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8

VOLUME I

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TECHNICAL DOCUMENTS SERIES 8

MODULAR PLANTS FOR WATER TREATMENT

VOLUME I

Text

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INTRODUCTION

The ten-year period 1981-1990 has been designated by the countries of the world as the "International Drinking Water Supply and Sanitation Decade". Its goal is to provide universal access to safe water and adequate sanitation. One of the principal strategies for attaining that goal will be the adoption of technologies which are appropriate for social, cultural, economic, and physiographic conditions in the countries and which lend themselves well to local manufacturing of supplies and equipment utilized. It is in that context that the Pan American Center for Sanitary Engineering and Environmental Sciences (CEPIS) of the Pan American Health Organization/World Health Organization presents this book on modular plants for water treatment.

In developing countries, meeting the water quality needs of rural communities and small to medium-sized cities is often hampered by scarce technical skills and limited resources. Even though it is preferable, it is simply too expensive and time-consuming to custom design individual water treatment plants for each and every situation. On the other hand, the design must yield an economical, reliable facility.

The aim of this modular approach is thus to provide design engineers with a "package" of solutions to a range of water treatment problems. From among the alternatives, it suggests how to select an appropriate treatment process on the basis of raw water quality, community development and type, and institutional operation and maintenance capacity. It then presents plans for typical modular designs--including pretreatment, slow sand filtration, direct upflow and downflow filtration, and rapid filtration. Through this approach it should be possible to avoid both overdesign and underdesign, unnecessary costs, many operational difficulties and consequent inadequate service.

Practice-oriented, easy for engineers to understand and apply, these simplified modular designs are space and money saving and should prove particularly applicable to small-scale water treatment processes. They are not meant to be taken as fool-proof for every such situation, and their proper application requires the use of sound engineering judgment and adaptation.

In publishing this document the ultimate aim is to avail those working in developing countries throughout the world a tool to provide more people greater access to water of better quality. If that effort succeeds, it will contribute a great deal to realizing the goal of the International Drinking Water Supply and Sanitation Decade.

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LIST OF ACRONYMS USED

AID/OU	Agency for International Development/Oklahoma University
ASCE	American Society of Civil Engineers
AWWA	American Water Works Association
CEPIS	Pan American Center for Sanitary Engineering and Environmental Sciences
CETESB	Companhia de Tecnologia de Saneamento Ambiental
CIFCA	Centro Internacional de Informaciones en Ciencias Ambientales
DGOS	Dirección General de Obras Sanitarias del Ministerio de Vivienda y Construcción
ETAPA	Empresa Pública Municipal de Teléfonos, Agua Potable y Alcantarillado
FSESP	Fundação de Serviço Especial de Saúde Pública
IDRC	International Development Research Centre
IRC	International Reference Centre
PAHO	Pan American Health Organization
SANAA	Servicio Autónomo Nacional de Acueductos y Alcantarillados
SANEPAR	Companhia de Saneamento do Paraná
SEMAPA	Servicio Municipal de Agua Potable y Alcantarillado
WHO	World Health Organization

SUMMARY

In the last decade many researchers have made significant technological contributions in the field of low-cost water treatment plant design, not only in scientific areas but in the determination of new parameters and design criteria of the processes and reactors applicable to water treatment.

The objectives of this document are to:

1. Suggest a methodology for selecting water treatment processes in accordance with the level of technical development of the community or region, the capacity of the institutions administering the systems and the quality of raw water.

2. Submit for the design engineer's consideration modular designs of water treatment plants for different sizes and types of communities.

The water treatment solutions suggested in this document are exclusively oriented towards "water purification," (removal of turbidity, color and pathogenic organisms), and for this reason, turbidity and E. Coli are chosen as parameters for selecting unit operations.

The modular designs presented here have been elaborated using new technological criteria, which emphasize simplicity of construction and operation.

The following typical designs have been prepared:

a. Pre-treatment. Pre-sedimentation and rough pre-filtration with horizontal and/or vertical flow.

b. Slow sand filtration. Slow sand filtration and simple high rate sedimentation, and a combination of processes of slow filtration, rough pre-filtration and simple high rate sedimentation.

c. Direct filtration. Downflow, upflow and upflow-downflow types.

d. Rapid filtration. Considering two alternatives: construction in-situ and pre-fabrication.

The preliminary designs of water purification plants for small to medium villages consider the possibility of providing service to communities of 500 to 2000 inhabitants. The preliminary designs of

water treatment plants for larger areas consider the possibility of providing service to communities of 1000 to 10000 inhabitants (and in some cases up to 20000 inhabitants).

Several plans have been prepared for nine modular treatment plant designs, some with several alternatives, and for three pre-treatment possibilities. Each design has been dimensioned for a wide range of capacities within the above-mentioned limits.

Table i.I details a classification of raw water quality according to two parameters: turbidity and E. Coli.

Table i.II , details are given on the plant types classified in accordance with: (a) the quality of the water to be treated (using turbidity as an indicator since disinfection is always provided); (b) the type of community: cities or villages; (c) the existing maintenance and operation capacity; and (d) the existing level of industrial development to permit the pre-fabrication of plants.

A brief study of problems related to the technological status of water supply is presented in Chapter I.

The factors that influence the selection of the technological level of a water treatment plant, the selection criteria for unit operations and plants, and the limits of the proposed projects are analyzed in Chapter II.

The proposed designs, at a preliminary level, are discussed in Chapter III, and the designs are detailed in a set of 48 plans in a separate VOLUME II.

The designs and methodology described in this manual are of a general nature and should be widely applicable. However, the use of this information should be subordinated in every case to prior studies of the raw water source and community characteristics to verify that the design assumptions are in fact applicable.

Table i.I

RAW WATER PARAMETERS FOR SELECTING UNIT OPERATIONS

PARAMETER	UNIT	RAW WATER RANGES			
TURBIDITY: AVERAGE	NU	10	50	150	750
MAXIMUM		20	100	250	1500
E.COLI (Av. values)	MPN per	10	100	1000	10000
(max. values)	100 ml	100	1000	10000	1000000

Table i.II

SUMMARY OF PROCESS AND DESIGN MODULE SELECTION

Type of community	Operation and maintenance capacity	Industrial development	Maximum turbidities					
			< 10/20	< 100	< 250	< 1,200	< 1,500	< 10,000
CITY	Low	Low	Slow sand filtration	Slow sand filtration	High rate sedimentation Slow sand filtration	Indirect intake High rate sedimentation Slow sand filtration	Pre-sedimentation High rate sedimentation Slow sand filtration	Change of source
			Type 1-2 plant	Type 1-2 plant	Type 3 plant	Indirect intake Type 3 plant	Pre-sedimentation Type 3 plant	
	High	Low	Direct downflow filtration	Direct upflow filtration	Direct upflow-downflow filtration	Rapid filtration	Pre-sedimentation Rapid filtration	Pre-sedimentation Rapid filtration
			Type 8 plant, filters only	Type 6 plant	Type 7A plant	Type 8 plant	Pre-sedimentation Type 8 plant	Pre-sedimentation Type 8 plant
		High	Direct downflow filtration	Direct upflow filtration	Direct upflow-downflow filtration	Rapid filtration	Pre-sedimentation Rapid filtration	Pre-sedimentation Rapid filtration
			Type 8 plant, filters only	Type 6 plant	Type 7B plant	Type 9 plant	Pre-sedimentation Type 9 plant	Pre-sedimentation Type 9 plant
VILLAGE	Low	Low	Disinfection	Slow sand filtration	Rough filtration Slow sand filtration	High-rate sedimentation Rough filtration Slow sand filtration	Pre-sedimentation High rate sedimentation Rough filtration Slow sand filtration	Change of source
			Hypochlorination	Type 2 plant	Type 4 plant	Type 5A-5B plant	Pre-sedimentation Type 5A-5B plant	

CHAPTER I

BACKGROUND OF THE PROJECT

1. INTRODUCTION

The United Nations Water Conference, held in March 1977 in Buenos Aires, established as a goal for 1990 the "provision of water services with adequate quality for everyone" 1/. Taking up this challenge, WHO has given major priority to the provision of water supply to those most seriously affected in terms of water-related diseases and the underserved, particularly in rural areas, placing special emphasis on the use of appropriate technical solutions, methods of technology transfer, and promotion of community participation 2/.

In spite of the great efforts made by the countries in the past decade, drinking water supply is still the major problem in the area of environmental health, both because of its physical and economic magnitude and of its direct and indirect impact on health and development. The absence or scarcity of this service and, consequently, the use of nonpotable water, affects health and gives rise to high mortality and morbidity rates which, in turn, lower economic productivity and inhibit socio-economic development.

It is estimated that in 1975 there were 2,000 million inhabitants in the developing countries, excluding China, and of these some 1,230 million were still without potable water supplies 1/. The great majority of the unserved population live in villages and dispersed areas, and the remainder are usually located in small towns or the fringe slum zones of the large metropolitan areas.

In order to achieve the water supply goal of the International Water and Sanitation Decade, current levels of activities for providing water supply for the under-and unserved population will have to be increased manyfold 1/.

Preliminary diagnostic studies indicate that there is a need to build thousands of relatively similar water supply systems. The physical magnitude of the problem and the existing constraints of human and financial resources compel the adoption of innovations to facilitate the design, construction and operation of water supply systems, with full justification for the use of standardized designs for intakes, storage tanks, water treatment plants, and water distribution systems 3/. Such standardization should also help to simplify operation and maintenance and reduce their cost.

In recognition of the potential advantages of standardization, WHO has sponsored the preparation of this manual on modular plants for water treatment. The objectives of this manual are to:

- Present modular designs for water treatment plants, illustrating methods of design and construction; and

- Suggest a methodology for selecting water treatment processes based on the level of technical development of the community or region, the capacity of the administrative institution to operate and maintain the system, and raw water quality.

2. TECHNICAL BACKGROUND

Water supply has generally progressed in the following manner:

- Provision of water
- Supply of safe water
- Supply of water with a quality in accordance with the standards for potability that regulate its physical, chemical and biological characteristics

To satisfy biological requirements, disinfection, usually with chlorine, is the common practice. Regarding the physical requirements, turbidity removal is usually given priority, and in some cases so is color removal. With regard to chemical aspects, some plants eliminate hardness, iron and manganese, and as an exception there are plants which eliminate heavy or toxic metals, biocides, surfactants and organics. The latter problems will take on increasingly more importance in this decade as population growth and industrialization increase the potential for pollution of water resources.

Attempts to satisfy the above treatment requirements in the developing world too often have depended upon the use of conventional plants and/or patented methods developed in the industrialized countries and in accordance with their design standards. As a result, several problems have arisen which can be summarized as follows:

- The indiscriminate importation of technology often results in the construction of treatment plants in the developing countries which exceed the local technical capacity for operation.

- This problem is aggravated when economic aspects are taken into account because notoriously high costs are incurred due to the complexity of plant designs and to an excess of equipment, usually imported.

- Even where local technology is used, if this originates from and is dependent on technological advances of the industrialized countries, then there is a need to create a capacity for operation and maintenance (personnel, equipment, chemicals, etc.) that in turn depends on the technology and the commercial processes of the developed nations.

- At the same time, the investments needed for potable water supply in this decade are increasing exponentially due to factors such as continued high population growth; increasing pollution of water sources; growing competition for use of water resources; the tendency toward increasing per capita consumption of water; and the persistence of a growing inflationary process.

The above problems indicate the need for developing low-cost treatment technology which is appropriate for use in third-world countries. Fortunately, there has been a substantial number of technological advances in the water treatment field in the last years which have given rise to modifications in the design of unit operations and to the use of new processes and systems, and which are suited to the development of simplified, low-cost treatment alternatives.

Furthermore, this state of rapid advance in water treatment technology has been accompanied by an appreciable decrease in time between technological discovery and application.

A literature review of recent studies and technological advances shows that these have been oriented towards the following aspects:

2.1 Establishment of a correlation between:

2.1.1 Infectious diseases (endemic and epidemic) and the pollution of water supplies by bacteria, protozoa, and viruses (see references 1 to 19*).

2.1.2 Chronic diseases and cancer, and the physical and chemical characteristics of waters (some of these studies are detailed in references 20 to 39*).

2.2 Several national, state and international organizations, based on research and water quality criteria, have established standards for potable water including permissible and/or recommendable

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* List of technical publications

limits (a partial list of the principal studies is included in references 40 to 47*).

2.3 Due to the fact that the policy of importing technological solutions in the water treatment field from industrialized countries to developing countries - which do not have the structural capacity to maintain and operate them - has not had favorable results, several authors and institutions have recommended selecting treatment processes not only based on the raw water quality but also in accordance with the development level and existing capacity both of the institutions in charge of the operation of the systems and of the community itself (references 48 to 61* include some works related to this topic).

2.4 In the specific field of unit operations, contributions of different authors have helped to characterize and establish a scientific basis for coagulation processes (see references 62 to 73*), criteria of design and operation, as well as new forms of reactors for rapid mixing (references 74 to 87*), flocculation (references 88 to 119*), sedimentation (references 120 to 128*), rapid filtration (references 139 to 174*), and slow sand filtration (references 175 to 236*).

2.5 There is a body of literature on water treatment plant design which is applicable to the developing world, including works by Sanks 47/, Smethurst 48/, Culp 49/, and institutions such as the AWWA 50/-51/ and WHO 52/.

2.6 In addition, there is now a number of documented cases of the use of appropriate technology for water treatment in the developing countries in Asia (references 70/ to 73/), and in Latin America (19/, 56/ to 69/).

In Latin America, CEPIS took one of the first steps toward technological updating and dissemination with the publication of the proceedings of the PAHO Symposium on Modern Methods of Water Treatment 54/ held in Asuncion, Paraguay in 1972, and the manual Theory, Design and Control of Water Clarification Processes by Arboleda 19/, culminating in the design of several plants of an experimental or demonstration nature.

In a second stage, CEPIS carried out two research projects to evaluate the new technology. The first project had the financial support of U.S. AID and the University of Oklahoma, and the collaboration

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* List of technical publications

of such local institutions as ETAPA, SEMAPA, SANEPAR and FSESP, and consisted of an evaluation of the treatment plants of Cuenca (Ecuador), Cochabamba (Bolivia), Prudentopolis (Parana, Brazil) and Linhares (Espirito Santo, Brazil) 74/. The second project had the sponsorship of the IDRC and consisted of the evaluation of the El Imperial treatment plant in collaboration with the Peruvian agency DGOS 75/.

These investigations concentrated on evaluating the degree of adaptability of the technological solutions used to local development levels, the efficiency of the unit operations, and the costs of construction and of operation and maintenance - criteria and concepts which led CEPIS to the preparation of the Water Treatment Technology Manual for Developing Countries 55/ with the financial support of CIFCA.

The preceding technical background has served as a basis for the preparation of the studies and preliminary designs which are the subject of this report.

CHAPTER II

METHODOLOGY FOR THE SELECTION OF TREATMENT PROCESSES AND PLANTS

1. INTRODUCTION

The efficient and economic design of a water treatment plant requires careful studies based on technical aspects, such as raw and treated water quality, the efficiencies of the unit operations and their economic viability, and administrative aspects. Unfortunately, there is no mathematical model that can simultaneously optimize all of these variables and permit the selection of processes and/or the type of plant that should be used in each specific case.

In this chapter an analysis is made of the principal factors to be considered in the selection process, and a methodology is suggested for choosing between the different types of plants and unit operations which are available.

2. FACTORS TO BE CONSIDERED

2.1 Selection of technology to be used

Keeping in mind that the most appropriate technological solution is that which maximizes technical efficiency in the least expensive and simplest form possible, technology should make use of the human resources and materials available in the country.

The technical alternatives for solving any specific water treatment problem should be evaluated in terms of:

- the degree of complexity, which is linked with the capacity of the institutions and the people involved to build, maintain and operate a plant with the efficiency specified in the original design;

- the appropriate technological level, which ought to have a degree of reliability compatible with the other water supply components and should not result in costly solutions affordable only by a limited number of users;

- the availability of water sources, so that a proper balance will exist between water demand and supply, taking into account not only the quantity of water needed but also the quality required for human consumption;

- the necessary materials and equipment, seeking a technological level which makes maximum use of materials and equipment produced or available locally (it is possible to obtain high-efficiency designs at low cost using almost exclusively local materials);

- the existing human and administrative resources, which takes into account the local technical and organizational capacity to supervise, construct, operate and maintain a design based on a particular technology, coupled with an adequate economic capacity to provide sufficient financial resources;

- the cost of a technological solution, including the costs of construction, installation, operation, maintenance and administration, and such factors as the cost of imported technology, direct and indirect benefits stemming from the use of a particular design, and the value of using short construction periods and simple construction processes;

- its relationship with other development projects, taking into account the consequences of integrating a project with existing plans and political programs, the impact that it may have on government actions and on community acceptance, and indirect impacts such as the employment and/or technical upgrading of local manpower, indirect economic benefits, and direct and indirect repercussions on health.

2.2 Raw water quality

The factor that most influences the selection of the unit operations used in treatment is the quality both of the "raw water" and of the final product, "treated water."

The suitability of water for domestic and drinking water supply is determined by a limited number of quality indicators and assessment criteria.

The main traditional indicators for drinking water quality are: physical, chemical, and biological components, some of which are of decisive significance for the public health aspects of water treatment.

From the standpoint of public health, the safety of drinking water is determined by indirect indicators, such as total bacteria, coliforms, viruses (or bacteriophages), and pathogenic intestinal bacteria, because of their possibility of survival in the relatively high temperature surface water found in most developing countries. In this study E. Coli is used as an indicator, as well as a unit operation selection parameter.

The important role of water as a factor in the bodily intake of a number of chemical substances is well known. The classification of these components and their maximum permissible concentrations in drinking water have been established in international and national standards for drinking water quality.

As this document is exclusively oriented towards water purification and clarification of surface water, it is supposed that raw water sources are within the permissible limits for chemical substances; otherwise, it will be necessary to select the appropriate unit operation, and add it to the water treatment plant designs detailed in Chapter III.

According to the data of a large number of authors, the physical properties of water have an important influence because water is simultaneously the medium in which physiological and chemical reactions take place, and a direct participant in those reactions. Additionally, some of these physical parameters are closely related to the biological quality of the water. The most important physical properties of water are: turbidity, color, total solids, and temperature.

In this study turbidity has been selected as an indicator of physical water quality. Turbidity may be caused by a large variety of suspended materials which range in size from colloidal (diameter $<$ 1 micron) to coarse suspensions ($>$ 1 mm). The turbidity removal efficiency of different unit operations can be greatly affected by the nature of the turbidity of raw water, so particular attention must be given to turbidity analysis, especially to determine the state of the matter that may cause turbidity (colloidal or suspension) and color prior to unit operations selection, particularly in pre-treatment before slow sand filtration.

3. CRITERIA FOR SELECTING UNIT OPERATIONS AND WATER TREATMENT PLANT TYPES

The following criteria have been adopted in order to select unit operations and water treatment plant types: raw water quality, type of community, water supply, operation and maintenance capacity, and level of industrial development.

3.1 Raw water quality

Due to their simplicity of analysis and their importance, two raw water characteristics have been chosen as parameters for the selection of the unit operations of a water treatment plant: turbidity and E. Coli, establishing four raw water qualities (Table 1) based exclusively on the removal efficiency of the selected unit operation.

Table 1

RAW WATER QUALITY CLASSIFICATION

Parameter	Raw water quality ranges			
Average Turbidity (NU)	10	50	150	750
E. Coli (MPN per 100 mℓ)	10-100	100-1000	1000-10000	10000-100000

"Normal turbidity" has been adopted as the average dry season turbidities; "average turbidity" is the arithmetic mean of the annual data; and "maximum turbidity" corresponds to the annual arithmetic mean plus two standard deviations.

Turbidity values of Table 2 are complementary to those previously detailed in Table 1.

Table 2

RAW WATER TURBIDITY VALUES USED AS UNIT OPERATIONS SELECTION CRITERIA

Normal	5	30	100	250	
Average	10	50	150	750	< 10000
Maximum	20	100	250	1500	

For use in villages with low operation capacity, slow sand filtration plants are being proposed with rough pre-filtration and/or high rate sedimentation (without the use of coagulants) for the removal of high turbidity levels. The design of these pre-treatment processes is based on the use of very low surface overflow rates and high removal efficiencies.

It should be kept in mind that the high rate sedimentation and the rough pre-filtration processes proposed for use in the slow sand filtration plants have been tested in pilot-scale plants. These experiments have been conducted with the turbidity indicated in Table 2, with particle diameters from 1 to 10 microns, so that these unit operations should not be used outside of the indicated ranges.

Generally, it is assumed that the raw water sources comply with all the permissible levels of physical, chemical and biological requirements to assure that the source is sufficiently safe to be used for drinking water supply.

3.2 Type of community

It is difficult to develop a classification of communities as a function of their degree of development. A two-level classification has been adopted here: villages and cities, for communities with "low" and "average" development levels respectively 6/. This classification serves as a criterion for choosing between proposed treatment technologies, suggesting the use of slow sand filtration plants for village and small communities with low development levels, and rapid sand filtration for urban communities with average and advanced development levels.

3.3 Capacity for operation and maintenance

As the third decision criterion for the selection of unit operations and types of plants, we have used the "existing capacity" to operate and maintain adequately the projected treatment plant, both for a local institution or directly by the community.

Where there is little operation and maintenance capacity, the use of slow sand filtration plants, which require a minimum of operation and maintenance is recommended; where there is a medium capacity, rapid or direct filtration plants are recommended with hydraulic mixing flocculation and units; and where there is a good capacity, the use of mechanical flocculators and rapid sand filtration is recommended, as well as the use of direct upflow and/or downflow filtration.

3.4 Industrial development

In small water treatment plants using new design criteria for flocculation, sedimentation and rapid filtration units with high surface overflow rates, normally a great percentage of the plant's area is occupied by structures (30-40%). The use of non-conventional structural designs - using steel and reinforced plastic pre-fabrication - may be economically justified. This solution would permit an appreciable savings in construction costs, with a notable reduction in the required construction time.

The use of these types of designs is only feasible where sufficient industrial development exists to permit pre-fabrication, in which case this may be an ideal solution. Only compact rapid filtration plants are suggested in this case.

4. SEQUENCE OF SELECTING PLANT TYPE

A schematic outline is given in Plan No. 1 of a sequential selection process for the unit operations which make up the different treatment plant designs, based on the above-mentioned selection criteria.

5. LIMITATIONS OF THE PROPOSED DESIGNS

The following points should be emphasized:

- When using "turbidity" as a selection criterion for the unit operation(s) of a treatment plant, a direct correlation has been assumed between turbidity and the bacteriological and chemical-sanitary characteristics of the water supply. Such a correlation does not always exist; otherwise, both turbidity and/or E. Coli will be considered as parameters to select unit operations.

- It is also assumed that all other physical, chemical, and bacteriological parameters of raw water source are under the permissible values established by national or international standards for raw water quality. If not, the necessary modifications should be made in the design parameters of the processes used, or adequate unit operations should be added to assure the potability of the water.

- In any case, to guarantee the "safety" of the water supply from a bacteriological and biological point of view, all designs include chlorine disinfection.

- A very conservative policy has been used in preparing the designs, incorporating design criteria which have already been used with success in Latin America, or introducing design modifications based on technical evaluations of said processes, or whose limitations have been verified in laboratory and pilot-scale plants. Such limitations are noted in the respective designs.

- If high rate sedimentation without coagulation is used, we recommend the use of settling tests in the laboratory for the determination of the overflow rates - real and apparent - as well as the removal efficiency.

- Likewise, when using rough pre-filtration with waters having turbidity originating from colloids, or high levels of color, oxidizable organic material, Fe, Mn, etc., for the sake of certainty, tests should be performed with models or pilot plants to determine surface overflow rates and removal efficiencies.

- For each specific design, limitations and specific restrictions on their use are detailed in the respective section on state of technological advance.

- We wish to emphasize that in this manual we are not presenting finished designs, but only several ideas for possible design solutions. The designs and methodology described are of a general nature and should be widely applicable. However, the use of this information should be subordinated in every case to prior studies of the raw water source and community characteristics to verify that the design assumptions are in fact applicable.

CHAPTER III

PROPOSED PRELIMINARY DESIGNS

1. Intake - Vertical Pre-filter

(Plan No. 2)

1. OBJECTIVE

Collect and pre-treat surface water of variable quality to be subsequently treated by slow sand filtration.

2. DESCRIPTION

This indirect intake is placed in the riverbed and is made up of the following elements:

2.1 Pre-filter (Section A-A)

The pre-filter uses gravel as the filter medium, with the following characteristics:

Layer	Depth m	Diameter mm
1	0.10	15 - 25
2	0.20	10 - 15
3	0.50	5 - 10

This is a vertical flow pre-filter designed with a filter rate of 0.25 m/h.

The collection system is formed by drains of perforated PVC pipes, which are connected with a main drain of the same material that leads to an intake chamber. To protect the filter from erosion the use on the top of a 20 cm stone layer is suggested.

The walls are formed by stone (without mortar) or bags of Portland cement type 1, sloped to the angle of repose of the riverbed material.

2.2 Direct intake

When the water is of sufficiently good quality to permit the direct use of slow sand filtration, the lateral intake chamber placed in the river bank will be used directly (Section C-C).

The inlet is protected by rack of steel bars of ϕ 1/4" with a separation of 2 cm to prevent the entry of floating material.

2.3 Control system

The control system is manual and consists of steel and/or wood sluice gates (details are indicated in Plan No. 21).

2.4 Plans

The design criteria, characteristics, and additional details are specified in Plan No. 2.

3. CAPACITY

Dimensions for 12 designs with capacities between 3.6 and 36 m^3/h, to serve communities with populations of approximately 1,000 to 10,000 inhabitants, are specified in Plan No. 2.

4. USE RESTRICTIONS

This type of intake is recommended for use with slow sand filtration plants with and without high rate sedimentation, for which maximum and average raw water turbidities should be lower than 250 and 150 NU respectively.

This type of rough filter is not adequate for removing colloidal material (diameter < 1 micron). Since dissolved oxygen concentrations in this type of pre-filter are usually quite low, it does not have the capacity to remove oxidizable organic matter, color, iron, and/or manganese.

It has been found that this type of pre-filter can work for periods up to five years without requiring change or cleaning.

5. STATE OF TECHNOLOGICAL ADVANCE

Direct pre-filtration of the downflow type has been widely used in Europe (as is reported by Baker 76/), in Africa 77/ and Asia 78/. The efficiency and design criteria for this type of intake have been studied experimentally at CEPIS. SANAA, in Honduras, is at present conducting tests in pilot projects, prior to use in a national rural water supply program.

2. Intake - Horizontal Pre-filter

(Plan No. 3)

1. OBJECTIVE

Collect and pre-treat surface water of variable quality to be subsequently treated by slow sand filtration.

2. DESCRIPTION

This type of indirect intake is located in the stream bank, and consists of the following elements:

2.1 Protective wall

To protect the intake from erosion the use of a retention wall of stone, without mortar and secured by steel mesh, is recommended. This wall must be constructed with open joints to be absolutely permeable.

2.2 Pre-filter

This is a horizontal flow type with a filter rate of 0.50 m/h. Gravel with the following characteristics is used as the filter medium.

Layer	Width m	Diameter mm
1	1.00	25 - 80
2	4.50	30 - 70
3	4.50	5 - 12

The drain system is made of a perforated PVC pipe which leads to an intake chamber. The lateral walls are formed by stones, without mortar, or by bags of Portland cement type 1.

To avoid the infiltration of surface runoff, the use of a layer of clay or a polyethylene liner in the upper part of the pre-filter is suggested.

2.3 Direct intake

The lateral intake chamber placed in the river bank will be used directly when the water is of sufficiently good quality to permit the use of direct slow sand filtration.

The entrance is protected by a rack of steel bars of ϕ 1/4" with a separation of 2 cm to prevent the entry of floating material.

2.4 Control system

The control system is manual and consists of steel and/or wood sluice gates (details are indicated in Plan No. 21).

2.5 Plans

The design criteria, characteristics and additional details are specified in Plan No. 3.

3. CAPACITY

Dimensions for 12 designs, with capacities between 3.6 and 36 m^3/h are specified in Plan No. 3.

4. USE RESTRICTIONS

This type of intake is recommended for use with slow sand filtration plants with or without high rate sedimentation, maximum and average raw water turbidities should be lower than 150 NU and 750 NU respectively.

This type of rough filter is not adequate for removing colloidal material (diameter < 1 micron). Since dissolved oxygen concentrations in this type of pre-filter are usually quite low, it does not have the capacity to remove oxidizable organic matter, color, iron, and/or manganese.

5. STATE OF TECHNOLOGICAL ADVANCE

Direct pre-filtration of the horizontal type has been widely used in Africa 77/ and in Asia 78/, and there exists a number of experimental works like those developed by Huntschik 79/ in Germany, Thanh and Ouano 73/ at the Asian Institute of Technology. Specific tests to determine the filter media, filter rates and efficiencies reported here were developed at CEPIS. SANAA, in Honduras, is at present conducting tests at the demonstration level with pilot projects as part of their rural water supply program.

3. Pre-sedimentation

(Plan No. 4)

1. OBJECTIVE

Pre-treat waters with high turbidity so that they can be treated by slow or rapid sand filtration.

2. DESCRIPTION

This unit consists of a triangular settling basin with variable depth, which helps to:

- achieve a uniform distribution of water both at the inlet and in the settling unit;
- avoid short circuits and dead spaces, and obtain longitudinally decreasing velocities and a lower overflow rate at the outlet;

factors that are expected to increase the efficiency of the process.

To uniformly distribute the flow, a slotted brick wall inlet has been designed. To minimize the cost of the structure only a concrete liner reinforced with wire mesh, or ferrocement, has been projected.

A "by-pass" channel has also been planned to be used when pre-sedimentation is not necessary or when the unit needs to be cleaned.

A drainage and discharge system has been designed at the bottom of the pre-sedimentation unit.

The details, design criteria, and other specifications are shown in Plan No. 4.

3. CAPACITY

The use of pre-sedimentation is required for economical treatment of waters with high turbidities over 1,000 NU; therefore, units have been dimensioned with capacities between 3.60 and 70 m^3/h.

4. USE RESTRICTIONS

The efficiency of this process should be optimized by determining the design overflow rate (Hazen's parameter) based on a simple sedimentation test in the laboratory.

Based on economic considerations, this unit will not work efficiently with raw waters of low turbidity or turbidity essentially originating from colloidal material (d $\leq$ 1 micron).

5. STATE OF TECHNOLOGICAL ADVANCE

Similar solutions have been used by Schmidt in Ruhr, Germany /77/.

4. Slow Sand Filtration with Variable Head

TYPE 1 PLANT

(Plans No. 5 to 11)

1. OBJECTIVE

Suggest modular designs for slow sand filtration plants to treat waters with good physical, chemical, and bacteriological characteristics, to be used in small and medium size water supply projects. This design contemplates the successive addition of pre-treatment to basic slow sand filters, as well as plants of various capacities.

2. DESCRIPTION

This project includes three alternatives. The first two (1-A and 1-B), with variable head and constant slow filtration rate, are conceptually identical and differ only in the construction material used. The third alternative (1-C) with a different structural solution, presents a design with variable filtration head and filtration rate.

2.1 Water inlet system

This includes a distribution chamber with an overflow weir and a sluice gate system to drain the unit and to control the flow; a sharp-crested triangular weir to measure the water flow; and a channel to distribute water to the filter units.

2.2 Slow sand filters

The filters are provided with a control weir at the outlet, which regulates the minimum head of water over the filter beds; as the filter media clogs, head loss is increased and the head of water consequently also is raised, until it reaches a maximum level regulated by an overflow spillway. If the inflow and filter section are constant (Types 1-A and 1-B), it is possible to have a constant rate filtration with variable head, without the use of any additional element to regulate the filtration rate.

Inflow to the filter is achieved by a wide broad-crested spillway which permits the development of a thin lamina of water in the inlet filter. A horizontal apron is provided at the top of the filter bed to prevent scouring.

The filtration rate is constant (0.10 m/h) for alternatives 1-A and 1-B, and variable (0.10 - 0.30 m/h) for 1-C.

The sand grain size distribution should be chosen in function of the water quality. There should be a sand depth of 1.20 m to achieve a resanding period of approximately five years.

The filter bed has four layers of supporting gravel. The drain system is formed by lateral brick drains which discharge to a main drain located near the dividing wall of the filters, which in turn, discharges to the outlet chamber where the control weir is located. It is suggested that the interior walls of the filter in contact with sand be given a rough finish to avoid short circuits.

2.3 Outlet, control, and discharge system

A group of chambers has been designed in a small area which permits control of the filtration rate, provides for evacuation of overflow and for drainage of the individual units, and allows for their interconnection so that any filter unit can be backfilled to avoid premature clogging of the filter by air bubbles.

2.4 Disinfection

Disinfection is accomplished by post-chlorination with calcium or sodium hypochlorite or other solid chlorine compounds, using a very simple system with a constant-head, calibrated orifice that can be hand regulated.

2.5 Plans

The design criteria, characteristics and additional details of the slow sand filtration plants are shown in Plans No. 5 and 6 (Type 1-A), Plans No. 7 and 8 (Type 1-B) and Plans No. 9, 10 and 11 (Type 1-C); while sluice gates, spillways and the disinfection system are given in Plans No. 21 and 22.

3. CAPACITY

Similar plants have been dimensioned with capacities between 3.6 and 36.0 m^3/h.

4. USE RESTRICTIONS

These types of plants are capable of treating waters with good physical, chemical, and biological characteristics, but should be avoided for waters with turbidities above 100 NU, temperatures below 4°C or when biocides are present, because they can modify or destroy the microbiological processes which serve as the basis for slow sand filtration.

Alternative 1-C, although it is more economical, may be less efficient than conventional constant head slow sand filters, especially in the beginning of filter runs.

Aeration of the raw water or recycling of oxygen-enriched effluent water to the supernatant water reservoir, will be necessary in slow sand filtration projects if the oxygen consumption in the filter bed leads to anaerobic conditions. For the designs proposed, aeration of the raw water in a simple weir before entering the supernatant water reservoir should be sufficient.

The third alternative (1-C) with sloping walls may not be watertight and, consequently, it should not be used where there is a high ground water table, because of danger of contaminating the filtered water or production of sub-pressure that can destroy the plant.

5. STATE OF TECHNOLOGICAL ADVANCE

IRC/WHO consultants 82/ have suggested that slow sand filters without rate controllers can be used; additionally, the experience gained in the evaluation of rapid, variable-rate filters 74/ supports this design, which has been tested in laboratory-scale experiments at CEPIS in Lima, Peru.

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5. Variable Head Slow Sand Filtration and Simple High Rate Sedimentation

TYPE 3 PLANT

(Plans No.12 to 14)

1. OBJECTIVE

Since the slow sand filtration process can only be used for relatively good water sources, a design is suggested that combines high rate, horizontal flow sedimentation with variable head slow sand filtration to treat raw water of average quality.

2. DESCRIPTION

The design incorporates alternative 1-C for slow sand filters (with variable head and variable rate of filtration) together with high rate, horizontal flow settling units. The project is complemented with water inlet and outlet discharge, metering, overflow control, drainage, and disinfection. The project has the following characteristics:

2.1 Inlet system

It consists of a distribution chamber which directs the raw water into the inlet channels of the settling units through a broad-crested weir, and drainage control sluice gate, which due to its design characteristics also acts as an overflow spillway. Water enters the distribution chamber from a raw water channel through a sharp-crested triangular weir.

2.2 High rate settling units

These units have been designed with: an inlet channel to assure a steady uniform flow in the settling zone; a high rate, horizontal flow settling zone, with inclined asbestos-cement plates which allow a maximum removal efficiency and constant sludge removal; a sludge accumulation zone with a manual drainage system; and a trough which serves simultaneously as settler outlet and filter inlet.

2.3 Slow sand filters with variable head and filtration rate

Similar to those described previously for the slow sand filter project, alternative 1-C.

2.4 Outlet and filter control system

Similar to that described for slow sand filter, alternative 1-C.

2.5 Disinfection

A system similar to that described for the slow sand filtration design, alternative 1-C is used.

2.6 Plans

The design criteria, details, and specifications are shown in Plans No. 12 to 14.

3. CAPACITY

The plants have been dimensioned with capacities between 3.60 and 36.00 m^3/h.

4. USE RESTRICTIONS

This type of simple high rate sedimentation and variable head slow sand filtration plant is able to treat waters with turbidities up to 500 NU, but only when the turbidity is due to particles with a diameter larger than 1 micron. Waters with turbidities due to particles in colloidal state ($\leq$ 1 micron) cannot be treated efficiently.

Furthermore, this type of plant has a very low aeration capacity and may not be suitable for removing color, oxidizable organic matter, iron or manganese.

This type of plant should not be used with waters of temperature less than 4°C, nor when any kind of algicides or biocides are present because these may affect the organisms responsible for biological filtration.

5. STATE OF TECHNOLOGICAL ADVANCE

The advantages and possible applications of simple high rate sedimentation (without coagulant) have been studied in Cuenca, Ecuador (reference 136*), and the efficiency of this process has been determined experimentally in CEPIS' laboratory.

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* List of technical publications

6. Slow Sand Filtration - Rural Area

TYPES 2, 4, AND 5 PLANTS

(Plans No. 15 to 20)

1. OBJECTIVE

Suggest modular designs for water treatment for village water supplies, incorporating different pre-treatment processes that will permit the use of slow sand filtration with high turbidity raw waters.

2. DESCRIPTION

Modular plants have been designed with different pre-treatment units, as indicated in Plan No. 15, and can be summed up as follows:

Water quality (turbidity JU)	Processes	Project
< 100	Slow sand filtration	Type 2
< 250	Pre-filtration and slow sand filtration	Type 4
< 1250	High rate sedimentation, pre-filtration and slow sand filtration	Type 5
< 1500	Pre-sedimentation, high rate sedimentation, pre-filtration and slow sand filtration	Type 5 + pre-sedimentation

The slow sand filters are similar to those proposed for the Type 3 Plant.

Slow sand filtration for the Type 2 Plant is very similar to that for the Type 1-C Plant, with a small difference in the clear water outlet, which consists of a siphon instead of a control weir.

The Type 4 Plant incorporates gravel pre-filters and the Type 5 Plant has additional simple high rate settling units, considering two alternatives for assembling the units.

2.1 5-A Plant

This plant consists of:

- Raw water inlet. Any type of pipe or channel that ends in an inlet chamber, with a sharp-crested triangular weir and an overflow spillway.

- High rate settler. The water is delivered through an inclined downflow channel to a high rate upflow sedimentation unit formed by asbestos-cement plates placed at a slope of 60°. Outflow is through a triangular section channel which connects the settler with the rough filter. The sludge zone is provided with a manual discharge system.

- Pre-filter. These pre-filters, or rough filtration units, are of horizontal flow and used with gravel of 1/4" diameter as filter media.

  The pre-filter's front and back walls are made of slotted bricks to allow a uniform and adequate distribution of flow in the unit. The bottom is a truncated prism filled with stones of 2" to 3" diameter to permit the rapid discharge of the unit during the washing period.

  To wash the pre-filter unit it is necessary to close the inlet sluice gates to the slow sand filters, and thus modify the water level of the plant; then the pre-filter discharge gate is opened. With these actions the velocities required to dislodge material deposited in the pre-filter gravel are reached.

- Slow sand filters. The slow sand filter, with variable head and filtration rate, has been designed following the principles indicated in the previous slow sand filtration projects, with one major modification: in this filter instead of using a control weir to establish the filtered water level, this is achieved by means of a siphon made of a 4" diameter PVC pipe, whose outlet elevation fixes the minimum water level in the filter unit.

The filters can be emptied for occasional scraping or cleaning through a discharge channel located beneath the interconnection channel of the pre-filters. A filter unit can be backfilled normally with the filtered effluent of the other unit.

- Disinfection. The disinfection system is similar to that indicated in the previous projects.

- Plans. The design criteria and additional details of the project are shown in Plans No. 16 and 17.

2.2 5-B Plant

This plant consists of:

- Raw water inlet. Formed by a channel provided with a sharp-crested triangular weir to measure the water flow and an overflow spillway. The channel distributes the water to two high rate settling units.

- High rate settling units. The settling units are of the horizontal flow type and are designed with asbestos-cement plates inclined at 60° to permit continuous sludge removal. The sludge zone is provided with a manual discharge system. Outflow is through the interconnecting channel to the pre-filter.

- Pre-filters. Rough filtration units that use 1/4" gravel as filter media. Both the inlet and the outlet are made of slotted brick walls to allow a uniform distribution of flow. The bottom has a steep slope to permit washing, which is done with a procedure similar to that described for the previous alternative (5-A).

- Slow sand filters. The slow sand filtration units are similar to those described in the preceding alternative (5-A).

- Disinfection. Similar to that indicated in previous designs.

- Plans. Details are shown in Plans No. 18 to 20.

3. CAPACITY

Five modular designs with capacities between 3.6 and 10.8 m^3/h have been dimesioned for each alternative.

4. USE RESTRICTIONS

The suggested designs are capable of treating water with the turbidity limits mentioned above, but only when turbidity particles are larger than 1 micron.

As in the previous designs, these plants are not able to treat waters of low temperature(($\leq$ 4°C), to appreciably reduce color or oxidizable organic matter, or to remove iron and manganese.

The use of raw waters with biocides of any kind that could affect the organisms for biological filtration should be avoided.

5. STATE OF TECHNOLOGICAL ADVANCE

The maximum permissible overflow and filtration rates for this design have been established taking into account experimental tests carried out in CEPIS with a safety factor. The existence of plants similar to those proposed is not known, but some studies made by different authors 77/, 78/, 79/, 80/, 82/ would seem to support the assumed efficiencies of the proposed designs. We recommend that experimental pilot projects be undertaken before attempting the large-scale application of these types of designs.

7. Direct Upflow Filtration

TYPE 6 PLANT

(Plans No. 23 to 26)

1. OBJECTIVE

Suggest water treatment plant projects based on coagulation-filtration processes to treat waters of good quality in communities having adequate conditions for operation and maintenance.

2. DESCRIPTION

The direct upflow filtration plant consists of:

2.1 Raw water inlet

Consists of a concrete tank with two sharp-crested rectangular weirs that allow the proportional distribution of water into the two water storage tanks for filtration and backwash respectively. It is also provided with a drain system.

2.2 Water storage

The water storage tank has two compartments with different volumes and depths: one for water to be filtered and one for filter backwash water. Each one is provided with a pipe system connecting to the filters. These tanks are placed at an elevation that will permit the correct operation and backwashing of the filters. These tanks are provided with the respective drainage and overflow systems.

2.3 Chemical feeding

An attempt has been made to design the simplest chemical feeding system possible, even though the technological level required for relatively more complex solutions may exist in the place of use.

The use of two kinds of chemical substances is foreseen - coagulants and pH modifiers - both in a solid state. Tanks for chemical feeding have been designed based on a constant head calibrated orifice device, with a single tank for coagulants and a double tank system for lime or pH modifiers. Asbestos-cement tanks are used for this purpose.

Logically, the type of chemicals, the degree of concentration of the chemical solutions, their dosage rates, etc., will depend on the quality of the water to be treated. The optimal selection of these parameters should be determined in the laboratory by the traditional jar test.

2.4 Rapid mixing

The addition and mixing of coagulants are done directly in the pipe connecting the raw water storage tank with the filters, creating good mixing conditions with an orifice plate placed in the pipe. The orifice diameter has to be determined so that it causes a loss of head that will produce a velocity gradient no greater than 500 s^{-1}.

Lime is added by means of a small diameter pipe with evenly spaced distribution orifices located immediately above the inlet weir to the filter water tank, and energy for mixing is provided by the waterfall.

2.5 Filters

This plant has two upflow filters and uses sand as the filter media in accordance with the following characteristics:

- Depth of the filter bed: 2.25 m
- Specific diameter: from 0.70 to 0.80 mm
- Uniform coefficient: < 2

To obtain the best result the following sand layers should be placed in decreasing order:

Layer No.	Diameters (ASTM sieve)	Height cm
1	12 - 14	18
2	14 - 16	31
3	16 - 18	52
4	18 - 20	65
5	20 - 25	36
6	25 - 30	23

The supporting layer and four types of gravel, as well as their characteristics are detailed in Plan No. 26.

The false bottom is formed by pre-fabricated Λ-shaped beams, with uniformly distributed orifices (using short PVC pipes - see details on Plan No. 43).

The water inlet to the filters is formed by pipes of 6" to 10" diameter (depending on the plant's capacity) with the respective butterfly valve.

The interior walls of the filter also serve as a spillway for the outflow of filtered water, and at the same time form the clear water channel. The filtration velocity is constant and equal to 120 m/day without any mechanical control system.

The filter backwash system is composed of a storage tank and by a 6" to 10" diameter pipe, with its corresponding accessories, which allow a backwashing velocity of 0.80 m/min.

The backwash water is collected in a trough located in the upper part of the filter box and is controlled by a manually operated sluice gate.

2.6 Disinfection

The disinfection unit is similar to that suggested in the preceding designs.

2.7 Plans

The design criteria, details, and general specifications are indicated in Plans No. 23 to 26.

3. CAPACITY

Dimensions are given for nine plant capacities ranging from 14 to 70 m^3/h, which can serve communities with up to 10,000 inhabitants.

4. USE RESTRICTIONS

Direct upflow filtration is a more economical solution than rapid filtration because of its lower construction and operation costs, but it represents a complex technological solution. For this reason its use is limited to communities or regions in which a sufficient technological level exists to adequately design, build, maintain, and operate this kind of water treatment plant.

With regard to raw water quality, this kind of water treatment plant achieves high removal efficiencies (> 99.8%) for water with turbidities up to 50 NU; thereafter efficiency declines geometrically with the increase of turbidity up to a maximum limit of application of 100 to 150 NU. There are no limitations regarding the size of particles that originate turbidity.

This plant is excellent for color removal when it is lower than 100 CU, with good results obtainable up to 150 CU.

5. STATE OF TECHNOLOGICAL ADVANCE

This kind of water treatment plant has been widely studied and used in Europe, especially in Russia and England; similar plants to the one proposed in this report have been designed and built by FSESP 57/ and by SANEPAR 56/ in Brazil, both of which were evaluated by CEPIS 74/ with excellent results.

8. Upflow and Downflow Direct Filtration

TYPE 7 PLANT

(Plans No. 27 to 38)

1. OBJECTIVE

Suggest water treatment solutions using coagulation and direct filtration processes to treat waters of fair quality, and to be used in communities having good conditions for operation and maintenance.

2. DESCRIPTION

This type of plant includes coagulation and rapid upflow filtration followed by rapid downflow filtration units, having the following elements:

2.1 Raw water inlet, storage, chemical feeding and rapid mixing

These elements are similar to those described in the direct upflow filtration projects, Type 6 Plant.

2.2 Upflow filtration

This plant has three rapid upflow filtration units, with similar characteristics to those described in the upflow filtration project, Type 6 Plant, differing only in the pipe connection system to the storage tanks for raw water and backwash water.

Project 7-B is exactly like Project 6, having two pipe systems, one for water to be filtered and another for backwash water.

Alternative 7-A has a single pipe system for delivering both raw water and backwash water, so that when any one of the upflow units has to be washed, operation of the two remaining units must be interrupted, complicating the plant's operation but simplifying its design and construction and lowering its initial cost.

2.3 Downflow filtration

For the final filtration process four downflow filters with dual media are included in the design. The units have variable head, and declining rate filtration.

The water inlet to the filters is through a common distribution channel which assures a sufficient inflow to all the filter units, without modifying their respective headloss rates.

Dual filter media are used (sand and anthracite or sand and any other less dense material: coconut shell, plastics, etc.). The supporting layer is formed by eight gravel layers of different sizes, placed in four layers of decreasing size over four layers of increasing size (see details on Plan No. 37).

For the false bottom, pre-fabricated Λ beams are used, with uniformly distributed orifices (formed using short PVC pipes), (see details on Plan No. 43).

The four downflow filters are interconnected to a common clear-water channel, having only one control weir which fixes the minimum head of water on the filters and at the same time regulates the necessary head of water to backwash any one of the filters with the outflow of the other three units.

The inlet of water to the filter and the washwater outlet are located in the same vertical axis and are controlled by a single sluice gate, such that it permits the inlet of water to the filter and closes the washwater outlet, and vice versa. Therefore, it is only necessary to operate one sluice gate to wash a filter.

In this way, this design introduces modifications which have already been used with success in many plants in Latin America, permitting the use of variable head, declining rate filtration, making it possible to backwash any filter unit with the clear water flow of the other units, and minimizing the degree of mechanization through elimination of filter rate control systems, headloss gauges, backwash equipment and pipe galleries. This results in appreciable savings in capital investments and operating costs.

Both alternatives 7-A and 7-B use the same technical solution for final downflow filtration.

2.4 Disinfection

The same disinfection unit described before and shown in Plan No. 22 is used.

2.5 Plans

The design criteria, specifications, and details for alternative 7-A are indicated in Plans No. 27 to 32, and in Plans No. 33 to 38 for alternative 7-B.

3. CAPACITY

Due to high costs originating in the thickness of the concrete and/or masonry walls, it is not feasible to use this type of design for small plants, so that only three capacities have been dimensioned: 36 m^3/h, 52.5 m^3/h and 70 m^3/h.

4. USE RESTRICTIONS

From the standpoint of water quality the proposed design can be used to treat waters with turbidities up to 150 NU and, for very short periods of time, to 250 NU. It can also remove average values of color up to 100 - 150 CU in short duration periods.

As these plants are relatively complex to design, build and operate, they should be restricted only to communities having high technological levels that will permit their correct operation and use.

5. STATE OF TECHNOLOGICAL ADVANCE

Plants similar to those proposed have been installed in Parana, and other Brazilian states 77/, 81/, with excellent efficiency.

9. Rapid Filtration

TYPE 8 PLANT

(Plans No. 39 to 44)

1. OBJECTIVE

Suggest rapid filtration plant solutions to treat waters of poor quality, and to be used in communities with low maintenance and operation capacities.

2. DESCRIPTION

This type of plant is composed of the following units: coagulation, flocculation, sedimentation, rapid filtration and disinfection, with the following characteristics:

2.1 Raw water inlet and rapid mixing

The raw water inlet is through a pipe or channel, with its corresponding valve or sluice gate, as may be the case. The inlet chamber is connected in turn to a second chamber through a sharp-crested triangular weir for rapid mixing and flow measurement.

2.2 Chemical feeding and rapid mixing

The chemical feeding system for coagulants and/or pH modifier is the same as that described in Projects No. 6 and 7. The addition of chemicals at the weir (rapid mixing unit) is done by a perforated PVC pipe.

The hydraulic rapid mixing unit (the weir) needs a velocity gradient of less than 2,000 s^{-1} and preferably near 1,000 s^{-1}. A gradient of 100 s^{-1} should be maintained in the interconnection between the rapid mixing and the flocculation units.

2.3 Flocculation

Flocculation is carried out hydraulically, in a horizontal flow unit formed by channels whose walls are made of corrugated asbestos-cement sheets. With this design it is possible to maintain the same velocity gradient both in the "straight" portions of the channels and in the "curves", improving the efficiency of the reactor and its structural resistance.

To obtain the desired velocity gradient (determined by the "jar test") it is only necessary to change the separation between sheets.

The flocculator is divided into three compartments to permit easy regulation of the velocity gradient.

An interconnection channel is provided between the flocculation and the sedimentation units. One wall of this channel will serve as a broad-crested submerged weir to the settler.

2.4 Sedimentation

A high rate settling unit with inclined asbestos-cement plates is placed longitudinally with a slope of 60° to obtain a horizontal laminar flow, and to produce a constant sludge runoff to the bottom.

Both the inlet and outlet zones of the sedimentation unit have the same depth as the sloped plates of the settling unit.

The outlet of settled water is through a broad-crested free-falling weir to a common water distribution channel for the filters.

The bottom sludge zone of the unit has the shape of a truncated pyramid for easy cleaning. The sludge can be discharged manually by activating a sluice gate.

2.5 Rapid filtration

Four downflow dual media filters with variable head declining rate filtration are used. The characteristics, operating principle, and details are similar to those indicated for Designs No. 6 and 7, with the only significant modification being that the control weir which fixes the minimum water level in the filters is integrated with the chlorine contact chamber.

In the event that raw water quality is relatively good (turbidity < 20 NU), it may be feasible to provide direct downflow filtration as the only treatment process. Where this can be justified, then it is possible to use only the filter units of this water treatment plant.

2.6 Disinfection

The same disinfection unit is used in this design (see details on Plan No. 22).

Considering the direct correlation existing between turbidity and the presence of microorganisms, the need for precautions in the disinfection stage of treatment is foreseen. Therefore, a chlorine contact chamber has been incorporated with a retention time of 17 minutes and adequate hydraulic conditions (velocity gradients) to guarantee the bacteriological quality of the treated water.

2.7 Plans

The plant is provided with the respective relief spillways and discharge elements, and is entirely hydraulically operated. Design criteria, specifications, and additional details are shown in Plans No. 39 to 44.

3. CAPACITY

For structural and economic reasons the proposed design is not appropriate for small communities, and only eight capacities from 18 to 70 m^3/h have been evaluated.

4. USE RESTRICTIONS

With capacities over 70 m^3/h, for economical and functional security, it is necessary to consider at least two units at the same time.

Also for reasons of economy, the water quality limits (turbidity) should be from 100 to 1,000 NU; clearer waters should be treated with direct filtration, and more turbid waters should in addition be treated by pre-sedimentation; with high turbidities it is always recommended to study as an economical alternative the use of pre-sedimentation.

This solution could be used in countries or areas with a medium-level of development and with average operating and maintenance capabilities.

5. STATE OF TECHNOLOGICAL ADVANCE

This type of plant is a modified design of one of the first rapid filtration plants proposed by CEPIS (1970-1975) 19/, based on the results of an evaluation performed by CEPIS 74/, 75/, with the support of AID/OU and IDRC.

The new design of the flocculation units was experimentally tested in a pilot unit by DGOS in Peru 64/, prior to the elaboration of the water treatment plant design for Barranca, now under construction.

The high rate settling units are in principle similar to those used in Asia and suggested by Smethurst 48/.

One of these modules is now under construction in Peru.

10. Rapid Filtration

TYPE 9 PLANT

(Plans No. 45 to 48)

1. OBJECTIVE

Suggest an alternative water treatment plant solution using rapid filtration for communities with high levels of technological and industrial development.

2. DESCRIPTION

This type of plant has a high removal efficiency, and is appropriate for countries or regions with enough industrial development to permit pre-fabrication and high levels of operation and maintenance. In such conditions this solution will reduce construction time and costs. The following material is suggested for use in the construction of this plant:

a. Steel, using an adequate epoxy paint or PVC coating; and

b. Epoxies or polyesters, reinforced with fiberglass (reinforced plastics).

Both alternatives require medium or advanced technological levels even though the suggested construction processes are relatively simple.

2.1 Chemical feeding

The dosing tanks are similar to those described for the preceding designs.

2.2 Rapid mixing

The addition of chemicals is done by direct injection to the raw water inlet pipe. To create the necessary turbulence an orifice plate is installed at the inlet of the mixing chamber. Relatively low velocity gradients have been used (less than 929 s^{-1}).

2.3 Flocculation

The flocculation unit is mechanical. It is located at the center of the plant. The energy is obtained from an electric motor of variable velocity that activates a single vertical shaft to which paddles are attached. The flocculator is divided into four compartments, with the possibility of varying both the paddles' effective radii and the velocity. A wide range of gradients is possible to treat waters with different qualities, as indicated in Plan No. 45.

The last compartment of the flocculator interconnects directly with the settling unit through a series of orifices near the bottom.

2.4 Sedimentation

High rate upflow sedimentation is used. The settling unit has the following elements:

- Sludge blanket zone with hydraulic fluidized bed; the sludge level is controlled with a weir. The periodical discharge of the sludge is made with a manual system.

- The high rate settling unit is formed by plywood plates treated with creosote or a plastic coating.

- The outlet consists of a free-falling weir which discharges to an annular channel that surrounds the flocculator and at the same time delivers the water to the rapid filters.

2.5 Rapid filtration

This unit consists of four filters with dual media (sand and anthracite or sand and/or other materials) of variable head and declining filtration rate. The filters are interconnected at the bottom by a common clear water channel. The outlet weir regulates both the head of water on the filters and the backwash conditions. Its operation and details are similar to those of the rapid filtration plant, Type 8, the major difference being only the material to be used for construction - reinforced concrete for in-situ construction (Type 8 Plant) and steel or reinforced plastic for pre-fabricated construction (Type 9 Plant).

2.6 Disinfection

Disinfection is carried out in the treated water chamber, using a chlorine system similar to that described for previous projects and detailed in Plan No. 22 .

2.7 Corrosion control

If corrosion control is necessary for this plant (or any of the previously described plants), the required chemicals, lime or soda ash can be added to the treated water after filtration using chemical feeder units similar to those proposed for the coagulation process. The use of lime with a high degree of impurities should be avoided as far as possible, because it could be deposited in the storage tanks or distribution system.

2.8 Plans

Design criteria, specifications and additional details are shown in Plans No. 45 to 48.

3. CAPACITY

Ten modules have been dimensioned with capacities from 7.20 to 35.25 m^3/h, to serve communities of approximately 1,000 to 10,000 inhabitants.

4. USE RESTRICTIONS

Small capacity plants (less than 8 and even 12.5 m^3/h) will generally have very high costs.

These plants are able to treat waters with turbidities between 100 and 1,200 NU. When treating waters with turbidities greater than 500 NU, it would be advisable to make an economic analysis to compare the use of simple pre-sedimentation versus incrementing coagulant doses. With turbidities exceeding 1,200 - 1,500 NU, the use of simple pre-sedimentation is imposed for economic reasons. Another alternative is to increase either raw or clear water storage capacity, instead of increasing the pre-treatment.

Finally, due to the great variety in size and origin of the particles that cause turbidity, we recommend that the design overflow rates for the sedimentation and pre-sedimentation units be determined experimentally in the laboratory by jar test.

5. STATE OF TECHNOLOGICAL ADVANCE

This project is a modification of the SANEPAR-CEPIS water treatment plant 56/, based on experience obtained in the evaluation of that plant made by SANEPAR-CEPIS 74/.

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