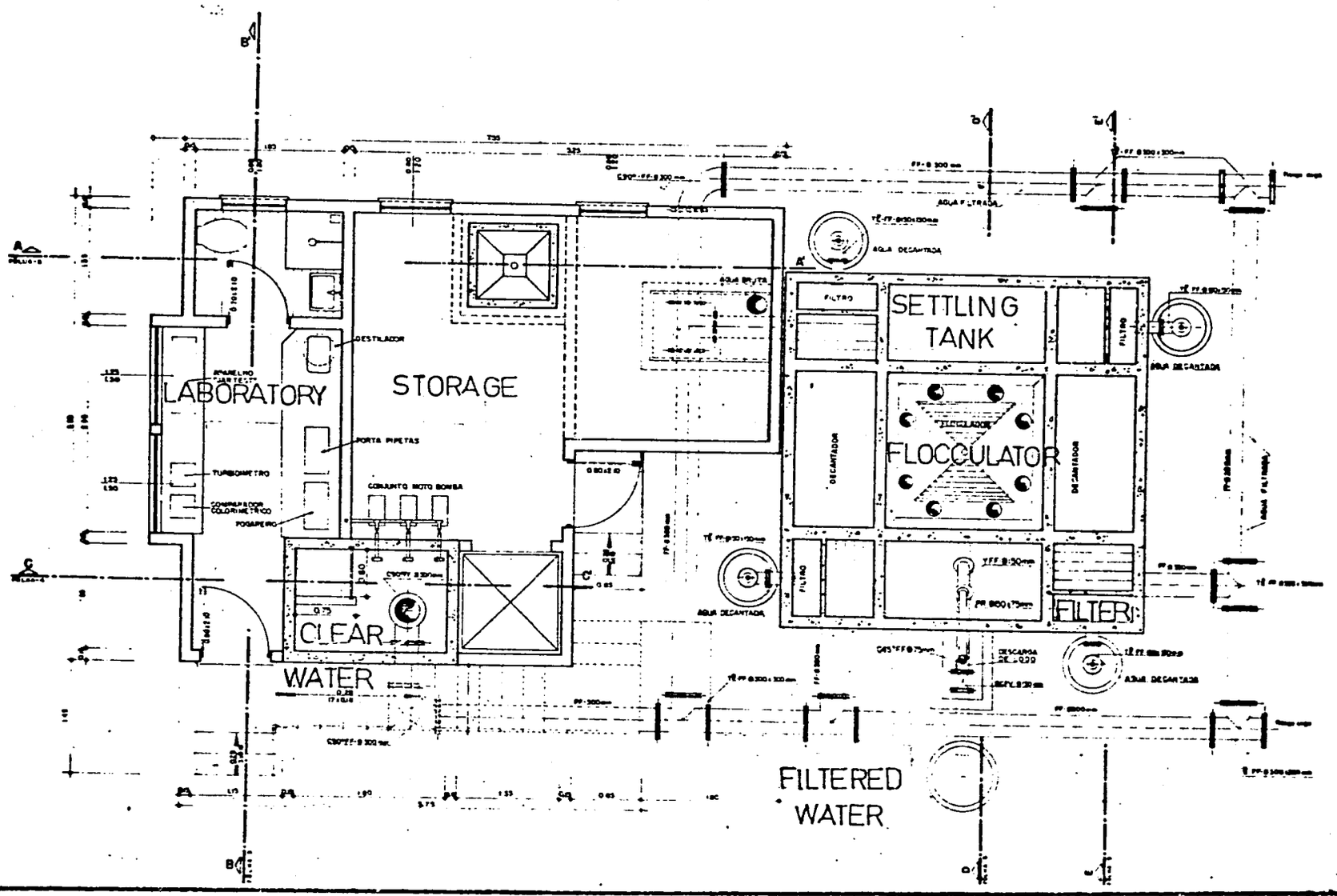
RAW WATER TURBIDITY - PRUDENTOPOLIS - DECEMBER 1975/MAY 1976

Turbidity JTU	Frequency (3 h)	%	Cumulative %
0 a 29.9	1 708	41.15	41.15
30 a 59.9	1 238	29.82	70.97
60 a 89.9	487	11.73	82.70
90 a 119.9	189	4.55	87.25
120 a 149.9	212	5.11	92.36
150 a 179.9	134	3.23	95.59
180 a 209.9	66	1.59	97.18
210 a 239.9	51	1.23	98.41
240 a 269.9	22	0.53	98.94
270 a 299.9	9	0.22	99.16
300	35	0.84	100.00

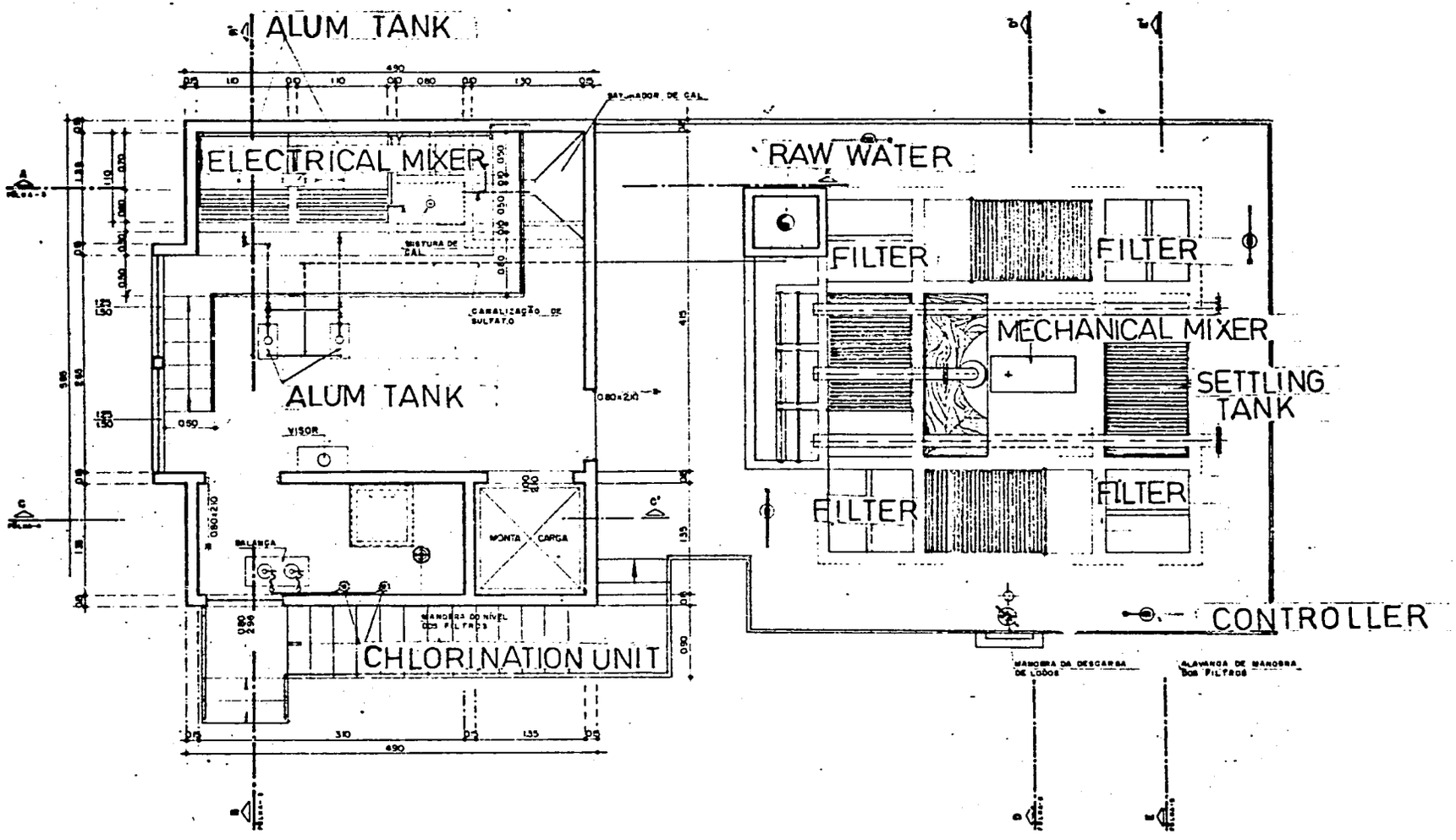
Table 5-3

RAW WATER COLOR - PRUDENTOPOLIS - DECEMBER 1975/MAY 1976

Color CU	Frequency	%	Cumulative %
0 a 99.9	923	66.31	66.31
100 a 199.9	260	18.68	84.99
200 a 299.9	82	5.89	90.88
300 a 399.9	55	3.95	94.83
400 a 499.9	37	2.66	97.49
500 a 600	35	2.51	100.00



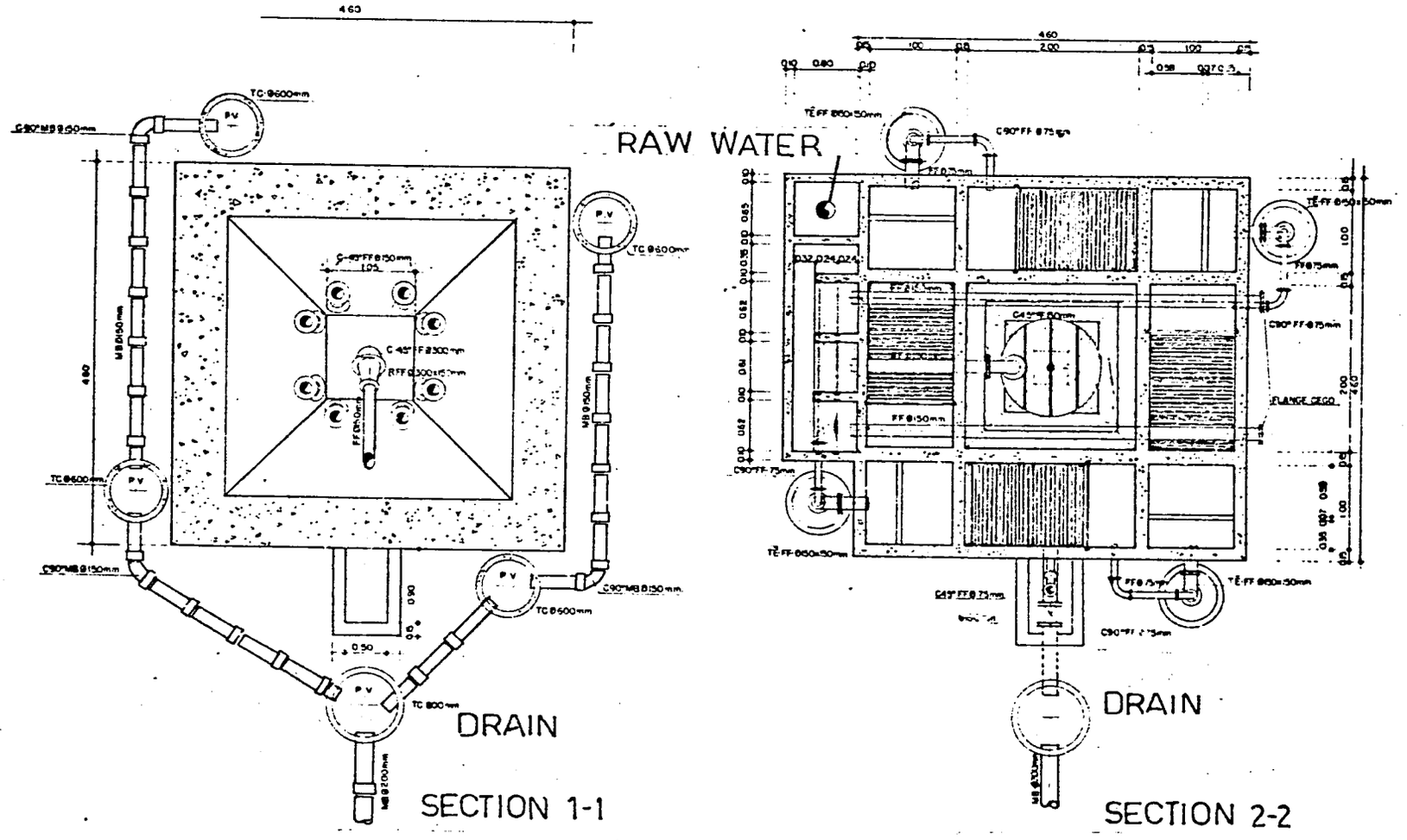
GENERAL PLAN – FIRST FLOOR	FIGURE 5-6
WATER TREATMENT PLANT – PRUDENTOPOLIS	



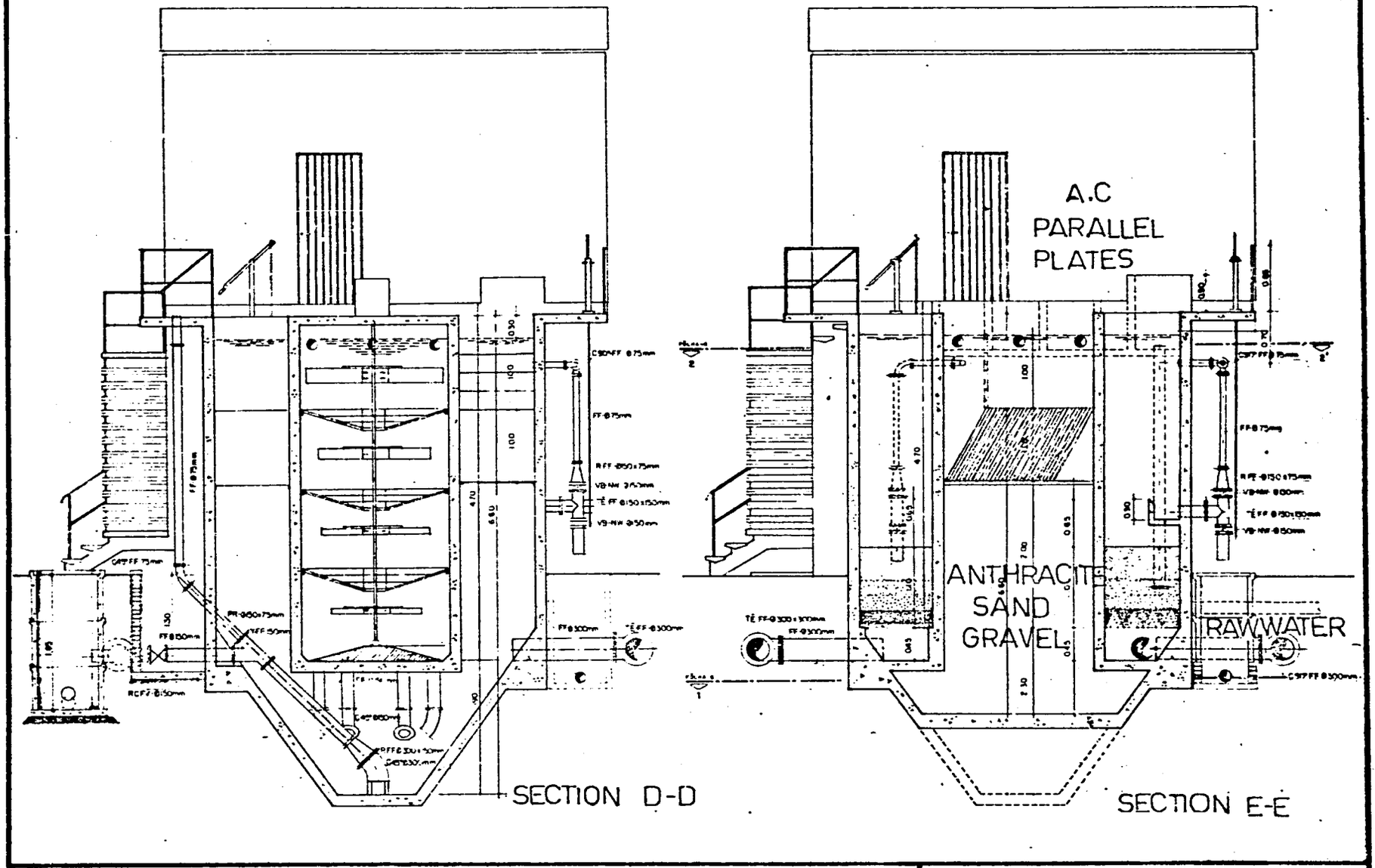
SECOND FLOOR – GENERAL PLAN

FIGURE 5-7

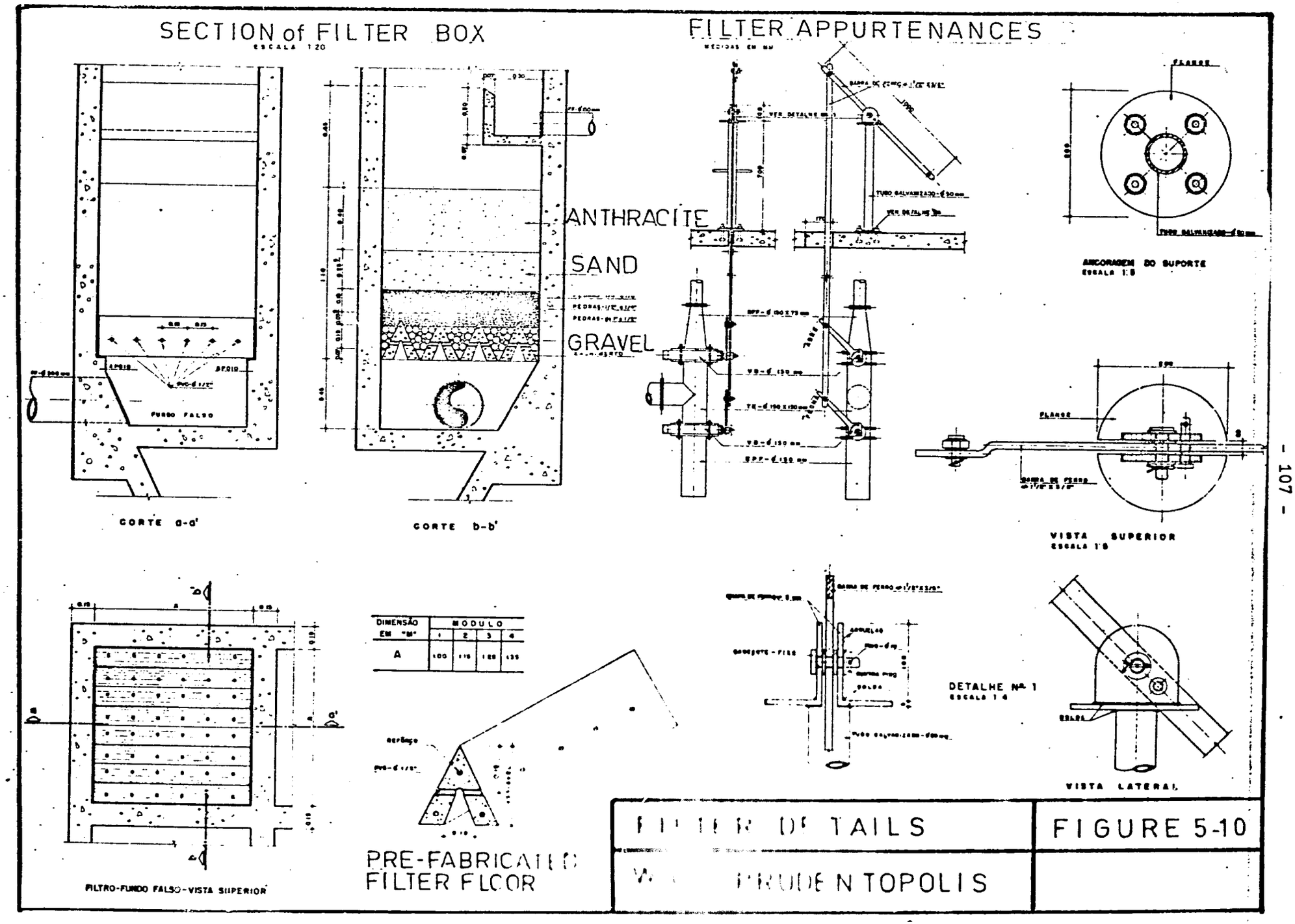
WATER TREATMENT PLANT-PRUDENTOPOLIS



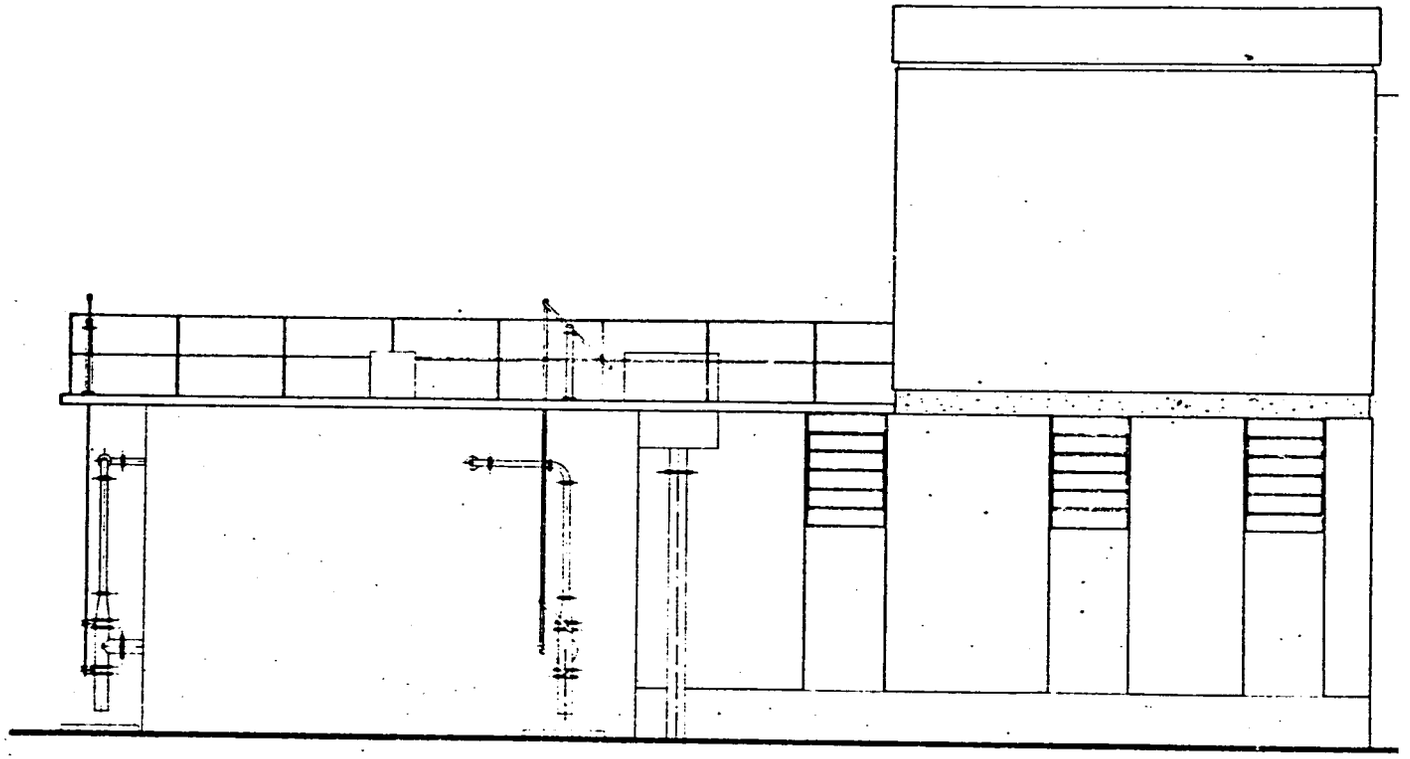
SECTIONS	FIGURE 5-8
WATER TREATMENT PLANT - PRUDENTOPOLIS	



GENERAL SECTIONS	FIGURE 5-9
WATER TREATMENT PLANT_PRUDENTOPOLIS	

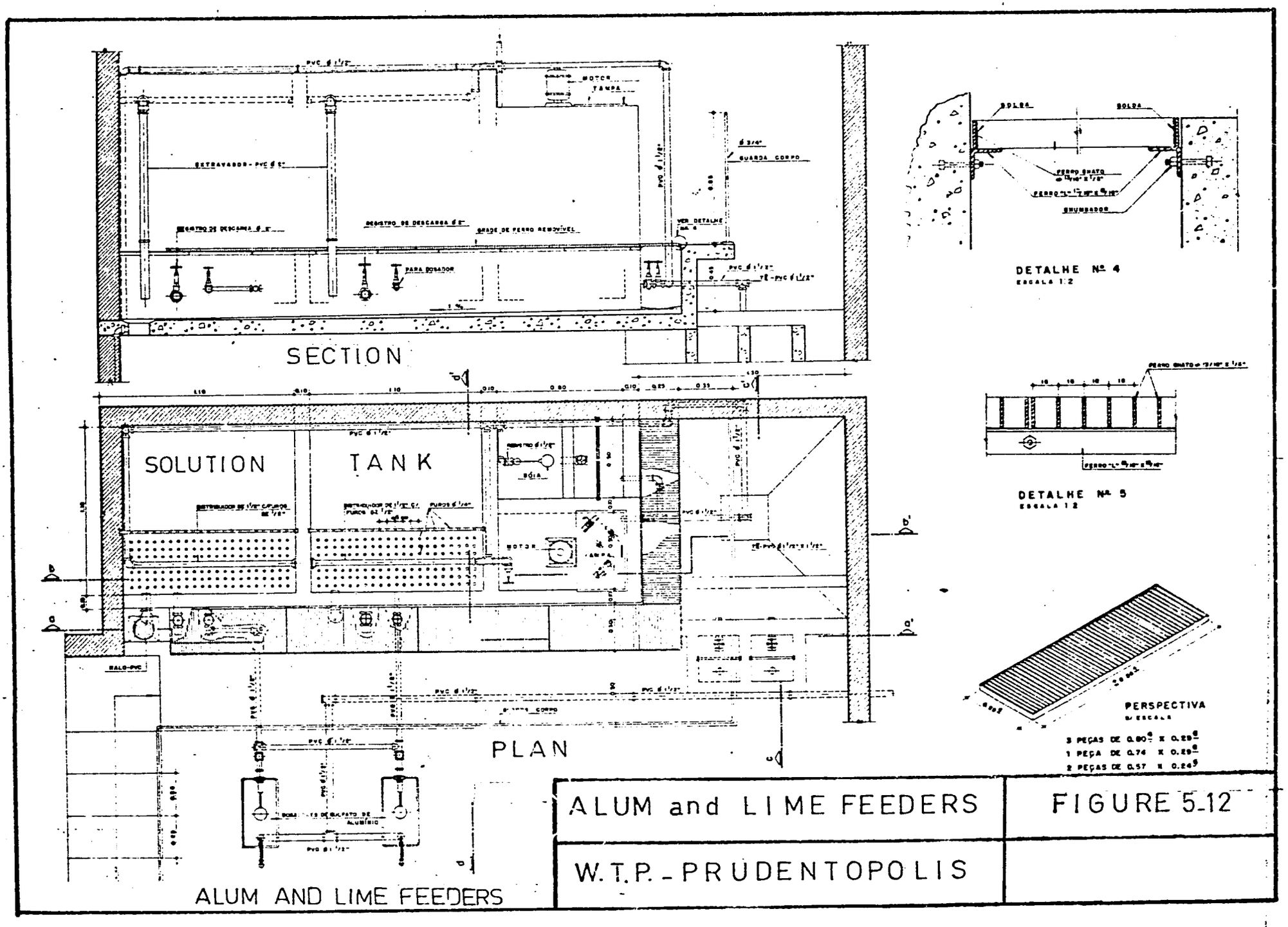


DIMENSÃO EM "M"	MODULO			
	1	2	3	4
A	100	115	130	135



FAÇADE Nº2

LEFT LATERAL FAÇADE	FIGURE 5-11
WATER TREATMENT PLANT- PRUDENTOPOLIS	



ALUM and LIME FEEDERS

FIGURE 5-12

W.T.P. - PRUDENTOPOLIS

All the pipes used to transport the aluminum sulfate solution are rigid PVC, class 12.

The lime is fed by a truncated pyramid saturator which has a 1/3 HP electric agitator. The area of the saturator is calculated with an application rate of 2 kg of CaO per hour. The water is supplied from a concrete tank. The lime suspension is collected in a box located in the upper part of the saturator. It is fed through two thin-walled weirs. All the pipes are made of rigid PVC, class 12, with easily removable joints and accessories for cleaning the entire system.

C. Raw water measurement and rapid mixing

The raw water enters the plant through a pipe with a circular weir 35 cm in diameter. A graduated scale attached to the lower generatrix of the weir is used to measure the flow. It is calibrated in such a way that loads of 8 cm and 20.5 cm above the generatrix of the weir correspond to flows of 11 and 60 l/s respectively. When two or three modules are used, the flow is split by means of triangular weirs installed in the side of the distribution channel.

D. Flocculation

This unit is made up basically of a square tank with a mechanical agitator with vertical axle and horizontal paddles, moved by a 1/2 HP motor with rotation velocities of 5.6 - 7.0 and 8.4 rpm. The paddles have slits which make it possible to vary their diameter, thus adjusting the velocity gradients from 16 to 94 s^{-1}, independently of speed changes in the reducer. In this manner the velocity gradients can be adjusted to the ideal flocculation conditions determined by jar tests.

The flocculator is divided into four chambers by wooden baffles. Wooden discs have also been placed above the paddles (except the last one), avoiding short-circuiting and improving the performance of the flocculators by increasing the number of compartments. The total detention time is 25 minutes.

From the flocculation tank the water flows through pipes toward the truncated cone bottom where the floc is deposited forming a hydraulic suspension sludge blanket which is extracted or regulated manually thus improving the subsequent settling process.

E. Sedimentation

This process takes place in four cells located beside the flocculation tank which have a common bottom (mentioned above) where the sludge blanket forms (figure 5-9).

The sludge is discharged periodically by hydraulic action through a manually operated siphon designed for this purpose.

The lower part of the settling unit (3 meters) functions like a vertical flow settler with upflow velocities of 125 $m^3/m^2/day$.

In the middle of the settler a high-rate sedimentation module has been installed made up of parallel plates one meter in length, set 5 cm

apart at an angle of 60°, yielding a sedimentation rate of 185 m^3/m^2/day and creating laminated flow conditions with Reynolds number below 100. Asbestos-cement plates or sheets are used. The relation between the length of the plate and the width of the cell is equal to 20.

Above the plates there is one meter of water. This zone serves as a conventional settler with an overflow rate of 12 m^3/m^2/hour.

The water is collected by a trough located at the end of the settling unit and flows through pipes to the filters.

F. Filtration

The filter system consists of four filters located at the corners of the modules. They have a square plant and a designed filtration rate of 250 m^3/m^2/day and backwash velocities of 0.60 m/min. The filter boxes have the following dimensions:

Width - 1.00 to 1.35 m depending on the size of the module	
Depth - 4.40 to 4.50 m depending on the size of the module	
Height of the false bottom -	0.45 m
Height of the supporting bed -	0.375 m
Height of the sand bed -	0.255 m
Height of the anthracite bed -	0.40 m
Freeboard -	0.65 m

The settled water enters through a pipeline which is connected to the wash water box. The inlet valves controlling the flow of the settled water into the filter and the valves controlling the discharge of the wash water have been designed so that they can be operated simultaneously with one lever, in such a way that when one valve is opened the other is closed, and vice versa, thus simplifying the operation of the filter.

The filters have been designed in such a way that their bottoms are connected to a common pipe which leads to the clear water tank with an overflow control. This enables the filters to operate with declining rates, and makes it possible to wash any one unit with the effluent of the others.

The false bottom is made up of prefabricated beams in the form of inverted Vs which are supported in the walls of the filter layers; the sides of the beams have 1/2" perforations 15 cm apart.

The filter medium consists of double sand and anthracite beds with the following characteristics:

Sand

Effective size	0.5 mm
Uniformity coefficient	1.65
Minimum size	0.3 mm
Maximum size	1.20 mm
Specific weight	2.60

Anthracite

Effective size	0.9 mm
Uniformity coefficient	1.1
Minimum size	0.8 mm
Maximum size	1.1 mm

The supporting gravel bed has the following characteristics:

Layer	Thickness	Size (")
1	7.5 cm	1 - 3/4
2	7.5	3/4 - 1/2
3	7.5	1/2 - 1/4
4	7.5	1/4 - 1/8

When the filtration process begins, the water reaches a minimum height above the filter wash water box. As the filter begins to clog, the head loss increases and the water level in the filter rises until it reaches the maximum height permitted by the system. At that time the filter must be backwashed, and to accomplish this the operator needs only to move the lever that closes the inlet valve and opens at the same time the wash water outlet valve.

The water level in the filter falls slowly until it reaches the edge of the wash water trough. Since the water level in the other filter boxes remains constant, the effluent of the other filters flows through the common pipes to the filter that is being washed and rises through the filter bed slowly at first and later with uniformly accelerated motion until the design backwash velocity is reached.

The backwashing operation is stopped by moving the same lever in the opposite direction, thereby opening the water inlet valve and closing the wash water outlet permitting the water to reach its original level. The filtration process is begun again; the clean filter takes a greater load (close to 450 $m^3/m^2/day$) than the other filters which are partially clogged.

In this way the filters operate with declining rates without a rate-of-flow controller.

G. Disinfection

In order to ensure the bacteriological quality of the water, it is disinfected by means of chlorine gas which is applied at the outlet of the clear water canal (final chlorination), using two feeders. The chlorinators are the vacuum type with a feeding capacity of up to 12 kg of chlorine per day, suitable for feeding chlorine gas in the form of an aqueous solution. The necessary pressure for correct operation is provided by a small pump with a similar capacity (12 kg of chlorine per day).

Flexible copper pipes are used to carry the chlorine to the chlorinator and rigid PVC pipes to transport the aqueous chlorine solution to the application points.

5.3.6 Storage

Thre is an elevated tank with a capacity of 150 m^3 to serve the upper zone of the city and a ground storage tank with a capacity of 400 m^3 which serves the lower part of the city.

5.3.7 Distribution system

The system, which is not yet completed, will include 14 000 meters of PVC pipe with diameters between 2 and 6 inches.

5.4 RESEARCH STUDIES

Research was carried out on the following aspects: determination of the general characteristics of the city, technical evaluation of the treatment plant and economic evaluation of plant construction, operation and maintenance costs.

5.4.1 General characteristics of the city

In order to fulfill the principal research objective of the University of Oklahoma, information on the following topics was gathered using a survey questionnaire:

A. Identification of the city and institution responsible for water supply services;

B. Technological and demographic data;

C. Basic socio-economic data.

The results are included in Appendices 5-A and 5-B.

5.4.2 Technical evaluation

During eight consecutive months the coagulation, flocculation, sedimentation and filtration processes were studied continuously, as well as the determination of the hydraulic characteristics of the reactors and the problems encountered during normal operation of the plant. The research was oriented mainly toward establishing and verifying the viability and applicability of the sedimentation and filtration theories of Yao, Hudson and Cleasby, as well as those of Greenleaf and Arboleda regarding filter backwashing using the flow from other units and the possibility of hydraulic control of simply-designed water treatment plants without the use of mechanized equipment.

The verification of the efficiency of the highly simplified treatment plant designed by engineer Carlos Richter confirms the work of the above-mentioned investigators and at the same time demonstrates the possibility of using advanced technology to obtain extremely simple designs in accordance with the socio-economic and industrial development of the region.

The following points were studied in detail:

A. Raw water quality

During the research period the turbidity of the water averaged 56 JTU, with values ranging between 17 and 370 JTU; the color varied between 30 and 700 CU, with an average value of 58 CU; the alkalinity was low with an average of 19 mg/l and the pH ranged from 6.3 to 6.8.

B. Process data

Data required by the University of Oklahoma regarding the technical characteristics of the processes used in the water treatment plant and a summary of operational and maintenance problems are included in Appendices 5-C and 5-E.

C. General plant performance

In spite of being a small rural water supply system, the quality of the treated water throughout the period under study met the WHO International Drinking Water Standards and the AWWA Standards.

Taking only the turbidity parameter, the values varied between 0.05 and 1 JTU, with an average of 0.13 JTU; 90% of the time the turbidity of the treated water was less than 0.55 JTU. These values indicate the high efficiency of the Prudentopolis plant, which is producing better quality water than that normally produced in large Latin American cities which have complex treatment systems. (Figure 5-13)

D. Coagulation tests

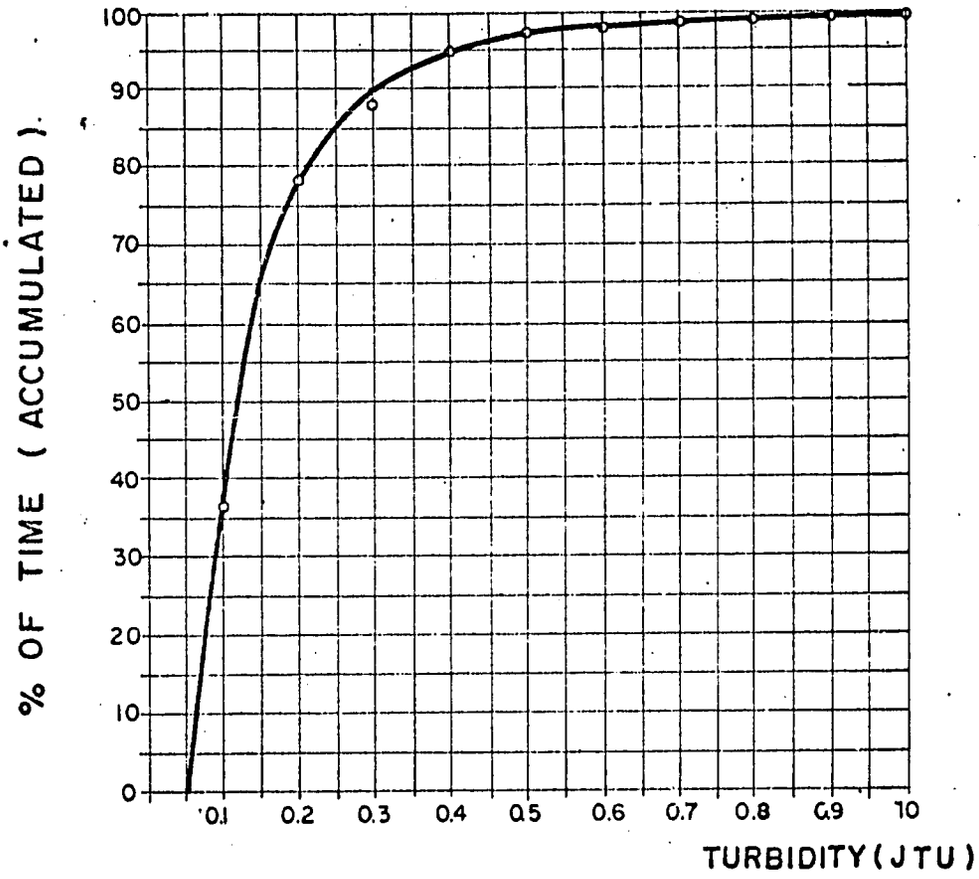
Because of the quality of the water in the Dos Patos River, especially during periods of low turbidity, it is relatively difficult to coagulate. Alum is used as the coagulant and lime to adjust the pH. Approximately 300 coagulation tests were run, varying the alum dose by 1 mg/l. It was found that the required dosage varied between 8 and 13 mg/l, and that the optimum dose was 10 mg/l. High turbidity levels do not require exact dosages. Since the principal problem is color removal, in all the tests it was found that acid conditions are suitable, with an optimum pH for coagulation of 6.1.

Figure 5-14 illustrates the alum dosages required in the jar tests and in tests conducted in the treatment plant. The correlation is defined by the equation: $y = 10.46 + 7.76 \text{ Ln } (x)$ with a goodness of fit of 0.89 when x is the optimum alum dosage in mg/l and y is the raw water turbidity in JTU. These results were used to prepare table 5-4 which is useful in providing a quick reference for the plant operators when selecting the coagulant dosage for the jar tests.

The influence of coagulant dosage and pH on the theoretical settling efficiency is shown in figure 5-15.

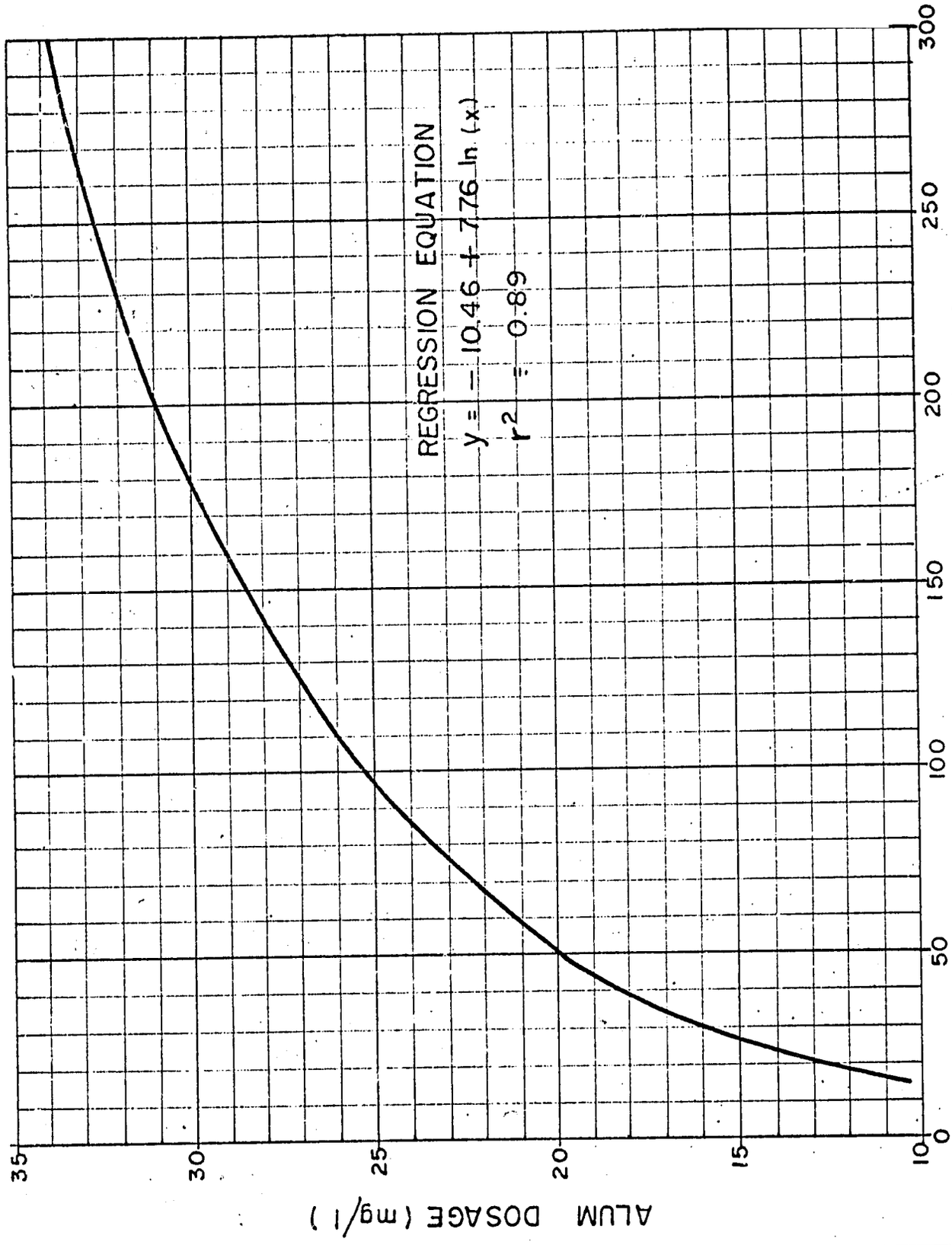
E. Chemical feeding

Due to the alkalinity of less than 30 mg/l when there is high turbidity the addition of lime alone is not enough to produce the optimum pH and another alkaline substance such as sodium carbonate must be added.

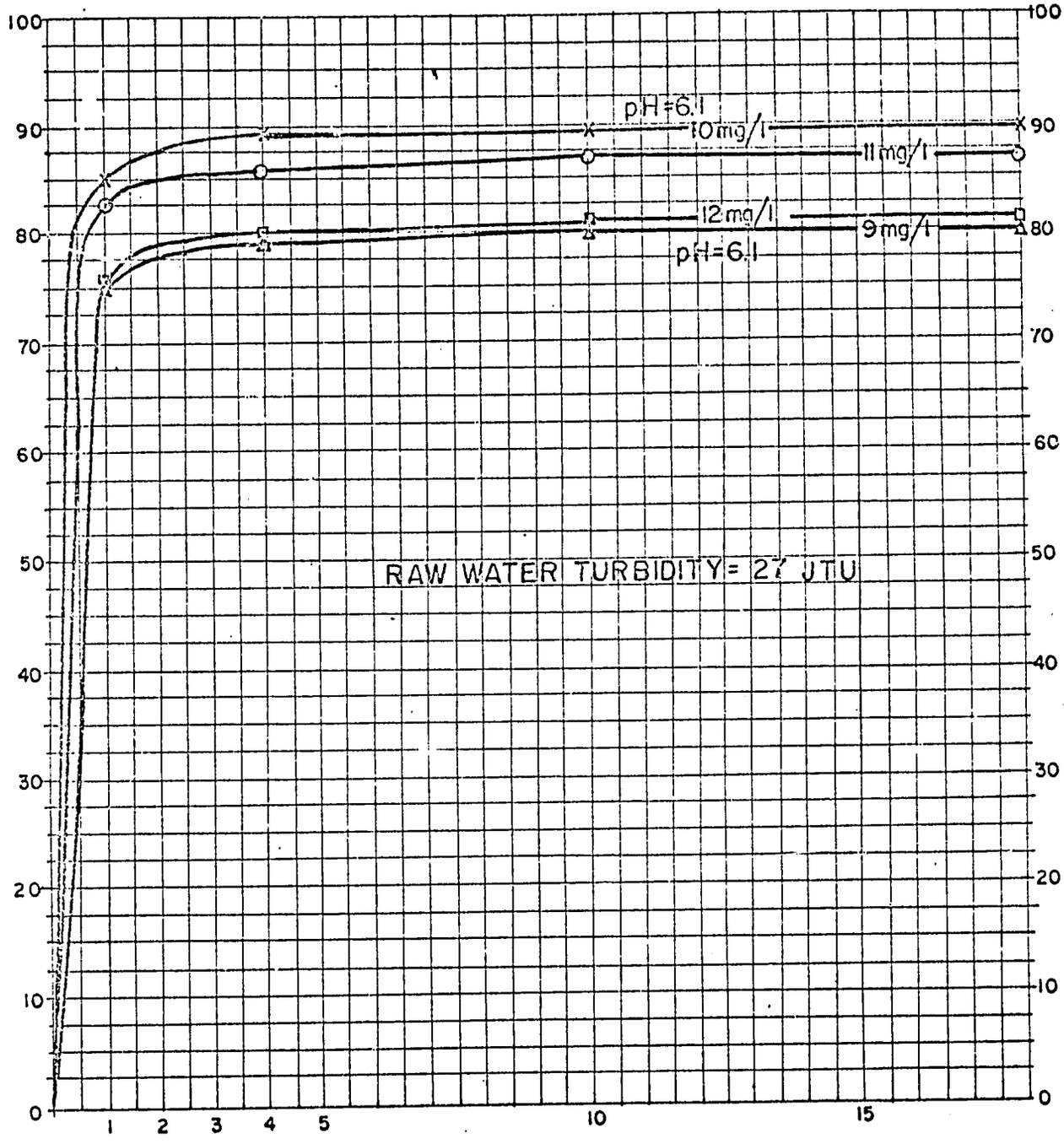


FILTERED WATER

CUMULATIVE FREQUENCY OF TREATED WATER TURBIDITY	FIGURE 5-13
WATER SUPPLY SYSTEM - PRUDENTOPOLIS	



CORRELATION BETWEEN COAGULANT DOSAGE AND RAW WATER TURBIDITY	FIGURE 5-14
WATER SUPPLY SYSTEM - PRUDENTOPOLIS	



ALUM DOSAGE AND TURBIDITY REMOVAL	FIGURE
WATER SUPPLY SYSTEM – PRUDENTOPOLIS	5-15

Table 5-4

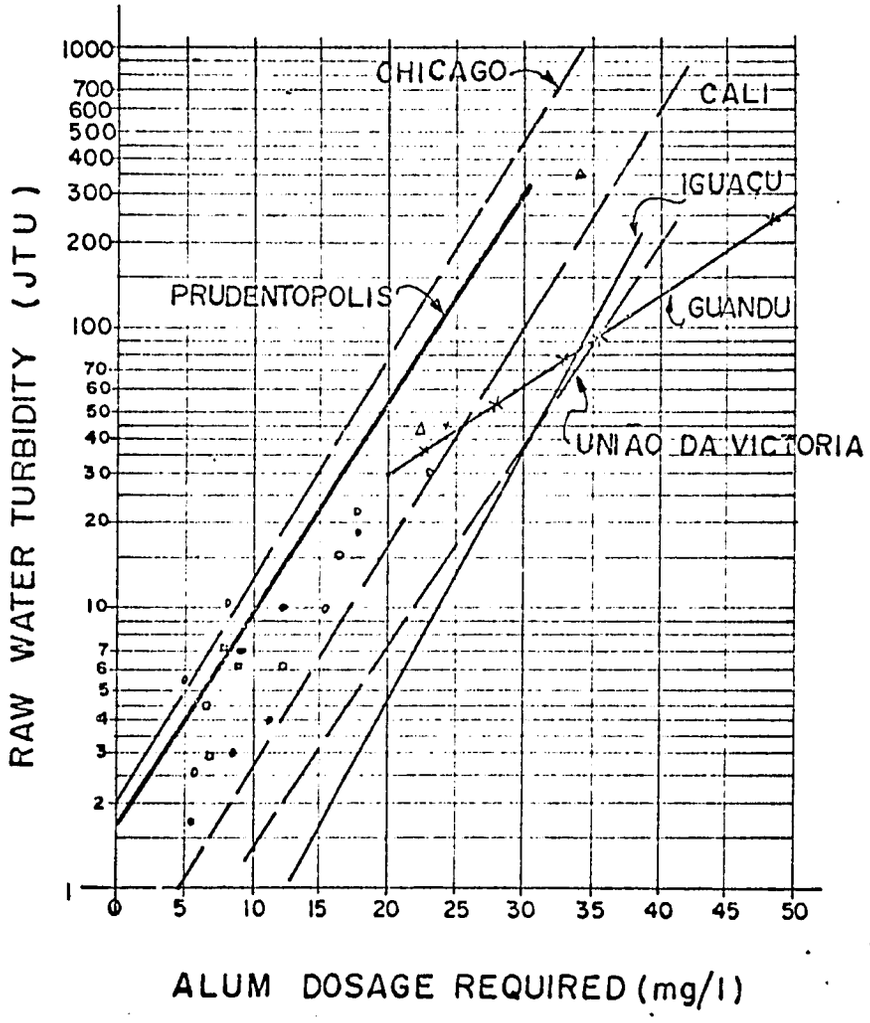
ALUM DOSAGE REQ

Turbidity JTU	Dosage mg/l
15	10.6
20	12.8
25	14.5
30	15.9
35	17.1
40	18.2
45	19.1
50	19.9
60	21.3
70	22.5
80	23.5
90	24.5
100	25.3
125	27.0
150	28.4
200	30.7
250	32.4
300	33.8

Problems were encountered in applying the exact dosage, because of the accuracy limits of the alum feeders, which proved to be inadequate for small systems with treatment capacities of less than 100 l/s, using the normal 5% alum solution. For this reason 1% concentrations were generally used which produced better coagulation, not so much due to the concentration itself but because a better, more uniform dispersion of the coagulant was obtained. The influence of the variation of the coagulant concentration on the efficiency of the plant was not studied. It was also found that the use of electrical agitators in the alum solution preparation tanks was not justified. Figure 5-16 shows the results of a comparative study of coagulant dosage and use in various treatment plants.

Since the lime suspension unit was designed on the basis of the maximum required dosage, when small quantities are used the suspension is kept for several days before it is used, which causes it to lose calcium hydroxide through its transformation into carbonate upon contact with the air. It is important to consider this factor in the application of lime since tests demonstrated that freshly-prepared samples had alkalinities (expressed as calcium carbonate) of about 88% due to hydroxides and 12% due to carbonates; after seven days the values were 47% due to hydroxides and 53% due to carbonates.

Since the normal dosage of alkaline substances is small, the feeders as designed cannot apply the exact dosage required.



ALUM DOSAGES REQUIRED FOR DIFFERENT TURBIDITY VALUES IN SELECTED WATER TREATMENT PLANTS	FIGURE 5-16
WATER SUPPLY SYSTEM - PRUDENTOPOLIS	

In summary, the problems encountered do not represent obstacles of any consequence, since they can be easily modified, both in the present plant and even more easily in new projects.

F. Coagulation-flocculation units

1) Velocity gradients

As indicated previously, the coagulation-flocculation system includes a mechanical agitator with a vertical axle which can be rotated at variable speeds (5.6, 7 and 8.4 rpm) in the four compartments and paddles whose size can be varied to obtain the following velocity gradients:

Compartment	Velocity gradient s^{-1}	
	Maximum	Minimum
1	94	49
2	75	35
3	50	28
4	35	16

To determine the optimum velocity gradients the results of theoretical jar tests were compared, obtaining ideal theoretical values of G=100, 50, 25 and 12.5 s^{-1}. In practice, however, it was found that equal or greater efficiency was obtained with values of 68, 50, 43 and 20 s^{-1}, due to the influence of the sludge blanket combined with a phenomenon of slow agitation (already described by Fair and Geyer) caused by a low velocity gradient in the pipes connecting the flocculator with the settler, which could not be duplicated in the laboratory. The results of these tests are presented in figure 5-17.

2) Hydraulic characteristics of the flocculator

The hydraulic behavior of the flocculator was determined by tracer studies, in this case using sodium chloride in a dosage of 67.8 mg/l during a period equal to four times the theoretical detention time.

The results are shown in figures 5-18 and 5-19. When analyzed using the theory of Wolf and Resnick (figure 5-20) they reveal the existence of 65% piston flow, 35% mixed flow and 3% dead spaces. In addition, from the analysis of the curve in figure 6-19 it is deduced that only 4% of the flow leaves the tank after 25% of the theoretical detention time (short circuiting) and that 30% of the flow is detained longer than the theoretical detention time.

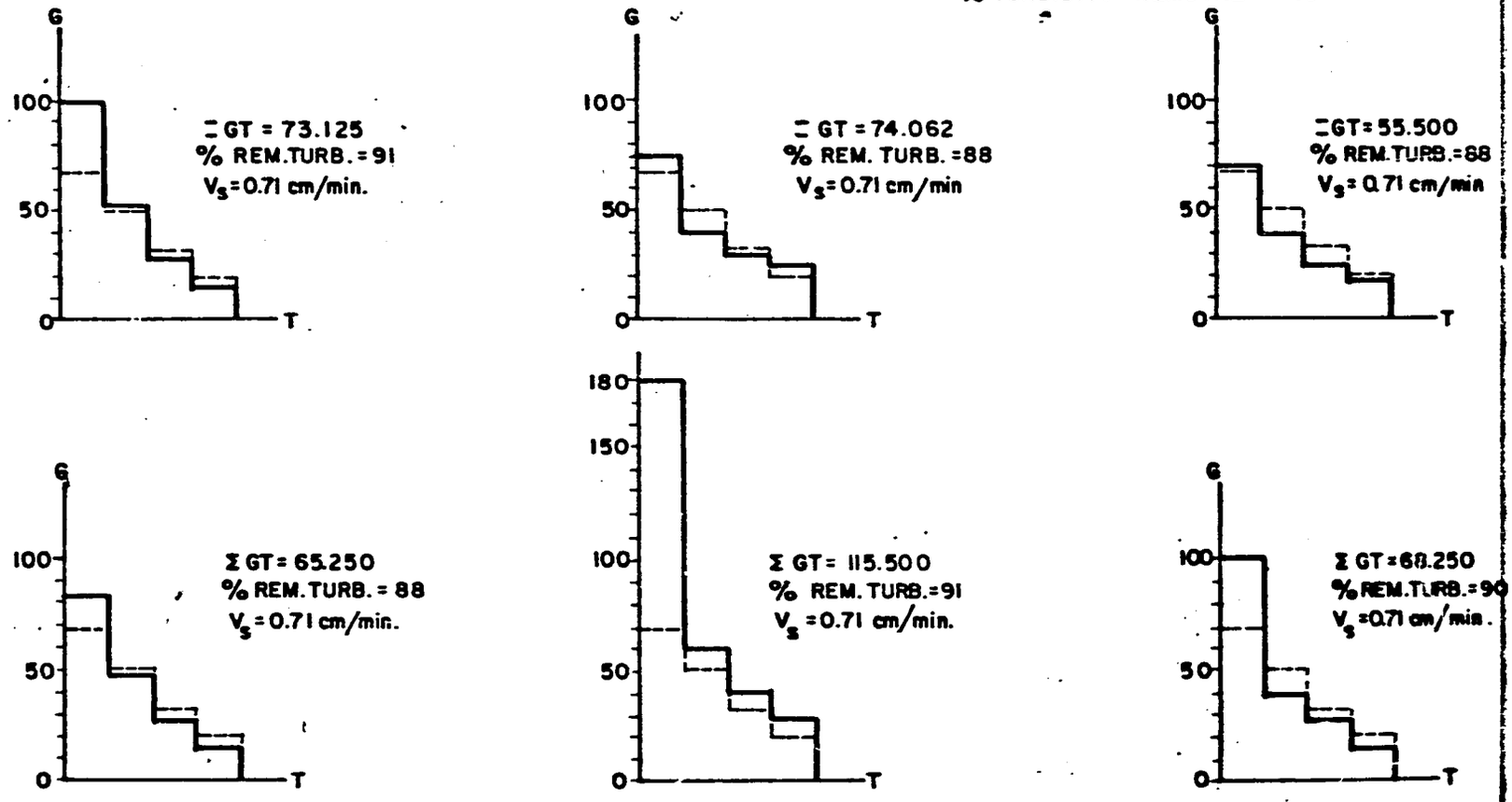
DATE : 26 FEBRUARY 1976

——— GRADIENTS IN JAR-TESTS

- - - - - GRADIENTS IN FLOCCULATOR

RAW WATER
- TURBIDITY = 27 JTU
- COLOR = 100
- ALKAL. = 18
- PH = 6.5

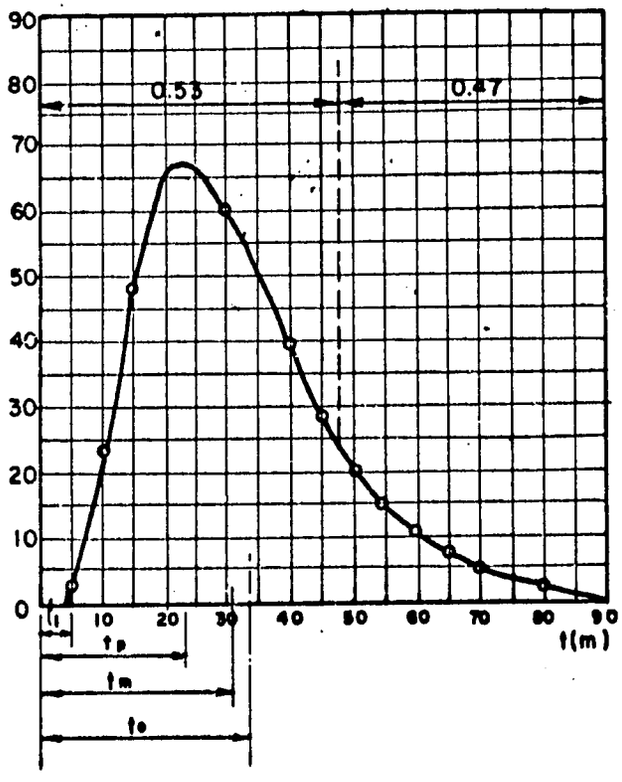
ALUM DOSAGE = 16.0 mg/L
SETTLED WATER IN PLANT = 1.5 JTU
% TURBIDITY REMOVAL = 95

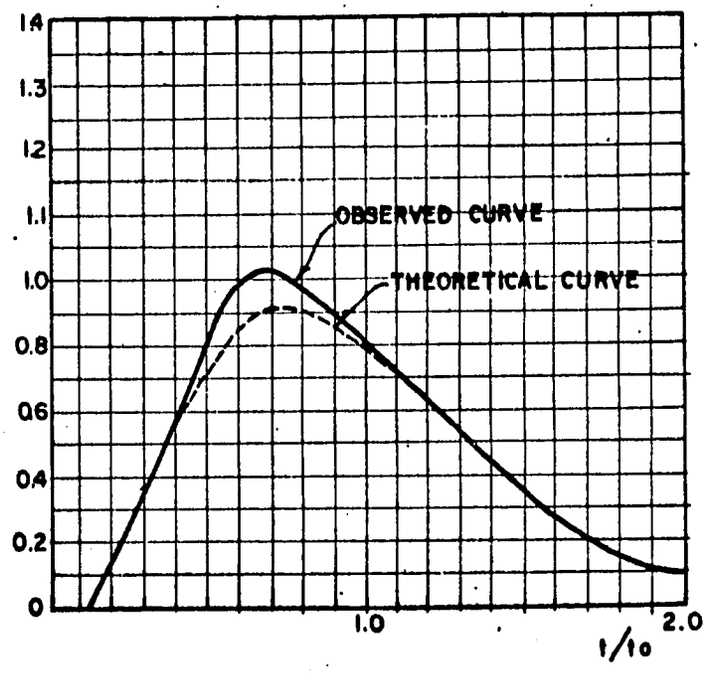


COAGULATION TESTS

WATER SUPPLY SYSTEM - PRUDENTOPOLIS

FIGURE 5-17

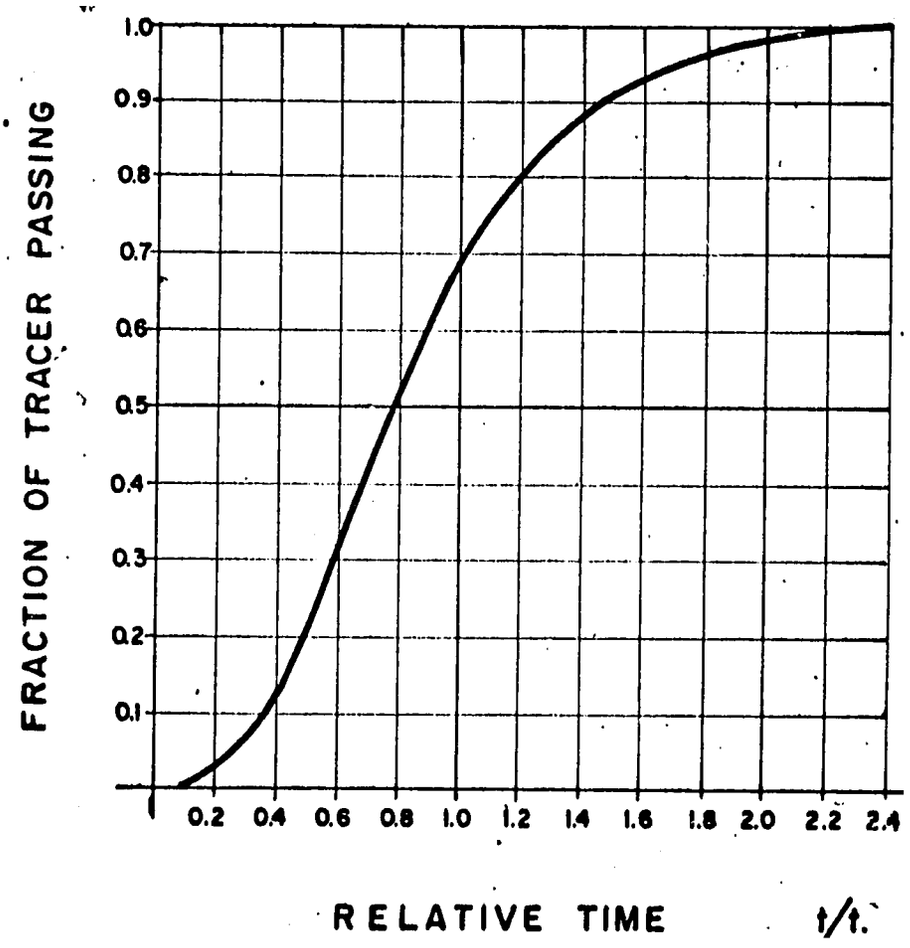




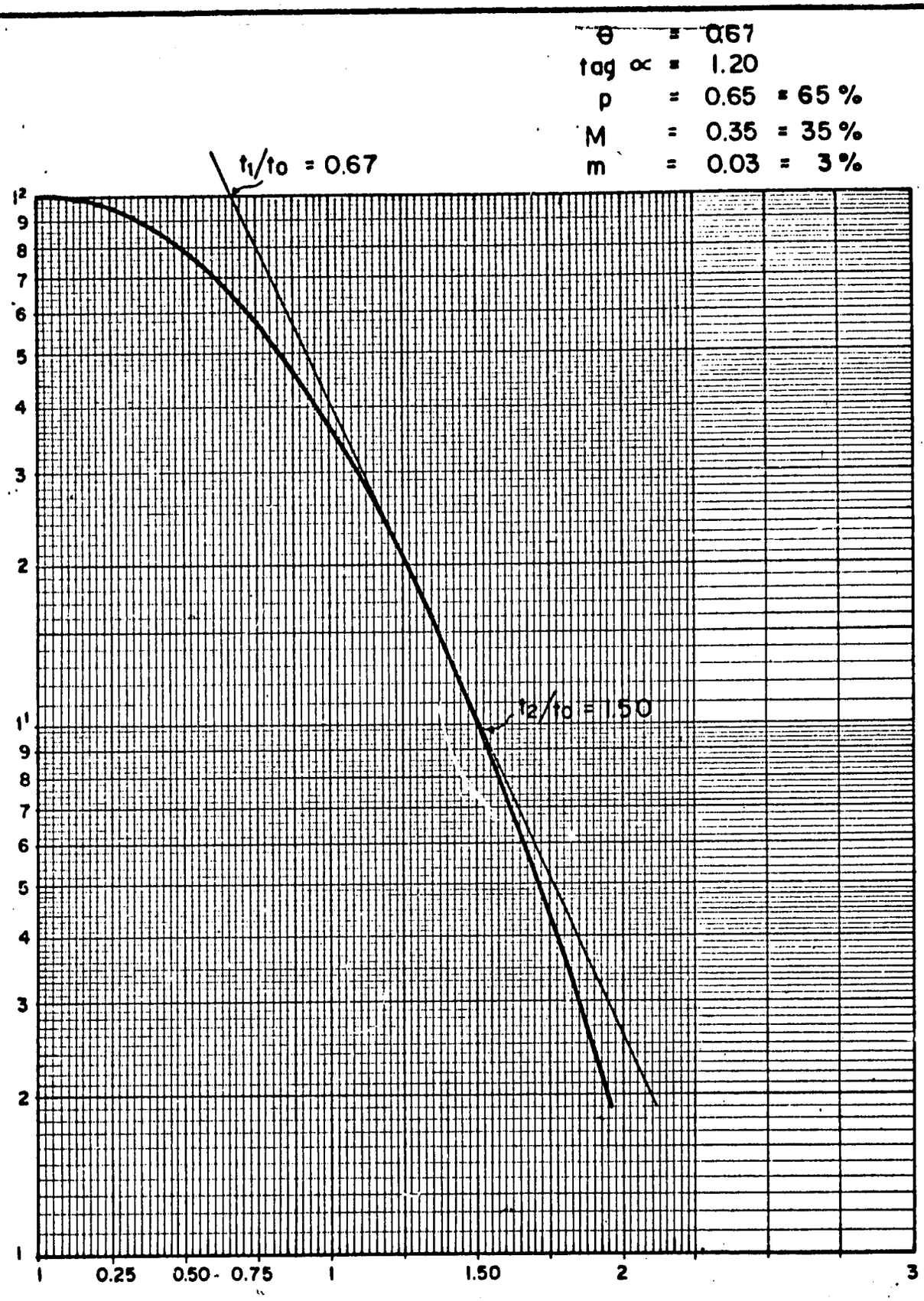
RESULTS OF TRACER TESTS IN THE FLOCCULATOR

WATER SUPPLY SYSTEM - PRUDENTOPOLIS

FIGURE 5-18



CUMULATIVE RESULTS OF TRACER TESTS IN THE FLOCCULATOR	FIGURE
WATER SUPPLY SYSTEM – PRUDENTOPOLIS	5-19



CHARACTERIZATION OF HYDRAULIC CONDITIONS IN THE FLOCCULATOR

FIGURE 5-20

WATER SUPPLY SYSTEM - PRUDENTOPOLIS

3) Conclusions

Although the efficiency of the flocculation units cannot be evaluated directly nor by the characterization of the type of flow, but rather in conjunction with the settling units, the results of the operational experiences demonstrate the high efficiency of the unit under study, which presents very favorable characteristics and conditions, especially the possibility of large variations in the velocity gradients, little short-circuiting and few dead spaces, simple construction and operation, and above all a highly efficient flocculation process, which makes it very suitable for water treatment projects. There are some small operational problems, especially in obtaining a complete coagulation when treating good quality water (low turbidity), since the required dosages of alum are equal to or less than 15 mg/l. Using 1% solution this is only one liter per minute or a few cubic centimeter per second, which makes it difficult to get a uniform distribution of the solution.

G. Settling units

1) Removal efficiency

With a minimum raw water turbidity value of 17 JTU a maximum value of 370 JTU, and an average value of 56 JTU, variable color and low alkalinity, the settled water turbidities were between 0.4 and 10 JTU with an average value of 1 JTU, with removal efficiencies as shown in figure 5-21. It should be pointed out that during 90% of the time the turbidity was less than 5 JTU which indicates an average efficiency of 98% during the entire period under study. This performance improved appreciably during the final months of the study when the average turbidity was 0.75 JTU, 65% of the time the values were below 1 JTU and 95% of the time they were less than 3 JTU, which indicates an average performance of 99% with overflow rates of 185 $m^3/m^2/day$.

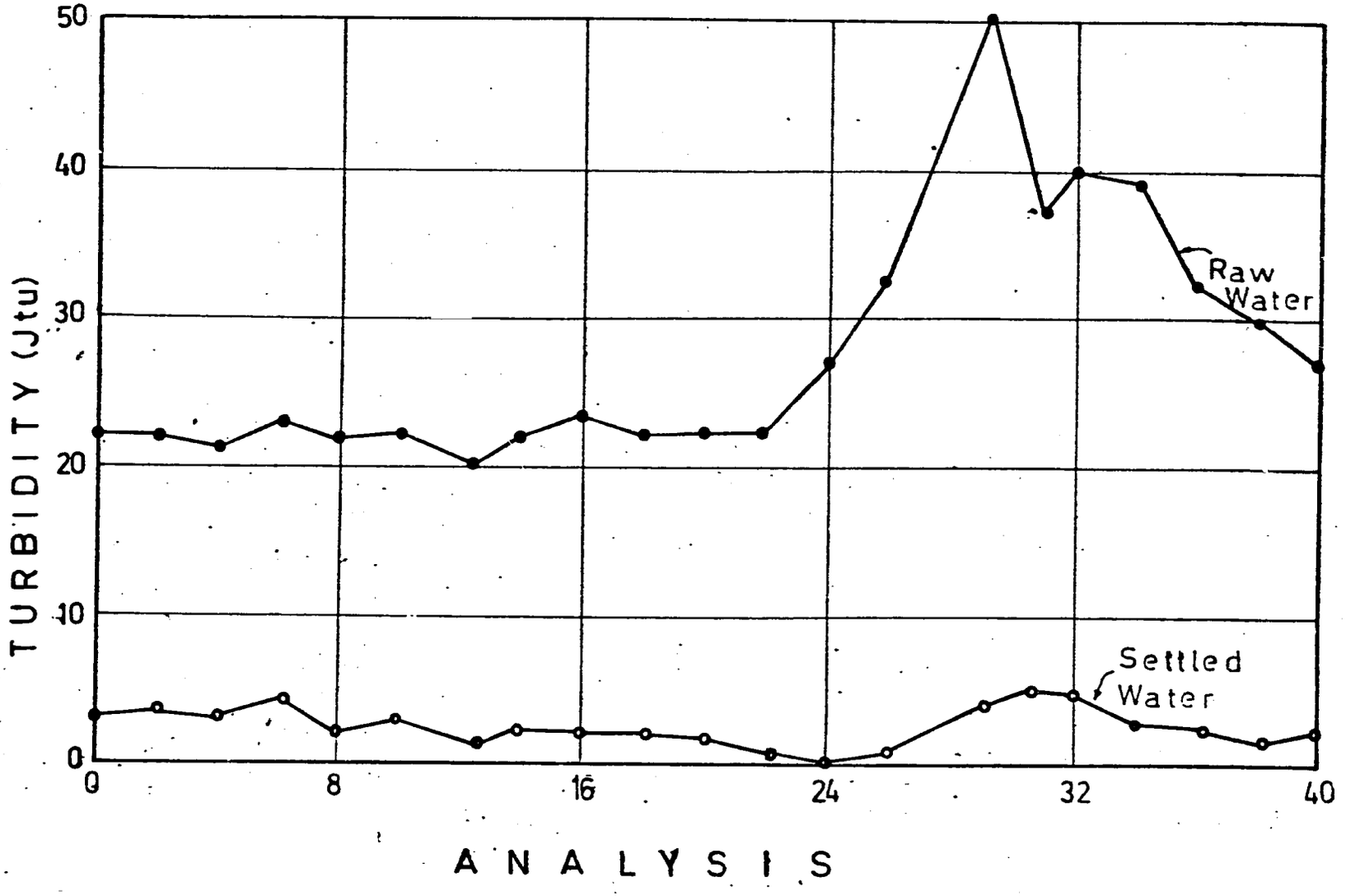
The cumulative frequency curve for settled water turbidity is shown in figure 5-22.

2) Comparison of actual and theoretical efficiency

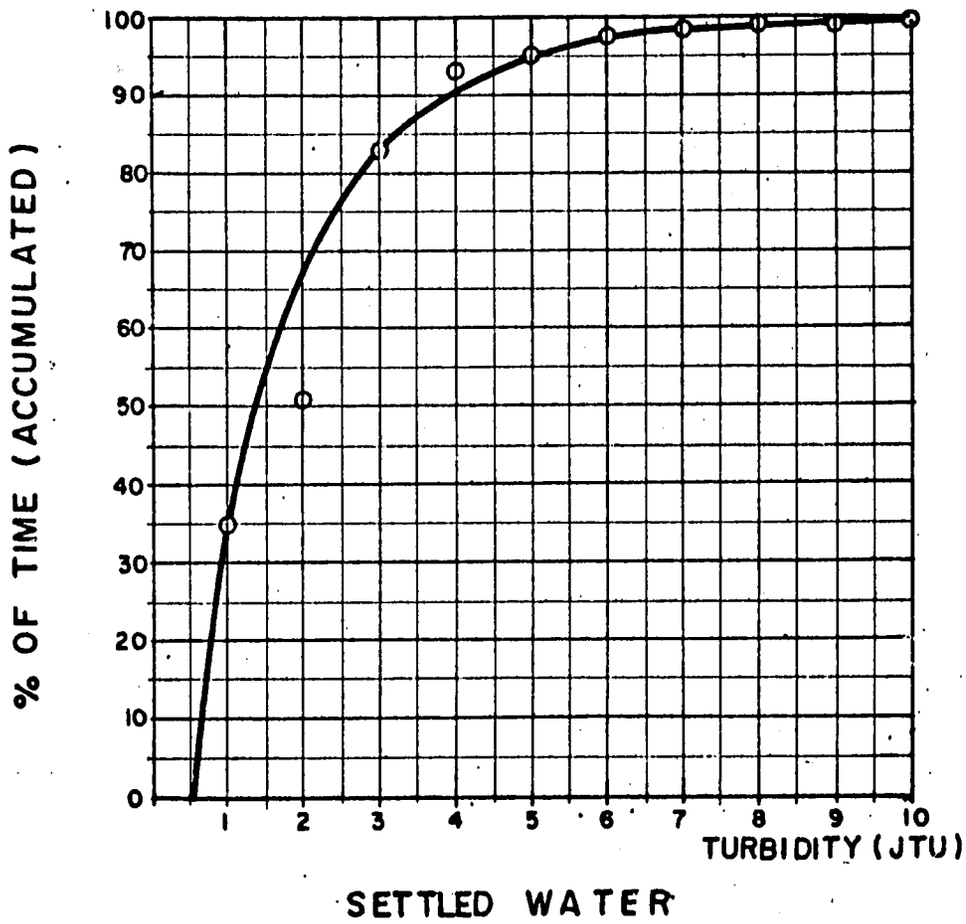
The combination of three settling processes - vertical settling, sludge blanket unit and high-rate settling unit - together with an adequate geometrical design and flocculation make it possible to obtain an actual efficiency above the theoretical level determined in the laboratory during 95% of the time. The average actual turbidities of the settler effluent were found to be 1 JTU, while the jar tests gave average values of 4.5 JTU. The results of these tests are illustrated in figures 5-23 and 5-24.

3) Influence of water quality on efficiency

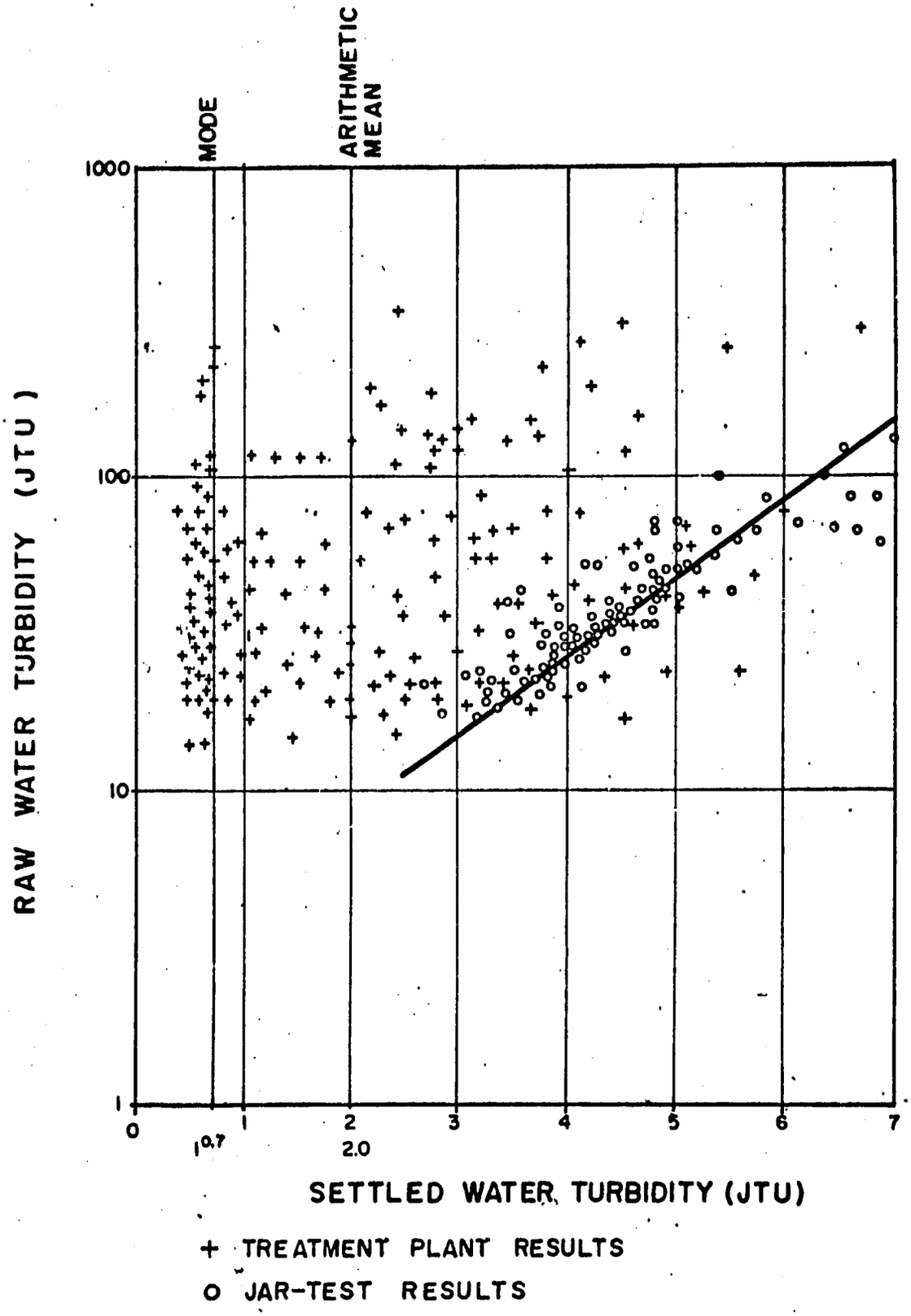
In the normal operation of the plant, the following correlation was found between raw water quality and settled water quality:



REMOVAL EFFICIENCY_SETTLING UNITS	FIGURE 5_21
WATER SUPPLY SYSTEM_PRUDENTOPOLIS	



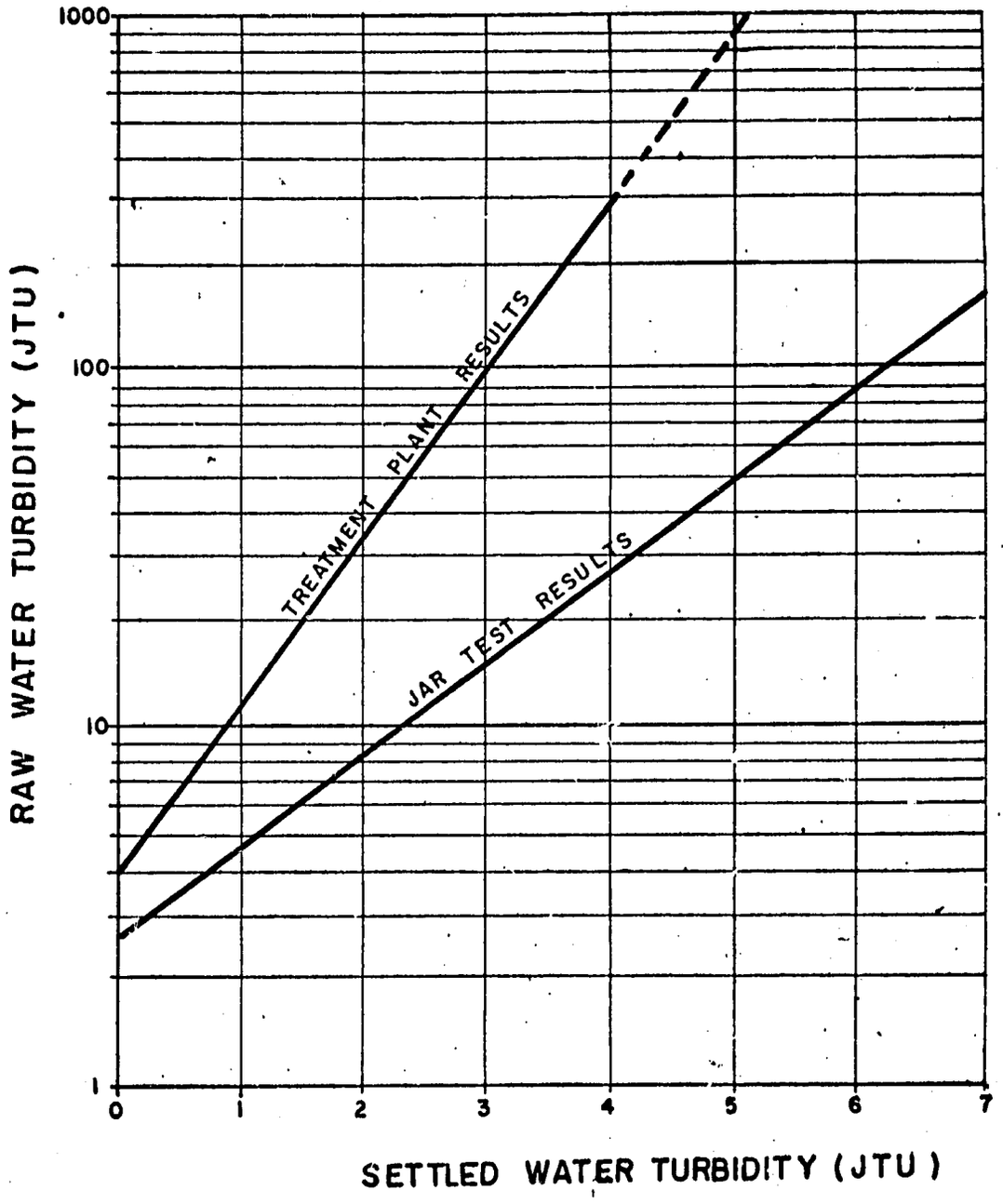
SETTLED WATER TURBIDITY CUMULATIVE FREQUENCY CURVE	FIGURE
WATER SUPPLY SYSTEM - PRUDENTOPOLIS	5-22



RELATION BETWEEN RAW WATER AND SETTLED WATER TURBIDITIES IN THE PLANT AND IN JAR-TESTS (PERIOD: DEC. 1975 TO MAY 1976)

WATER SUPPLY SYSTEM – PRUDENTOPOLIS

FIGURE 5-23



RAW WATER AND SETTLED WATER TURBIDITIES IN THE TREATMENT PLANT COMPARED WITH JAR TEST RESULTS (PERIOD: DEC.1975 TO MAY 1976

FIGURE 5-24

WATER SUPPLY SYSTEM - PRUDENTOPOLIS

$$y = a e^{bx}$$

the transform of which is

$$\ln y = A + Bx$$

and with specific values of

$$\log y = 0.61 + 0.46 x$$

with a perfect fit ($r^2 = 1$) for turbidities of less than 300 JTU.

Figure 5-25 shows the correlation of raw water and settled water turbidities by month from December through May 1976. Taking all the values which occurred during the period, an average efficiency of 91% is obtained for water with low turbidity (10 JTU) and 99% for more turbid water (300 JTU).

In figure 5-26 data on the efficiency of other treatment plants in Brazil with horizontal flow settlers, is compared with that of the plant under study, and in figure 5-27 the efficiency of the Prudentopolis plant is compared with that of other plants in the Americas. The performance of the Prudentopolis settling units is superior to all of the other plants cited.

4) Influence of the time of operation on the removal efficiency of the settler

In a study of the efficiency of the plate settler alone, samples of the influent and effluent showed efficiencies of 20% when the unit started operating in December and efficiencies of 95% in April.

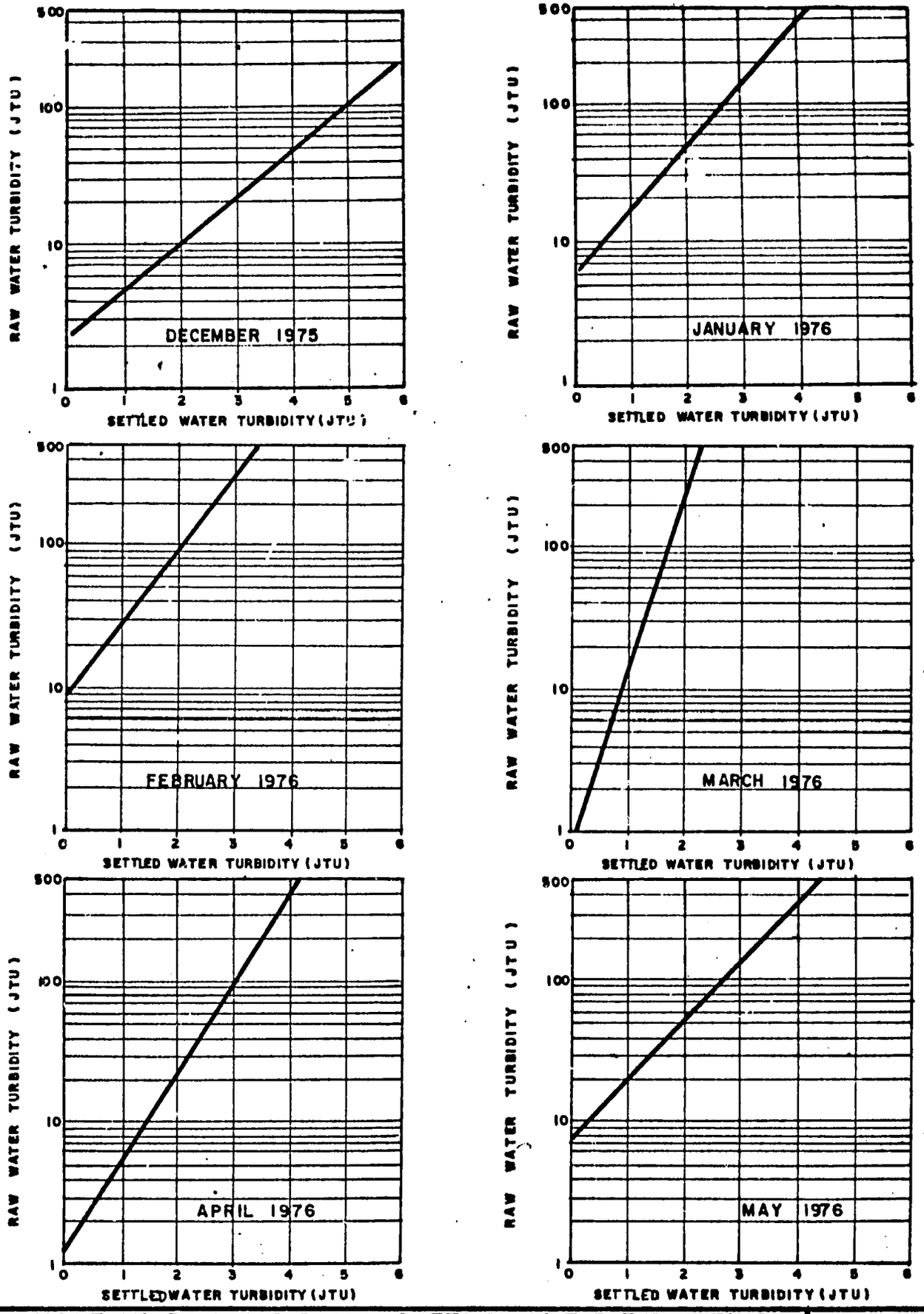
Figure 5-28 illustrates the variation in performance over time. This variation could be due to two factors - improvement of operational conditions and possibly a process of sedimentation self-interference that improved with time, as well as the production of velocity gradients and perikinetic flocculation conditions which favor the formation and deposit of the floc.

5) Hydraulic behavior of the settler

In order to determine the hydraulic conditions of the settler, tracer studies were done by adding calcium chloride at the flocculator outlet. Applying the equations of Wolf and Resnick to the concentrations obtained at the outlet of the settling unit, the following hydraulic characteristics were obtained:

Piston flow = 71%
Mixed flow = 29%

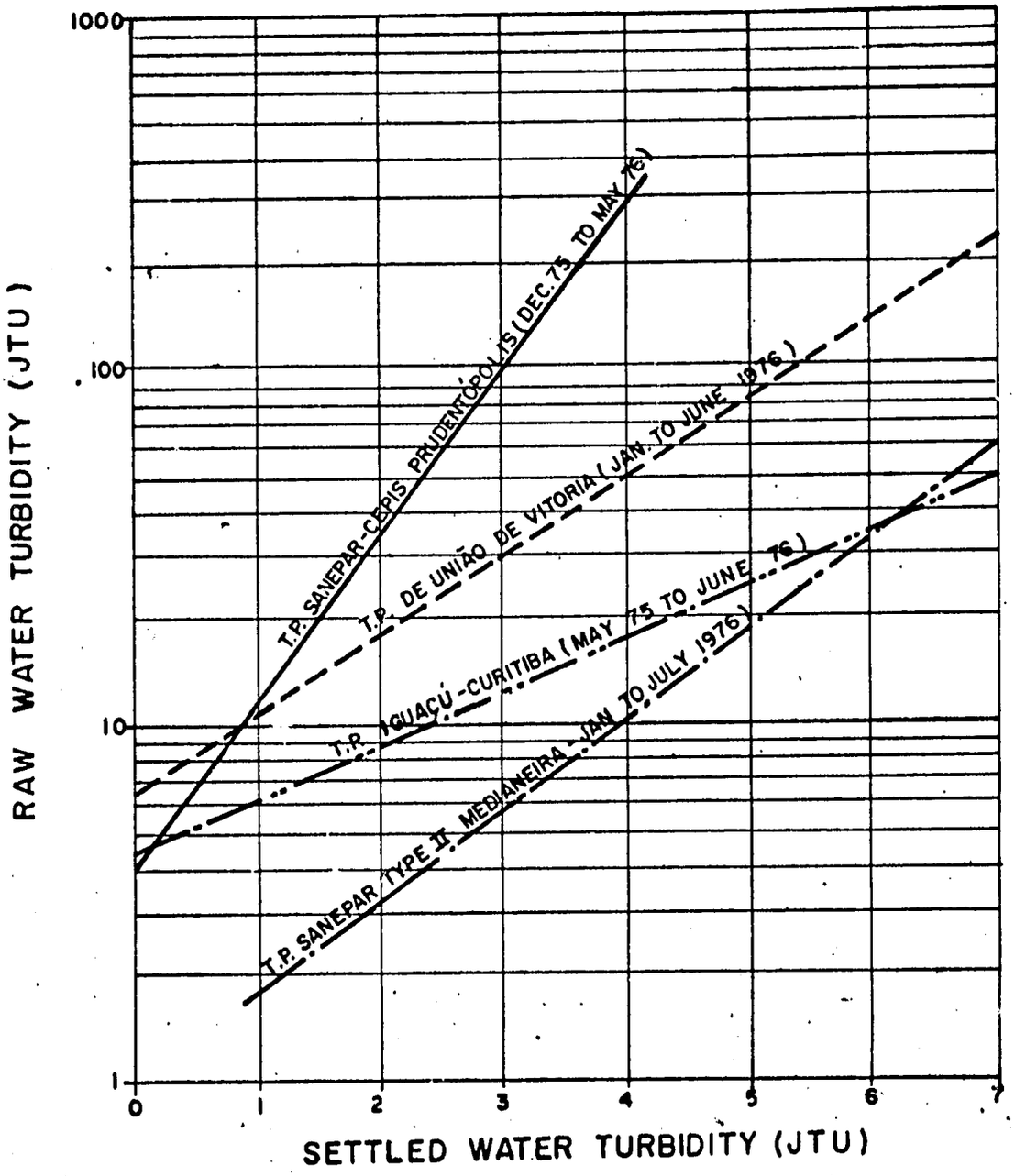
with a dead space volume of 4%.



MONTHLY RAW WATER AND SETTLED WATER TURBIDITIES
(PERIOD: DEC. 1975 TO MAY 1976)

FIGURE 5-25

WATER SUPPLY SYSTEM – PRUDENTOPOLIS



REGRESSION EQUATION

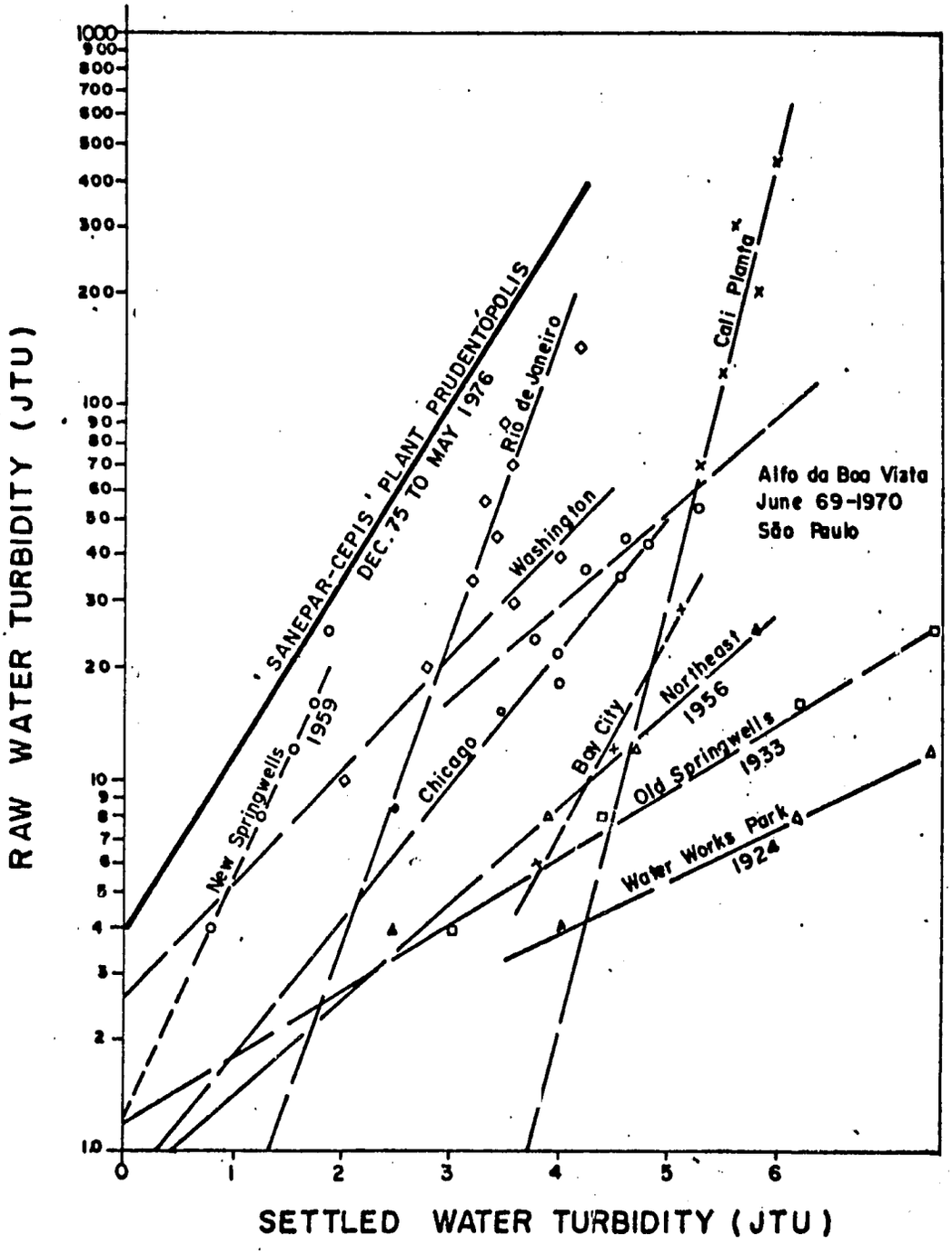
$\log y = a + b\ x$

y = raw water turbidity

x = treated water turbidity

goodness fit: $r^2 = 1$

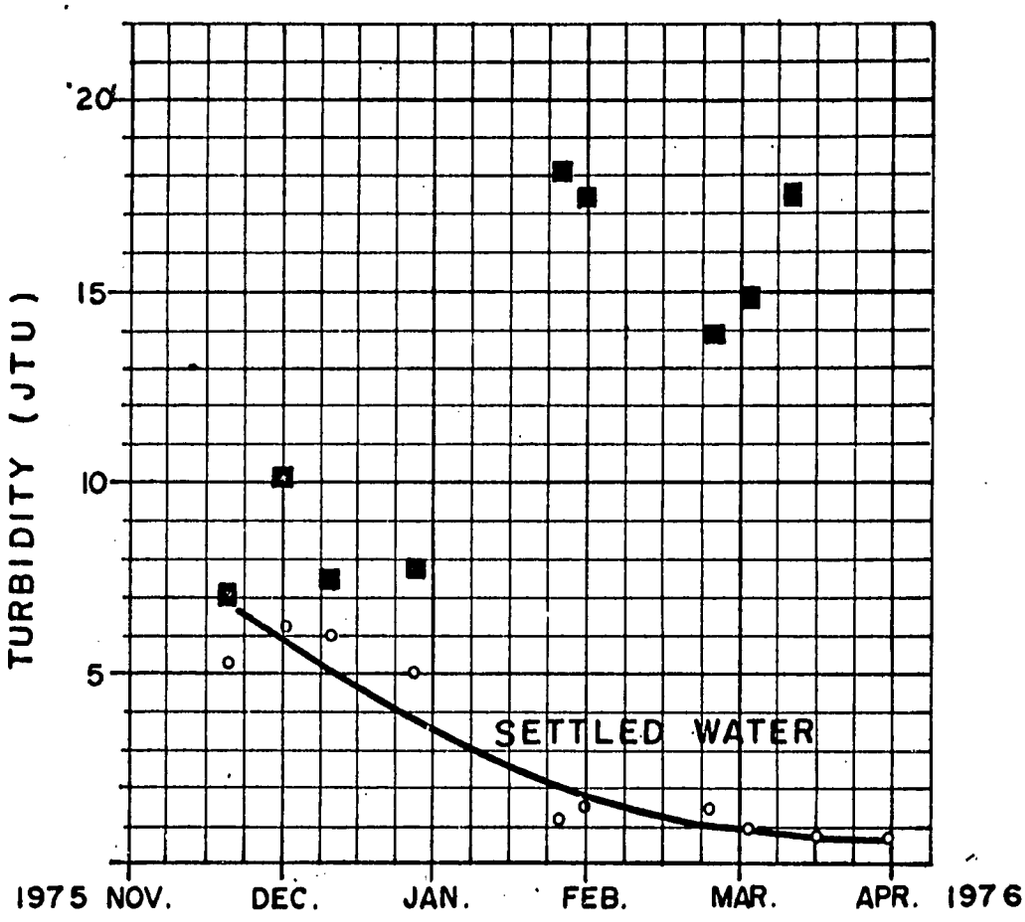
RAW WATER AND SETTLED WATER TURBIDITIES OF SANEPAR-CEPIS TREATMENT PLANT COMPARED WITH RESULTS OF TREATMENT PLANTS WITH CONVENTIONAL HORIZONTAL FLOW SETTLERS	FIGURE 5-26
WATER SUPPLY SYSTEM - PRUDENTOPOLIS	



RAW WATER AND SETTLED WATER TURBIDITIES WITH HORIZONTAL SETTLERS (ACCORDING TO HUDSON) COMPARED WHIT THE PLATE SETTERS IN 'SANEPAR-CEPIS' PLANT

FIGURE 5-27

WATER SUPPLY SYSTEM — PRUDENTOPOLIS



VARIATION OF PLATE SETTLER EFFICIENCY OVER TIME	FIGURE
WATER SUPPLY SYSTEM- PRUDENTOPOLIS	5-28

Since the sludge zone at the bottom of the settler accounts for 21% of the volume of the unit, it can be assumed that mixed flow predominates in that area, and consequently that pure piston flow predominates in the zone of upflow and high-rate sedimentation.

Analyzing the results using the equations of H. A. Baroudi, the following results were obtained:

Mixed flow = 26%
Piston flow = 38%
Variable flow = 36%

which are more in accordance with the geometrical characteristics of the settler.

6) Conclusions

Normal plant operation demonstrated the high efficiency of the settling unit and the viability of applying the theory of high-rate sedimentation to water treatment plants of simple design with very high efficiency. No operational problems whatsoever were encountered. The parameters which have an important influence on the efficiency of the settlers include water quality, pre-treatment and operating time. It was not possible to correlate the efficiency with the type of flow or the geometry of the settler. Part of the floc adheres to the surface of the plates and slowly slides to the bottom of the module. For this reason, the texture of the plate surface is important. When the settler is emptied, the floc deposited in the modules is easily removed.

H. Filtration

Although the results of the evaluation of the filters show a greater technical efficiency, in general they are similar to those obtained in Cochabamba. Therefore, only the most outstanding facts and those which complement the Cochabamba findings will be analyzed here. (Figure 5-29)

The turbidity of the influent water ranged from a minimum of 0.4 JTU to a maximum of 10 JTU, with an average value of 1 JTU; during 90% of the time the influent turbidity was less than 5 JTU. (Figure 5-13)

The filter showed high removal efficiency, since the effluent turbidity ranged between a minimum of 0.05 JTU and a maximum of 1 JTU, with an average value of 0.13 JTU; 90% of the time the turbidity was less than 0.50 JTU.

High turbidity values were due to the presence of oil in the raw water.

Regarding color removal, when the filter influent had between 5 and 25 CU, the filtered water values ranged from 0 to 2.5 CU. The majority of the time (84%) the filtered water presented color values below 2.5 CU. When the influent water showed slightly less than 25 CU, the filter water had values of 5 CU; with high color (more than 45 CU) the filtered water presented values near 25 CU. This demonstrates a low color removal efficiency for the filter when the influent water has color values above 5 CU.

Tests indicate an average filtration rate of 250 $m^3/m^2/day$, which is 4% more than the average design rate.

The three filtration stages discussed in relation to the Cochabamba filters were also observed in the Prudentopolis plant. Maximum initial filtration rates of 450 $m^3/m^2/day$ did not affect the quality of the filtered water.

Due to effective pretreatment, the water entering the filter had total influent turbidity values (per run) of 41 to 188 (Σt_i) with average values of 108 and impediment coefficient which varied between 0.0111 and 0.0147 with an average value of 0.00135 ($\frac{\Sigma t_i - \Sigma te}{\Sigma t_i \cdot L}$). This yields efficiency indices which vary between 1 and 2.7 with average values of 1.76; the filter runs were relatively long, ranging from 41 to 188 hours, with an average of 108 hours.

The backwashing process using the flow of the other filters is done in the usual manner, until a backwash rate of 0.60 m/min is reached. This is sufficient to fluidize the filter media and produce an expansion of about 50%. With backwash rates of 0.69 m/min, the expansion is 65%. Usually, the first stage of the backwash process takes a relatively short time (1 minute) because the water inlet valve and the wash water outlet valve are operated simultaneously.

No problems were encountered in washing the filters; there were no mud balls nor movements of the supporting bed which demonstrates the uniformity and efficiency of the washing process.

The special tests and the results of normal filter operation during the one year trial period that the treatment plant has been in operation have demonstrated the efficiency and proper functioning of both the filtration process and the backwashing procedure.

5.4.3 Economic evaluation

A. Construction costs

According to the initial budget, the approximate cost of the Prudentopolis water supply system was US$448 000; and the treatment plant cost US$64 000, or 14% of the total cost of the water system. Table 5-5 gives the breakdown of costs for the different parts of the system.

Comparative price studies done by SANEPAR indicate that the cost of the plant represents between 40 and 50% of the cost of conventional water treatment plants of similar capacity which have been built in the area.

Table 5-6 gives the breakdown of costs for the treatment plant itself. The largest expense (83.3%) was the civil works.

B. Operating costs

The costs of chemicals, electricity and wages are considered as the operating costs, since no other type of expenses (maintenance or repairs) were incurred during the research period.

Based on the prevailing local unit prices indicated in table 5-7 and the disbursements made during the research period, the operating cost is calculated to be US$13.74 per 1000 m^3, as shown in table 5-8

Table 5-5

APPROXIMATE COST OF THE PRUDENTOPOLIS WATER SUPPLY SYSTEM

Item	Cost US$	% of total cost
1. Collection and pumping	86 000	19
2. Supply line	60 000	13
3. Treatment plant	64 000	14
4. Pumping station	21 000	5
5. Storage	46 000	10
6. Distribution network (1st stage)	151 000	34
7. Miscellaneous	20 000	5
Total	448 000	100

Table 5-6

BREAKDOWN OF COSTS FOR THE PRUDENTOPOLIS TREATMENT PLANT

Item	Cost US$	% of total cost
Civil works	53 300	83.3
Pipelines, valves and accessories	7 000	11.0
Equipment: chemical feeders, agirators	3 700	5.7
Total	64 000	100.0

Table 5-7

UNIT PRICES - 1976

Item	Unit	Cost US$
Alum	ton	108.00
Hydrated lime	ton	51.00
Chlorine	kg	0.258
Electricity	1000 m^3	0.246
Wages	man/month	327.00

Table 5-8

OPERATING COSTS PER 1000 M^3

Item	Cost US$	% of total cost
Chemicals	2.38	17.3
Electricity	0.24	1.8
Personnel	11.16	80.9
Total	13.79	100.0

In general, the annual operating cost in US$ can be estimated using the equation

$$Co = 11.17 + 2.63\ Q$$

where Q is the capacity of the plant in thousands of cubic meters per day, with values between 1000 and 6000 m^3/day.

C. General economic data

Basic economic data required by the University of Oklahoma to meet the final research objective are included in Appendices 5-E and 5-F.

6. EVALUATION OF THE WATER TREATMENT PLANT OF CUENCA, ECUADOR (RESEARCH PROJECT No. 4)

6.1 INTRODUCTION

When it became difficult to supply the entire city of Cuenca with potable water, the Municipality created the Empresa de Teléfonos, Agua Potable y Alcantarillado (ETAPA). The first activity of the agency was to conduct a study of the water supply system. Three alternatives for expanding the treatment plant were presented as part of the study: expansion of the existing rapid filtration plant using conventional methods as described in a study done by the Instituto Ecuatoriano de Obras Sanitarias (IEOS); the use of patented methods by requesting bids from foreign firms; and the formulation of a project based on high-rate sedimentation and declining-rate dual media filters. This final alternative was chosen because of its technical efficiency and low cost. The project was carried out with advice and collaboration from CEPIS.

CEPIS was contracted by the University of Oklahoma to evaluate water treatment plants designed with new technological concepts in order to determine the degree of adaptability of the new criteria to the prevailing conditions in the developing countries, and to evaluate the technical efficiency of the processes involved. The Cuenca treatment plant was chosen as one of the research sites because of the innovations in its design, the fact that the basic units of the plant were already constructed and could be easily evaluated with only slight modifications, and because the socio-economic characteristics of Cuenca can be considered as representative of Latin America. An agreement was signed with ETAPA for the execution of field research including:

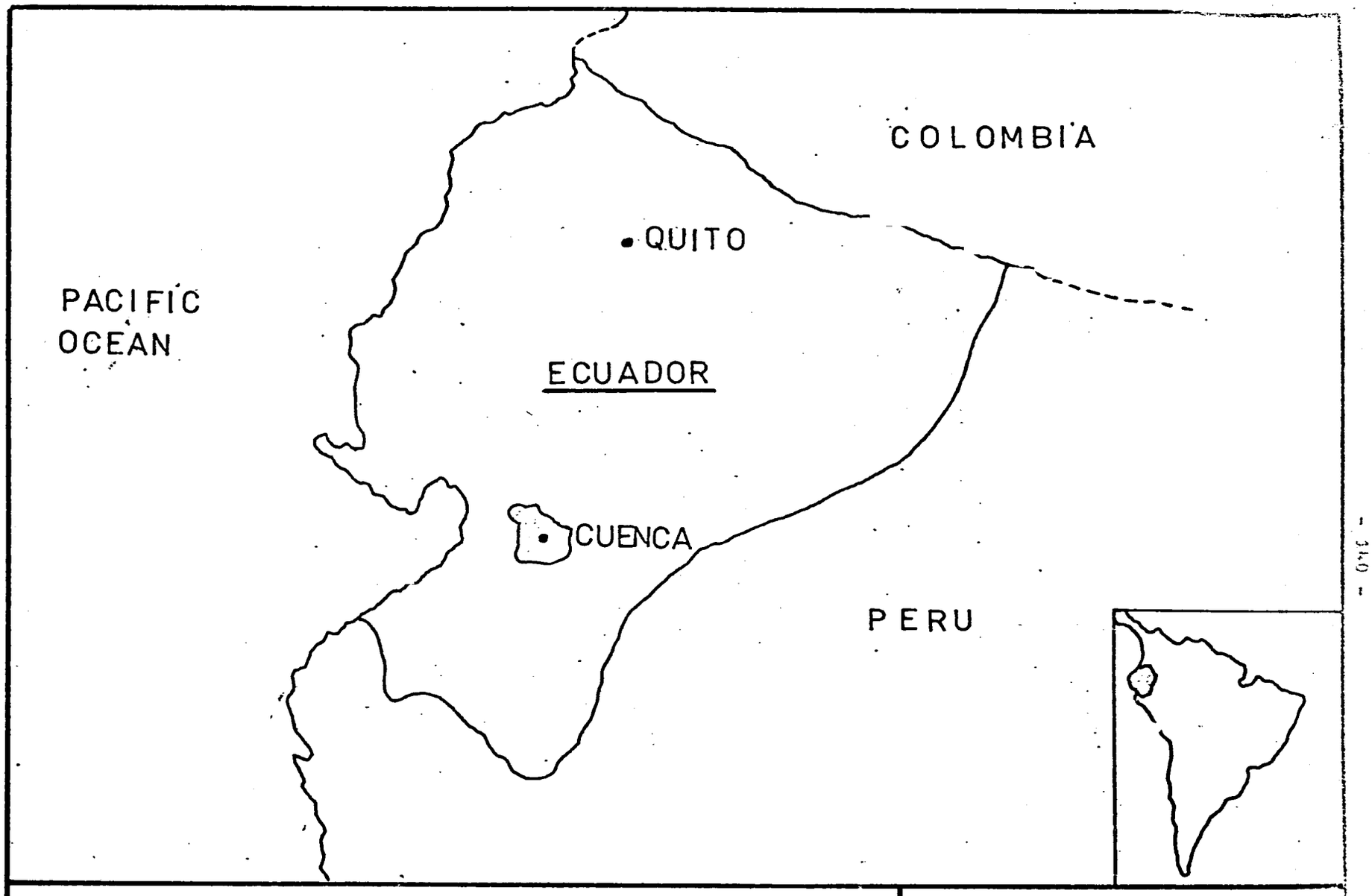
- Study of the general demographic and socio-economic conditions.
- Technical evaluation of the characteristics and efficiency of each unit of the treatment plant.
- Economic study of the initial investments and operation and maintenance costs.

The results of these studies are described in this chapter.

6.2 GENERAL INFORMATION ABOUT THE CITY

Cuenca, the third city of Ecuador, is located in the Province of Azuay; its geographical position is 79°05' longitude west and 2°49' latitude south (figure 6-1).

It has a temperate climate with an average temperature of 14°C and an average precipitation of 864 mm/year.



LOCATION OF CUENCA - ECUADOR	FIGURE 6-1
WATER TREATMENT PLANT CUENCA	

The population of Cuenca is 110 700 inhabitants (1975) and it has been estimated that it will reach 244 000 inhabitants in the year 2000. Table 6-1 gives the estimated population growth for the city.

Table 6-1

ESTIMATED POPULATION GROWTH FOR THE CITY OF CUENCA

Year	Population	
	Minimum	Maximum
1970	93 563	98 146
1975	105 276	116 288
1980	118 213	138 138
1985	132 716	164 188
1990	149 015	196 188
1995	167 313	232 138
2000	187 855	274 000

Source: Technical Report, Water Treatment Plant, 1970

6.3 GENERAL DESCRIPTION OF THE WATER SUPPLY SYSTEM

La Empresa de Teléfonos, Agua Potable y Alcantarillado (ETAPA) is responsible for the design, construction, operation and maintenance of the water supply system for the city of Cuenca. Figure 6-2 shows the basic layout of the water supply system which has the following characteristics:

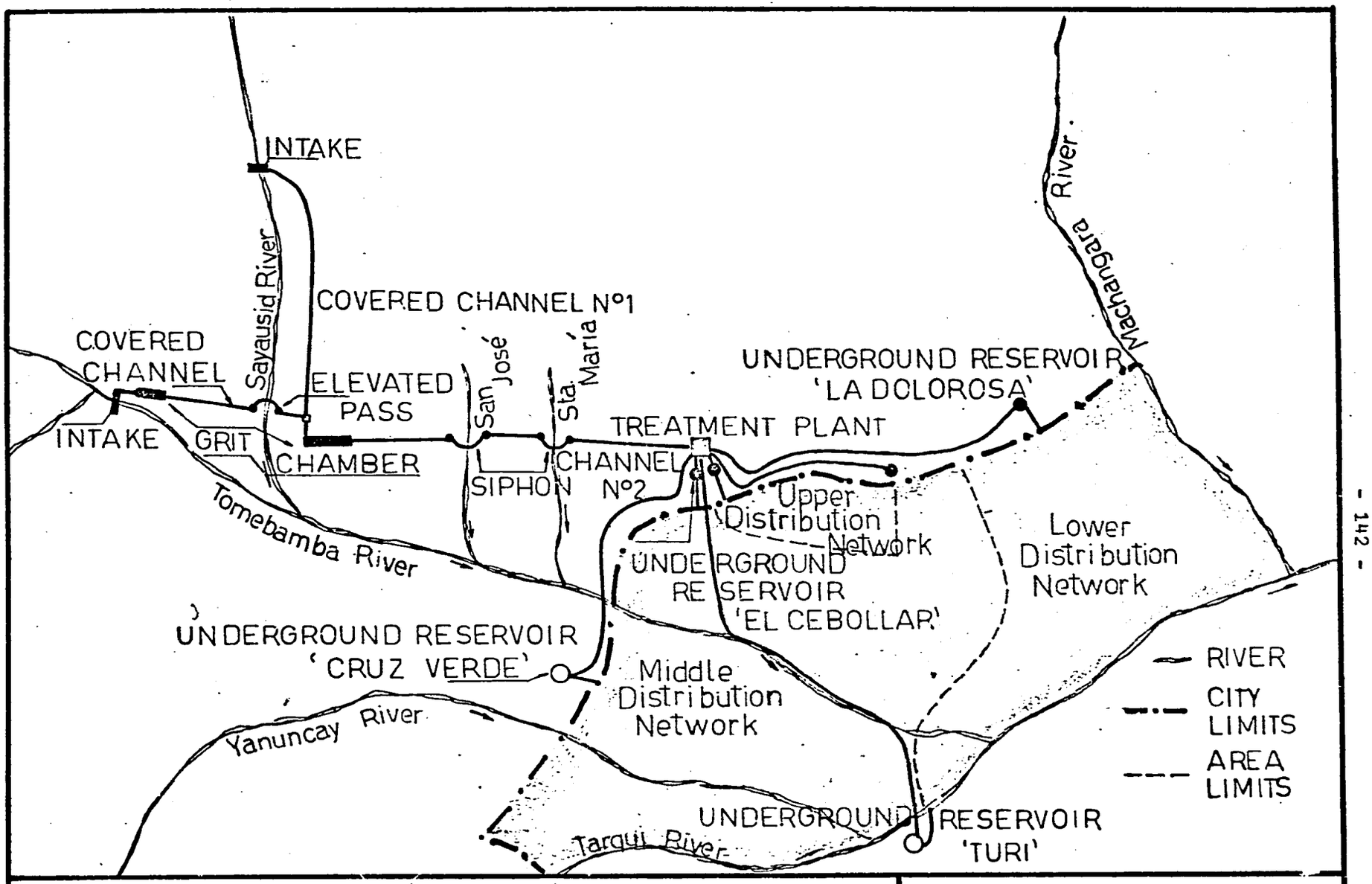
6.3.1 Design flow

With a unit consumption of 166 and 220 l/cap/day, the average daily consumption in 1970 was 235 l/s. The consumption estimated for the year 2000 will be 860 l/s. The coefficient for the maximum day is 1.40. Figure 6-3 illustrates the daily consumption estimates (average, maximum and hourly maximum).

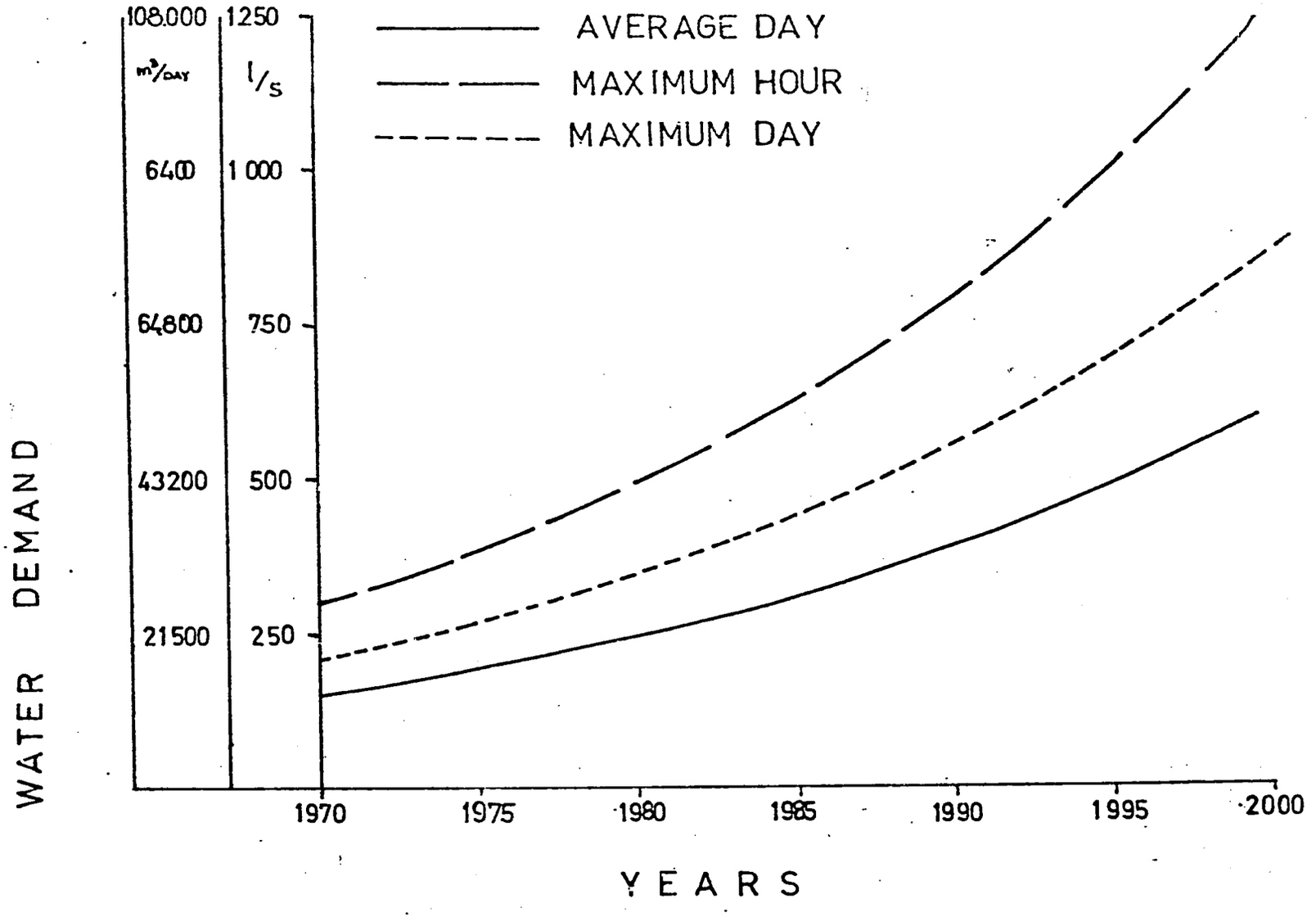
6.3.2 Sources

The waters of the Tomebamba River, a high mountain river, with gradients above 4%, are being used as a new source of water; the catchment area above the intakes is small (234 km^2); the land is of glacial origin. The flow during the dry season is 600 l/s and during the flood season it reaches a maximum of 85 m^3/s; the average flow is 3.60 m^3/s. (Period of record = 30 years).

The physical-chemical quality of the waters of the Tomebamba and Sayausid Rivers is acceptable. No corrective treatment except disinfection is needed during 76% of the year (278 days). Table 6-2 gives the results of representative analyses.



GENERAL LAYOUT	FIGURE 6-2
WATER SUPPLY SYSTEM - CUENCA	



WATER CONSUMPTION	FIGURE 6 - 3
WATER SUPPLY SYSTEM – CUENCA	

Table 6-2

REPRESENTATIVE ANALYSES: PHYSICAL, CHEMICAL, BACTERIOLOGICAL

PERIOD 1968-1971 TOTAL NUMBER OF ANALYSES: 49

Riverflow conditions / Parameter / Sample Nº	Maximum flood flow				Normal flood flow						Normal flow														Minimum observed value	Average value (Mode)	Maximum observed value
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24			
Temperature	-	-	-	-	-	-	-	-	-	-	11	11	10	10	10	11	12	11	12	11	10	10	10	10	8	11.2	13
Apparent color	500	130	600	180	30	35	31	36	120	195	25	14	15	17	13	13	15	10	9	9	10	9	8	12	0	2.8	600
True color	10	10	12	6	3	3	3	3	3	5	2	1	1	2	1	1	1	0	0	0	0	0	0	0	10	3.4	12
Turbidity	350	120	500	300	25	30	27	29	93	150	12	11	10	10	12	12	13	10	8	8	10	8	8	10	6	20.9	500
pH	7.5	7.7	7.6	7.4	7.3	7.3	7.2	7.9	7.2	7.4	7.3	6.5	7.5	7.2	7.6	7.5	7.3	7.4	7.4	7.7	7.4	7.2	7.3	7.3	6.5	7.4	7.9
Alkalinity	42	43	42	42	34	31	28	49	31	45	58	37	61	59	58	59	58	62	57	60	60	57	60	64	28	47.3	61
Hardness	40	41	39	41	34	30	27	45	30	41	55	39	58	58	57	55	55	55	52	55	55	55	55	60	27	45.9	98
Soluble iron	1.2	0.9	0.8	0.7	0.1	0.1	0.2	0.1	0.01	0.02	0	0	0.02	0	0	0.02	0.01	0.01	V	V	V	0.05	0	0	0	0.08	1.2
Colloidal iron	2.0	1.2	2.0	1.8	0.14	0.5	0.8	0.6	0.16	0.20	0	0	0.13	0	0	0.15	0.15	0.1[illegible]	0.08	0.10	0.22	0.20	0	0	0	0.17	2.0
TOTAL	3.2	2.1	2.8	2.5	0.15	0.6	0.9	0.7	0.17	0.22	0	0	0.15	0	0	0.17	0.16	0.15	0.08	0.10	0.22	0.25	0	0	0	0.25	[illegible].2
CO_2	3.5	1.5	0.9	1.2	1.9	0.7	1.2	0.8	1.2	1.8	6	0	0	1.7	1.9	0	0	0.9	2.6	2.2	2.2	2.2	1.76	0	0	0.80	3.5
Total coliforms																									980	8.758	75.00
MPN																									30	396	1.40

Note: A total of 49 analyses were done. Samples 1-24 are representative of specific characteristics under the different flora conditions; the number of samples for each condition in proportional to the number of total occurrences.

Table 6-3

LEAST FAVORABLE ANALYSES: CHEMICAL, PHYSICAL, BACTERIOLOGICAL

SOURCE: TOMEBAMBA RIVER AND THE NEW COLLECTION SITE

Parameter \ Date		3 April 1968	8 April 1968	22 April 1968	11 July 1968	15 July 1968
TEMPERATE °C		14.5	15	16	13	13
ODOR WHEN COLD		E-2	Impercept.	Impercept.		
APPARENT COLOR		15		10	9	40
TRUE COLOR		9		5	4	
TURBIDITY		13.5	8.5	10.5	14	40
pH		7.6	7.7	7.8	7.7	7.3
ALKALINITY	p.p.m. ($CaCO_3$)	31		40	31	34
HARDNESS	p.p.m. ($CaCO_3$)	44	44	50	48	34
CARBON DIOXIDE	p.p.m. (CO_2)	0.9		0.8	1.5	3.5
CALCIUM	p.p.m. (Ca)	20.5		33.0	11.2	
TOTAL IRON	p.p.m. (Fe)	0.6	0.9	0.6	0.8	0.2
CHLORIDES	p.p.m. (Cl^-)	6		8	8	6.3
SULFATES	p.p.m. (SO_4)	10		5	5	12
SULFITES	p.p.m. (SO_3)	0		0		
NITRATES	p.p.m. (NO_3)	5		0.6		0
PHOSPHATES	p.p.m. (PO_4)	1.9		1.0		
SILICA	p.p.m. (SiO_2)	13		12		
FLUORINE	p.p.m. (F)	0		0		0.1
COPPER	p.p.m. (Cu)	0		0		
CHROMATE	p.p.m. (CrO_4)	0		0		
AGAR PLATE COUNT		75 000	23 600	9 800		
MOST PROBABLE NUMBER		1 400	460	750		

SOLUBLE IRON	2.0 p.p.m.
COLLOIDAL IRON	1.2 p.p.m.
TOTAL IRON	3.2 p.p.m.

During the winter months (January through May) the run-off increases and the quality of the water deteriorates (as indicated in table 6-3) making it necessary to remove its color, turbidity, iron content, and to use stabilization and disinfection processes.

6.3.3 Collection works

These consist of a diversion dam with a caucasian intake. A flow of 900 l/s is taken from the Tomebamba River. There are also auxiliary works such as grids, grit chambers and a flood weir.

6.3.4 Supply line

The supply line is a new canal of reinforced concrete, 1.00 m deep, 0.60 m wide, and 1 820 m long, with gradients of approximately 1% and a capacity of 838 l/s; the old canal with a capacity of 789 l/s is 8 200 m long Complementary works include the pass over the Sayausid River, two large siphons with five 20" cast-iron pipelines, and two grit chambers.

6.3.5 Treatment plant

The present treatment plant (figures 6-4 to 6-15) is the result of modifications and additions to a conventional type rapid filtration plant, and its characteristics are as follows:

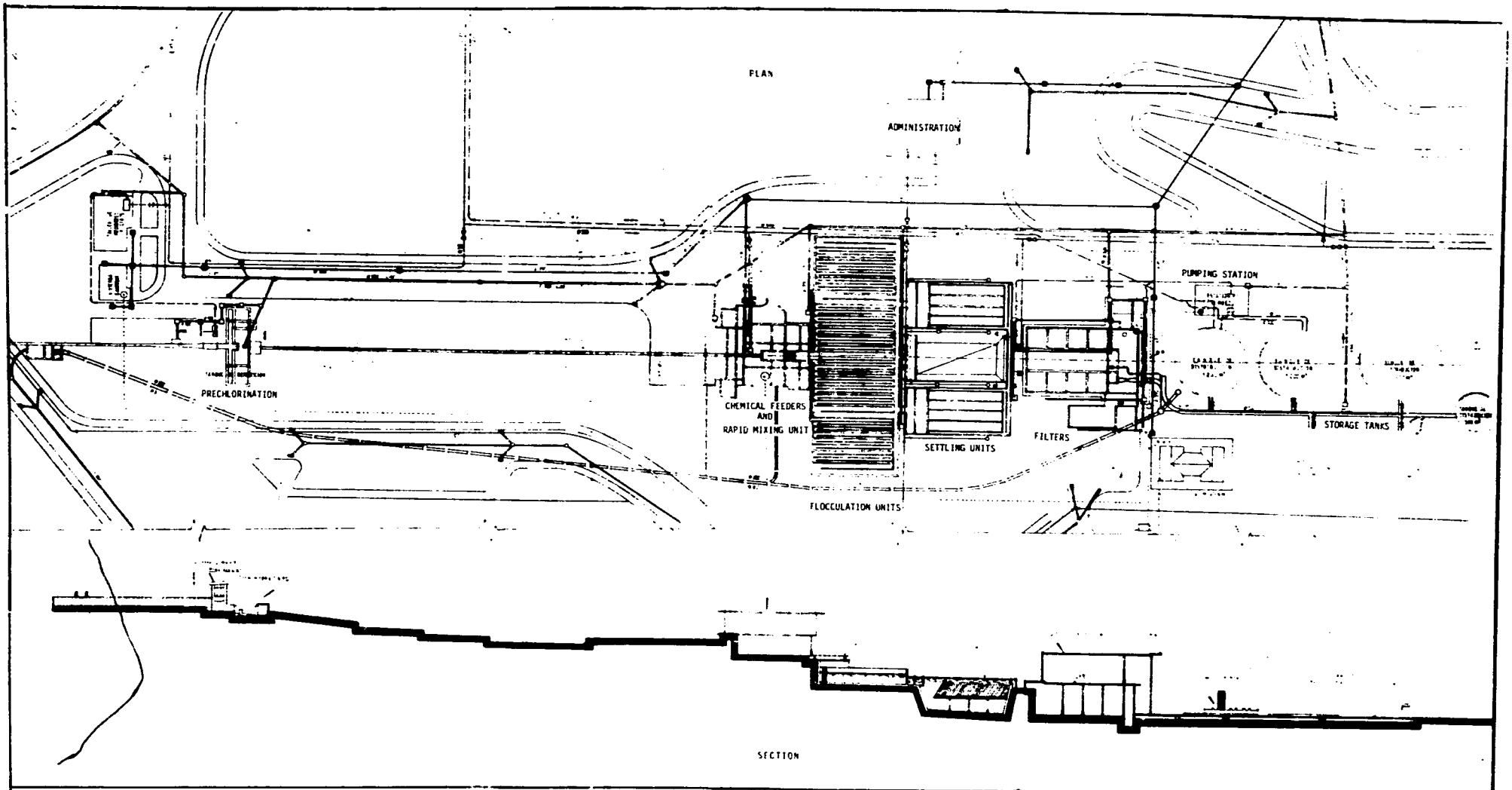
A. Design flow
860 l/s which under normal conditions could meet the maximum daily consumption demand in 1994.

B. Flow measurement and prechlorination
Flow is measured using a Parshall meter; two Wallace and Tiernan chlorine gas chlorinators can provide up to 10 ppm of chlorine to remove iron and some of the color.

C. Feeding and mixing
Aluminum sulfate and lime are used. The equipment consists of Pivet-type tower for saturation feeding of alum cake and a suspension unit and piston pump feeders for lime.

A hydraulic jump with a velocity gradient of 1 281 s^{-1} and a detention time of 6 seconds is used for rapid mixing.

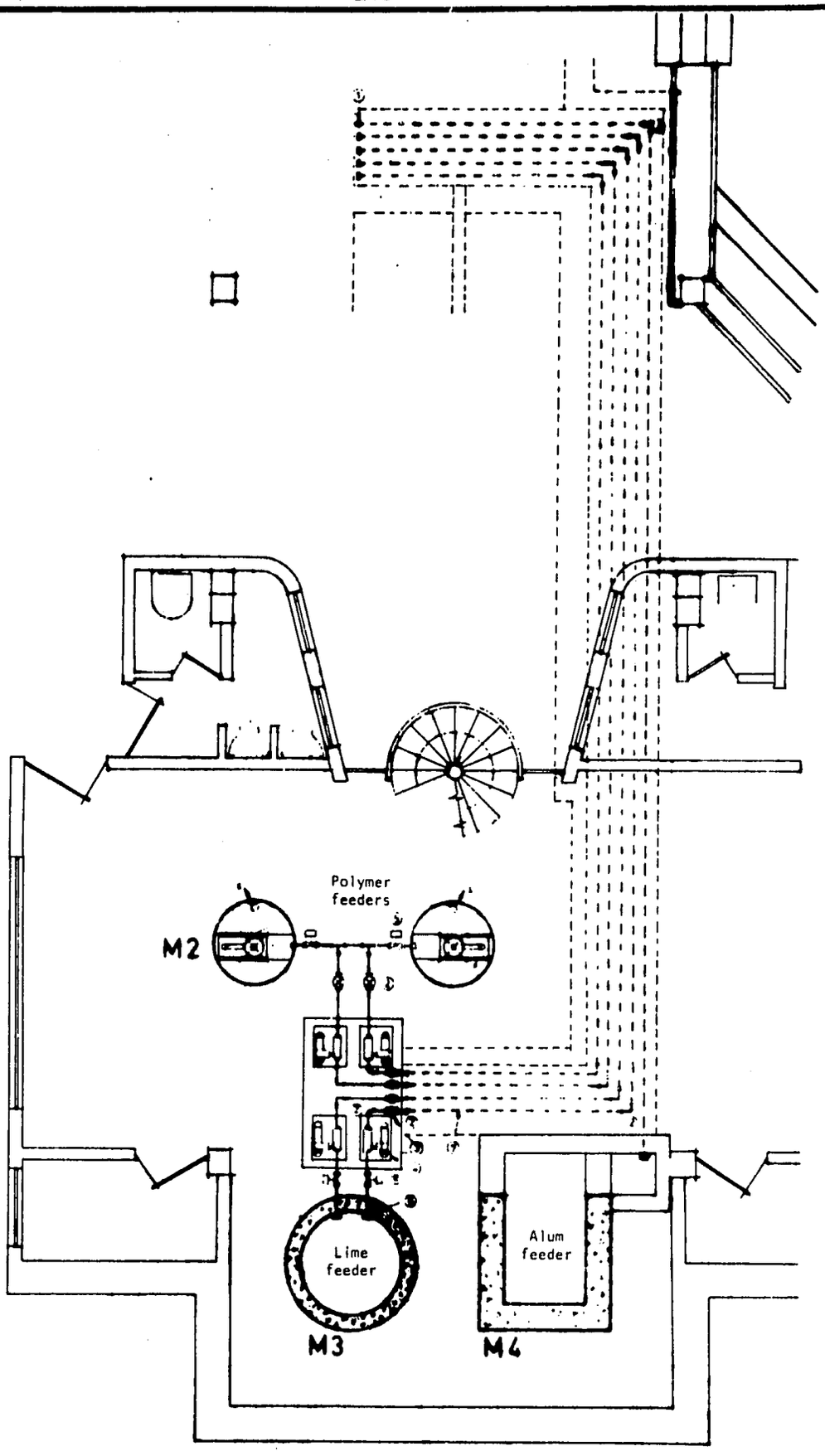
D. Flocculation
Flocculation takes place in four hydraulic flocculators of horizontal flow and vertical baffles, producing velocity gradients of 250 s^{-1} at the inlet, 35 s^{-1} in the first third, 25 and 15 s^{-1} in the other thirds. The total detention time is 22.5 minutes and the mean velocity is 0.24 m/s. The canals are 3.50 m high and their width is variable; each flocculator has a total area of 600 m^2.



GENERAL PLAN

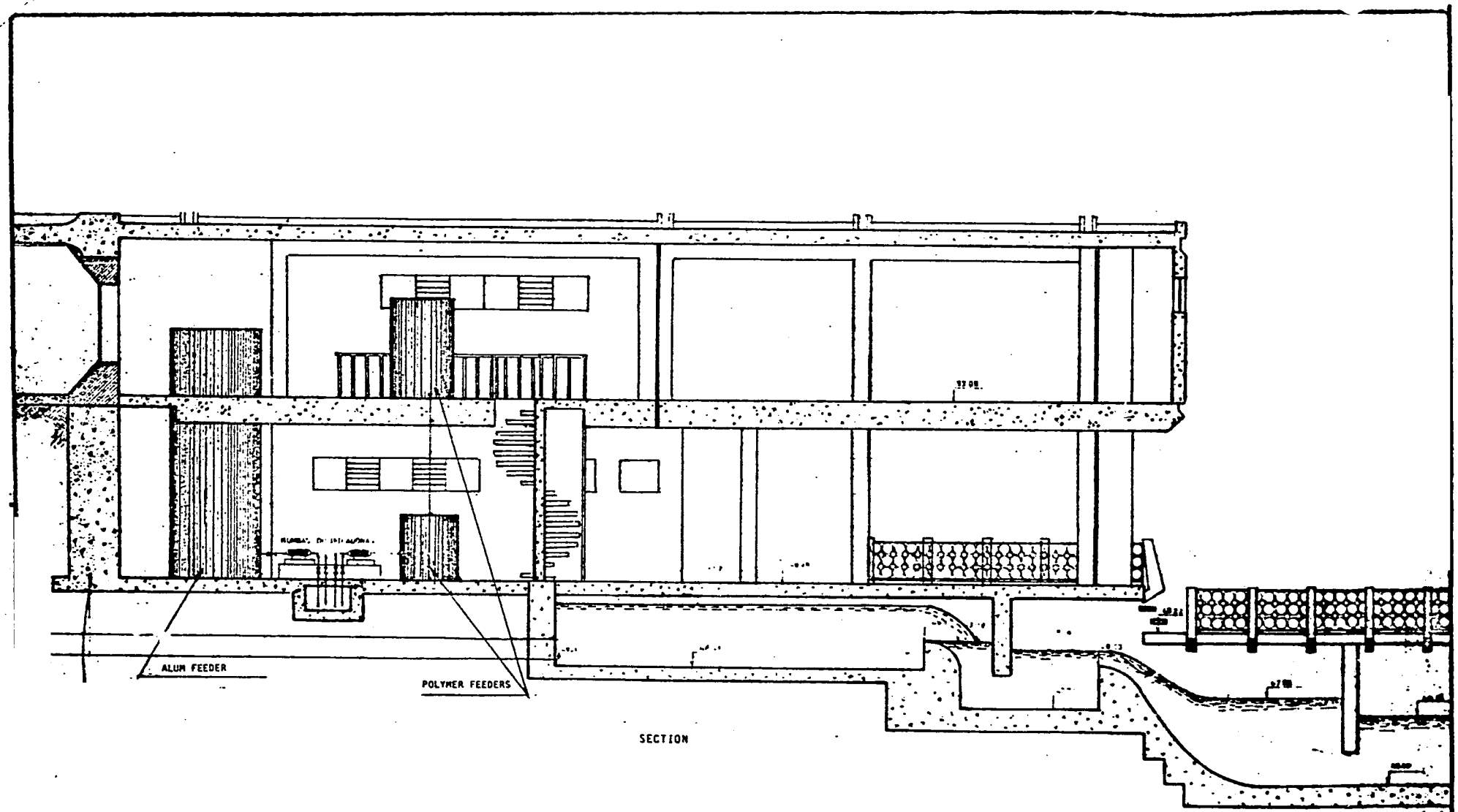
FIGURE 6_4

WATER TREATMENT PLANT_ CUENCA

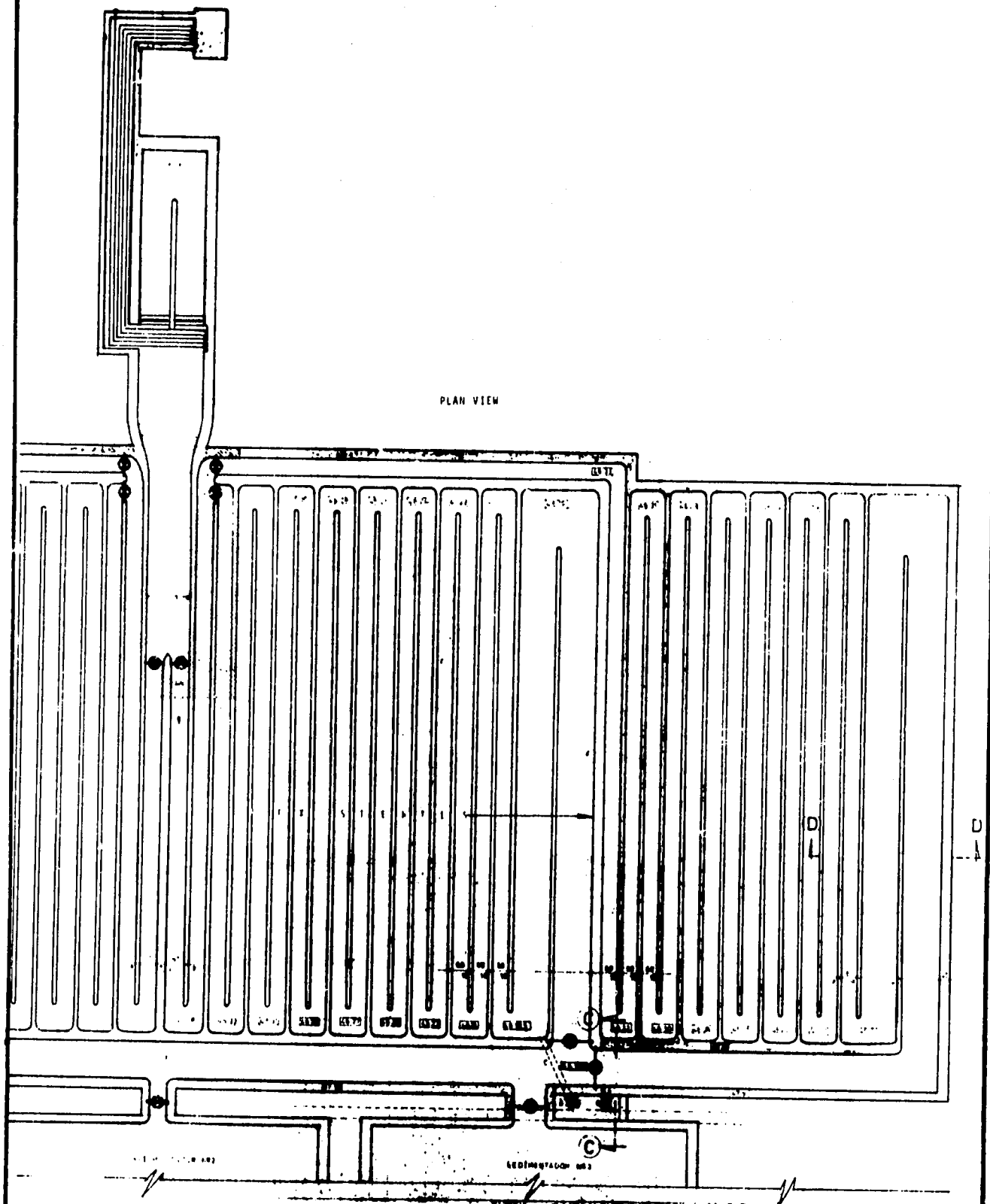


PLAN VIEW

CHEMICAL FEEDERS	FIGURE 6.5
WATER TREATMENT PLANT-CUENCA	



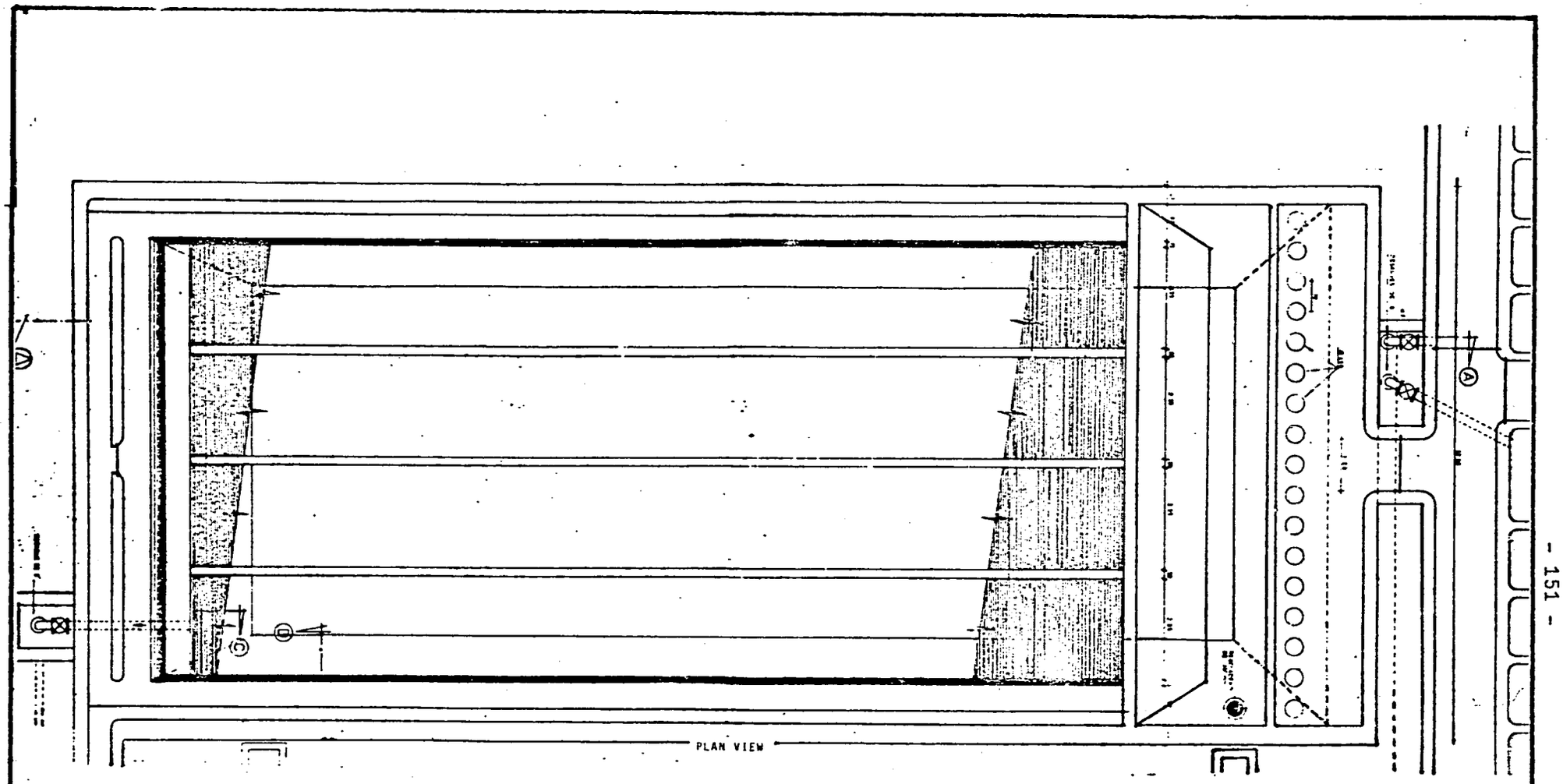
RAPID MIXING UNIT	FIGURE 6_6
WATER TREATMENT PLANT_CUENCA	



RAPID MIXING and FLOCCULATION UNITS

FIGURE 6-7

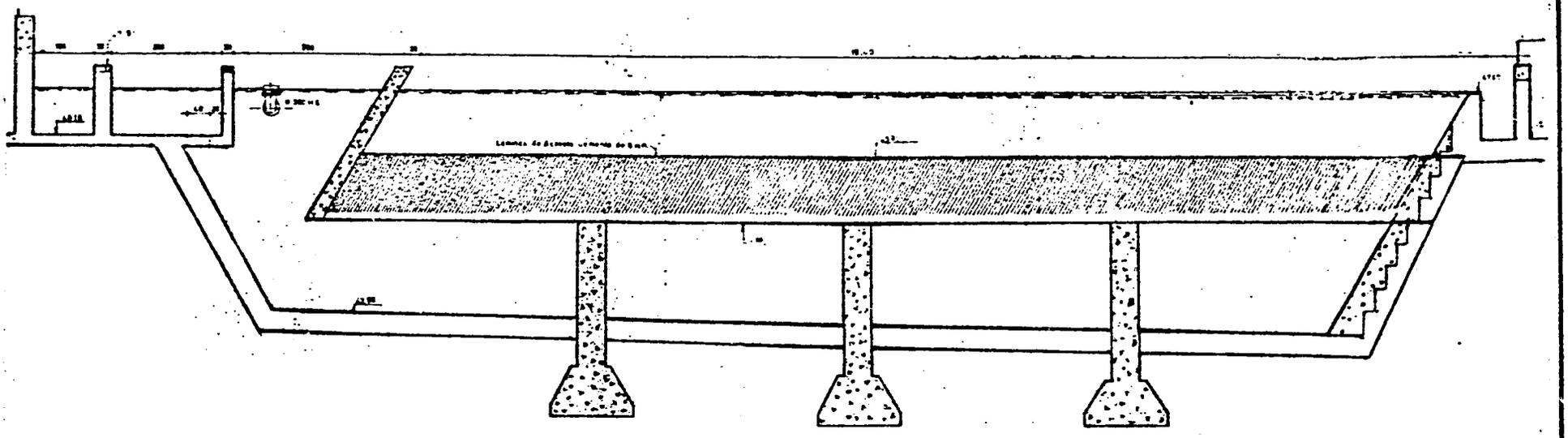
WATER TREATMENT PLANT_CUENCA



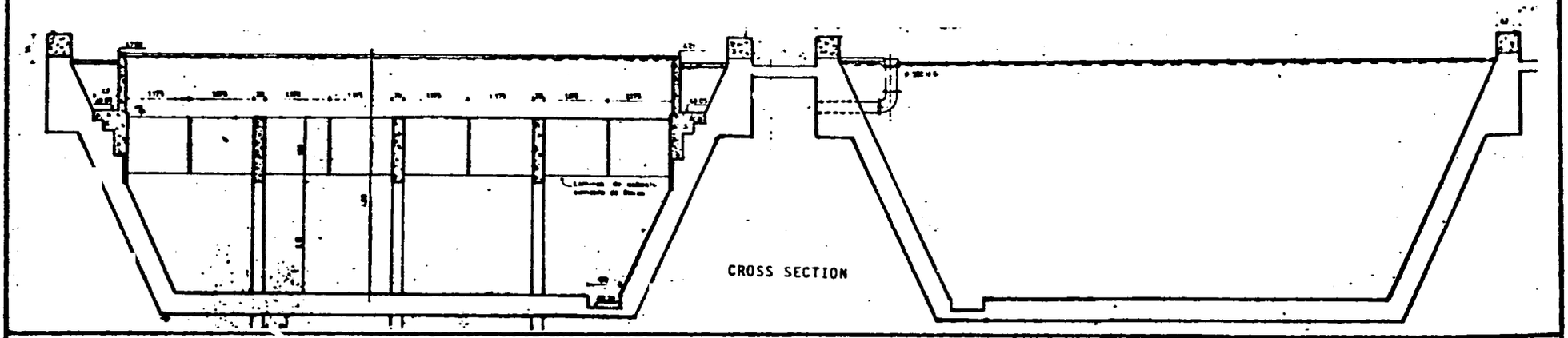
SETTLING UNITS

WATER TREATMENT PLANT_CUENCA

FIGURE 6_8

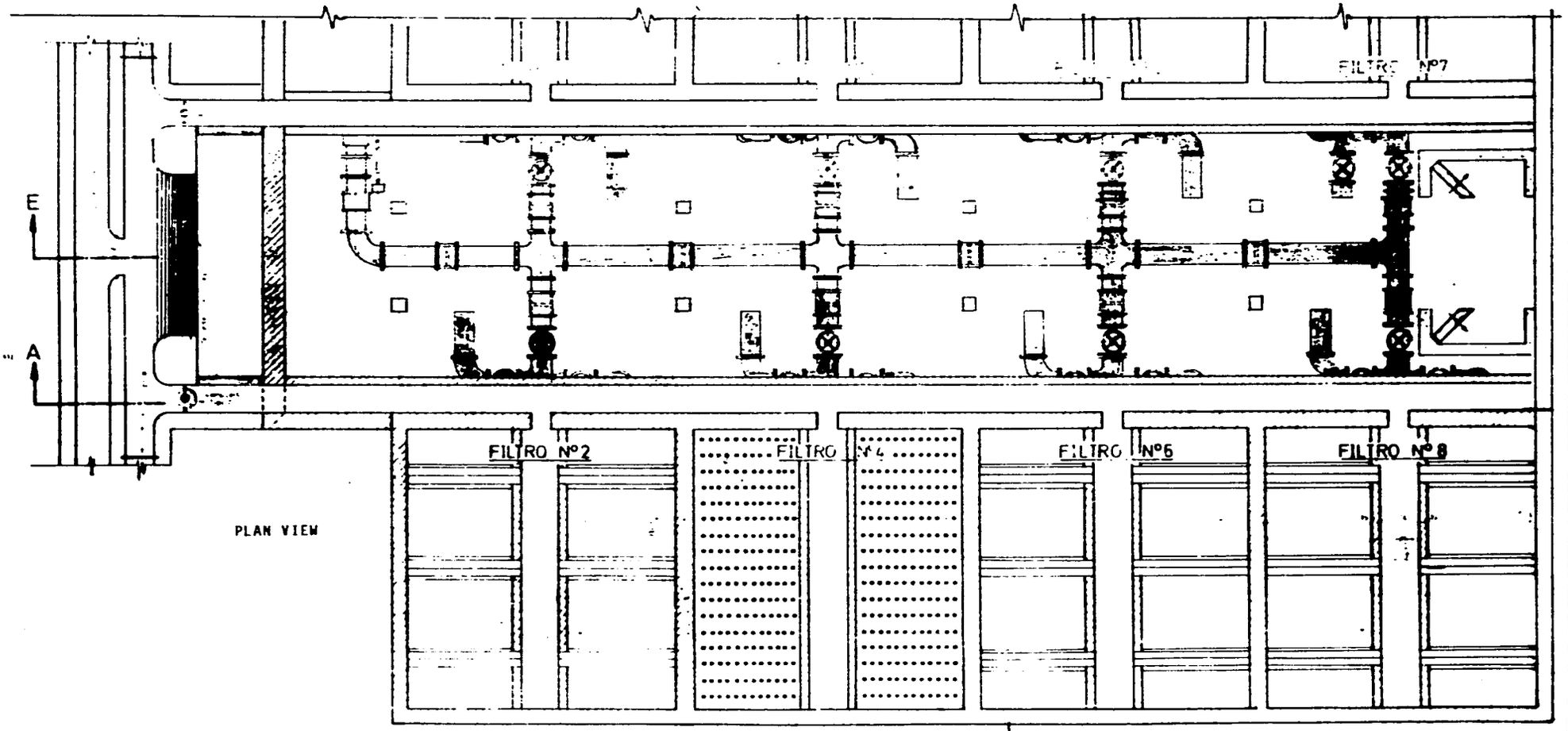


LONGITUDINAL SECTION



CROSS SECTION

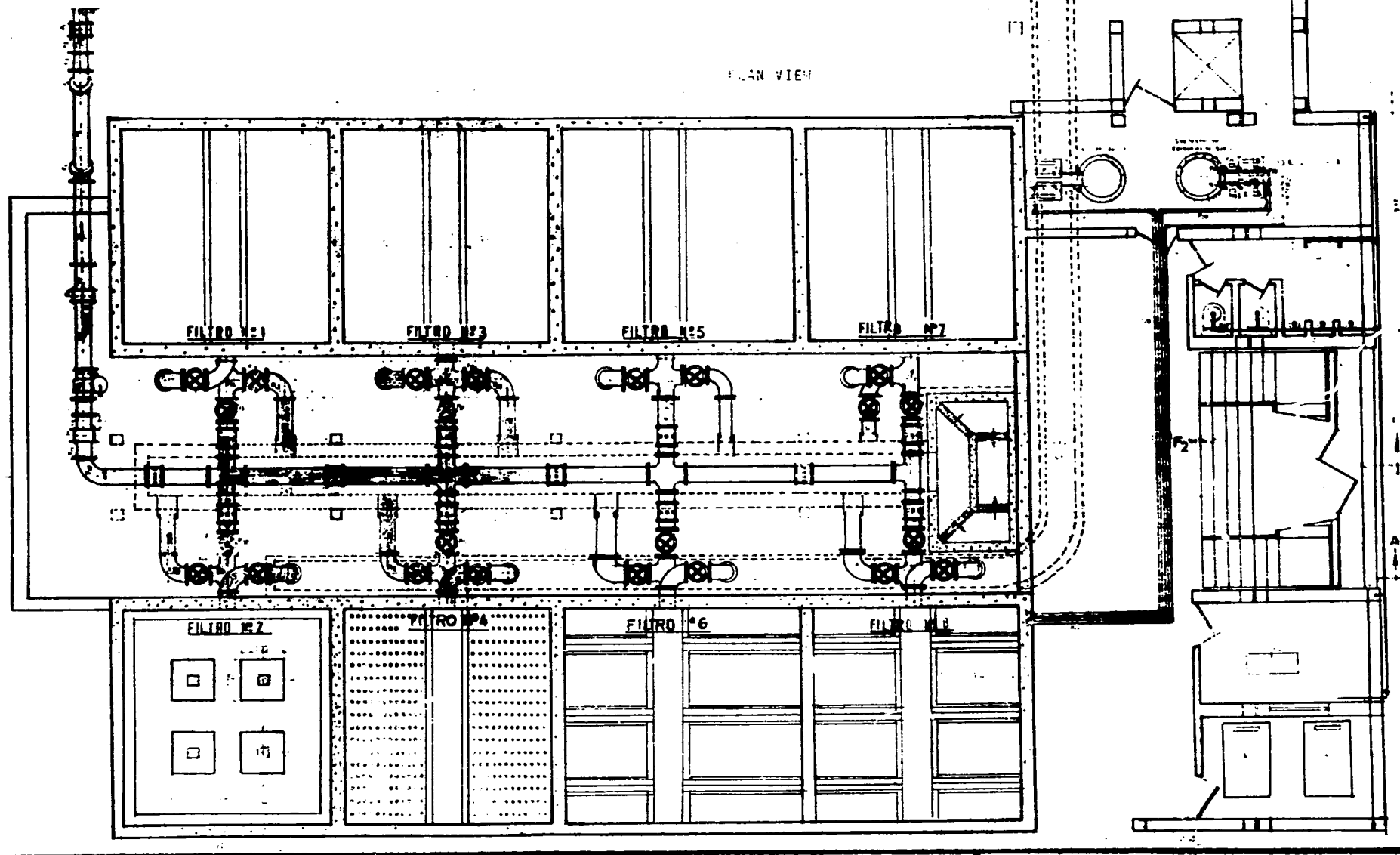
SETTLING UNITS	FIGURE 6.9
WATER TREATMENT PLANT_CUENCA	



FILTER INLET

FIGURE_6_10

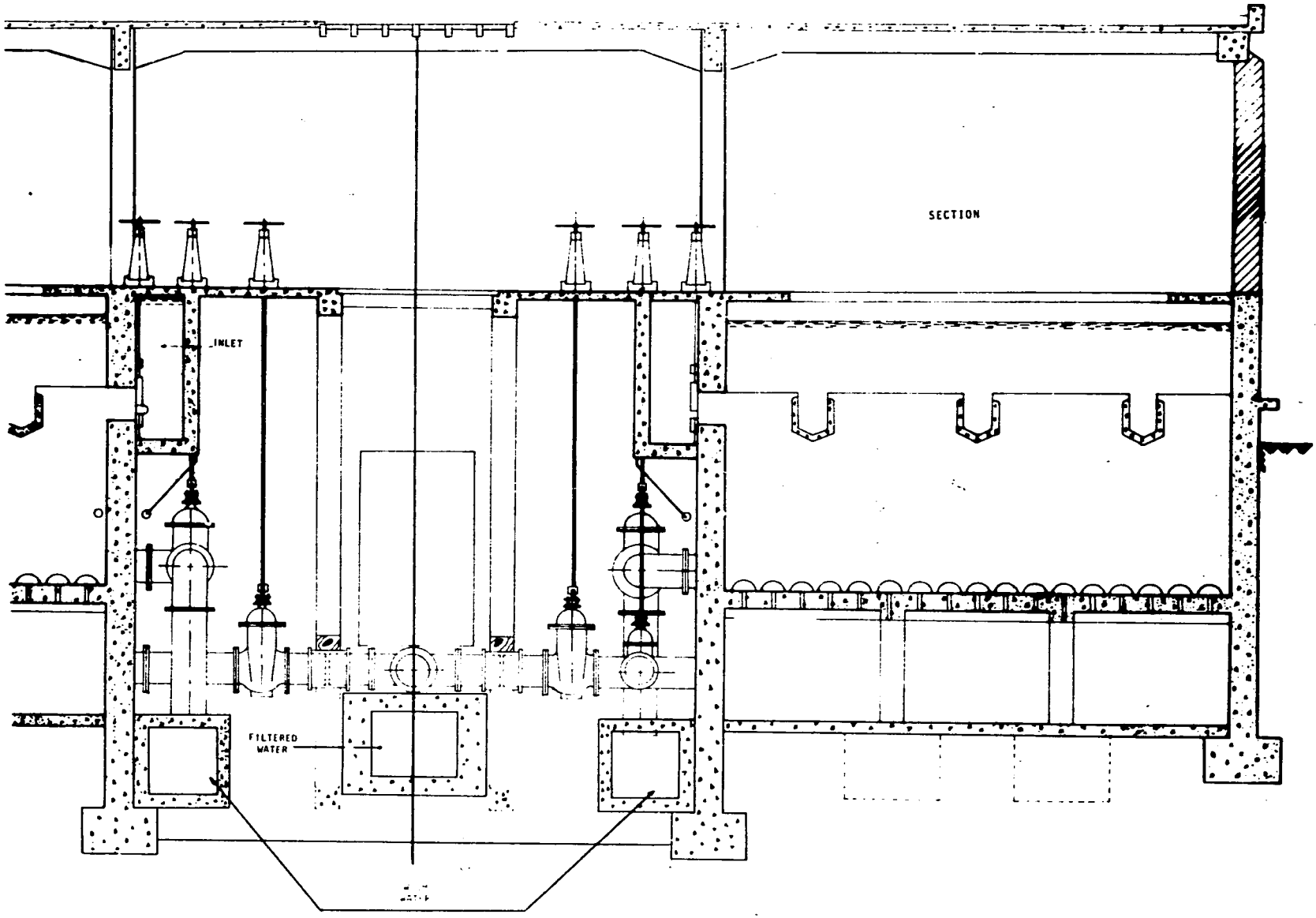
WATER TREATMENT PLANT_ CUENCA



FILTER GALLERY

FIGURE 6_11

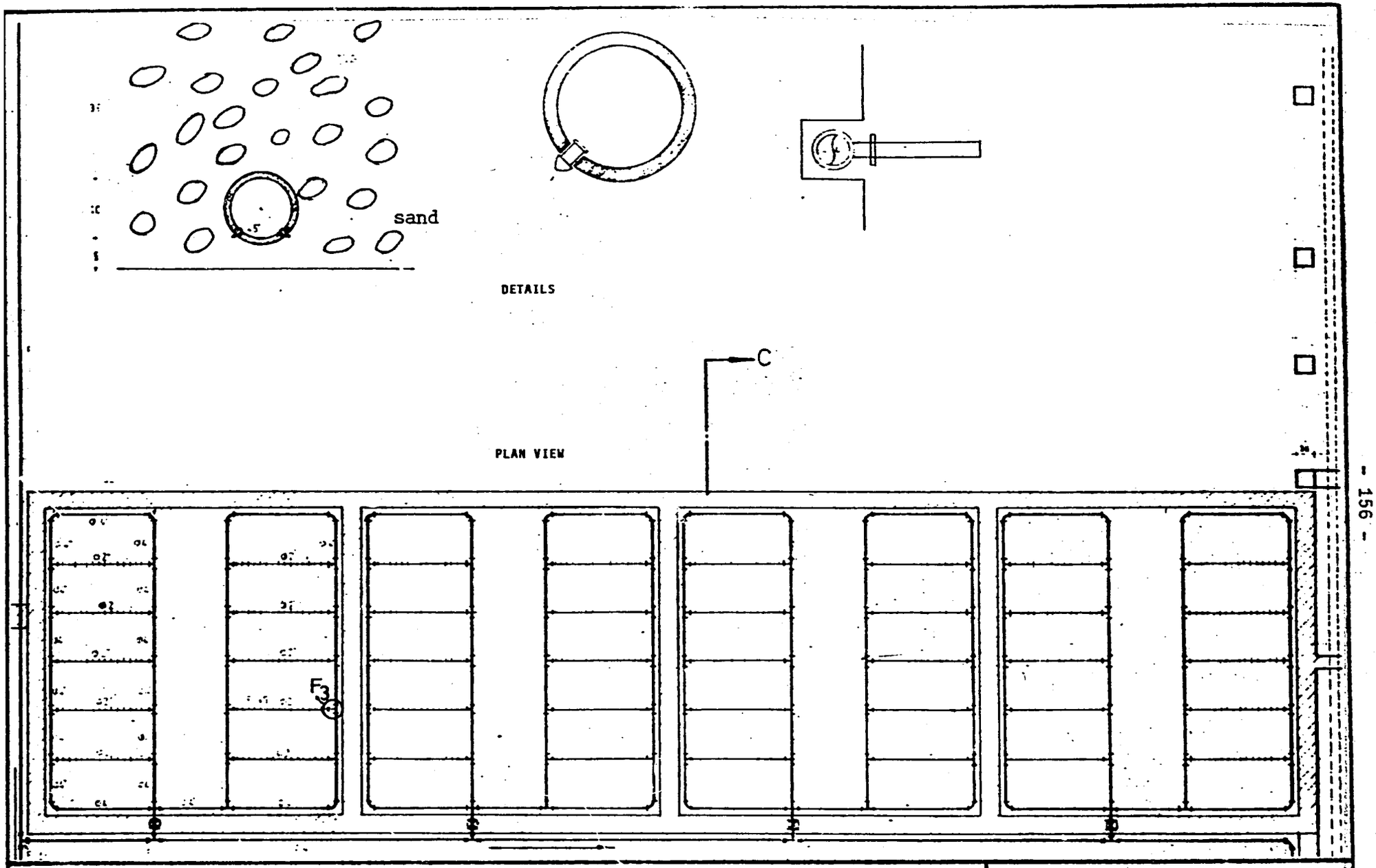
WATER TREATMENT PLANT_CUENCA



FILTER GALLERY

FIGURE 6.12

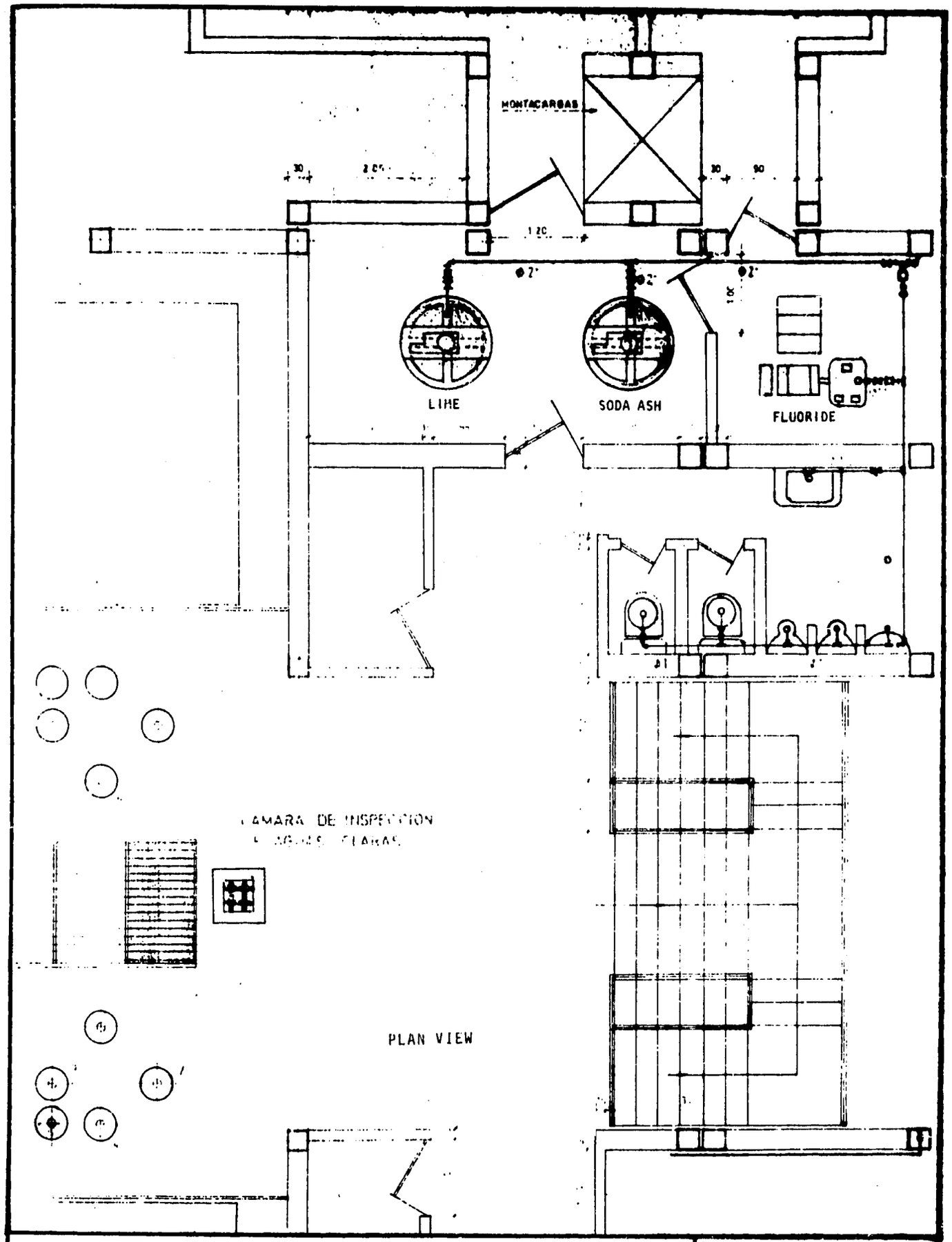
WATER TREATMENT PLANT_ CUENCA



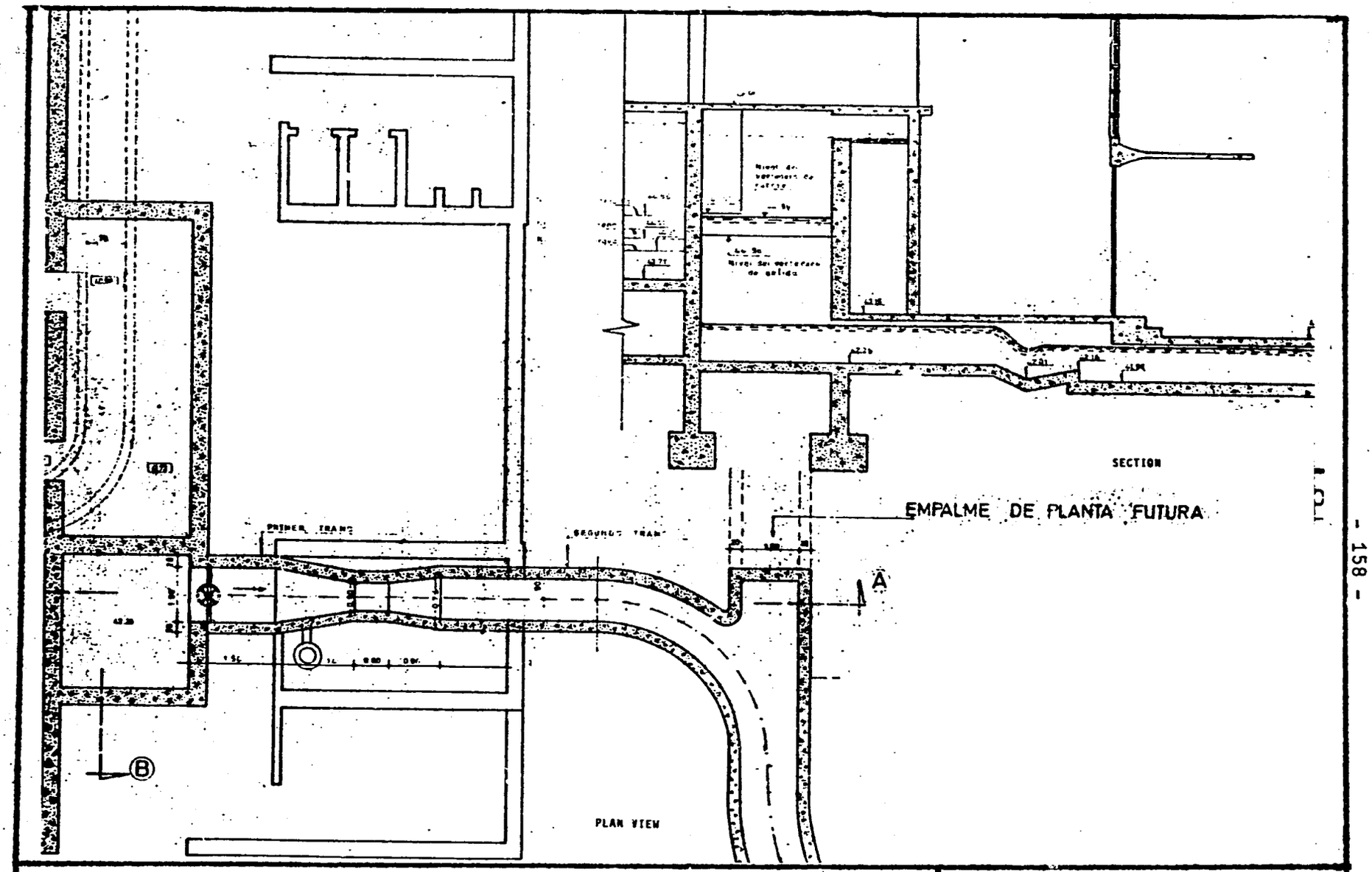
SUB_SURFACE FILTER WASH SYSTEM

FIGURE 6_13

WATER TREATMENT PLANT_CUENCA



Ph ADJUSTMENT and FLUORIDATION	FIGURE 6_14
WATER TREATMENT PLANT_CUENCA	



POSTCHLORINATION

FIGURE 6.15

WATER TREATMENT PLANT - CUENCA

The flocculators are connected to the sedimentation tanks by a peripheral canal whose section is 1.80 x 1.00; at all points between the flocculators and the sedimentation tanks the velocity is maintained below 0.10 m/s and the velocity gradients are less than 15 s^{-1}.

E. Sedimentation

Sedimentation takes place in a conventional settling tank with horizontal flow and in two high-rate settling tanks.

1) Conventional settling tank:

Treatment capacity - 73 l/s
Overflow rate - 30 $m^3/m^2/day$
Average length - 21.50 m
Average width - 10.00 m
Average depth - 4.00 m
Sludge storage capacity - 20% of the settling tank volume

2) High-rate settling units:

The inlet is a channel with orifices in the bottom where the water velocity is 0.10 m/s; the velocity gradient in the orifices is 15 s^{-1}. A transition zone between the inlet and high-rate settling zone represents 30% of the total volume.

The high-rate settling zone is filled with flat asbestos-cement plates, 1.22 m long, set at an angle of 60° with 6 cm between plates.

Overflow rate - 135 $m^3/m^2/day$
detention time in the cells - 6.17 minutes
Reynolds number - 176

The water is collected in peripheral canals located along the sides and at the end of the settling tank, with an overflow of 5 l/s/m and a head loss in the entire length of the canal of 2.5 cm.

F. Filtration

Filtration takes place in eight dual media sand and anthracite filters. These are declining rate filters with influent flow divided between two batteries of four filters each with the following characteristics:

Area of each filter - 25 m^2
Maximum filtration rate - 240 $m^3/m^2/day$
Maximum turbidity of influent water - 15 JTU
Maximum turbidity of effluent water - 1 JTU

The drainage system uses perforated pipe in which the following conditions are produced:

Velocity of water entering the orifices - 0.10 m/s
Velocity of water in the drain - 0.20 m/s
Velocity in the clear water canal - 0.34 m/s

At the end of the clear water canal there is a compensatory chamber with a detention time of two minutes, in which a weir is located to control the rate of flow through the filters.

The auxiliary submerged washing system is located in the anthracite, 5 cm above the sand and it has the following characteristics:

Wash velocities - 3 $l/s/m^2$
Washing time - 4 minutes
Pressure in the nozzles - 2 kg/cm^2

The necessary pressure and flows are obtained by means of an independent network connected to a hydropneumatic system. The normal backwashing of the filters is done by the conventional method using reverse flow and water velocities of 0.6 m/min. For this purpose the plant is provided with a tank which allows the continuous backwashing of up to two filters.

G. Disinfection

The water is disinfected by means of two V-800 chlorinators of the chlorine gas solution type, with automatic proportioning control and automatic residual chlorine indicator and recorder.

H. Fluoridation

Sodium silico-fluoride is added in amounts of 1 mg/l by means of a volumetric dry feeder with a helicoidal feeding system.

I. Stabilization

In the outlet weir of the filter canals sodium carbonate is added to stabilize the water, using a solution feeder with two displacement pumps.

6.3.6 Distribution and storage system

The distribution system is made up of three sub-systems called upper, medium and lower, because of the topographical elevation, which have a total of approximately 20 km of supply mains with diameters between 12 and 20", 65 km of main pipelines with diameters between 6 and 12" and 150 km of secondary pipelines with diameters between 2 and 4". When operating at full capacity the system will supply 150 000 household connections.

The storage system presently includes five underground tanks with a total capacity of 6 000 m^3. When completed, the system will have 13 tanks with a total storage capacity of 18 000 m^3.

6.3.7 Control systems

The flow, pressure and levels in the distribution and storage system will be controlled by sensors and measuring devices installed at critical points in the systems and connected to the city telephone system, which transmits operational and recording signals to the central system located in the water treatment plant, in order to achieve automatic operation of the systems.

Additionally, there are automatic recorders (turbidity, color, pH, alkalinity) at the inlets and outlets of all treatment units. The chemical feeders (coagulants, pH adjusters, fluorides, pre and post-chlorination) also have automatic recorders.

6.4 RESEARCH STUDIES

Research was carried out on the following aspects: determination of the general characteristics of the city, technical evaluation of the treatment plant, and economic evaluation of plant construction, operation and maintenance costs.

6.4.1 General characteristics of the city

In order to fulfill the principal research objective of the University of Oklahoma, information on the following topics was gathered using a survey questionnaire:

A. Identification of the city and institution responsible for water supply services;

B. Technological and demographic data;

C. Basic socio-economic data.

The results are included in Appendices 6-A and 6-B.

6.4.2 Technical evaluation

In the studies conducted in the Cuenca water treatment plant special emphasis was given to the determination of the characteristics that influence the performance of the high-rate settling units, carrying out a series of tests in the laboratory and pilot plant, and verifying the results during the normal operations of the treatment plant.

A. Raw water quality

The results of the analyses correspond to the period between May and July which is the beginning of the dry season; during this time no important water quality deficiencies were observed.

The main problem was color which ranged from 10 to 70 CU with an average value of 15 CU. The turbidity ranged from 5 to 27 JTU with an average value of 16 JTU; the pH was between 7.1 and 7.4; the alkalinity was low, varying from 20 to 50 mg/l with an average value of 33 mg/l.

The results of the principal parameters are included in table 6-4.

Table 6-4

ATER CHARACTERISTICS

Parameter	Min.	Max.	Aver.	Units
Color	10	70	15	CU
Turbidity	5	27	15	JTU
pH	7.1	7.4	7.3	
Alkalinity	20	50	33	mg/l
Hardness	25	52	34	mg/l
CO_2	0.88	2.4	1.76	mg/l
SO_4	5	10	7	mg/l
Ca	20	45	30	mg/l
SiO_2	10	12	11	mg/l
Fe (total)	0.1	0.6	0.2	mg/l
Chlorides	0.0	2.0	0.5	mg/l
Temperature	8	12	10	°C

B. Chemical feeding.

Color removal was the main treatment problem, and to a lesser degree the removal of turbidity and iron (present in the colloidal state). Aluminum sulfate was used as the coagulant, and the influence of the addition of clay "nuclei" and sludge deposits was studied.

1) Optimum pH

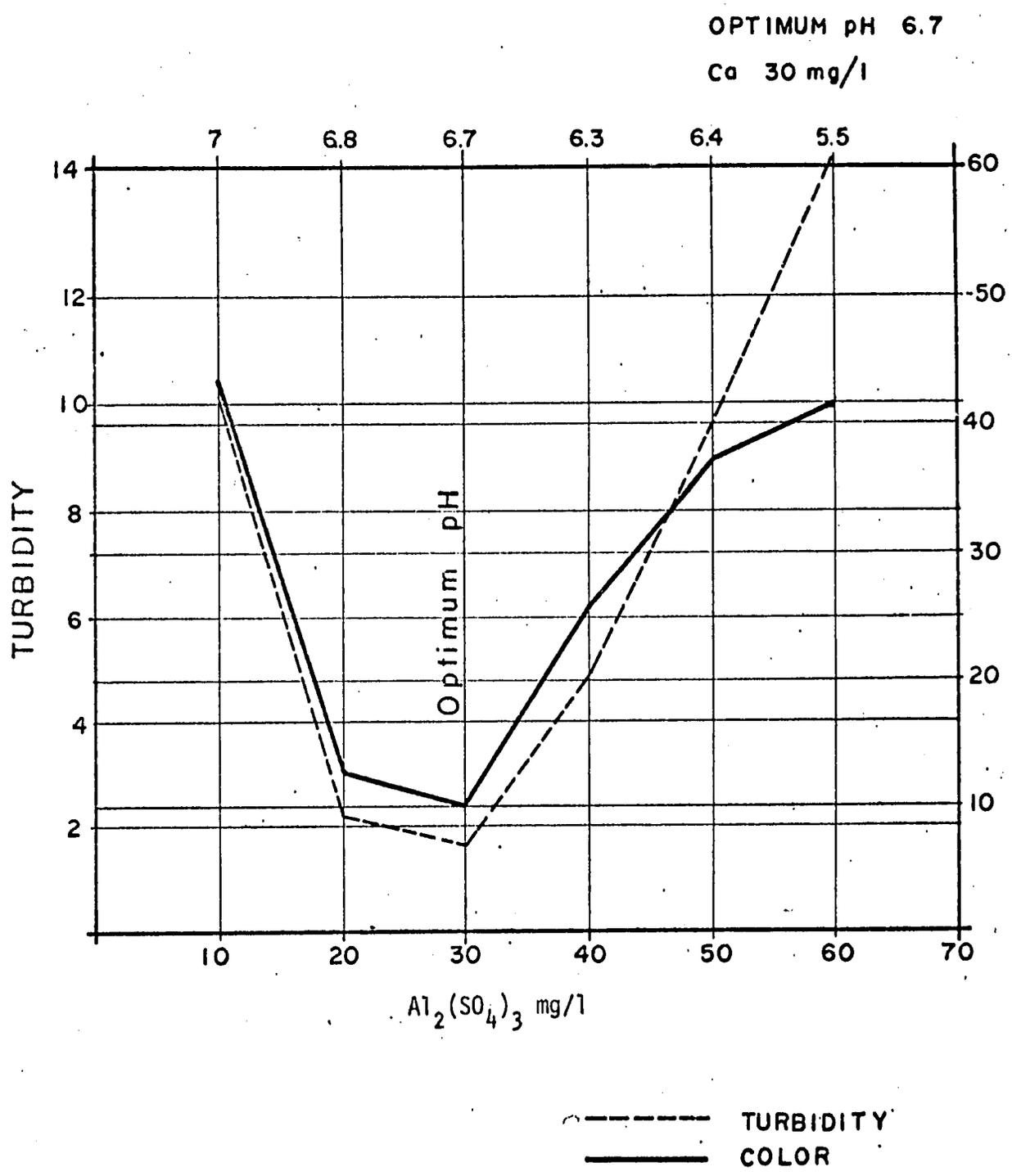
Laboratory tests demonstrated that the optimum pH range for coagulation is between 6.5 and 7.1 (the average of 38 experiments as illustrated in figure 6-16), depending on the predominance of color or turbidity. In general, 6.7 can be taken as the mean value. Pre-chlorination is used for iron reduction with chlorine dosages ranging from 1.0 to 2.5 mg/l. The results are shown in figure 6-17.

2) Relation of coagulant dosage and raw water quality

From the initial jar tests which were verified during normal plant operation, a clear correlation was obtained between raw water turbidity and alum dosage, with equations of the type $y = a + b.Lg(x)$. The results of these tests are illustrated in figure 6-18.

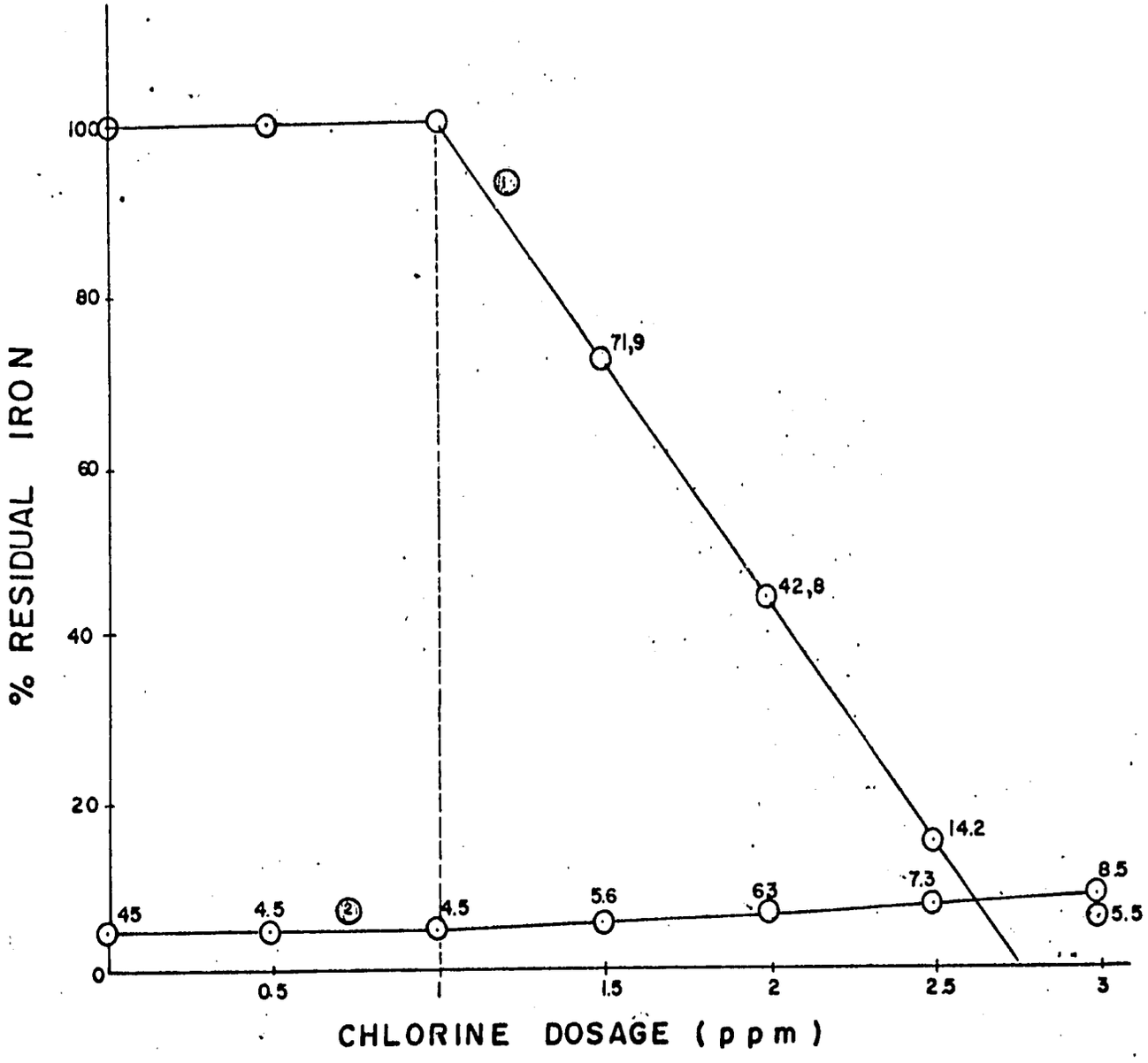
3) Influence of nuclei

Since the water is relatively difficult to treat because of its low turbidity, color and alkalinity, large dosages of coagulant are needed to produce good flocculation. Therefore, the influence of clay nuclei and sludge deposited in the settling units was studied, using the same water quality and coagulant dosages. The turbidity removal efficiency of the coagulation and sedimentation processes



OPTIMUM pH FOR COAGULATION	FIGURE 6-16
WATER SUPPLY SYSTEM - CUENCA	

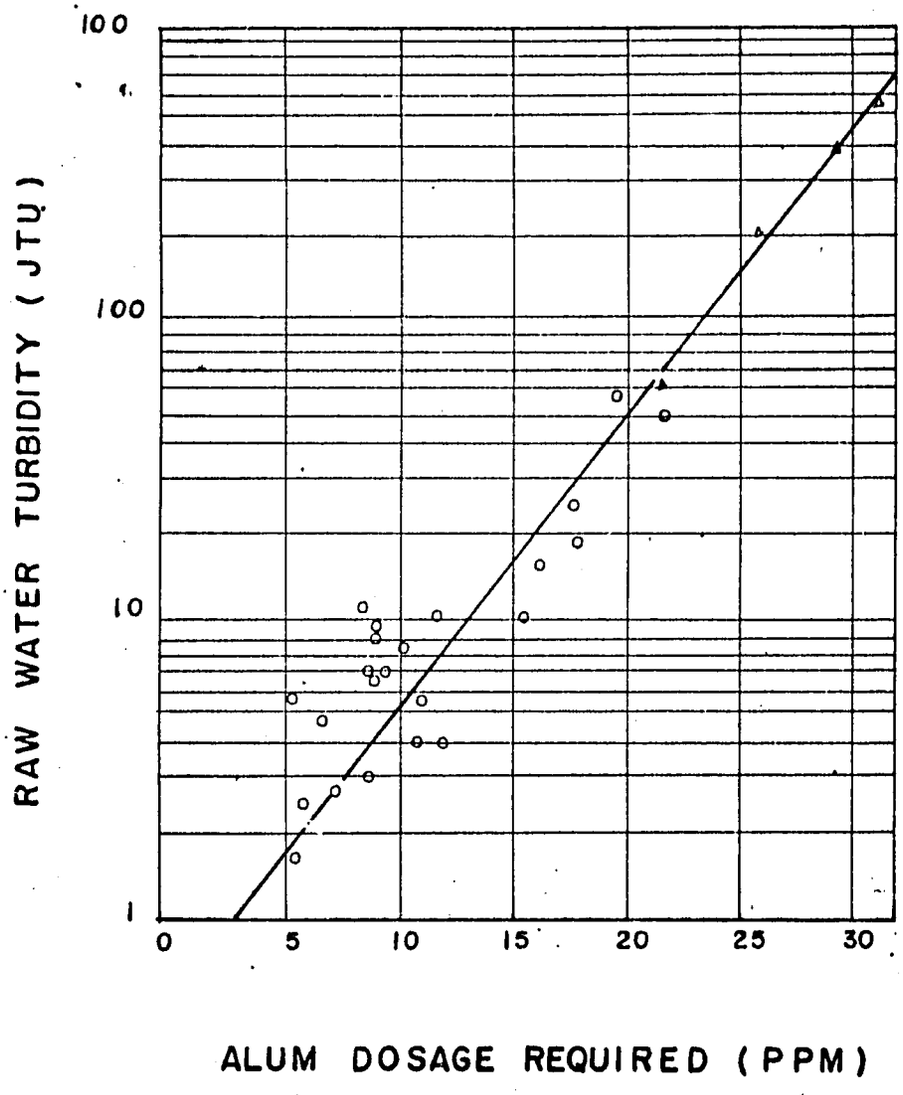
WATER TREATMENT PLANT - CUENCA.



① IRON IN THE FERROUS STATE

② IRON IN THE FERRIC STATE % IN RELATION TO FERROUS IRON

RESULTS OF IRON REDUCTION TESTS WITH PRE-CHLORINATION	FIGURE
WATER SUPPLY SYSTEM - CUENCA	6-17



CORRELATION OF RAW WATER TURBIDITY AND COAGULANT DOSAGE	FIGURE
WATER SUPPLY SYSTEM - CUENCA	6-18

improved notably from 84.6% to 94.5% and 96.2% with the addition of sludge and clay respectively in laboratory tests, and from 51.9% to 93.2% with sludge in the plant itself.

The performance of the clarification process as a whole also improved from 92.3% to 95% and 97.7% with the addition of sludge and clay respectively. Table 6-5 gives the results obtained in the laboratory tests and during normal plant operation.

Table 6-5

CHEMICAL DOSAGE TESTS
SERIES I - WITH ALUM AND LIME (OPTIMUM PH = 6.9)

a) Jar tests

Characteristics	Units	Water			Efficiency	
		Raw	Settled	Filtered	Settling	Filtration
Turbidity	JTU	13	2	1	84.6	92.3
Color	CU	35	10	7	71.4	80.0
Alkalinity	mg/l	28	22	22	-	-
pH		7.3	6.9	6.9	-	-

b) Treatment plant

Characteristics	Units	Water			Efficiency	
		Raw	Settled	Filtered	Settling	Filtration
Color	CU	52	25	8	51.9	84.6
pH		7.3	6.9	6.9	-	-

SERIES II - WITH ALUM, LIME AND SETTLED SLUDGE (OPTIMUM PH = 6.9)

a) Jar tests

Characteristics	Units	Water			Efficiency	
		Raw	Settled	Filtered	Settling	Filtration
Turbidity	JTU	13	.5	.3	96.2	97.2
Color	CU	35	5	4	85.7	88.6
Alkalinity	mg/l	28	30	30	-	-
pH		7.3	6.9	6.9	-	-

b) Treatment plant

Characteristics	Units	Water			Efficiency	
		Raw	Settled	Filtered	Settling	Filtration
Turbidity	JTU	15	1	0.36	93.3	97.6
Color	CU	24	8	5	66.7	79.2
Alkalinity	mg/l	45	30	30	-	-
pH		7.3	6.9	6.9	-	-

SERIES III - WITH ALUM, LIME AND CLAY (OPTIMUM pH 6.8)

a) Jar tests

Characteristics	Units	Water			Efficiency	
		Raw	Settled	Filtered	Settling	Filtration
Turbidity	JTU	20	1.1	1.0	94.5	95.0
Color	CU	38	8	4	78.9	89.5
Alkalinity	mg/l	30	28	28		
pH		7.1	6.8	6.9		

C. Rapid mixing, coagulation and flocculation

Since the mixing, coagulation and flocculation units are of conventional design, they were not evaluated directly, but rather indirectly through their influence on the high-rate settling units.

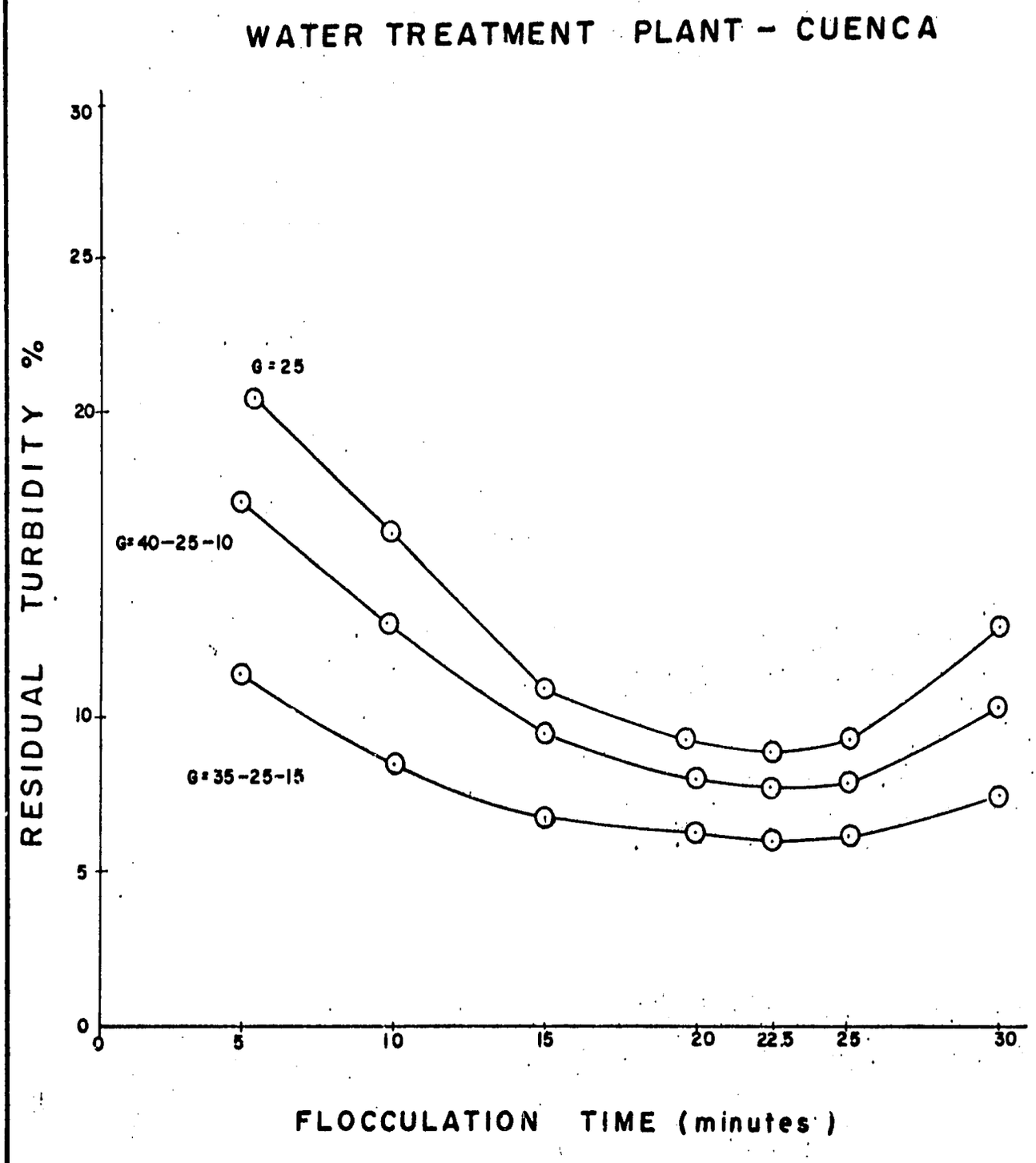
Before the plant was expanded, two series of tests were run to determine the optimum flocculation conditions (detention time and velocity gradients). In the first series velocity gradients were kept constant; in the second series variable velocity gradients were used. Greater efficiencies (94%) were obtained with variable velocity gradients of 35, 25 and 15 s^{-1} (figure 6-19).

D. Settling units

1) General efficiency

With relatively good raw water quality (turbidity between 5 and 27 JTU with average values of 16) the settled water turbidity ranged between 1 and 4 JTU with average values of 1.76 JTU. This represents an average efficiency of high-rate settler of 88.9% with overflow rates of 120 $m^3/m^2/day$. Figure 6-20 illustrates the removal efficiency achieved by the high-rate settlers.

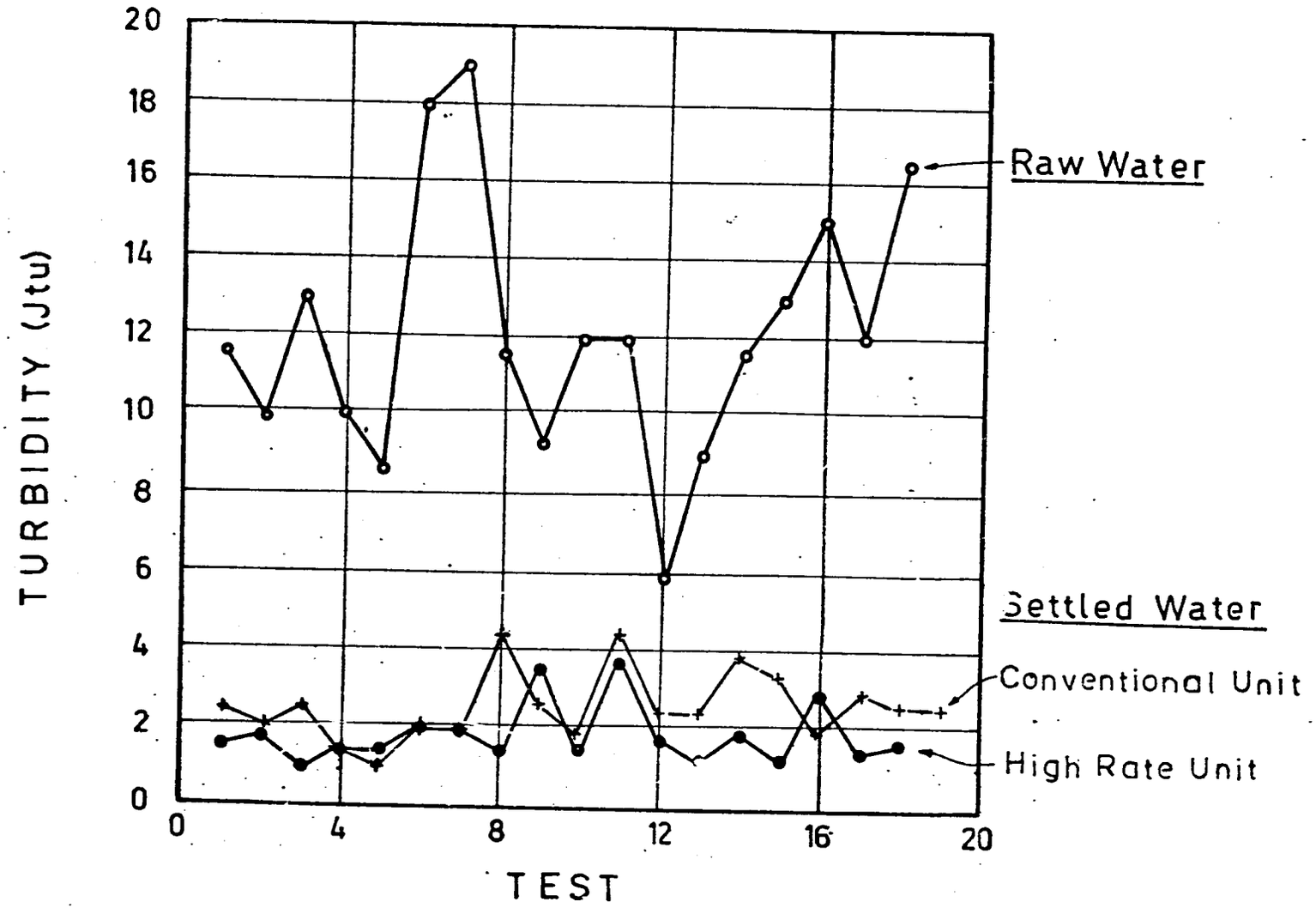
In laboratory tests, with raw water turbidities between 13 to 20 JTU (with the same settling velocity as in the plant) settled water turbidities between 0.5 and 2 JTU were obtained. These correspond to performances between 84.6% and 96.2% with an average value of 91.77%. On the other hand, the average turbidity of the settled water in the plant was 1 JTU and the average performance was 84.6%. Therefore, the actual settling efficiency was 8% less than that obtained in the jar tests.



RESULT OF FLOCCULATION TESTS

FIGURE 6-19

WATER SUPPLY SYSTEM - CUENCA



COMPARATIVE STUDY of THE EFFICIENCY of SETTLING UNITS	FIGURE 6-20
WATER SUPPLY SYSTEM - CUENCA	

For color removal, the efficiencies obtained in the normal plant operation were lower than those obtained in the laboratory tests. With raw water color between 24 and 52 CU, laboratory tests produced settled water with values ranging between 5 and 10 CU, which is equal to an average performance of 78.67%. In the plant these values were between 8 and 15 CU, with an average performance of 67.67%. Thus the actual performance of the settling units for color removal under the conditions of the study is 14% less than the theoretical efficiency as determined in the laboratory.

2) Comparative study with conventional settlers

Parallel tests of the performance of the two high-rate settlers and the conventional horizontal flow settling unit were run using water of the same quality. The comparative efficiencies are indicated in figure 6-20. While the high-rate settlers operate with overflow rates of 120 $m^3/m^2/day$, and a performance of 88.9%, the conventional settling units, operating with overflow rates of approximately 25 $m^3/m^2/day$, produce water with between 1 and 4.6 JTU of turbidity, and average values of 2.63 JTU, and have an average performance of 83.6%. In other words, the high-rate settlers, operating with overflow rates five times greater than the conventional unit, are 7% more efficient.

3) Influence of water quality

Unfortunately, during the period under study the variations in turbidity were not great enough to establish a correlation equati between the water quality and the efficiency of the settlers. Th turbidity removal efficiency for raw water turbidity values between 6 and 19 JTU was 88.9%.

In only one case, which occurred prior to the period under study, the water had a turbidity of 1 500 JTU and settled water turbidity values of 5 JTU were obtained, indicating a 99.7% efficiency.

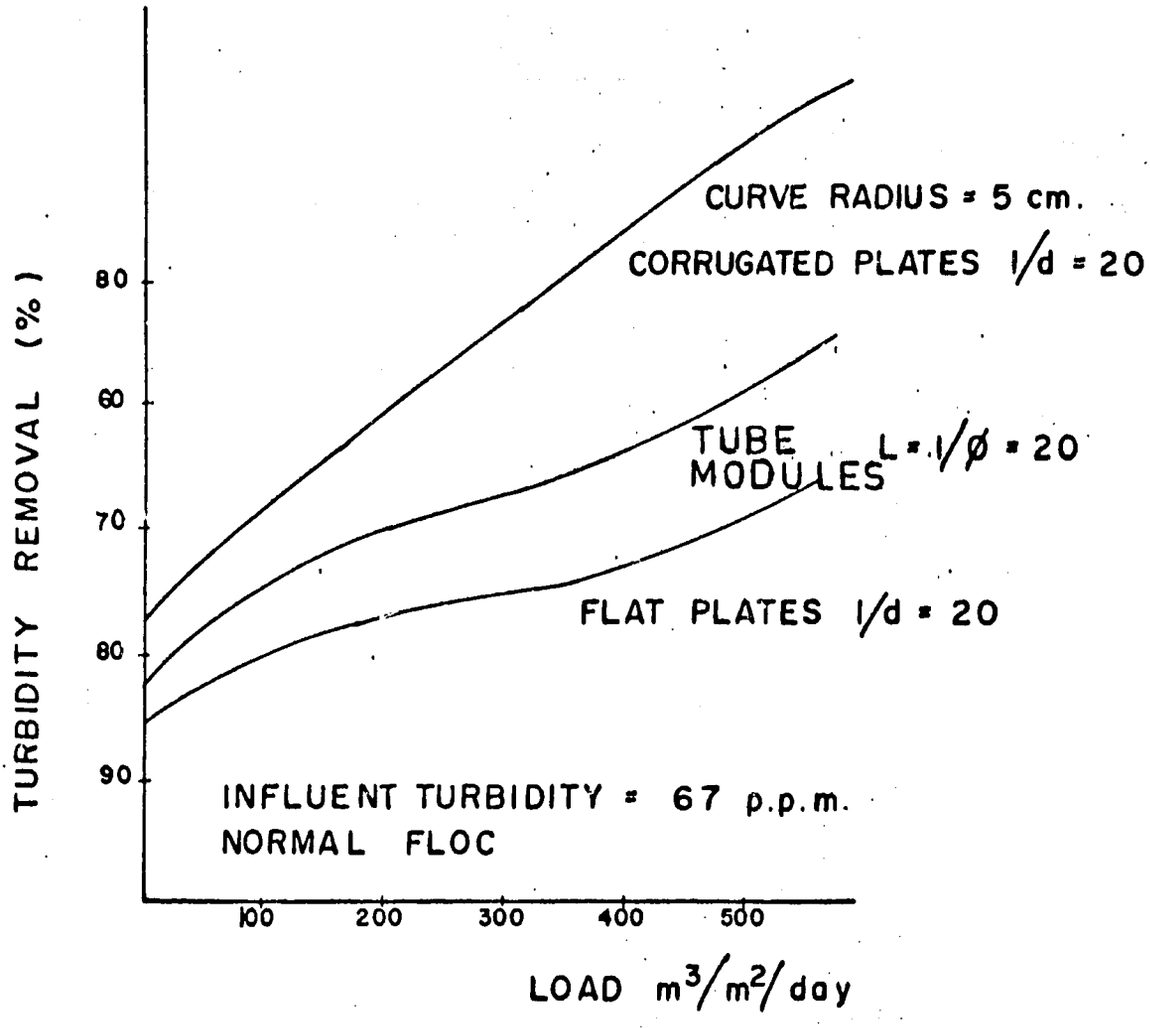
These data lead to the general conclusion that the efficiency of high-rate settlers is proportional to the solid content (turbidity).

4) Influence of the type of plates

In the pilot plant a study was conducted of the efficiency of three types of modules - flat and corrugated parallel plates, and tube modules - all of which had a relative length (l/d) of 20. With the same water quality, better turbidity removal was obtained with the flat parallel plates. The results of the efficiencies for the various modules and overflow rates are shown in figure 6-21.

5) Influence of the relative length of the plates

In the pilot plant a study was also made of the influence of the equivalent length (l/d) in the performance of settlers with flat and corrugated parallel plates using different overflow rates.



COMPARATIVE STUDY OF THE EFFICIENCY OF HIGH RATE SETTLERS	FIGURE
WATER SUPPLY SYSTEM - CUENCA	6-21

It was found that efficiency increases with greater relative lengths as shown in figures 6-22 to 6-24, but lengths greater than 20 would not be justified because the cost would jump considerably without a proportional increase in efficiency.

6) Influence of coagulation

Both laboratory tests and pilot plant studies, as well as the normal plant operation, indicate that the coagulation process is the predominant factor influencing the performance of the high-rate settler. Without flocculation with raw water turbidities of 76 JTU, the removal efficiency was around 15%, while with optimum coagulation the efficiency rose to 92% (for overflow rates of 120 $m^3/m^2/day$).

Figures 6-25 shows the variation of the efficiency of an experimental plate settler as a function of the overflow rates and water quality.

7) Filtration

Studies carried out prior to the modification of the plant included a series of comparative tests of two groups of four conventional rapid sand filters. The first group of filters, operated with a constant filtration rate of 120 $m^3/m^2/day$, produced a flow of 120 l/s with an average turbidity of 3.5 JTU; in the second group the rate-of-flow controllers were removed, allowing the filter to operate at a variable rate. In this case, an average flow of 160 l/s was obtained and the water quality improved to 0.5 JTU.

6.4.3 Analysis of investments and economic evaluation

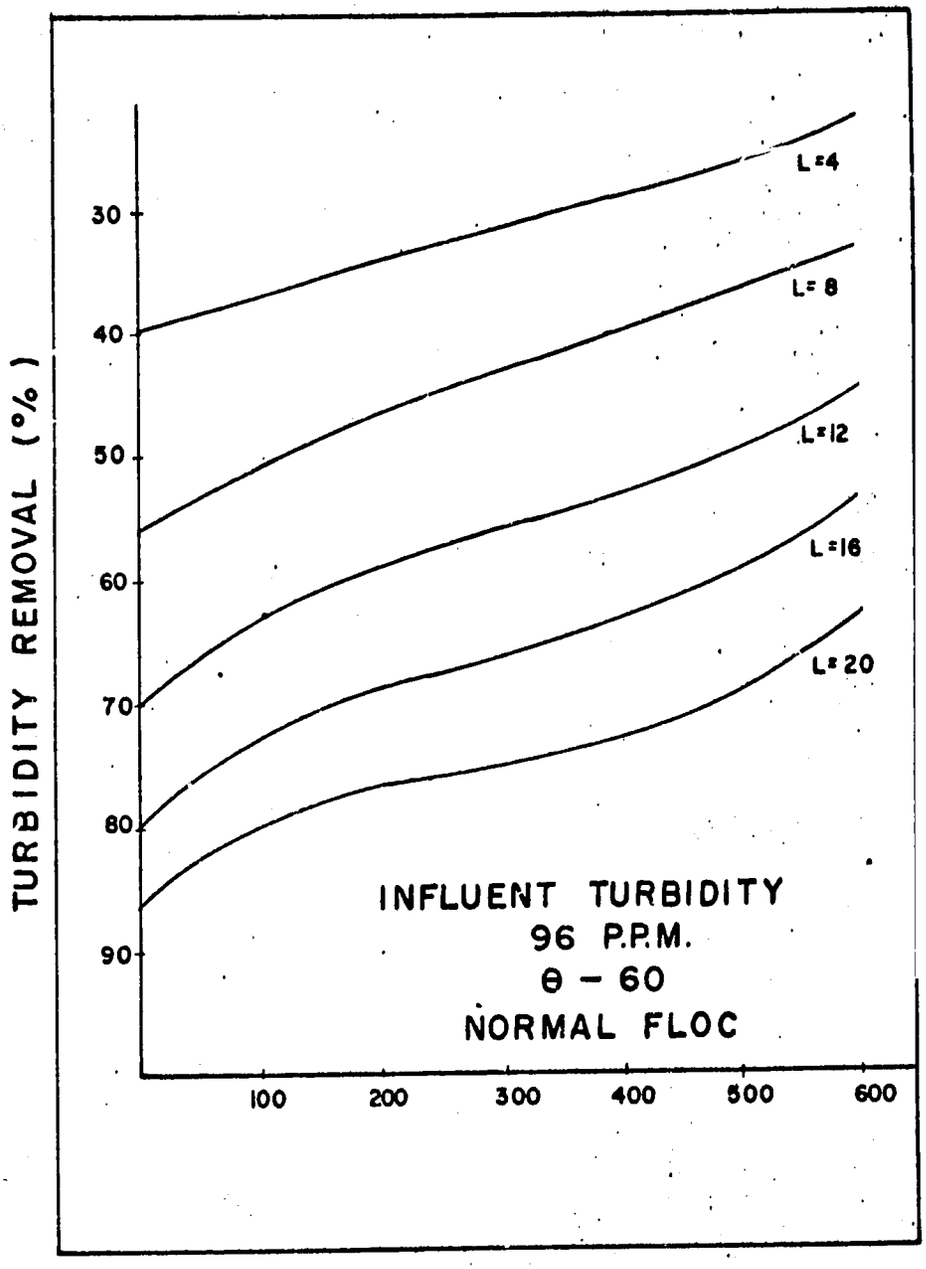
A. Construction cost

The approximate cost of the Cuenca water supply system at the pre-design stage was estimated (1970) to be US$4 195 000, 38% of which corresponded to a preliminary study of conventional rapid filter treatment plants with a reference cost of US$1 600 000. Table 6-6 gives the reference values for the different components of the water supply system.

Table 6-6

COST SUMMARY OF THE PRE-PROJECT FOR THE CUENCA WATER SUPPLY SYSTEM

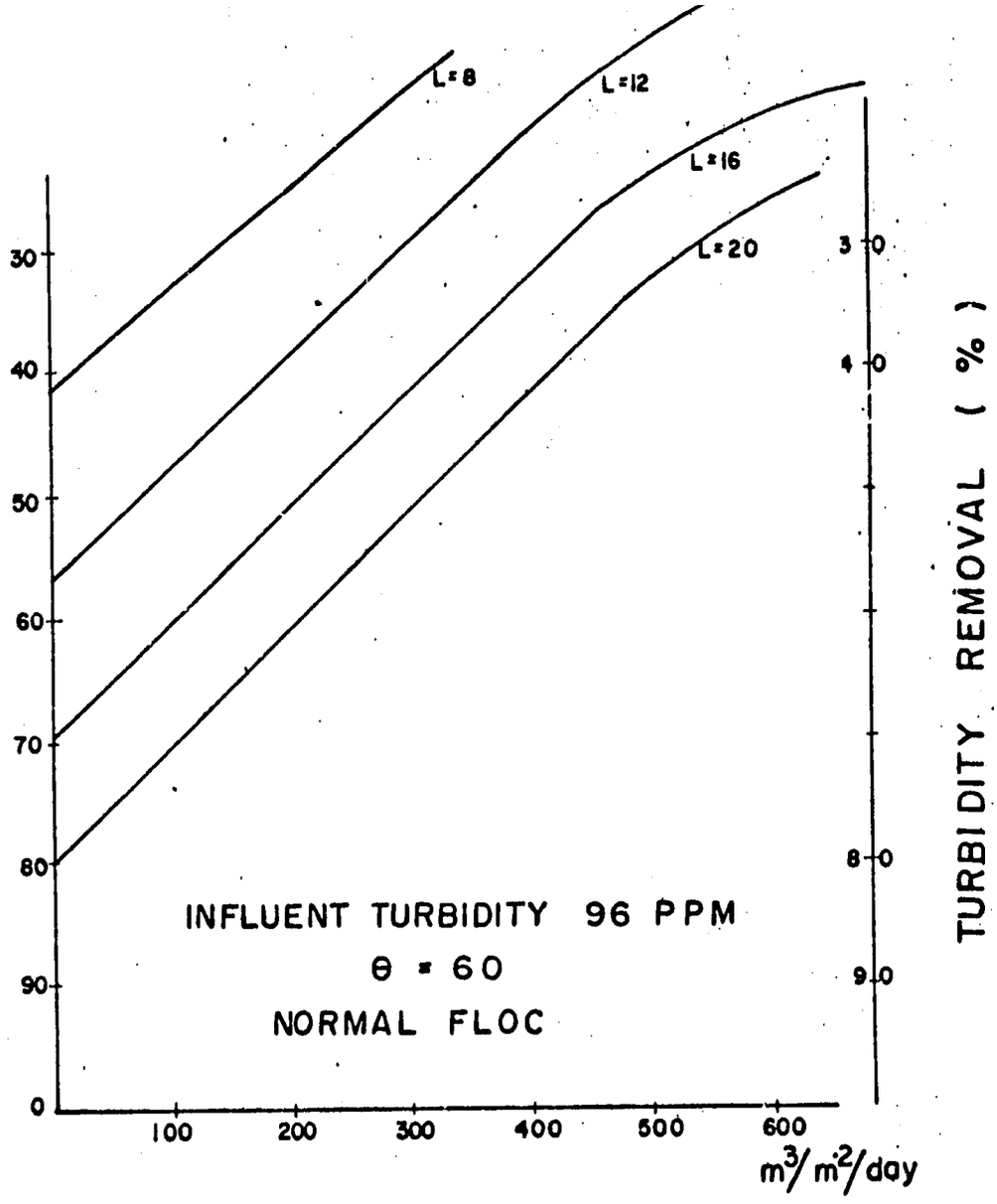
Work	Value US$	%
Collection works	10 000	1
Supply line	145 000	3
Treatment	1 600 000	38
Storage	360 000	8
Distribution network	1 000 000	24
Household connections	1 000 000	24
Expropriations	40 000	1
Miscellaneous	40 000	1
Total	4 195 000	100



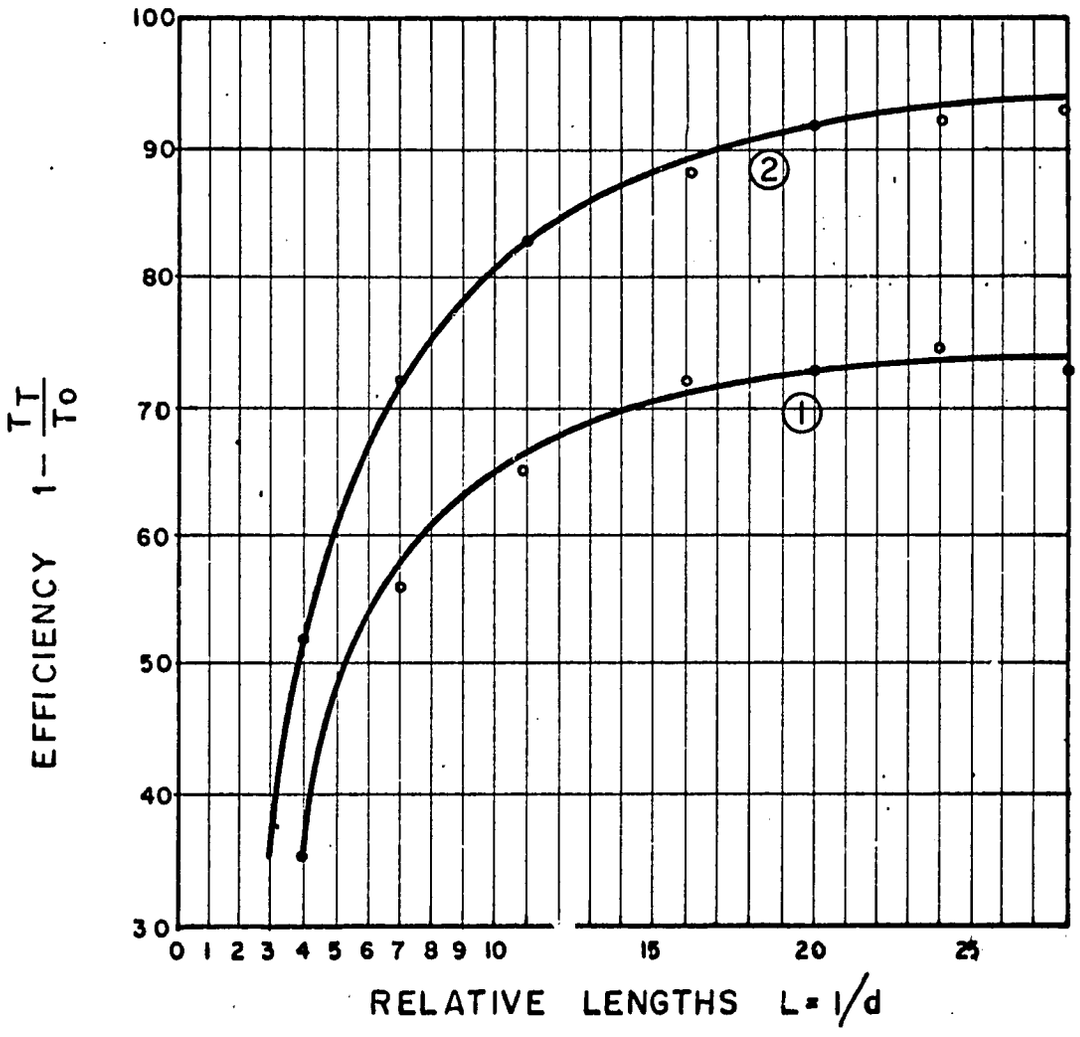
PERFORMANCE OF PARALLEL-PLATE SETTLERS

FIGURE 6-22

WATER SUPPLY SYSTEM - CUENCA



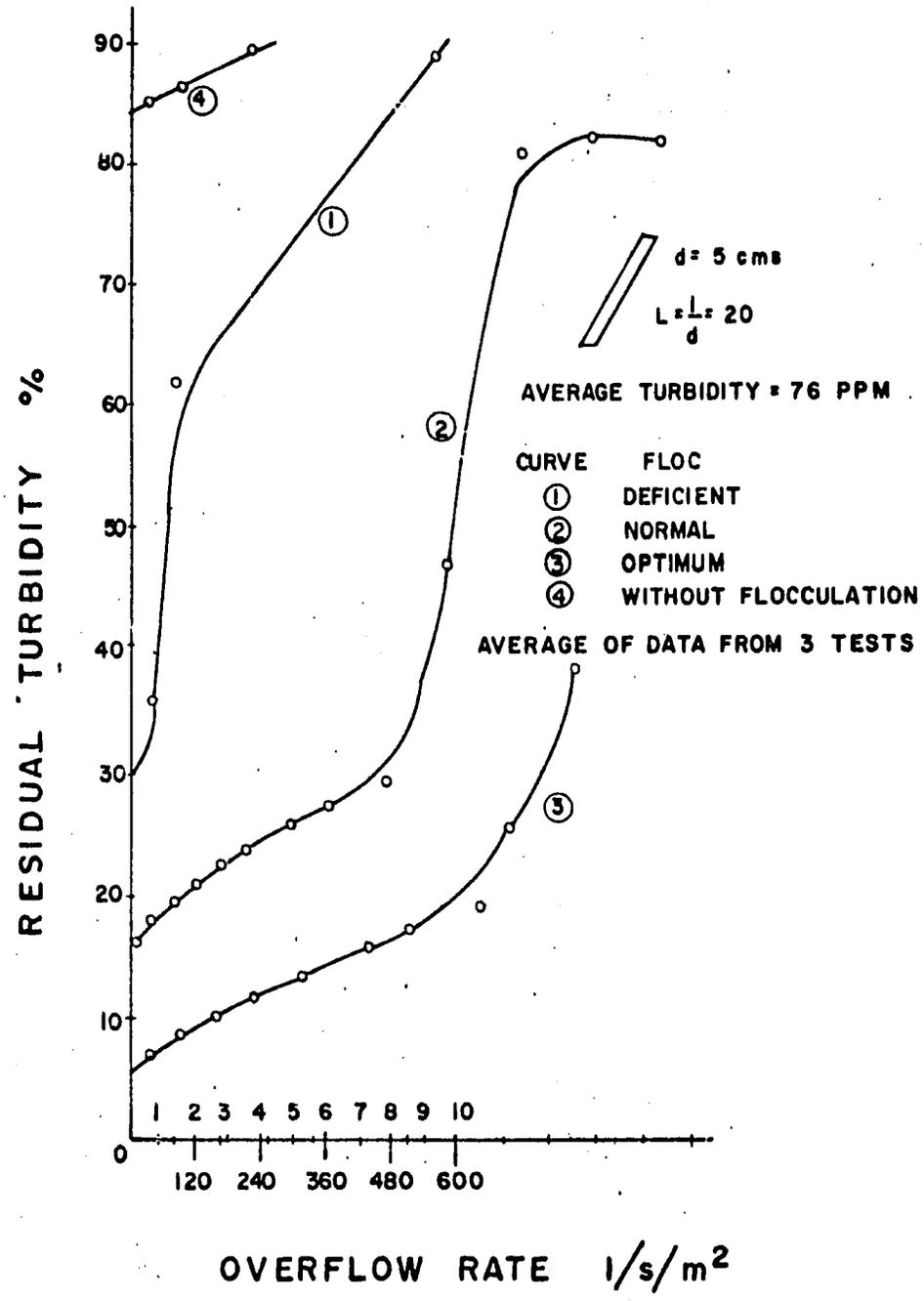
PERFORMANCE OF CORRUGATED - PLATE SETTLERS	FIGURE
WATER SUPPLY SYSTEM - CUENCA	6-23



VARIATION OF EFFICIENCY AS A FUNCTION OF THE RELATIVE LENGTH OF THE PARALLEL PLATE MODULES

FIGURE 6-24

WATER SUPPLY SYSTEM - CUENCA



PERFORMANCE OF THE PARALLEL PLATE SETTLERS - PILOT PLANT	FIGURE
WATER SUPPLY SYSTEM — CUENCA	6-25

Subsequently, ETAPA made a detailed study of three alternatives for expanding the treatment plant from a capacity of 240 to 870 l/s.

1) Use of conventional methods at a unit cost of US$ 3 233 per l/s;

2) Use of patented methods, at a unit cost of US$ 2 221 per l/s;

3) Use of new treatment methods at a unit cost of US$ 889.30 per l/s;

This means that by applying new technology to the modification of existing plants, it is possible to design projects at 27% of the cost of conventional methods or 40% of the cost of patented processes.

The total cost of the water treatment project reached US$ 560 294.00 (1972) distributed in the following manner: 36% for the purchase of imported construction equipment, machinery, pumps, feeders, chlorinators and pipelines; 30% for local purchases and materials; 23% for labor, 6% for miscellaneous and unforeseen expenses; and 5% for management and administration.

B. Basic economic data requested by the University of Oklahoma are included in Appendices 6-E and 6-F.

4.4 Conclusions

A. From the technical point of view it is possible and advisable to use new design criteria when expanding water treatment plants, since in general better quality water can be produced at overflow rates 3 and 4 times greater than those of conventional plants being operated under normal conditions in Latin America.

B. It is possible to design treatment plants that are easy to operate and maintain by adapting advanced technology to the socio-economic conditions and levels of industrial development in Latin America.

C. From the economic point of view, appreciable savings (73%) are obtained in comparison with the cost of expanding or modifying treatment plants using conventional technology.

D. Since the technical and economic viability and particularly the advantages of using new technology in expanding and modifying treatment plants have been demonstrated, the principal parameters that influence the efficiency of high-rate settlers were studied in order to obtain design criteria for new treatment units, such as the influence of pre-treatment, overflow rate, water quality, type of module and the relative length of the module.

E. It is not possible to do a detailed evaluation of the efficiency of the plant or the filtration process because ETAPA has not yet completed the technical evaluation studies.

7. CONCLUSIONS

Based on the evaluation of normal operations of four water treatment plants designed with new technological criteria, as well as special tests conducted to determine the response of the reactors to variations in flow and comparative tests run in the laboratory or in pilot plants, the following conclusions were obtained:

7.1 GENERAL TECHNICAL-ECONOMIC CONCEPTS

7.1.1 New technological criteria for water treatment plant design can be used successfully to produce very compact and simple solutions.

7.1.2 The new technology implies, in general, the use of higher unit loadings than those used in conventional designs (standards), which results in smaller and less-expensive plants (US$ 900 to 1 200 per liter per second), or in the possibility of increasing flow rates in plants designed with conventional criteria, by making minor modifications at a cost of US$ 800 to US$ 900 per liter/second. This represents savings of 60-70%.

7.1.3 The application of new technological design criteria is not limited by the size of the plant, but rather by raw water quality.

7.1.4 The new technological concepts that lead to "low-cost" solutions also imply the simplification of the processes and operation of the reactors making them more appropriate for countries in the initial stages of industrial development.

7.1.5 It is possible to eliminate the need for mechanized equipment by using hydraulic controls, which produces considerable savings since local non-skilled construction workers can be used and imported materials are practically eliminated.

7.1.6 When using appropriate technological criteria, design parameters must be obtained by laboratory tests, instead of using conventional standards and parameters. This leads to specific solutions with greater technical efficiency than that generally obtained, at greater cost, using conventional procedures and parameters (standards).

7.1.7 The optimization of processes results in a reduction in the amount of chemicals required, thus reducing operating costs.

7.2 CHEMICAL FEEDING

7.2.1 The following correlation tendencies exist between water quality and coagulant dosage:

A. With low turbidities (less than 10 JTU) large amounts of coagulants are required since coagulation is produced as the metal hydroxides drag down the suspended particles.

B. With average turbidity values between 10 and 50 JTU, there is a correlation expressed by the equation:

$$y = a + bx$$

where y = coagulant dosage
x = raw water turbidity
a and b = specific constants for each type of water.

C. With turbidities above 50 or 100 JTU the correlation is expressed by the equation:

$$y = a + b \log(x)$$

7.2.2 It is possible to obtain the same accuracy using solution or saturation feeders of simple design as with the dosing equipment normally used in conventional water treatment plants. This helps simplify the construction and operation of the plants and minimize their cost.

7.2.3 The use of saturation feeders makes it possible to use inexpensive chemical compounds of low purity which are available locally, thereby simplifying the operation while obtaining the desired performance by preventing the polymerization of the coagulant. When used in small treatment plants with very small flows (daily capacity of 1 000 m^3), the dosage is not exact.

7.3 RAPID MIXING

7.3.1 Rapid mixing is influenced mainly by water quality characteristics (suspended solids, temperature) and by the characteristics of the reactors (detention time, velocity gradients), whose relation is expressed by the equation:

$$G \cdot T \cdot C^n = K$$

where G = velocity gradient
T = detention time
C = coagulant dosage, which is a function of water quality
$(n),(K)$ = specific constants, different for each type of water.

7.3.2 Apparently, the hydraulic gradient is important not only in the mixing unit, but in the sequence of gradients downstream.

7.3.3 High velocity gradients (1 000 to 2 000 s^{-1}) in the mixing units produce smaller but more compact floc, which is easier to settle and especially to filter, thus producing better quality water.

7.3.4 Very high velocity gradients (> 2 000 s^{-1}) hinder the formation and appearance of the floc in the flocculation units, causing a decrease in efficiency in these units by modifying their effective detention times.

7.3.5 Apparently, high mixing gradients are required for relatively clear waters and lower gradients for turbid waters (with the same detention time).

7.3.6 Apparently mixing units with a predominance of piston flow (hydraulic units) are more efficient (larger agglomeration factor) than mechanical units (retro-mixing type). Hydraulic units are also more economical and simpler to operate and maintain.

7.3.7 The point of injection of the chemicals is very important.

7.3.8 The use of the average velocity gradient as the only element to measure the efficiency of a mixing reactor seems to be inadequate.

7.3.9 Different velocity gradients should be used with different types of mixing systems.

7.3.10 Proper characterization of the mixing unit can reduce the amount of coagulant required and, in addition, can modify the flocculation units.

7.4 FLOCCULATION

7.4.1 In flocculation, water quality is important (physical characteristics such as suspended solids and chemical characteristics such as alkalinity pH, etc.) as well as the characteristics of the reactor including hydraulic gradients, detention time, types of flow, short-circuiting, dead spaces, number of units, etc.

In general, the relation between the main parameters can be expressed by the equation:

$$G^n T = K$$

where G = velocity gradient
T = detention time
(n) and (K) = specific constants depending on water quality.

7.4.2 In general, high velocity gradients are required for relatively clear waters and lower gradients for turbid waters (with the same detention time). This fact should influence the selection of the type of flocculator to be used.

7.4.3 Both the hydraulic flocculators (Cochabamba and Cuenca) and the mechanical type (Prudentopolis) demonstrated high efficiency. Thus, the efficiency does not seem to depend on the type of flow, but rather on other factors and conditions indicated previously, in addition to the geometric characteristics of the reactor which can permit short-circuiting or dead spaces.

7.4.4 The efficiency of a flocculator as related to the detention times is expressed by a parabolic curve for a specific velocity gradient. Each velocity gradient has its own optimum efficiency value and an optimum detention time.

7.4.5 Maximum flocculation efficiency is obtained with a hyperbolic correlation of the velocity gradients and detention times.

7.4.6 The flocculation process has a considerable influence on the rest of the treatment process, i.e. sedimentation and filtration.

7.4.7 Tracer tests are useful to define the type and conditions of flow, but they do not reveal the trajectories of the particles. They are useful for giving an approximate idea of the performance of these units by evaluating short-circuiting and dead spaces.

7.5 HIGH-RATE SEDIMENTATION

7.5.1 The use of high-rate sedimentation in water treatment plants makes it possible to obtain very economical and technically efficient solutions which are easy to operate and maintain.

7.5.2 In two treatment plants (Prudentopolis and Cochabamba) the results obtained were superior to the laboratory results (95% and 42% of the time respectively) with efficiencies of 99% and 95%. In the case of Cuenca, the efficiency was 8% less than that obtained in the laboratory tests.

7.5.3 In comparative tests of high-rate settler performance with overflow rates five times greater (120 $m^3/m^2/day$) than conventional settling units (25 $m^3/m^2/day$) the high-rate settler performance was 7% greater.

7.5.4 According to the tests, high-rate settlers with parallel plates are more efficient than tube modules, and the latter are more efficient than corrugated plates. The respective efficiencies are 89%, 78%, and 68% with overflow rates of 120 $m^3/m^2/day$.

7.5.5 In all types of high rate settlers, efficiency decreases as the overflow rate is increased. A 500% increase in overflow rate produces a relative decrease in efficiency of 50%. With loadings of 120 $m^3/m^2/day$ an efficiency of 90% is easily obtainable; with 500 $m^3/m^2/day$ efficiencies of around 60% were achieved.

7.5.6 The efficiency of the high-rate settling units varied directly as a function of suspended solids. With relatively clear waters (less than 20 JTU) efficiencies of 88.9% were obtained. With high turbidity (1 500 JTU) efficiencies of 99.7% were achieved.

7.5.7 The factor which has the greatest influence on high-rate sedimentation is pretreatment. With proper pretreatment and overflow rates of 120 $m^3/m^2/day$, efficiencies of 90% can be obtained. If flocculation is poor, the efficiency decreases to about 40%.

7.5.8 According to the tests carried out in Prudentopolis, there is an appreciable increase in efficiency as a function of time. In six months of operation the efficiency improved from 20 to 95%.

7.5.9 One of the factors that influences the performance of high-rate settlers is water temperature (a factor not normally considered in plant design) since in Cochabamba it was found that variations in temperature of 7°C caused reductions in efficiencies from 91 to 82%.

7.5.10 The influence of geometric factors (type of cross section, relative length and inclination) on high-rate settler performance was verified. The results obtained are in agreement with the theoretical postulates which state that settlers with flat parallel plates are the most efficient and the most economical (30% of the cost of conventional settling units); relative lengths greater than 20 are not economically justifiable; and an inclination of 60° produces a downward movement of the floc deposited on the plates.

7.5.11 Tracer tests are useful for defining the flow conditions in the settlers but they do not indicate the trajectory of the particles. By defining dead spaces and short-circuits, evaluation criteria can be obtained indirectly.

The tracer tests run in the settling units in Cochabamba and Cuenca show a large percentage of dead spaces (40%), which leads to the conclusion that in designing new water treatment plants it is not advisable to use the same geometric forms for high-rate settlers as for conventional settlers.

7.5.12 When running tracer tests, it is advisable to apply small amounts of the tracer during a period equal to at least 1/60 of the theoretical detention time before beginning the test. The injection of the tracer substance should also be done over a period not less than 1/60 of the theoretical detention time in order to get the most accurate results possible.

7.5.13 It does not seem advisable to use sludge deposit zones with slopes of less than 60°, in order to eliminate dead storage spaces.

7.5.14 Although variations in water temperature have a great influence on the efficiency of high-rate settlers, it seems that these are more stable in the face of variations in overflow rates or water quality.

7.5.15 High-rate settlers do not present special construction or operational problems, and should be considered for low-cost projects in developing countries.

7.6 TERMINAL FILTERS

7.6.1 Dual-media filters

A. The superiority of dual-media (sand and anthracite) filters in comparison with conventional sand filters was verified. Higher filtration rates (186 $m^3/m^2/day$) were obtained with better quality effluent (in general less than 0.50 JTU).

B. Longer filter runs (an average of 65 hours) can be obtained with dual-media filters.

C. The head loss in dual-media filters is less than in conventional rapid filters using only sand or anthracite.

D. With high flow rates, the filter is very sensitive to a greater penetration of the floc and there is a tendency to sudden filter bed breakthrough.

7.6.2 False bottom and supporting layer

A. Prefabricated false bottoms were found to be efficient, both from the structural and hydraulic point of view, producing a good distribution of wash water.

B. The use of plastic balls filled with cement for the supporting layer was found to be inefficient, since the filling process is inadequate because low abrasion values cause the plastic to break.

7.6.3 Declining-rate filtration

A. Tests conducted prior to the construction of the Cuenca plant, as well as the normal operation of declining-rate filters in the plants in Prudentopolis and Cochabamba demonstrated the high efficiency of this type filter, which is capable of producing greater amounts of water (more than 150%) than conventional filters with a better effluent quality (0.50 JTU) at a lower construction cost. This statement is valid for filters with or without a final control weir.

B. Three characteristic stages are produced in each filter run:

1) Increasing - with normal flow rates from 325 to 375 $m^3/m^2/day$ and a maximum of 450 $m^3/m^2/day$.

2) Decreasing - with flow rates declining from 375 to 50 $m^3/m^2/day$.

3) Relatively stable - with flow rates between 50 and 30 $m^3/m^2/day$.

A correlation is established between the variation of head loss, water level in the filter units and variation in effluent water quality. There is a definite possibility of optimizing the process in such a way as to reach simultaneously the minimum flow rate, use of maximum available water level, and the limit of water quality. This is feasible by adjusting the conditioning processes (coagulation, flocculation, and sedimentation) to regulate the size and strength of the floc.

7.6.4 Filter backwashing with the flow of other units

A. The possibility of backwashing a filter with the flow of other units working with declining rate was verified. This procedure simplifies operation and reduces construction costs considerably.

B. Three characteristic stages are produced during backwashing:

1) Increasing backwash rates from 0 to the maximum value (usually 0.60 m/min) with a duration of 1 to 5 minutes.

2) Once the maximum rate is reached, it remains constant for a period of not less than 10 or 12 minutes.

3) Recovery period.

This sequence of backwash rates produces normal expansions of 40% and the fluidization needed in this type of filters (dual-media).

When one filter is washed, the other units experience three stages of flow variation (which is inversely proportional to the number of units and is distributed in proportion to the filtration rate existing in each unit):

1) Increase of flow to a maximum of 30% of the filtration rate in the unit when the backwashing is started.

2) Stabilization of flow at the maximum.

3) Recovery which takes two or three times as long as the backwash time.

C. Backwashing produces an initial reduction of 0.20 JTU in the quality of the filtered water. Half of this loss is slowly recovered until the final deterioration is 0.10 JTU.

D. No mud balls were found in the filters, which have been operating for more than one year. There has been no appreciable movement of the supporting gravel bed.

E. There should be a minimum of four filters for the procedure to operate smoothly.

By using the above-mentioned concepts (multi-media, prefabricated false bottoms, variable filtration rate, hydraulic control, backwash with flow from other units) it is possible to produce solutions with high technical performance which are easy to build and operate and, above all, very economical. It has been verified that with the use of the above-mentioned solutions it possible to completely eliminate the filter gallery without producing a deterioration of water quality. On the contrary, the result is more and better quality water.

7.7 DIRECT FILTRATION

7.7.1 It was verified that with good quality water (less than 50 units of turbidity and color) the use of direct filtration or contact units constitutes a more efficient (more than 99.7% removal) solution than conventional processes and the construction cost is lower. In general, the effluent has turbidity values below 0.50 JTU, except at the beginning of the run when the turbidity is slightly more than 1 JTU for a short time.

7.7.2 It is possible to use direct filtration with up to 100 units of color and/or turbidity. In this case the removal efficiencies are greater than 96%. Beyond this limit, the effluent quality deteriorates considerably.

7.7.3 The suitability of using upflow filters in contact units was demonstrated.

7.7.4 The effluent quality was not affected by loadings of up to 260 $m^3/m^2/day$. There seems to be a correlation between the existing velocity gradients and the efficiency of the contact unit. There could be an optimum velocity gradient that would produce maximum efficiency, but this factor was not studied in detail nor is it usually considered when designing these units.

7.7.5 Apparently, lower coagulant dosages are required than in conventional plants (coagulation - flocculation - sedimentation - filtration).

7.7.6 Average filter funs of 30 hours, with maximum values of 60 hours are obtained.

7.7.7 A greater amount of wash water is required than is normally used in rapid filters. A longer washing time is also needed, usually twice the normal time.

7.7.8 With these units there is a danger of fluidization of the filter bed, which would produce a noticeable reduction in filtered water quality. Very careful operation and control is needed to avoid this problem.

7.7.9 There is a danger of mixing the wash water with the filtered water. Careful operation is also required to prevent this problem.

7.7.10 This solution is cheaper than conventional treatment methods because it involves fewer processes and consequently requires a smaller area.

7.8 PERSONNEL

7.8.1 The adoption of solutions based on new technological criteria brings with it the need for greater specialization of the professional staff in charge if the project, since the concepts involved are relatively new.

7.8.2 The use of solutions which are radically different from conventional methods causes a certain reticence on the part of designers and management staff, which was even more pronounced when it became evident that these solutions had an unbelievably low cost.

7.8.3 Plants designed with new criteria are easier to operate than conventional solutions, but they still require skilled personnel for their operation and control since operational errors can produce greater deficiencies in water quality due to the high flow rates used. No special operational or maintenance problems were encountered, except those indicated for contact units.

7.9 CONSTRUCTION COSTS

7.9.1 Treatment plants designed using new technological criteria cost much less than conventional solutions. Existing plants can be modified at a cost of US$ 800 to US$ 900 per liter/second, which represents from 30 to 40% of the cost of expanding a plant using conventional solutions (with capacities from 500 to 700 l/s).

7.9.2 New treatment plants cost between US$ 900 and US$ 1 200 per liter/second which is between 40 and 50% of the cost of conventional type solutions.

7.9.3 It costs less to treat relatively clear waters by using contact units rather than by the classic poocesses (flocculation - sedimentation - filtration) regardless of whether these processes are designed according to conventional or new techonological criteria. The reference cost for a capacity of 70 l/s is 67% of the cost of a plant with flocculation - sedimentation - filtration processes designed with new technological criteria.

7.9.4 The unit costs of treatment plants designed with new technological criteria are inversely proportional to their size. Table 7-1 gives the variation of unit costs as a function of plant capacity.

Table 7-1

UNIT COSTS AS A FUNCTION OF PLANT CAPACITY

Capacity l/s	Unit cost US$/l/s	Remarks
2 650	100 - 500	*
1 000	600 - 700	*
680	800 - 900	**
230	1 000 - 1 150	**
60	1 600 - 1 700	**
22	2 600 - 2 700	**

* Reference costs of other projects
** Researched costs

7.10 OPERATING COSTS

Operating costs are slightly lower than those in conventional plants, ranging from 3.91 to 16.29 per 1 000 m^3. Since the plants were built recently, there were no maintenance costs.

APPENDIX TO CHAPTER 3

DATA IDENTIFICATION

FACILITY TITLE:

PLANTA DE TRATAMIENTO DE AGUA POTABLE DE COCHABAMBA

RESPONDENT:

Name: SERVICIO DE AGUA POTABLE, ALCANTARILLADO Y DESAGUES PLUVIALES COCHABAMBA

Title: "S.E.M.A.P.A."

Address: Plaza Colón No. 5697 Acera Este; P.O. Box 1647

OWNERSHIP OF THE FACILITY:

"S.E.M.A.P.A."

Owner's Address: Same as above

NAME OF COMMUNITY TO BE SERVED BY THE FACILITY:

Town or City: COCHABAMBA

State or Province: COCHABAMBA

Country: BOLIVIA

APPENDIX 3.A

DEMOGRAPHIC AND TECHNOLOGY DATA

Please check the appropriate category in each question. If exact figures are not available, give the closest estimate.

POPULATION

1. Present Population - The figure or estimate of the present population should reflect the number of inhabitants that the proposed water or wastewater treatment facility is going to serve.

____ (1) Between 500 and 2,500 people

____ (2) 2,500 - 15,000

____ (3) 15,000 - 50,000

____ (4) 50,000 - 100,000

X (5) Other (specify) 100,000 - 150,000

Total population + 160,000

For each question from number 2 to number 9, if local or site figure is not available, please use national figure and also indicate whether it is national or local figure.

2. Annual population growth rate

☐ National ☒ Local

____ (1) Less than 1%

____ (2) 1% - 3%

X (3) 3% - 5%

____ (4) 5% - 10%

____ (5) 10% - 20%

____ (6) Greater than 20%

3. Life expectancy of population in years

[X] National [ ] Local

____ (1) Less than 40 years old

__X__ (2) 40 - 50

____ (3) 50 - 60

____ (4) 60+

4. Birth Rate: The average number of newborn each year per 1,000 population.

[X] National [ ] Local

____ (1) Less than 10

__X__ (2) 10 - 30

____ (3) 30 - 50

____ (4) 50 - 100

____ (5) 100 - 200

____ (6) More than 200

5. Infant (under one year of age) mortality rate per 1,000 population each year.

[X] National [ ] Local

____ (1) Greater than 100

____ (2) 50 - 100

____ (3) 30 - 50

__X__ (4) 10 - 30

____ (5) Less than 10

6. Survival Rate: The percentage of inhabitants expected to survive during any given year.

[ ] National [X] Local

____ (1) Less than 80%

____ (2) 80% - 90%

____ (3) 90% - 95%

_X_ (4) 95% - 97%

____ (5) 97% - 99%

____ (6) More than 99%

7. % of Emigrants: The percentages of the total population that leave the area and begin to live in another community each year.

[ ] National [X] Local

_X_ (1) Less than 1%

____ (2) 1% - 3%

____ (3) 3% - 5%

____ (4) 5% - 10%

____ (5) 10% - 20%

____ (6) Greater than 20%

8. % of Immigrants: The percentages of the total population that have just arrived to live in the community on a permanent basis each year.

[ ] National [X] Local

_X_ (1) Less than 1%

____ (2) 1% - 3%

____ (3) 3% - 5%

____ (4) 5% - 10%

____ (5) 10% - 20%

____ (6) Greater than 20%

9. Calories intake per day per person

[ ] National [X] Local

____ (1) Less than 1,000

____ (2) 1,000 - 1,500

X (3) 1,500 - 2,000 { Information not provided by respondent, estimated in CEPIS;

____ (4) Greater than 2,000

TECHNOLOGY

10. Level of water treatment technology development in the local community.

Type of Water Supply System	% of Population Being Served			
	0-25%	25-50%	50-75%	75-100%
(1) Central village or street pump	25%			
(2) Piped water supply to houses		40%		

11. Level of sewage treatment technology development in the local community.

Type of System	% of Population Being Served			
	0-25%	25-50%	50-75%	75-100%
(1) Sewage collection system		30%		
(2) Sewage treatment	0%			

In the judgement of the respondent, which of the following most appropriately describes this project.

12. Technology Advancement

____ (1) Simply transfer of a process that had been successful elsewhere.

_X_ (2) An adaptation of another process but altered to be more suited to local characteristics.

____ (3) A unique process developed especially for the characteristics of this site.

13. Quality of Project for Research

_X_ (1) A breakthrough for enhancing the development of this country.

____ (2) An important feature for the local people but not significant to overall development of the country.

____ (3) Redundant, of little use to the people.

APPENDIX 3.B

SOCIO-ECONOMIC DATA

Check the appropriate category for the following.

1. Average level of education obtained for the community.

	Level	None	Primary	High School	Technical Institute	College
____	(1)	95%	4%	1%	0%	0%
____	(2)	70%	19%	7%	3%	1%
____	(3)	55%	22%	14%	6%	3%
X	(4)	9% (8.48%)	34% (36.06%)	42% (31.36%)	8% (12.27%)	7% (11.83%)

2. Average distribution of Labor Force in the community.

	Level	Unskilled	Semi-Skilled	Professional
____	(1)	97%	2%	1%
____	(2)	80%	16%	4%
X	(3)	61%	27%	12%
____	(4)	45% (67.20%)	30% (24.43%)	25% (8.37%)

3. Annual average income per family in your country currency.

29,400	$b (US$1470.00)
amount	unit

If available, also check the approximated U. S. dollars equivalency of this amount shown in the following

____ (1) Less than $100

____ (2) $100 - $1,000

X (3) $1,000 - $3,000

____ (4) Greater than $3,000

4. Among the highly skillful and technical workers (for example, engineer, chemist, etc.) what percentages of these are non-local or non-native people.

__X__ (1) Less than 10%
____ (2) 10% - 25%
____ (3) 25% - 50%
____ (4) 50% - 75%
____ (5) 75% - 100%

5. Are the primary and secondary schools operated by voluntary or missionary organizations?

____ (1) Yes __X__ (2) No

6. What is the highest grade offered by local schools on a regular basis? (Circle one)

1 2 3 4 5 6 7 8 9 10 11 12 (12-

7. If the number selected in #8 above is less than 12, how far away is the nearest high school offering the 12th grade?

____ (1) Less than 10 miles (or less than 16 kilometers)
____ (2) 10 - 30 miles (or 16 - 48 kilometers)
____ (3) 30 - 50 miles (or 48 - 60 kilometers)
____ (4) Greater than 50 miles. (greater than 60 kilometers)
____ (5) Other (specify) _____

8. Are there any technical or vocational schools in the community?

__X__ (1) Yes ____ (2) No

9. Has the community achieved compulsory primary education of at least six years?

__X__ (1) Yes ____ (2) No

10. Are there any formal in-service training programs by either the government or local industry for their employees?

X (1) Yes ____ (2) No

11. Is there a college or university in the community?

X (1) Yes ____ (2) No

12. Does the university have a chemistry department or laboratory?

X (1) Yes ____ (2) No

13. How do you rate the ability of the community to finance a water and sewage treatment project?

____ (1) Unable to repay; the project is a pure charity scheme because the beneficiaries are poor.

X (2) Limited ability to repay; however, the social benefits exceed the social costs.

____ (3) Repayment prospects are good; the beneficiaries have comparatively high incomes.

14. Is unemployment widespread?

____ (1) Yes X (2) No

If available, give the percentage of unemployment among the total population.

4,0 % of unemployment

15. Are advisory services widely available to farmers for community development or for other programs designed to upgrade the skills and enlist the participation of the masses?

X (1) Yes ____ (2) No

16. Do most college or university students of the community receive their education in neighboring communities, neighboring countries, or other foreign countries?

X (2) Yes X (2) No Yes and no, depending on the area of the study; for Sanitary Engineer yes

17. The level of technology available can generally be classified as

___ (1) Hand tools only
X (2) Mechanical tools (i.e., gasoline powered equipment)
___ (3) Chemical products (fertilizers, chlorine)
___ (4) Electronic technology

18. Does the government dominate the labor market?

___ (1) Yes X (2) No

19. Are public employment services readily available?

___ (1) Yes X (2) No

Questions 20 - 23 relate to the availability of materials and equipment. Check those items that are never available in the Community.

20. Operation: Which of the following are never available in the local community.

X (1) Meters (not immediately, they can be ordered in a request basis)
___ (2) Lawn mowers " " " " " "
___ (3) Blowers " " " " " "
X (4) Recording devices " " " " " "
___ (5) Laboratory equipment (partially)
___ (6) Portable power plant
___ (7) Motors
___ (8) Pumps (Depending on the type)

Available, as products coming from neighbor countries and under the demand and stock of representative houses.

21. Process: Which of the following are never available in the local community.

____ (1) Pipe (clay, steel, cement, plastic, copper, etc.)
X (2) Pipe fittings
____ (3) Paint
X (4) Valves
____ (5) Tanks
____ (6) Gauges
X (7) Heat exchangers

22. Operation and Maintenance: Which of the following are never available in the local community.

____ (1) Silica sand
____ (2) Graded gravel
____ (3) Clean water
____ (4) Gasoline
X (5) Anthracit

23. Chemicals: Which of the following are never available in the local community.

X (1) Al_2SO_4 (aluminum sulfate)
X (2) $FeCl_2$ (ferric chloride)
X (3) Activated charcoal
____ (4) Lime
X (5) Soda ash
X (6) Chlorine (there is not at present, the factory is being installed and will begin producing in June, 1976.
X (7) Ozone
____ (8) Laboratory chemicals (there are some)

24. Major Water Source (check appropriate category)

X (1) River or stream
X (2) Lake or impoundment
____ (3) Wells
____ (4) Sea or brackish

25. Approximate per capita water demand (daily)

(1) Current demands 200 in l/hab/day (units)

(2) 10 year projection: 215 l/hab/day

26. Is groundwater available?

X (1) Yes ____ (2) No

27. Are wells already drilled?

X (1) Yes ____ (2) No

28. Is a central wastewater collection system in existence?

X (1) Yes ____ (2) No

29. Is the following wastewater data available? Please fill in the percentage of people in the community that are:

(1) Currently connected to the system 30 %

(2) To be connected within 5 years of the start of the project 70 %

(3) To be connected within 10 years 80 %

30. Are industrial and commercial concerns using the waste water system and if so, in what quantity? (in thousands of gallons)

(1) Currently -

(2) Within 5 years -

(3) Within 10 years -

There are few industries at present but there is a plan to form the Industrial Park out of the city.
It is very difficult to characterize the class of industry to be installed.

APPENDIX 3.C

PROCESS DATA

Please supply the following data related to the treatment process of the project. If there are more than one treatment plant, please fill in ONE data sheet FOR EACH PLANT.

For Water treatment process, please fill in PART I; and for Sewage treatment, fill in PART II. Indicate the data either in metric unit or in British unit.

PART I: WATER TREATMENT PROCESS

1. Type of Process: Coagulation, sedimentation, filtration and disinfection.

2. Please check the appropriate water treatment process or processes in the following which fit the one(s) used at your treatment plant.

____ (1) PW1* Drilled Well

____ (2) PW2 Pre-Treatment

____ (3) PW3 Slow Sand Filtration

____ (4) PW4 Rapid Sand Filter - Conventional

X (5) PW5 Rapid Sand Filter - Advanced

____ (6) PW6 Softening

X (7) PW7 Disinfection

____ (8) PW8 Taste-Odor - Fe, Mn

____ (9) PW9 Desalting - Salt (Sea water)

____ (10) PW10 Desalting - Brackish

____ (11) PW11 Coagulation Pressure Filtration

---

* PW1, PW2, PW3, etc., are process codes used in the OU/USAID project.

3. Source

X (1) River or stream

____ (2) Lake or impoundment

____ (3) Wells

____ (4) Sea or brackish

See 24 Appendix B

Treatment capacity of the plant (4)

	British unit	Metric unit
		235 l/s (nominal capacity) It can be operated up to 300 l/s

Sub-treatment methods used

4. Settling

____ (1) Plain sedimentation

X (2) Coagulation

X (3) Tube or plate

____ (4) Upflow

____ (5) Coagulation material

X a. Al_2SO_4

____ b. $FeCl_3$

____ c. Polymer

X d. Other (lime)

____ (6) Approximate design criteria used

British Unit		Metric Unit	
a. Loading rate (Q/A)			
284,1 (a) Less than 500 gpd/ft^2	or	11,57 (a) Less than 20 m/day	
____ (b) 500 - 1,000	or	____ (b) 20 - 40	
____ (c) Greater than 1,000	or	X (c) Greater than 40 120 m^3/m^2/day	

b. Detention time in hours

X (a) ½ - 1 six minutes for high-rate settling unit

____ (b) 1 - 2

____ (c) 2 - 4

(d) Greater than 4

c. Mixing: Mean velocity gradient, G

____ (a) 10 - 25

____ (b) 25 - 50

__X__ (c) 50 - 75 · 100 - 68 - 50 s^{-1}

d. Design capacity (Total plant)

	British Unit			Metric Unit
____	(a) Less than 0.5 MGD	or	____	(a) Less than 0.025 m^3/s
__X__	(b) 0.5 - 5	or	__X__	(b) 0.025 - 0.25
____	(c) 5 - 20	or	____	(c) 0.25 - 1.0
____	(d) Greater than 20	or	____	(d) Greater than 1.0

e. Stirring and/or mixing devices

__X__ (a) Baffle

____ (b) Paddle

____ (c) Air

5. Filters

(1) Rate of flow

____a. Slow (0.05 to 0.10 gpm/ft^2 or 0.002 to 0.004 M/min)

____b. Rapid (approximately 2 gpm/ft^2 or 0.08 M/min)

__X__c. Greater than 2 gpm/ft^2 or 0.08 M/min

(2) Filter media

____a. Sand

__X__b. Multi-media = sand and anthracite

____c. Other

(3) Hydraulic mean size (10% by weight on sieve analysis)

____a. 0.2 mm

X b. 0.6 mm sand (0.50 mm)

____c. 1.0 mm anthracite

(4) Depth of media

British Unit		Metric Unit	
____a. Less than 40 inches	or	0.20 a. Less than 100 cm	Sand
____b. 40 - 50	or	0.55 b. 100 - 125	Anthracit
____c. Greater than 50	or	____c. Greater than 125	

(5) Controls for backwash

____a. Mechanical or hydraulic X

____b. Simplified or operator controlled

(6) Direction of flow through filter

____a. Upward

X b. Down flow

____c. Both

(7) Control of Filtration rate

____a. Rate controller

X b. Declining head

____c. Siphon head

____d. Other (specify)

6. Disinfection Method

X (1) Cl_2

____ (2) Lime

____ (3) Ultra-violet

____ (4) Ozone

____ (5) Other

APPENDIX 3.E

OPERATIONAL DATA

Please check the appropriate category related to the operation of the treatment plant.

1. Type of treatment plant.

__X__ (1) Water treatment

____ (2) Sewage treatment

OPERATORS

2. Availability of trained or skilled operators

__X__ (1) Easy to find

____ (2) Difficult to find

3. Existance of a standard or system for evaluating the qualifications of operators

____ (1) Yes

__X__ (2) No

4. Short course or other training programs for operators available

____ (1) Yes

__X__ (2) No

5. Reason for leaving employment at the treatment plant

__X__ (1) Better job

____ (2) Discharged

____ (3) Others (specify) _____

6. Average age of operators

____ (1) Less than 20 years old

__X__ (2) 20 - 30

____ (3) 30 - 40

____ (4) Older than 40

7. Quality of operators

____ (1) Not dependable

____ (2) Fair

X (3) Good

____ (4) Excellent

CHEMICALS

8. Location (distance) for obtaining chemicals

____ (1) Local

____ (2) In-country

X (3) Out-of-country

9. Availability of chemicals

____ (1) Easy to obtain locally

X (2) Difficult to obtain locally } Both

X (3) Easy to obtain non-locally } Both

____ (4) Difficult ot obtain non-locally

MACHINERY, PARTS, ETC.

10. Cause of machinery breakdown

____ (1) Operator error

____ (2) Product failure

____ (3) Others (specify) Plant in the initial operational stage

11. Time interval for replacement of machinery or parts

____ (1) Too often as compared to the expected life of the item

____ (2) Not as often as compared to the expected life of the item

____ (3) Routine replacement

The plant does not have this kind of problems yet.

12. Delivery time of ordered parts

____ (1) Less than 1 week

____ (2) Between 1 and 4 weeks

X (3) Between 1 and 6 months (one month)

____ (4) Between 6 months and a year

____ (5) More than one year

13. Parts replaced are usually

____ (1) Ordered specially

_X_ (2) Off the shelf (common parts) (As SEMAPA's policy)

____ (3) Other (specify) _____

14. Repair of machinery

_X_ (1) Repaired locally

____ (2) Repaired in-country

____ (3) Repaired out-of-country

____ (4) No repair, replaced by new one

OPERATIONAL FAILURE (TECHNICAL)

15. Characteristic of raw water causing difficulty in treatment

_X_ (1) Turbidity (Sudden variations)

____ (2) Algae

____ (3) Other (specify) Volume variations 50 - 200% of flow

16. Operational failure due to the following

____ (1) Storage

____ (2) Pumps

____ (3) Lack of Water

_X_ (4) Other (specify) Operator's fault

17. Failure due to the designed process

____ (1) Under-designed

____ (2) Improper design

____ (3) Adequate design

____ (4) Over loading

____ (5) Other (specify) None

SUPERVISORY CONTROL

18. Inspection of plant

____ (1) Regular inspection

__X__ a. Local

____ b. Regional

____ c. National

____ d. Other (specify) _____

____ (2) Active supervision at the plant

____ (3) Other (specify) _____

19. Laboratory location

__X__ (1) At plant

____ (2) Regional

____ (3) Central

____ (4) Mobile

____ (5) Non-existant

PROBLEMS NOT SOLVED BY PRESENT FACILITY

20. Technical problems of effluent

____ (1) Odor of water

____ (2) Taste of water

____ (3) Color of water

__X__ (4) None

____ (5) Other (specify) _____

21. Monetary problems in operations

____ (1) Extreme difficulty in financing

__X__ (2) Moderate difficulty in financing

____ (3) No difficulty in financing

22. Operational cost and capacity

(1) Capacity in million gallon/day or in m^3/day.

12 960	m^3/día
Amount	Unit

(2) Total annual operational cost

45 000.-	US$
Amount	Currency Unit

(3) Annual operational cost for personnel (payroll)

12 000.-	US$
Amount	Currency Unit

23. Administrative problems

X (1) Personnel (low salaries)

____ (2) Managerial

____ (3) Supervisory

____ (4) Operators

____ (5) None

____ (6) Others (specify) _____

APPENDIX 3.F

FACILITY CONSTRUCTION COST DATA

Please answer the following related to the construction cost of the project. If there are more than one facility involved, please fill in ONE questionnaire FOR EACH.

1. Type of the treatment: check whether it is water or sewage treatment.

X Water treatment

Type of the process: Potable water: flocculation, high rate sedimentation, declining rate filtration and cloration.

___ Sewage treatment

Type of the process: _____

2. (1) Year the plant was built 1.974 - 1.975

(2) Population served by the plant 74.000 inhabitants

(3) Construction cost in U.S. dollars $ 261.380.55

or construction cost in your country currency 5'227.611.01 $b
amount currency

3. Percent of total cost for labor

___ (1) Less than 10%

___ (2) 10% - 25%

X (3) 25% - 50% (33.37)

___ (4) 50% - 75%

___ (5) 75% - 90%

___ (6) Greater than 90%

4. Percent of total cost for material

___ (1) Less than 10%

___ (2) 10% - 25%

___ (3) 25% - 50%

X (4) 50% - 75% (60.63)

___ (5) 75% - 90%

___ (6) Greater than 90%

5. Percent of total cost for engineering fee

____ (1) Less than 2%

____ (2) 2% - 4%

____ (3) 4% - 6%

_X_ (4) 6% - 10% (including supervision in construction and direct administratio

____ (5) Greater than 10%

(The plant was built in part by contract and in part by direct administration)

6. Percent of the total labor cost spent for skilled labor

_X_ (1) Less than 25%

____ (2) 25% - 50%

____ (3) 50% - 75%

____ (4) Greater than 75%

7. Approximate daily wage for unskilled labor in your country's currency

46.25 (amount) Bolivian Pesos (currency unit)

or, if available, please check the category of U. S. dollar equivalent shown below

____ (1) Less than $1/day

_X_ (2) $1 - $3/day (2.31$/day)

____ (3) $3 - $5/day

____ (4) $5 - $10/day

____ (5) $10 - $15/day

____ (6) More than $15/day

8. Approximate daily wage for skilled labor in your country's currency

66.00 (amount) Bolivian Pesos (currency unit)

or, if available, please check the category of U. S. dollar equivalent shown below

____ (1) Less than U. S. $2/day

_X_ (2) $2 - $5/day (3.30 US$)

____ (3) $5 - $10/day

____ (4) $10 - $15/day

____ (5) $15 - $20/day

____ (6) More than $20/day

9. Of the total cost spent for material, what percent of material was found in-country?

____ (1) Less than 10%

____ (2) 10% - 25%

____ (3) 25% - 50%

____ (4) 50% - 75%

X (5) 75% - 100% 84.4%

APPENDIX TO CHAPTER 4

DATA IDENTIFICATION

FACILITY TITLE:

SISTEMA DE TRATAMENTO D'AGUA DA CIDADE DE LINHARES - ESTADO DO ESPIRITO SANTO - BRASIL

RESPONDENT:

Name: SERVICO AUTONOMO DE AGUA E ESGOTO DE LINHARES

Title: SAAE - LIN

Address: FUNDACAO SERVICOS DE SAUDE PUBLICA - FSESP

OWNERSHIP OF THE FACILITY:

MUNICIPIO DE LINHARES, ESTADO DO ESPIRITO SANTO

Owner's Address: Same as above

NAME OF COMMUNITY TO BE SERVED BY THE FACILITY:

Town or City: LINHARES

State or Province: ESPIRITO SANTO

Country: BRAZIL

APPENDIX 4.A

DEMOGRAPHIC AND TECHNOLOGY DATA

Please check the appropriate category in each question. If exact figures are not available, give the closest estimate.

POPULATION

1. Present Population - The figure or estimate of the present population should reflect the number of inhabitants that the proposed water or wastewater treatment facility is going to serve.

____ (1) Between 500 and 2,500 people

____ (2) 2,500 - 15,000

_X_ (3) 15,000 - 50,000

____ (4) 50,000 - 100,000

____ (5) Other (specify) _____

For each question from number 2 to number 9, if local or site figure is not available, please use national figure and also indicate whether it is national or local figure.

2. Annual population growth rate

☐ National ☒ Local

____ (1) Less than 1%

____ (2) 1% - 3%

_X_ (3) 3% - 5%

____ (4) 5% - 10%

____ (5) 10% - 20%

____ (6) Greater than 20%

3. Life expectancy of population in years

[ ] National [X] Local

____ (1) Less than 40 years old

____ (2) 40 - 50

_X_ (3) 50 - 60

____ (4) 60+

4. Birth Rate: The average number of newborn each year per 1,000 population.

[X] National [ ] Local

____ (1) Less than 10

____ (2) 10 - 30

_X_ (3) 30 - 50

____ (4) 50 - 100

____ (5) 100 - 200

____ (6) More than 200

5. Infant (under one year of age) mortality rate per 1,000 population each year.

[X] National [ ] Local

____ (1) Greater than 100

____ (2) 50 - 100

____ (3) 30 - 50

_X_ (4) 10 - 30

____ (5) Less than 10

6. Survival Rate: The percentage of inhabitants expected to survive during any given year.

[X] National [ ] Local

____ (1) Less than 80%

_X_ (2) 80% - 90%

____ (3) 90% - 95%

____ (4) 95% - 97%

____ (5) 97% - 99%

____ (6) More than 99%

7. % of Emigrants: The percentages of the total population that leave the area and begin to live in another community each year.

[ ] National [X] Local

_X_ (1) Less than 1%

____ (2) 1% - 3%

____ (3) 3% - 5%

____ (4) 5% - 10%

____ (5) 10% - 20%

____ (6) Greater than 20%

8. % of Immigrants: The percentages of the total population that have just arrived to live in the community on a permanent basis each year.

[ ] National [X] Local

____ (1) Less than 1%

____ (2) 1% - 3%

_X_ (3) 3% - 5%

____ (4) 5% - 10%

____ (5) 10% - 20%

____ (6) Greater than 20%

9. Calories intake per day per person

[X] National [ ] Local

____ (1) Less than 1,000

____ (2) 1,000 - 1,500

X (3) 1,500 - 2,000

____ (4) Greater than 2,000

TECHNOLOGY

10. Level of water treatment technology development in the local community.

Type of Water Supply System	% of Population Being Served			
	0-25%	25-50%	50-75%	75-100%
(1) Central village or street pump	X			
(2) Piped water supply to houses			X	

11. Level of sewage treatment technology development in the local community.

Type of System	% of Population Being Served			
	0-25%	25-50%	50-75%	75-100%
(1) Sewage collection system	X			
(2) Sewage treatment	X			

In the judgement of the respondent, which of the following most appropriately describes this project.

12. Technology Advancement

____ (1) Simply transfer of a process that had been successful elsewhere.

_X_ (2) An adaptation of another process but altered to be more suited to local characteristics.

____ (3) A unique process developed especially for the characteristics of this site.

13. Quality of Project for Research

_X_ (1) A breakthrough for enhancing the development of this country.

____ (2) An important feature for the local people but not significant to overall development of the country.

____ (3) Redundant, of little use to the people.

APPENDIX 4.B

SOCIO-ECONOMIC DATA

Check the appropriate category for the following.

1. Average level of education obtained for the community.

	Level	None	Primary	High School	Technical Institute	College
____	(1)	95%	4%	1%	0%	0%
____	(2)	70%	19%	7%	3%	1%
____	(3)	55%	22%	14%	6%	3%
X	(4)	9%	34%	42%	8%	7%

2. Average distribution of Labor Force in the community.

	Level	Unskilled	Semi-Skilled	Professional
____	(1)	97%	2%	1%
____	(2)	80%	16%	4%
____	(3)	61%	27%	12%
X	(4)	45%	30%	25%

3. Annual average income per family in your country currency.

1,200.00 (amount) dollars (unit)

If available, also check the approximated U. S. dollars equivalency of this amount shown in the following

____ (1) Less than $100

X (2) $100 - $1,000

____ (3) $1,000 - $3,000

____ (4) Greater than $3,000

4. Among the highly skillful and technical workers (for example, engineer, chemist, etc.) what percentages of these are non-local or non-native people.

____ (1) Less than 10%
_X_ (2) 10% - 25%
____ (3) 25% - 50%
____ (4) 50% - 75%
____ (5) 75% - 100%

5. Are the primary and secondary schools operated by voluntary or missionary organizations?

_X_ (1) Yes ____ (2) No

6. What is the highest grade offered by local schools on a regular basis? (Circle one)

1 2 3 4 5 6 7 8 9 10 11 (12) 12+

7. If the number selected in #8 above is less than 12, how far away is the nearest high school offering the 12th grade?

____ (1) Less than 10 miles (or less than 16 kilometers)
____ (2) 10 - 30 miles (or 16 - 48 kilometers)
____ (3) 30 - 50 miles (or 48 - 60 kilometers)
____ (4) Greater than 50 miles. (greater than 60 kilometers)
____ (5) Other (specify) _____

8. Are there any technical or vocational schools in the community?

____ (1) Yes _X_ (2) No

9. Has the community achieved compulsory primary education of at least six years?

_X_ (1) Yes ____ (2) No

10. Are there any formal in-service training programs by either the government or local industry for their employees?

____ (1) Yes X (2) No

11. Is there a college or university in the community?

____ (1) Yes X (2) No

12. Does the university have a chemistry department or laboratory?

____ (1) Yes X (2) No

13. How do you rate the ability of the community to finance a water and sewage treatment project?

____ (1) Unable to repay; the project is a pure charity scheme because the beneficiaries are poor.

____ (2) Limited ability to repay; however, the social benefits exceed the social costs.

X (3) Repayment prospects are good; the beneficiaries have comparatively high incomes.

14. Is unemployment widespread?

____ (1) Yes X (2) No

If available, give the percentage of unemployment among the total population.

<2 % of unemployment

15. Are advisory services widely available to farmers for community development or for other programs designed to upgrade the skills and enlist the participation of the masses?

X (1) Yes ____ (2) No

16. Do most college or university students of the community receive their education in neighboring communities, neighboring countries, or other foreign countries?

____ (2) Yes X (2) No

17. The level of technology available can generally be classified as

X (1) Hand tools only
____ (2) Mechanical tools (i.e., gasoline powered equipment)
____ (3) Chemical products (fertilizers, chlorine)
____ (4) Electronic technology

18. Does the government dominate the labor market?

____ (1) Yes X (2) No

19. Are public employment services readily available?

____ (1) Yes X (2) No

Questions 20 - 23 relate to the availability of materials and equipment. Check those items that are never available in the Community.

20. Operation: Which of the following are never available in the local community.

X (1) Meters
____ (2) Lawn mowers
____ (3) Blowers
X (4) Recording devices
X (5) Laboratory equipment
X (6) Portable power plant
____ (7) Motors (small)
____ (8) Pumps (small)

21. Process: Which of the following are never available in the local community.

____ (1) Pipe (clay, steel, cement, plastic, copper, etc.)
____ (2) Pipe fittings
____ (3) Paint
____ (4) Valves
_X_ (5) Tanks
_X_ (6) Gauges
_X_ (7) Heat exchangers

22. Operation and Maintenance: Which of the following are never available in the local community.

____ (1) Silica sand
____ (2) Graded gravel
____ (3) Clean water
____ (4) Gasoline

23. Chemicals: Which of the following are never available in the local community.

_X_ (1) Al_2SO_4 (aluminum sulfate)
_X_ (2) $FeCl_2$ (ferric chloride)
_X_ (3) Activated charcoal
____ (4) Lime
____ (5) Soda ash
____ (6) Chlorine
_X_ (7) Ozone
_X_ (8) Laboratory chemicals

24. Major Water Source (check appropriate category)

_X_ (1) River or stream
____ (2) Lake or impoundment
____ (3) Wells
____ (4) Sea or brackish

25. Approximate per capita water demand (daily)

(1) Current demands 300 in 1/inhabitant/day (units)

(2) 10 year projection: 400 1/inhabitant/day

26. Is groundwater available?

X (1) Yes ____ (2) No

27. Are wells already drilled?

____ (1) Yes X (2) No

28. Is a central wastewater collection system in existence?

X (1) Yes ____ (2) No

29. Is the following wastewater data available? Please fill in the percentage of people in the community that are:

(1) Currently connected to the system 17 %

(2) To be connected within 5 years of the start of the project + 33 %

(3) To be connected within 10 years + 20 %

30. Are industrial and commercial concerns using the waste water system and if so, in what quantity? (in thousands of gallons)

(1) Currently <10

(2) Within 5 years ____

(3) Within 10 years ____

APPENDIX 4.C

PROCESS DATA

PLANT 1

Please supply the following data related to the treatment process of the project. If there are more than one treatment plant, please fill in ONE data sheet FOR EACH PLANT.

For Water treatment process, please fill in PART I; and for Sewage treatment, fill in PART II. Indicate the data either in metric unit or in British unit.

PART I: WATER TREATMENT PROCESS

1. Type of Process: upflow filtration

2. Please check the appropriate water treatment process or processes in the following which fit the one(s) used at your treatment plant.

____ (1) PW1* Drilled Well

____ (2) PW2 Pre-Treatment

____ (3) PW3 Slow Sand Filtration

____ (4) PW4 Rapid Sand Filter - Conventional

_X_ (5) PW5 Rapid Sand Filter - Advanced

____ (6) PW6 Softening

____ (7) PW7 Disinfection

____ (8) PW8 Taste-Odor - Fe, Mn

____ (9) PW9 Desalting - Salt (Sea water)

____ (10) PW10 Desalting - Brackish

____ (11) PW11 Coagulation Pressure Filtration

* PW1, PW2, PW3, etc., are process codes used in the OU/USAID project.

3. Source

X (1) River or stream

___ (2) Lake or impoundment

___ (3) Wells

___ (4) Sea or brackish

Treatment capacity of the plant (4)

70 l/s total (two units of 30 l metric unit

Sub-treatment methods used

4. Settling

___ (1) Plain sedimentation

___ (2) Coagulation

___ (3) Tube or plate

___ (4) Upflow

___ (5) Coagulation material

X a. Al_2SO_4

___ b. $FeCl_3$

___ c. Polymer

___ d. Other

___ (6) Approximate design criteria used

British Unit		Metric Unit
a. Loading rate (Q/A)		
___ (a) Less than 500 gpd/ft^2	or	___ (a) Less than 20 m^3/day
___ (b) 500 - 1,000	or	___ (b) 20 - 40
___ (c) Greater than 1,000	or	___ (c) Greater than 40

b. Detention time in hours

___ (a) ½ - 1

___ (b) 1 - 2

___ (c) 2 - 4

___ (d) Greater than 4

c. Mixing: Mean velocity gradient, G

____ (a) 10 - 25

____ (b) 25 - 50

____ (c) 50 - 75

d. Design capacity

British Unit		Metric Unit
____ (a) Less than 0.5 MGD	or	____ (a) Less than 0.025 m^3/sec
____ (b) 0.5 - 5	or	____ (b) 0.025 - 0.25
____ (c) 5 - 20	or	____ (c) 0.25 - 1.0 (Total of the plant)
____ (d) Greater than 20	or	____ (d) Greater than 1.0

e. Stirring and/or mixing devices

_X_ (a) Baffle

____ (b) Paddle

____ (c) Air

5. Filters

(1) Rate of flow

____a. Slow (0.05 to 0.10 gpm/ft^2 or 0.002 to 0.004 M/min)

____b. Rapid (approximately 2 gpm/ft^2 or 0.08 M/min)

_X_c. Greater than 2 gpm/ft^2 or 0.08 M/min

(2) Filter media

____a. Sand

_x_b. Multi-media

____c. Other

(3) Hydraulic mean size (10% by weight on sieve analysis)

__X__ a. 0.2 mm

____ b. 0.6 mm

____ c. 1.0 mm

(4) Depth of media

British Unit		Metric Unit
____ a. Less than 40 inches	or	____ a. Less than 100 cm
____ b. 40 - 50	or	__X__ b. 100 - 125
____ c. Greater than 50	or	____ c. Greater than 125

(5) Controls for backwash

__X__ a. Mechanical or hydraulic

____ b. Simplified or operator controlled

(6) Direction of flow through filter

__X__ a. Upward

____ b. Down flow

____ c. Both

(7) Control of Filtration rate

____ a. Rate controller

__X__ b. Declining head

____ c. Siphon head

____ d. Other (specify)

6. Disinfection Method

__X__ (1) Cl_2

____ (2) Lime

____ (3) Ultra-violet

____ (4) Ozone

____ (5) Other

APPENDIX 4.C

PROCESS DATA

PLANT 2

Please supply the following data related to the treatment process of the project. If there are more than one treatment plant, please fill in ONE data sheet FOR EACH PLANT.

For Water treatment process, please fill in PART I; and for Sewage treatment, fill in PART II. Indicate the data either in metric unit or in British unit.

PART I: WATER TREATMENT PROCESS

1. Type of Process: Flocculation, sedimentation and conventional rapid filtratio

2. Please check the appropriate water treatment process or processes in the following which fit the one(s) used at your treatment plant.

____ (1) PW1* Drilled Well

____ (2) PW2 Pre-Treatment

____ (3) PW3 Slow Sand Filtration

__X__ (4) PW4 Rapid Sand Filter - Conventional

____ (5) PW5 Rapid Sand Filter - Advanced

____ (6) PW6 Softening

____ (7) PW7 Disinfection

____ (8) PW8 Taste-Odor - Fe, Mn

____ (9) PW9 Desalting - Salt (Sea water)

____ (10) PW10 Desalting - Brackish

____ (11) PW11 Coagulation Pressure Filtration

---

* PW1, PW2, PW3, etc., are process codes used in the OU/USAID project.

3. Source

X (1) River or stream

____ (2) Lake or impoundment

____ (3) Wells

____ (4) Sea or brackish

Treatment capacity of the plant (4)

50 l/s

metric unit

Sub-treatment methods used

4. Settling

____ (1) Plain sedimentation

X (2) Coagulation

____ (3) Tube or plate

____ (4) Upflow

____ (5) Coagulation material

X a. Al_2SO_4 and lime

____ b. $FeCl_3$

____ c. Polymer

____ d. Other

____ (6) Approximate design criteria used

	British Unit		Metric Unit
a.	Loading rate (Q/A)		
____	(a) Less than 500 gpd/ft^2	or	X (a) Less than 20 m/day
____	(b) 500 - 1,000	or	____ (b) 20 - 40
____	(c) Greater than 1,000	or	____ (c) Greater than 40

b. Detention time in hours

____ (a) ½ - 1

____ (b) 1 - 2

X (c) 2 - 4

____ (d) Greater than 4

c. Mixing: Mean velocity gradient, G

____ (a) 10 - 25

X (b) 25 - 50

____ (c) 50 - 75

d. Design capacity

British Unit		Metric Unit
____ (a) Less than 0.5 MGD	or	____ (a) Less than 0.025 m^3/s
____ (b) 0.5 - 5	or	X (b) 0.025 - 0.25
____ (c) 5 - 20	or	____ (c) 0.25 - 1.0
____ (d) Greater than 20	or	____ (d) Greater than 1.0

e. Stirring and/or mixing devices

X (a) Baffle

____ (b) Paddle

____ (c) Air

5. Filters

(1) Rate of flow

____a. Slow (0.05 to 0.10 gpm/ft^2 or 0.002 to 0.004 M/min)

X b. Rapid (approximately 2 gpm/ft^2 or 0.08 M/min)

____c. Greater than 2 gpm/ft^2 or 0.08 M/min

(2) Filter media

X a. Sand

____b. Multi-media

____c. Other

(3) Hydraulic mean size (10% by weight on sieve analysis)

X a. 0.2 mm

___ b. 0.6 mm

___ c. 1.0 mm

(4) Depth of media

British Unit		Metric Unit
___ a. Less than 40 inches	or	___ a. Less than 100 cm
___ b. 40 - 50	or	X b. 100 - 125
___ c. Greater than 50	or	___ c. Greater than 125

(5) Controls for backwash

X a. Mechanical or hydraulic

___ b. Simplified or operator controlled

(6) Direction of flow through filter

___ a. Upward

X b. Down flow

___ c. Both

(7) Control of Filtration rate

X a. Rate controller

___ b. Declining head

___ c. Siphon head

___ d. Other (specify) _____

6. Disinfection Method

X (1) Cl_2

___ (2) Lime

___ (3) Ultra-violet

___ (4) Ozone

APPENDIX 4.E

OPERATIONAL DATA

Please check the appropriate category related to the operation of the treatment plant.

1. Type of treatment plant.

 X (1) Water treatment

 ____ (2) Sewage treatment

OPERATORS

2. Availability of trained or skilled operators

 ____ (1) Easy to find

 X (2) Difficult to find

3. Existance of a standard or system for evaluating the qualifications of operators

 X (1) Yes

 ____ (2) No

4. Short course or other training programs for operators available

 X (1) Yes

 ____ (2) No

5. Reason for leaving employment at the treatment plant

 X (1) Better job

 ____ (2) Discharged

 ____ (3) Others (specify) _____

6. Average age of operators

 ____ (1) Less than 20 years old

 ____ (2) 20 - 30

 X (3) 30 - 40

 ____ (4) Older than 40

7. Quality of operators

____ (1) Not dependable
____ (2) Fair
_X_ (3) Good
____ (4) Excellent

CHEMICALS

8. Location (distance) for obtaining chemicals

____ (1) Local
_X_ (2) In-country
____ (3) Out-of-country

9. Availability of chemicals

____ (1) Easy to obtain locally
____ (2) Difficult to obtain locally
_X_ (3) Easy to obtain non-locally
____ (4) Difficult ot obtain non-locally

MACHINERY, PARTS, ETC.

10. Cause of machinery breakdown

____ (1) Operator error
____ (2) Product failure
____ (3) Others (specify) _____

11. Time interval for replacement of machinery or parts

____ (1) Too often as compared to the expected life of the item
____ (2) Not as often as compared to the expected life of the item
_X_ (3) Routine replacement

12. Delivery time of ordered parts

____ (1) Less than 1 week
____ (2) Between 1 and 4 weeks
_X_ (3) Between 1 and 6 months (in the country)
_X_ (4) Between 6 months and a year (out of the country)
____ (5) More than one year

13. Parts replaced are usually

__X__ (1) Ordered specially

____ (2) Off the shelf (common parts)

____ (3) Other (specify) _____

14. Repair of machinery

__X__ (1) Repaired locally

____ (2) Repaired in-country

____ (3) Repaired out-of-country

____ (4) No repair, replaced by new one

OPERATIONAL FAILURE (TECHNICAL)

15. Characteristic of raw water causing difficulty in treatment

____ (1) Turbidity

__X__ (2) Algae

____ (3) Other (specify) _____

16. Operational failure due to the following

____ (1) Storage

____ (2) Pumps

____ (3) Lack of Water

____ (4) Other (specify) Change of water quality

17. Failure due to the designed process

____ (1) Under-designed

____ (2) Improper design

____ (3) Adequate design

____ (4) Over loading

____ (5) Other (specify) The design is adequate and does not cause failures

SUPERVISORY CONTROL

18. Inspection of plant

X (1) Regular inspection

X a. Local

X b. Regional

X c. National

___ d. Other (specify) _____

___ (2) Active supervision at the plant

___ (3) Other (specify) _____

19. Laboratory location

X (1) At plant

X (2) Regional

___ (3) Central

___ (4) Mobile

___ (5) Non-existant

PROBLEMS NOT SOLVED BY PRESENT FACILITY

20. Technical problems of effluent

___ (1) Odor of water

___ (2) Taste of water

___ (3) Color of water

X (4) None

___ (5) Other (specify) _____

21. Monetary problems in operations

___ (1) Extreme difficulty in financing

X (2) Moderate difficulty in financing

(3) No difficulty in financing

22. Operational cost and capacity

(1) Capacity in million gallon/day or in m^3/day.

3,024	m^3/day	(each filter)
Amount	Unit	

(2) Total annual operational cost

180,000.00	Cruzeiros
Amount	Currency Unit

(3) Annual operational cost for personnel (payroll)

59,600.00	Cruzeiros
Amount	Currency Unit

23. Administrative problems

____ (1) Personnel

____ (2) Managerial

____ (3) Supervisory

_X_ (4) Operators

____ (5) None

____ (6) Others (specify) _____

APPENDIX 4.F

FACILITY CONSTRUCTION COST DATA

Please answer the following related to the construction cost of the project. If there are more than one facility involved, please fill in ONE questionnaire FOR EACH.

1. Type of the treatment: check whether it is water or sewage treatment.

   X Water treatment

   Type of the process: flocculation, sedimentation and upflow filtration.

   ____ Sewage treatment

   Type of the process: _____

2. (1) Year the plant was built 1968 - 1973

   (2) Population served by the plant 25,000 inhabitants

   (3) Construction cost in U.S. dollars $_____
   or construction cost in your country currency 646,000 (amount) cruzeiros (currency)

   Only for the contact unit (new water treatment plant)

3. Percent of total cost for labor

   ____ (1) Less than 10%

   ____ (2) 10% - 25%

   X (3) 25% - 50%

   ____ (4) 50% - 75%

   ____ (5) 75% - 90%

   ____ (6) Greater than 90%

4. Percent of total cost for material

   ____ (1) Less than 10%

   ____ (2) 10% - 25%

   X (3) 25% - 50%

   ____ (4) 50% - 75%

   ____ (5) 75% - 90%

   (6) Greater than 90%

5. Percent of total cost for engineering fee

____ (1) Less than 2%
____ (2) 2% - 4%
____ (3) 4% - 6%
__X__ (4) 6% - 10%
____ (5) Greater than 10%

6. Percent of the total labor cost spent for skilled labor

__X__ (1) Less than 25%
____ (2) 25% - 50%
____ (3) 50% - 75%
____ (4) Greater than 75%

7. Approximate daily wage for unskilled labor in your country's currency

15 (amount) cruzeiros (currency unit)

or, if available, please check the category of U. S. dollar equivalent shown below

____ (1) Less than $1/day
__X__ (2) $1 - $3/day
____ (3) $3 - $5/day
____ (4) $5 - $10/day
____ (5) $10 - $15/day
____ (6) More than $15/day

8. Approximate daily wage for skilled labor in your country's currency

50 (amount) cruzeiros (currency unit)

or, if available, please check the category of U. S. dollar equivalent shown below

____ (1) Less than U. S. $2/day
____ (2) $2 - $5/day
__X__ (3) $5 - $10/day
____ (4) $10 - $15/day
____ (5) $15 - $20/day
____ (6) More than $20/day

9. Of the total cost spent for material, what percent of material was found in-country?

____ (1) Less than 10%

____ (2) 10% - 25%

____ (3) 25% - 50%

____ (4) 50% - 75%

_X_ (5) 75% - 100%

APPENDIX TO CHAPTER 5

DATA IDENTIFICATION

FACILITY TITLE:

ESTACAO DE TRATAMENTO DE AGUA DE PRUDENTOPOLIS

RESPONDENT:

Name: S.A.N.E.P.A.R.

Title: CIA. DE SANEAMENTO DO PARANA

Address: Rua Engenheiros Rebouças, 1376

OWNERSHIP OF THE FACILITY:

COMPANHIA DE SANEAMENTO DO PARANA - SANEPAR

Owner's Address: Same as above

NAME OF COMMUNITY TO BE SERVED BY THE FACILITY:

Town or City: Prudentópolis

State or Province: Paraná

Country: Brazil

APPENDIX 5.A

DEMOGRAPHIC AND TECHNOLOGY DATA

Please check the appropriate category in each question. If exact figures are not available, give the closest estimate.

POPULATION

1. Present Population - The figure or estimate of the present population should reflect the number of inhabitants that the proposed water or wastewater treatment facility is going to serve.

____ (1) Between 500 and 2,500 people

_X_ (2) 2,500 - 15,000 (7,500 inhabitants)

____ (3) 15,000 - 50,000

____ (4) 50,000 - 100,000

____ (5) Other (specify) ___

For each question from number 2 to number 9, if local or site figure is not available, please use national figure and also indicate whether it is national or local figure.

2. Annual population growth rate

[ ] National [X] Local

_X_ (1) Less than 1%

____ (2) 1% - 3%

____ (3) 3% - 5%

____ (4) 5% - 10%

____ (5) 10% - 20%

____ (6) Greater than 20%

3. Life expectancy of population in years

[ ] National [X] Local

____ (1) Less than 40 years old

X (2) 40 - 50

____ (3) 50 - 60

____ (4) 60+

4. Birth Rate: The average number of newborn each year per 1,000 population.

[ ] National [X] Local

____ (1) Less than 10

X (2) 10 - 30 Information not provided by respondent, estimated in CEPIS, figures will be verified.

____ (3) 30 - 50

____ (4) 50 - 100

____ (5) 100 - 200

____ (6) More than 200

5. Infant (under one year of age) mortality rate per 1,000 population each year.

[ ] National [X] Local

____ (1) Greater than 100

____ (2) 50 - 100

____ (3) 30 - 50

X (4) 10 - 30

____ (5) Less than 10

6. Survival Rate: The percentage of inhabitants expected to survive during any given year.

[ ] National [X] Local

____ (1) Less than 80%

X (2) 80% - 90%

____ (3) 90% - 95%

____ (4) 95% - 97%

____ (5) 97% - 99%

____ (6) More than 99%

7. % of Emigrants: The percentages of the total population that leave the area and begin to live in another community each year.

[ ] National [X] Local

X (1) Less than 1%

____ (2) 1% - 3%

____ (3) 3% - 5%

____ (4) 5% - 10%

____ (5) 10% - 20%

____ (6) Greater than 20%

8. % of Immigrants: The percentages of the total population that have just arrived to live in the community on a permanent basis each year.

[ ] National [X] Local

X (1) Less than 1%

____ (2) 1% - 3%

____ (3) 3% - 5%

____ (4) 5% - 10%

____ (5) 10% - 20%

____ (6) Greater than 20%

9. Calories intake per day per person

[ ] National [X] Local

____ (1) Less than 1,000

____ (2) 1,000 - 1,500

X (3) 1,500 - 2,000 - Information not provided by respondent. estimated in CEPIS

____ (4) Greater than 2,000

TECHNOLOGY

10. Level of water treatment technology development in the local community.

Type of Water Supply System	% of Population Being Served			
	0-25%	25-50%	50-75%	75-100%
(1) Central village or street pump	X			
(2) Piped water supply to houses		X		

11. Level of sewage treatment technology development in the local community.

Type of System	% of Population Being Served			
	0-25%	25-50%	50-75%	75-100%
(1) Sewage collection system		X		
(2) Sewage treatment	X			

In the judgement of the respondent, which of the following most appropriately describes this project.

12. Technology Advancement

____ (1) Simply transfer of a process that had been successful elsewhere.

_X_ (2) An adaptation of another process but altered to be more suited to local characteristics.

____ (3) A unique process developed especially for the characteristics of this site.

13. Quality of Project for Research

_X_ (1) A breakthrough for enhancing the development of this country.

____ (2) An important feature for the local people but not significant to overall development of the country.

____ (3) Redundant, of little use to the people.

APPENDIX 5.B

SOCIO-ECONOMIC DATA

Check the appropriate category for the following.

1. Average level of education obtained for the community.

	Level	None	Primary	High School	Technical Institute	College
____	(1)	95%	4%	1%	0%	0%
____	(2)	70%	19%	7%	3%	1%
____	(3)	55%	22%	14%	6%	3%
X	(4)	9%	34%	42%	8%	7%

2. Average distribution of Labor Force in the community.

	Level	Unskilled	Semi-Skilled	Professional
____	(1)	97%	2%	1%
____	(2)	80%	16%	4%
____	(3)	61%	27%	12%
X	(4)	45%	30%	25%

3. Annual average income per family in your country currency.

1,300.00 (amount) dollars (unit)

If available, also check the approximated U. S. dollars equivalency of this amount shown in the following

____ (1) Less than $100

X (2) $100 - $1,000

____ (3) $1,000 - $3,000

____ (4) Greater than $3,000

4. Among the highly skillful and technical workers (for example, engineer, chemist, etc.) what percentages of these are non-local or non-native people.

X (1) Less than 10%
___ (2) 10% - 25%
___ (3) 25% - 50%
___ (4) 50% - 75%
___ (5) 75% - 100%

5. Are the primary and secondary schools operated by voluntary or missionary organizations?

X (1) Yes x (2) No

6. What is the highest grade offered by local schools on a regular basis? (Circle one)

1 2 3 4 5 6 (7) 8 9 10 11 12 12+

7. If the number selected in #8 above is less than 12, how far away is the nearest high school offering the 12th grade?

X (1) Less than 10 miles (or less than 16 kilometers)
___ (2) 10 - 30 miles (or 16 - 48 kilometers)
___ (3) 30 - 50 miles (or 48 - 60 kilometers)
___ (4) Greater than 50 miles. (greater than 60 kilometers)
___ (5) Other (specify) _____

8. Are there any technical or vocational schools in the community?

X (1) Yes ___ (2) No

9. Has the community achieved compulsory primary education of at least six years?

X (1) Yes ___ (2) No

10. Are there any formal in-service training programs by either the government or local industry for their employees?

__X__ (1) Yes ____ (2) No

11. Is there a college or university in the community?

____ (1) Yes __X__ (2) No

12. Does the university have a chemistry department or laboratory?

____ (1) Yes ____ (2) No

13. How do you rate the ability of the community to finance a water and sewage treatment project?

____ (1) Unable to repay; the project is a pure charity scheme because the beneficiaries are poor.

__X__ (2) Limited ability to repay; however, the social benefits exceed the social costs.

____ (3) Repayment prospects are good; the beneficiaries have comparatively high incomes.

14. Is unemployment widespread?

__X__ (1) Yes ____ (2) No

If available, give the percentage of unemployment among the total population.

_____20____% of unemployment

15. Are advisory services widely available to farmers for community development or for other programs designed to upgrade the skills and enlist the participation of the masses?

__X__ (1) Yes ____ (2) No

16. Do most college or university students of the community receive their education in neighboring communities, neighboring countries, or other foreign countries?

X (2) Yes ____ (2) No

17. The level of technology available can generally be classified as

X (1) Hand tools only
____ (2) Mechanical tools (i.e., gasoline powered equipment)
____ (3) Chemical products (fertilizers, chlorine)
____ (4) Electronic technology

18. Does the government dominate the labor market?

____ (1) Yes X (2) No

19. Are public employment services readily available?

____ (1) Yes X (2) No

Questions 20 - 23 relate to the availability of materials and equipment. Check those items that are never available in the Community.

20. Operation: Which of the following are never available in the local community.

X (1) Meters
____ (2) Lawn mowers
X (3) Blowers
X (4) Recording devices
X (5) Laboratory equipment
X (6) Portable power plant
____ (7) Motors (small)
X (8) Pumps (small)

21. Process: Which of the following are never available in the local community.

____ (1) Pipe (clay, steel, cement, plastic, copper, etc.)
____ (2) Pipe fittings
____ (3) Paint
X (4) Valves
____ (5) Tanks
X (6) Gauges
X (7) Heat exchangers

22. Operation and Maintenance: Which of the following are never available in the local community.

____ (1) Silica sand
____ (2) Graded gravel
____ (3) Clean water
____ (4) Gasoline

23. Chemicals: Which of the following are never available in the local community.

X (1) Al_2SO_4 (aluminum sulfate)
X (2) $FeCl_2$ (ferric chloride)
____ (3) Activated charcoal
____ (4) Lime
____ (5) Soda ash
X (6) Chlorine
X (7) Ozone
X (8) Laboratory chemicals

24. Major Water Source (check appropriate category)

X (1) River or stream
____ (2) Lake or impoundment
____ (3) Wells
____ (4) Sea or brackish

25. Approximate per capita water demand (daily)

(1) Current demands 120 in l/h/day (units)

(2) 10 year projection: 150

26. Is groundwater available?

____ (1) Yes ____ (2) No

27. Are wells already drilled? It has not been studied

____ (1) Yes ____ (2) No

28. Is a central wastewater collection system in existence?

x (1) Yes ____ (2) No

29. Is the following wastewater data available? Please fill in the percentage of people in the community that are:

(1) Currently connected to the system 25 %

(2) To be connected within 5 years of the start of the project ____ %

(3) To be connected within 10 years ____ %

30. Are inoustrial and commercial concerns using the waste water system and if so, in what quantity? (in thousands of gallons)

(1) Currently 2%

(2) Within 5 years ____

(3) Within 10 years ____

APPENDIX 5.C

PROCESS DATA

Please supply the following data related to the treatment process of the project. If there are more than one treatment plant, please fill in ONE data sheet FOR EACH PLANT.

For Water treatment process, please fill in PART I; and for Sewage treatment, fill in PART II. Indicate the data either in metric unit or in British unit.

PART I: WATER TREATMENT PROCESS

1. Type of Process: Coagulation, sedimentation, filtration and disinfection

2. Please check the appropriate water treatment process or processes in the following which fit the one(s) used at your treatment plant.

____ (1) PW1* Drilled Well

____ (2) PW2 Pre-Treatment

____ (3) PW3 Slow Sand Filtration

____ (4) PW4 Rapid Sand Filter - Conventional

X (5) PW5 Rapid Sand Filter - Advanced

____ (6) PW6 Softening

____ (7) PW7 Disinfection

____ (8) PW8 Taste-Odor - Fe, Mn

____ (9) PW9 Desalting - Salt (Sea water)

____ (10) PW10 Desalting - Brackish

____ (11) PW11 Coagulation Pressure Filtration

---

* PW1, PW2, PW3, etc., are process codes used in the OU/USAID project.

3. Source

__X__ (1) River or stream

____ (2) Lake or impoundment

____ (3) Wells

____ (4) Sea or brackish

Treatment capacity of the plant (4)

2,000 m^3/day (23 l/s)
metric unit

Sub-treatment methods used

4. Settling

____ (1) Plain sedimentation

__X__ (2) Coagulation

__X__ (3) Tube or plate

____ (4) Upflow

____ (5) Coagulation material

__X__ a. Al_2SO_4 and lime

____ b. $FeCl_3$

____ c. Polymer

____ d. Other

____ (6) Approximate design criteria used

British Unit		Metric Unit	
a. Loading rate (Q/A)			
____ (a) Less than 500 gpd/ft^2	or	____ (a) Less than 20 m/day	
____ (b) 500 - 1,000	or	____ (b) 20 - 40	
____ (c) Greater than 1,000	or	__X__ (c) Greater than 40	125 m/day

b. Detention time in hours

__X__ (a) ½ - 1

____ (b) 1 - 2

____ (c) 2 - 4

____ (d) Greater than 4

c. Mixing: Mean velocity gradient, G

X (a) 10 - 25
X (b) 25 - 50
X (c) 50 - 75

For different sections of mechanically agitated floculator.

d. Design capacity

British Unit		Metric Unit
____ (a) Less than 0.5 MGD	or	____ (a) Less than 0.025 m^3/s
____ (b) 0.5 - 5	or	____ (b) 0.025 - 0.25
____ (c) 5 - 20	or	____ (c) 0.25 - 1.0
____ (d) Greater than 20	or	____ (d) Greater than 1.0

e. Stirring and/or mixing devices

____ (a) Baffle

X (b) Paddle

____ (c) Air

5. Filters

(1) Rate c_ ____

____a. Slow (0.05 to 0.10 gpm/ft^2 or 0.002 to 0.004 M/min)

____b. Rapid (approximately 2 gpm/ft^2 or 0.08 M/min)

X c. Greater than 2 gpm/ft^2 or 0.08 M/min

(2) Filter media

____a. Sand

X b. Multi-media

____c. Other

(3) Hydraulic mean size (10% by weight on sieve analysis)

__X__ a. ~~0.2 mm~~ Sand: 0.50

__X__ b. ~~0.6 mm~~ Anthracite: 0.90

____ c. 1.0 mm

(4) Depth of media

British Unit		Metric Unit	
____ a. Less than 40 inches	or	__X__ a. Less than 100 cm	25 cms.
____ b. 40 - 50	or	__X__ b. 100 - 125	40 cms.
____ c. Greater than 50	or	____ c. Greater than 125	

(5) Controls for backwash

____ a. Mechanical or hydraulic __X__

____ b. Simplified or operator controlled

(6) Direction of flow through filter

____ a. Upward

__X__ b. Down flow

____ c. Both

(7) Control of Filtration rate

____ a. Rate controller

__X__ b. Declining head

____ c. Siphon head

____ d. Other (specify) _

6. Disinfection Method

__X__ (1) Cl_2

____ (2) Lime

____ (3) Ultra-violet

____ (4) Ozone

____ (5) Other

APPENDIX 5.E

OPERATIONAL DATA

Please check the appropriate category related to the operation of the treatment plant.

1. Type of treatment plant.

 X (1) Water treatment

 ____ (2) Sewage treatment

OPERATORS

2. Availability of trained or skilled operators

 ____ (1) Easy to find

 X (2) Difficult to find

3. Existance of a standard or system for evaluating the qualifications of operators

 X (1) Yes

 ____ (2) No

4. Short course or other training programs for operators available

 X (1) Yes

 ____ (2) No

5. Reason for leaving employment at the treatment plant

 X (1) Better job

 ____ (2) Discharged

 ____ (3) Others (specify)

6. Average age of operators

 ____ (1) Less than 20 years old

 X (2) 20 - 30

 ____ (3) 30 - 40

 ____ (4) Older than 40

7. Quality of operators

____ (1) Not dependable
X (2) Fair
____ (3) Good
____ (4) Excellent

CHEMICALS

8. Location (distance) for obtaining chemicals

____ (1) Local
X (2) In-country
____ (3) Out-of-country

9. Availability of chemicals

____ (1) Easy to obtain locally
____ (2) Difficult to obtain locally
X (3) Easy to obtain non-locally
____ (4) Difficult ot obtain non-locally

MACHINERY, PARTS, ETC.

10. Cause of machinery breakdown

____ (1) Operator error
X (2) Product failure
____ (3) Others (specify) ____

11. Time interval for replacement of machinery or parts

____ (1) Too often as compared to the expected life of the item
____ (2) Not as often as compared to the expected life of the item
____ (3) Routine replacement
There is no experience becaus the plant has recently been built.

12. Delivery time of ordered parts

____ (1) Less than 1 week
X (2) Between 1 and 4 weeks
____ (3) Between 1 and 6 months
____ (4) Between 6 months and a year
____ (5) More than one year

13. Parts replaced are usually

____ (1) Ordered specially

_X_ (2) Off the shelf (common parts)

____ (3) Other (specify) ____

14. Repair of machinery

_X_ (1) Repaired locally

____ (2) Repaired in-country

____ (3) Repaired out-of-country

____ (4) No repair, replaced by new one

OPERATIONAL FAILURE (TECHNICAL)

15. Characteristic of raw water causing difficulty in treatment

____ (1) Turbidity

_X_ (2) Algae

____ (3) Other (specify) Personnel

16. Operational failure due to the following

____ (1) Storage

_X_ (2) Pumps

____ (3) Lack of Water

____ (4) Other (specify) ____

17. Failure due to the designed process

____ (1) Under-designed

____ (2) Improper design

____ (3) Adequate design

____ (4) Over loading

____ (5) Other (specify) There are not failures due to the designed process

SUPERVISORY CONTROL

18. Inspection of plant

X (1) Regular inspection

____ a. Local

X b. Regional

____ c. National

____ d. Other (specify) _____

____ (2) Active supervision at the plant

____ (3) Other (specify) _____

19. Laboratory location

X (1) At plant

____ (2) Regional

____ (3) Central

____ (4) Mobile

____ (5) Non-existant

PROBLEMS NOT SOLVED BY PRESENT FACILITY

20. Technical problems of effluent

____ (1) Odor of water

____ (2) Taste of water

____ (3) Color of water

X (4) None

____ (5) Other (specify) _

21. Monetary problems in operations

____ (1) Extreme difficulty in financing

X (2) Moderate difficulty in financing

____ (3) No difficulty in financing

22. Operational cost and capacity

(1) Capacity in million gallon/day or in m^3/day.

2,000	m^3/day
Amount	Unit

(2) Total annual operational cost

4,905.00	dollars
Amount	Currency Unit

(3) Annual operational cost for personnel (payroll)

3,924.00	dollars
Amount	Currency Unit

23. Administrative problems

X (1) Personnel

____ (2) Managerial

____ (3) Supervisory

____ (4) Operators

____ (5) None

____ (6) Others (specify) ____

APPENDIX 5.F

FACILITY CONSTRUCTION COST DATA

Please answer the following related to the construction cost of the project If there are more than one facility involved, please fill in ONE questionnaire FOR EACH.

1. Type of the treatment: check whether it is water or sewage treatment.

____ Water treatment

Type of the process: Coagulation, sedimentation and high rate filtrati and disinfection

____ Sewage treatment

Type of the process: ____

2. (1) Year the plant was built 1973

(2) Population served by the plant at present: 5000; in the future 12,000

(3) Construction cost in U.S. dollars $ 57,726.00 (actual); $64,000.00(budgete or construction cost in your country currency 300,480.00 cruzeiros
amount currency

3. Percent of total cost for labor

____ (1) Less than 10%

____ (2) 10% - 25%

X (3) 25% - 50%

____ (4) 50% - 75%

____ (5) 75% - 90%

____ (6) Greater than 90%

4. Percent of total cost for material

____ (1) Less than 10%

____ (2) 10% - 25%

____ (3) 25% - 50%

X (4) 50% - 75%

____ (5) 75% - 90%

____ (6) Greater than 90%

5. Percent of total cost for engineering fee

____ (1) Less than 2%
____ (2) 2% - 4%
_x_ (3) 4% - 6%
____ (4) 6% - 10%
____ (5) Greater than 10%

6. Percent of the total labor cost spent for skilled labor

_X_ (1) Less than 25%
____ (2) 25% - 50%
____ (3) 50% - 75%
____ (4) Greater than 75%

7. Approximate daily wage for unskilled labor in your country's currency

16.80 (amount) cruzeiros (currency unit)

or, if available, please check the category of U. S. dollar equivalent shown below

____ (1) Less than $1/day
_x_ (2) $1 - $3/day
____ (3) $3 - $5/day
____ (4) $5 - $10/day
____ (5) $10 - $15/day
____ (6) More than $15/day

8. Approximate daily wage for skilled labor in your country's currency

26.00 (amount) cruzeiros (currency unit)

or, if available, please check the category of U. S. dollar equivalent shown below

____ (1) Less than U. S. $2/day
_X_ (2) $2 - $5/day
____ (3) $5 - $10/day
____ (4) $10 - $15/day
____ (5) $15 - $20/day
____ (6) More than $20/day

9. Of the total cost spent for material, what percent of material was found in-country?

____ (1) Less than 10%

____ (2) 10% - 25%

____ (3) 25% - 50%

____ (4) 50% - 75%

_X_ (5) 75% - 100%

APPENDIX TO CHAPTER 6

DATA IDENTIFICATION

FACILITY TITLE:

PLANTA DE TRATAMIENTO DE AGUA POTABLE

RESPONDENT:

Name: EMPRESA PUBLICA MUNICIPAL DE TELEFONOS, AGUA POTABLE Y ALCANTARILLADO

Title: E.T.A.P.A.

Address: Casilla 297 - Cuenca

OWNERSHIP OF THE FACILITY:

E.T.A.P.A.

Owner's Address: Casilla 297, Cuenca, Ecuado

NAME OF COMMUNITY TO BE SERVED BY THE FACILITY:

Town or City: Cuenca

State or Province: Azuay

Country: Ecuador

APPENDIX 6.A

DEMOGRAPHIC AND TECHNOLOGY DATA

Please check the appropriate category in each question. If exact figures are not available, give the closest estimate.

POPULATION

1. Present Population - The figure or estimate of the present population should reflect the number of inhabitants that the proposed water or wastewater treatment facility is going to serve.

____ (1) Between 500 and 2,500 people

____ (2) 2,500 - 15,000

____ (3) 15,000 - 50,000

____ (4) 50,000 - 100,000

X (5) Other (specify) 110,700 Present population (1975)
Design population: 190,000 - 230,000

For each question from number 2 to number 9, if local or site figure is not available, please use national figure and also indicate whether it is national or local figure.

2. Annual population growth rate

☐ National ☒ Local

____ (1) Less than 1%

____ (2) 1% - 3%

X (3) 3% - 5%

____ (4) 5% - 10%

____ (5) 10% - 20%

____ (6) Greater than 20%

3. Life expectancy of population in years -

[X] National [ ] Local

____ (1) Less than 40 years old

____ (2) 40 - 50

X (3) 50 - 60

____ (4) 60+

4. Birth Rate: The average number of newborn each year per 1,000 population.

[ ] National [ ] Local

____ (1) Less than 10

____ (2) 10 - 30

X (3) 30 - 50

____ (4) 50 - 100

____ (5) 100 - 200

____ (6) More than 200

5. Infant (under one year of age) mortality rate per 1,000 population each year.

[ ] National [X] Local

____ (1) Greater than 100

____ (2) 50 - 100

____ (3) 30 - 50

X (4) 10 - 30

____ (5) Less than 10

6. Survival Rate: The percentage of inhabitants expected to survive during any given year.

[ ] National [X] Local

____ (1) Less than 80%

____ (2) 80% - 90%

____ (3) 90% - 95%

X (4) 95% - 97%

____ (5) 97% - 99%

____ (6) More than 99%

7. % of Emigrants: The percentages of the total population that leave the area and begin to live in another community each year.

[ ] National [X] Local

____ (1) Less than 1%

____ (2) 1% - 3%

X (3) 3% - 5%

____ (4) 5% - 10%

____ (5) 10% - 20%

____ (6) Greater than 20%

8. % of Immigrants: The percentages of the total population that have just arrived to live in the community on a permanent basis each year.

[ ] National [X] Local

____ (1) Less than 1%

____ (2) 1% - 3%

X (3) 3% - 5%

____ (4) 5% - 10%

____ (5) 10% - 20%

____ (6) Greater than 20%

9. Calories intake per day per person

[ ] National [x] Local

____ (1) Less than 1,000

____ (2) 1,000 - 1,500

X (3) 1,500 - 2,000

____ (4) Greater than 2,000

TECHNOLOGY

10. Level of water treatment technology development in the local community.

Type of Water Supply System	% of Population Being Served			
	0-25%	25-50%	50-75%	75-100%
(1) Central village or street pump	X			
(2) Piped water supply to houses				X

11. Level of sewage treatment technology development in the local community.

Type of System	% of Population Being Served			
	0-25%	25-50%	50-75%	75-100%
(1) Sewage collection system			X	
(2) Sewage treatment	0%			

Information not provi
by respondent, estima
in CEPIS

In the judgement of the respondent, which of the following most appropriately describes this project.

12. Technology Advancement

____ (1) Simply transfer of a process that had been successful elsewhere.

_X_ (2) An adaptation of another process but altered to be more suited to local characteristics.

____ (3) A unique process developed especially for the characteristics of this site.

13. Quality of Project for Research

_X_ (1) A breakthrough for enhancing the development of this country.

____ (2) An important feature for the local people but not significant to overall development of the country.

____ (3) Redundant, of little use to the people.

APPENDIX 6.B

SOCIO-ECONOMIC DATA

Check the appropriate category for the following.

1. Average level of education obtained for the community.

	Level	None	Primary	High School	Technical Institute	College
____	(1)	95%	4%	1%	0%	0%
____	(2)	70%	19%	7%	3%	1%
____	(3)	55%	22%	14%	6%	3%
X	(4)	9%	34%	42%	8%	7%
X		10.8%	57.7%	24.7%	2.0%	5.4%

2. Average distribution of Labor Force in the community.

	Level	Unskilled	Semi-Skilled	Professional
____	(1)	97%	2%	1%
X	(2)	80%	16%	4%
____	(3)	61%	27%	12%
____	(4)	45%	30%	25%

3. Annual average income per family in your country currency.

30,000 (amount) sucres (unit)

If available, also check the approximated U. S. dollars equivalency of this amount shown in the following

____ (1) Less than $100

____ (2) $100 - $1,000

X (3) $1,000 - $3,000

____ (4) Greater than $3,000

4. Among the highly skillful and technical workers (for example, engineer, chemist, etc.) what percentages of these are non-local or non-native people.

____ (1) Less than 10%
____ (2) 10% - 25%
____ (3) 25% - 50%
____ (4) 50% - 75%
_X_ (5) 75% - 100% Information provided by respondent, figures are uncertain and will be verified.

5. Are the primary and secondary schools operated by voluntary or missionary organizations?

____ (1) Yes _X_ (2) No

6. What is the highest grade offered by local schools on a regular basis? (Circle one)

1 2 3 4 5 6 7 8 9 10 11 (12) 12+

7. If the number selected in #8 above is less than 12, how far away is the nearest high school offering the 12th grade?

____ (1) Less than 10 miles (or less than 16 kilometers)
____ (2) 10 - 30 miles (or 16 - 48 kilometers)
____ (3) 30 - 50 miles (or 48 - 60 kilometers)
____ (4) Greater than 50 miles. (greater than 60 kilometers)
____ (5) Other (specify) _____

8. Are there any technical or vocational schools in the community?

_X_ (1) Yes ____ (2) No

9. Has the community achieved compulsory primary education of at least six years?

_X_ (1) Yes ____ (2) No

10. Are there any formal in-service training programs by either the government or local industry for their employees?

X (1) Yes ____ (2) No

11. Is there a college or university in the community?

X (1) Yes ____ (2) No

12. Does the university have a chemistry department or laboratory?

X (1) Yes ____ (2) No

13. How do you rate the ability of the community to finance a water and sewage treatment project?

____ (1) Unable to repay; the project is a pure charity scheme because the beneficiaries are poor.

X (2) Limited ability to repay; however, the social benefits exceed the social costs.

____ (3) Repayment prospects are good; the beneficiaries have comparatively high incomes.

14. Is unemployment widespread?

____ (1) Yes X (2) No

If available, give the percentage of unemployment among the total population.

< 3 % of unemployment

15. Are advisory services widely available to farmers for community development or for other programs designed to upgrade the skills and enlist the participation of the masses?

X (1) Yes ____ (2) No

16. Do most college or university students of the community receive their education in neighboring communities, neighboring countries, or other foreign countries? Depending on the area of study

____ (2) Yes X (2) No

17. The level of technology available can generally be classified as

____ (1) Hand tools only
X (2) Mechanical tools (i.e., gasoline powered equipment)
____ (3) Chemical products (fertilizers, chlorine)
____ (4) Electronic technology

18. Does the government dominate the labor market?

____ (1) Yes X (2) No

19. Are public employment services readily available?

____ (1) Yes X (2) No

Questions 20 - 23 relate to the availability of materials and equipment. Check those items that are never available in the Community.

20. Operation: Which of the following are never available in the local community.

____ (1) Meters
____ (2) Lawn mowers
____ (3) Blowers
X (4) Recording devices Available in Quito or Guayaquil in a week
X (5) Laboratory equipment
____ (6) Portable power plant
____ (7) Motors
____ (8) Pumps

21. Process: Which of the following are never available in the local community.

____ (1) Pipe (clay, steel, cement, plastic, copper, etc.,
____ (2) Pipe fittings
____ (3) Paint
X (4) Valves (imported)
____ (5) Tanks
X (6) Gauges (imported)
X (7) Heat exchangers

22. Operation and Maintenance: Which of the following are never available in the local community.

____ (1) Silica sand
____ (2) Graded gravel
____ (3) Clean water
____ (4) Gasoline

23. Chemicals: Which of the following are never available in the local community.

X (1) Al_2SO_4 (aluminum sulfate) (imported)
X (2) $FeCl_2$ (ferric chloride) or $FeCl_3$ imported
X (3) Activated charcoal (imported)
____ (4) Lime
____ (5) Soda ash
X (6) Chlorine (imported)
X (7) Ozone
____ (8) Laboratory chemicals
Some are available locally, others in Quito or Guayaquil and others are imported.

24. Major Water Source (check appropriate category)

X (1) River or stream
____ (2) Lake or impoundment
____ (3) Wells
____ (4) Sea or brackish

25. Approximate per capita water demand (daily)

(1) Current demands 235 in l/H/day (units)

(2) 10 year projection: 220 l/inhabitants/day

Program for water losses control and increase the number of meter.

26. Is groundwater available?

___ (1) Yes X (2) No There is groundwater not very deep but it is not used.

27. Are wells already drilled?

___ (1) Yes X (2) No

28. Is a central wastewater collection system in existence?

X (1) Yes ___ (2) No

29. Is the following wastewater data available? Please fill in the percentage of people in the community that are:

(1) Currently connected to the system 55 %

(2) To be connected within 5 years of the start of the project + 10 %

(3) To be connected within 10 years + 15 %

30. Are industrial and commercial concerns using the waste water system and if so, in what quantity? (in thousands of gallons)

(1) Currently Approximately 5% of the total belongs to the industries

(2) Within 5 years 2%

(3) Within 10 years --

APPENDIX 6.C

PROCESS DATA

Please supply the following data related to the treatment process of the project. If there are more than one treatment plant, please fill in ONE data sheet FOR EACH PLANT.

For Water treatment process, please fill in PART I; and for Sewage treatment, fill in PART II. Indicate the data either in metric unit or in British unit.

PART I: WATER TREATMENT PROCESS

1. Type of Process: Coagulation, floculation, sedimentation of high rate, filtration with double medium, disinfection with Chlorine

2. Please check the appropriate water treatment process or processes in the following which fit the one(s) used at your treatment plant.

____ (1) PW1* Drilled Well

____ (2) PW2 Pre-Treatment

____ (3) PW3 Slow Sand Filtration

____ (4) PW4 Rapid Sand Filter - Conventional

_X_ (5) PW5 Rapid Sand Filter - Advanced

____ (6) PW6 Softening

_X_ (7) PW7 Disinfection

____ (8) PW8 Taste-Odor - Fe, Mn

____ (9) PW9 Desalting - Salt (Sea water)

____ (10) PW10 Desalting - Brackish

____ (11) PW11 Coagulation Pressure Filtration

* PW1, PW2, PW3, etc., are process codes used in the OU/USAID project.

3. Source

X (1) River or stream

___ (2) Lake or impoundment

___ (3) Wells

___ (4) Sea or brackish

Treatment capacity of the plant (4)

560 l/s (actual capacity)

metric unit

860 l/s (future capacity)

Sub-treatment methods used

4. Settling

___ (1) Plain sedimentation

___ (2) Coagulation

X (3) Tube or plate

___ (4) Upflow

___ (5) Coagulation material

X a. Al_2SO_4 and lime

___ b. $FeCl_3$

___ c. Polymer

___ d. Other

___ (6) Approximate design criteria used

British Unit		Metric Unit
a. Loading rate (Q/A)		
___ (a) Less than 500 gpd/ft^2	or	___ (a) Less than 20 m/day
___ (b) 500 - 1,000	or	___ (b) 20 - 40
___ (c) Greater than 1,000	or	X (c) Greater than 40

b. Detention time in hours

X (a) ½ - 1 (6.17 minutes in the high-rate settling unit)

___ (b) 1 - 2

___ (c) 2 - 4

___ (d) Greater than 4

c. Mixing: Mean velocity gradient, G

____ (a) 10 - 25

__X__ (b) 25 - 50 35 - 25 - 15 s^{-1}

____ (c) 50 - 75

d. Design capacity

British Unit		Metric Unit	
____ (a) Less than 0.5 MGD	or	____ (a) Less than 0.025 m^3/s	
____ (b) 0.5 - 5	or	____ (b) 0.025 - 0.25	
____ (c) 5 - 20	or	__X__ (c) 0.25 - 1.0 (total of the plant)	
____ (d) Greater than 20	or	____ (d) Greater than 1.0	

e. Stirring and/or mixing devices

__X__ (a) Baffle

____ (b) Paddle

____ (c) Air

5. Filters

(1) Rate of flow

____a. Slow (0.05 to 0.10 gpm/ft^2 or 0.002 to 0.004 M/min)

____b. Rapid (approximately 2 gpm/ft^2 or 0.08 M/min)

__X__c. Greater than 2 gpm/ft^2 or 0.08 M/min

(2) Filter media

____a. Sand

__X__b. Multi-media

____c. Other

(3) Hydraulic mean size (10% by weight on sieve analysis)

0.5 a. ~~0.2 mm~~ Sand

0.8 b. ~~0.6 mm~~ Anthracite

____ c. 1.0 mm

(4) Depth of media

British Unit		Metric Unit
____ a. Less than 40 inches	or	X a. Less than 100 cm
____ b. 40 - 50	or	____ b. 100 - 125 40 cm
____ c. Greater than 50	or	____ c. Greater than 12

(5) Controls for backwash

____ a. Mechanical or hydraulic

X b. Simplified or operator controlled

(6) Direction of flow through filter

____ a. Upward

X b. Down flow

____ c. Both

(7) Control of Filtration rate

____ a. Rate controller

X b. Declining head

____ c. Siphon head

____ d. Other (specify) _

6. Disinfection Method

X (1) Cl_2

____ (2) Lime

____ (3) Ultra-violet

____ (4) Ozone

____ (5) Other ...

APPENDIX 6.E

OPERATIONAL DATA

Please check the appropriate category related to the operation of the treatment plant.

1. Type of treatment plant.

 X (1) Water treatment

 ____ (2) Sewage treatment

OPERATORS

2. Availability of trained or skilled operators

 ____ (1) Easy to find

 X (2) Difficult to find

3. Existance of a standard or system for evaluating the qualifications of operators

 ____ (1) Yes

 X (2) No

4. Short course or other training programs for operators available

 ____ (1) Yes

 X (2) No

5. Reason for leaving employment at the treatment plant

 ____ (1) Better job

 ____ (2) Discharged

 ____ (3) Others (specify) __

In the last ten years no operators have left.

6. Average age of operators

 ____ (1) Less than 20 years old

 ____ (2) 20 - 30

 X (3) 30 - 40

 ____ (4) Older than 40

7. Quality of operators

____ (1) Not dependable
X (2) Fair
____ (3) Good
____ (4) Excellent

CHEMICALS

8. Location (distance) for obtaining chemicals

____ (1) Local lime
____ (2) In-country
X (3) Out-of-country CL_2 y AL_2SO_4

9. Availability of chemicals

____ (1) Easy to obtain locally
____ (2) Difficult to obtain locally
X (3) Easy to obtain non-locally
____ (4) Difficult ot obtain non-locally

MACHINERY, PARTS, ETC.

10. Cause of machinery breakdown

____ (1) Operator error
____ (2) Product failure
____ (3) Others (specify) The time of use of the equipment

11. Time interval for replacement of machinery or parts

____ (1) Too often as compared to the expected life of the item
____ (2) Not as often as compared to the expected life of the item
X (3) Routine replacement

12. Delivery time of ordered parts

X (1) Less than 1 week
____ (2) Between 1 and 4 weeks
____ (3) Between 1 and 6 months
____ (4) Between 6 months and a year
____ (5) More than one year

13. Parts replaced are usually

____ (1) Ordered specially

_X_ (2) Off the shelf (common parts)

____ (3) Other (specify) _____

14. Repair of machinery

_X_ (1) Repaired locally

____ (2) Repaired in-country

____ (3) Repaired out-of-country

____ (4) No repair, replaced by new one

OPERATIONAL FAILURE (TECHNICAL)

15. Characteristic of raw water causing difficulty in treatment

____ (1) Turbidity

____ (2) Algae

_X_ (3) Other (specify) color

16. Operational failure due to the following

_X_ (1) Storage

____ (2) Pumps

____ (3) Lack of Water

____ (4) Other (specify) Deficiency in operation

17. Failure due to the designed process

____ (1) Under-designed

____ (2) Improper design

____ (3) Adequate design

____ (4) Over loading

____ (5) Other (specify) The design is adequate and does not cause failures

SUPERVISORY CONTROL

18. Inspection of plant

X (1) Regular inspection

X a. Local

___ b. Regional

___ c. National

___ d. Other (specify) _____

(2) Active supervision at the plant

___ (3) Other (specify) _____

19. Laboratory location

X (1) At plant

___ (2) Regional

___ (3) Central

___ (4) Mobile

___ (5) Non-existant

PROBLEMS NOT SOLVED BY PRESENT FACILITY

20. Technical problems of effluent

___ (1) Odor of water

___ (2) Taste of water

___ (3) Color of water

___ (4) None

___ (5) Other (specify) Corrosiveness because the plant is under construction

21. Monetary problems in operations

___ (1) Extreme difficulty in financing

X (2) Moderate difficulty in financing

___ (3) No difficulty in financing

22. Operational cost and capacity

(1) Capacity in million gallon/day or in m^3/day.

48,384	m^3/day
Amount	Unit

(2) Total annual operational cost

5'993,327.00	sucres
Amount	Currency Unit

(3) Annual operational cost for personnel (payroll)

1'476,220.00	sucres
Amount	Currency Unit

23. Administrative problems

____ (1) Personnel

____ (2) Managerial

____ (3) Supervisory

X (4) Operators

____ (5) None

____ (6) Others (specify) Training of personnel

APPENDIX 6.F

FACILITY CONSTRUCTION COST DATA

Please answer the following related to the construction cost of the project. If there are more than one facility involved, please fill in ONE questionnaire FOR EACH.

1. Type of the treatment: check whether it is water or sewage treatment.

____ Water treatment

Type of the process: Coagulation, flocculation, sedimentation, rapid filtration and chlorination

____ Sewage treatment

Type of the process: ___

2. (1) Year the plant was built 1958 modified in 1975

(2) Population served by the plant 80,000 inhabitants (presently)

(3) Construction cost in U.S. dollars $ 560,000.00

or construction cost in your country currency 14'007,373 (amount) Sucres (currency)

The plant is under construction.

3. Percent of total cost for labor

____ (1) Less than 10%

X (2) 10% - 25%

____ (3) 25% - 50%

____ (4) 50% - 75%

____ (5) 75% - 90%

____ (6) Greater than 90%

4. Percent of total cost for material

____ (1) Less than 10%

____ (2) 10% - 25%

____ (3) 25% - 50%

X (4) 50% - 75%

____ (5) 75% - 90%

____ (6) Greater than 90%

5. Percent of total cost for engineering fee

____ (1) Less than 2%
____ (2) 2% - 4%
_X_ (3) 4% - 6%
____ (4) 6% - 10%
____ (5) Greater than 10%

6. Percent of the total labor cost spent for skilled labor

_X_ (1) Less than 25%
____ (2) 25% - 50%
____ (3) 50% - 75%
____ (4) Greater than 75%

7. Approximate daily wage for unskilled labor in your country's currency (local value)

50 (amount) sucres (currency unit)

or, if available, please check the category of U. S. dollar equivalent shown below

____ (1) Less than $1/day
_x_ (2) $1 - $3/day = $2.00
____ (3) $3 - $5/day
____ (4) $5 - $10/day
____ (5) $10 - $15/day
____ (6) More than $15/day

8. Approximate daily wage for skilled labor in your country's currency (local val

150 (amount) sucres (currency unit)

or, if available, please check the category of U. S. dollar equivalent shown below.

____ (1) Less than U. S. $2/day
____ (2) $2 - $5/day
_X_ (3) $5 - $10/day
____ (4) $10 - $15/day
____ (5) $15 - $20/day
____ (6) More than $20/day

9. Of the total cost spent for material, what percent of material was found in-country?

____ (1) Less than 10%

____ (2) 10% - 25%

____ (3) 25% - 50%

____ (4) 50% - 75%

_X_ (5) 75% - 100%

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