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Slow Sand Filtration for Community Water Supply in Developing Countries   Technical Paper No. 11

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December 1978

Slow Sand Filtration for Community Water Supply in Developing Countries

A Design and Construction Manual

11

ABSTRACT

"Slow Sand Filtration for Community Water Supply in Developing Countries, A Design and
Construction Manual".
WHO International Reference Centre for Community Water Supply, Voorburg (The Hague), The
Netherlands, approx. 180 pp, December 1978.

Slow sand filtration is an excellent low-cost purification technique for polluted surface
waters in tropical developing countries. Topics discussed in this design and construction
manual include the principles of slow sand filtration, its performance and applicability,
suitable pre-treatment techniques for the removal of turbidity, and comprehensive guide-
lines for the design and construction of small slow sand filters. The manual comprises
four typical designs, with capacities between 25 - 960 m3/d, including sets of construct-
ional drawings and bills of quantities.

Key words: Low cost water treatment, slow sand filters, design of slow sand filters,
              construction of slow sand filters, rural water supply, developing countries,
              pre-treatment for slow sand filters, implementation of slow sand filters,
              application of local building materials for slow sand filters.

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WHO INTERNATIONAL REFERENCE CENTRE
FOR
COMMUNITY WATER SUPPLY

Slow Sand Filtration
for Community Water Supply
in Developing Countries

A Design and Construction Manual

PREPARED BY
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PREFACE

Although the field of water treatment offers a variety of
technological choices, only a few of them can in principle
fully meet the specific requirements of developing countries.
One such method is slow sand filtration - a simple, efficient
and reliable technique for the treatment of water. Its costs
generally lie within the resources of the community and/or
country and the skills for design, construction, operation
and maintenance are usually available locally or can be
fairly easily acquired.
Because slow sand filtration can readily be adapted to the
local situation without using imported equipment, and communities
can be actively involved in the various stages of introduction
and use of the water supply, slow sand filtration plants may
provide a long lasting service.

To demonstrate that rural water supplies can benefit from
these characteristics, a number of institutions in developing
countries have started a Slow Sand Filtration Project in
close collaboration with the IRC. The following institutions
carried out applied research programmes in the first phase
of the project: the University of Science and Technology,
Kumasi and the Ghana Water and Sewerage Corporation, Ghana;
the National Environmental Engineering Research Institute,
India; the University of Nairobi, Kenya; the Institute of
Public Health Engineering and Research, Pakistan; the University
of Khartoum, Sudan and the Asian Institute of Technology and
the Rural Water Supply Division in Thailand. A special
vote of thanks goes to all those involved in these programmes
and in particular to the Principal Investigators.
Based on the experiences gained so far in this project, this
manual has been prepared under an agreement between the IRC,
and J.C. van Dijk and J.H.C.M. Oomen of the Technical Working
Group for Development Cooperation (TWO), a non-profit organ-
ization associated with the TOOL foundation, and sponsored
by DHV Consulting Engineers.

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Appreciation is expressed for the extensive work done by the
authors in reviewing and processing the available information
and in compiling this design and construction manual.
The support given by TWO and particularly the unfailing
assistance of Messrs. J. Jonker, J. de Lange and C. Pieck is
gratefully acknowledged.

A draft version of the manual was circulated to several
reviewers. The IRC is grateful for their observations and
comments, according to which the manual has been revised. A
list of reviewers is attached to this report.

Although the manual covers a range of applications of slow
sand filtration and presents typical examples, it is not
presumed to be either exhaustive or final. It is recognized
that the practical value and accessibility of the manual can
only be proven in the field. By exposing it in its present
version to an extended readership, the IRC intends to create
an opportunity for testing and feedback of information. The
reader therefore is invited to give his comments and
suggestions for changes, corrections and additions which he
considers necessary or useful. Such contributions will be
gratefully accepted by the IRC and will be used in the
future revision of the manual.

The present document covers only briefly the topic of
operation and maintenance of small slow sand filtration
schemes. A more comprehensive description of the knowledge
and skills required for the task of the caretaker of a slow
sand filter, as well as an outline for a training programme
will be given in a separate manual to be published soon as a
companion document to the present Design and Construction
Manual.

P. Kerkhoven
Programme Officer

1.   INTRODUCTION

A safe and convenient water supply is of paramount importance
to human health and the well-being of society as a whole. A
satisfactory water supply for domestic purposes, such as
human consumption and personal hygiene, is characterized by
adequate standards regarding the availability of water, its
quantity, its quality and the reliability of the supply.
Data collected periodically by international agencies show
that a substantial part of the world's population, in particular
a great many people in developing countries, do not have
reasonable access to an adequate water supply. In recent
years many efforts have been made to improve this situation.

As part of its activities in the field of water supply, the
International Reference Centre for Community Water Supply
and Sanitation at Voorburg (The Hague) is supporting an
international research and demonstration project on Slow
Sand Filtration in order to promote this reliable and low
cost method for biological treatment of drinking water in
rural and urban fringe areas of developing countries. As the
first step, reliable information on the design, construction,
operation and maintenance of slow sand filters under local
conditions is being generated by means of a programme which
comprises applied research, field investigations and literature
studies. The programme is being carried out simultaneously
by institutions in eight participating countries (viz.
Colombia, Ghana, India, Jamaica, Kenya, Pakistan, Sudan and
Thailand) which represent a wide spectrum of developing
countries.

The Design and Construction Manual deals with the application
of slow sand filtration for biological purification of
surface water polluted by human or animal excreta.
Groundwater treatment by means of slow sand filtration, (for
example for iron removal) is not covered in the present
document.
The manual is directed towards communal systems (as distinrt
from household units) for communities ranging from 1.000 to
20.000 inhabitants.
The content, text and illustrations of the manual are primarily
attuned to a sub-professional readership, although professional
engineers may also find the manual useful.
Specific professional terminology that could not be avoided
is explained in the glossary. The use of formulas is restricted
to the minimum. Where certain calculations may be difficu..
to make in practice, "rules of thumb" are also given.
The many practical tables and graphs are meant to provide an
instrument for field officers such as field engineers,
technicians and public health officers to take initiatives
in rural and urban water development activities.

In the second chapter of the manual some background information
on domestic water consumption, water quality criteria and
water related diseases is given. The third chapter contains
a short description of the theory and purification principles
of slow sand filtration. Those who would like to obtain more
information on this subject are referred to the WHO document
"Slow Sand Filtration" by L. Huisman and W.E. Wood (1), and
the various reports on the slow sand filtration programmes
in the countries that participate in this project (2 to 7).
In the following chapters a step-by-step description is
given of the most essential activities involved in the
design and construction of a slow sand filtration unit.
In other words, starting from the need for a water treatment
unit for a community of some hundreds or thousands of

people, guidelines are given on how to choose a suitable raw
water source, how to select a proper treatment system, how
to design this system, how to choose a site, how to carry
out the structural designing, etc.

To illustrate the approach, outlined in Chapters 4 and 5,
Chapter 6 gives four typical designs for capacities varying
from 25 to 960 m3/d, including sets of construction drawings
and bills of quantities. The following types of slow sand
filters are described:
- protected sloping wall filter
- circular ferro-cement filter
- circular masonry filter
- rectangular reinforced concrete filter

Chapter 7 provides information on the implementation of
small slow sand filtration plants. Successively, the major
aspects of tendering, planning, organization and building
instructions are discussed.
In appendix 2 simple pre-treatment units that may be applied
in combination with slow sand filters are described, whereas
in appendix 3 additional information on safety chlorination
is given.
In appendix 5 attention is paid to the building materials
that can be used for the construction of slow sand filters
in developing countries.

Although it is believed that the methodology described and
the figures given in this manual are generally applicable,
it should be born in mind that in principle each raw water
source and each community requires its own custom-made water
supply.
The user of this manual should note this fact and handle the
information given with caution.
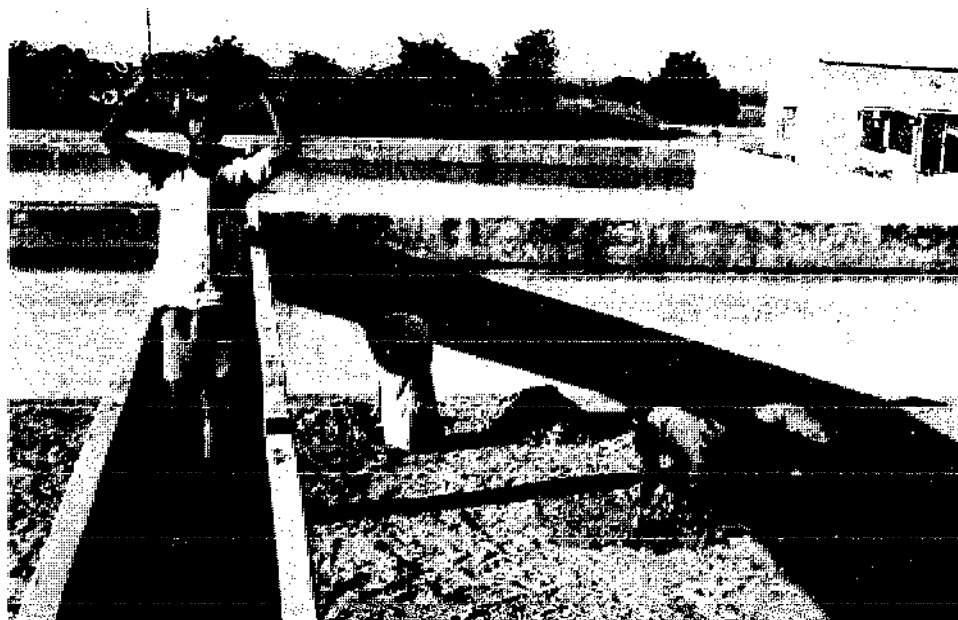
Rectangular stone masonry filters, Umrer, India
(filter in the foreground is being cleaned).
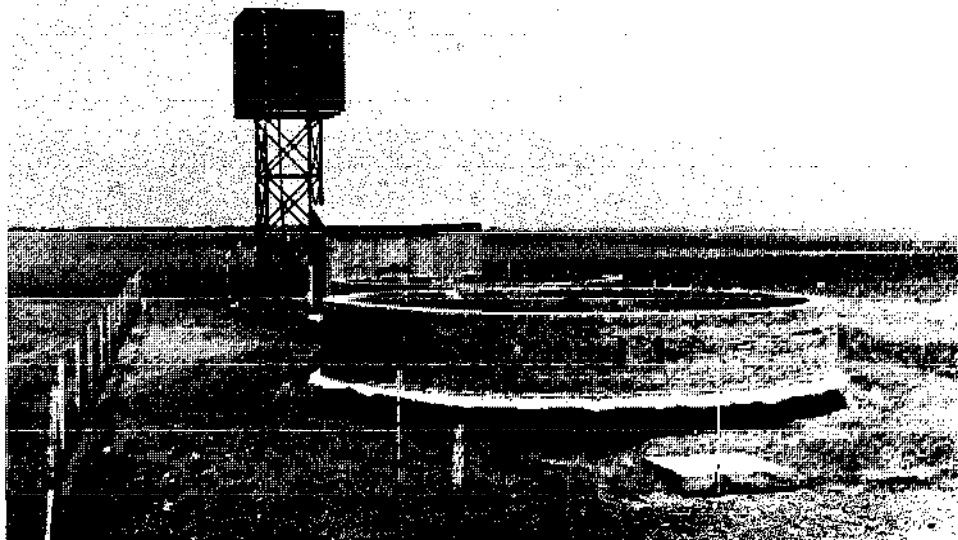
Circular brick masonry filter, Gezira-Region,
Sudan (background: pumphouse and overhead-tank).

2. WATER CONSUMPTION, WATER QUALITY CRITERIA AND WATER RELATED DISEASES

2.1. WATER CONSUMPTION

Water is indispensable to the existence of all living creatures, including man. More than 60% of the weight of the human body is water. To perform its physiological functions properly, the human body needs about 2-10 litres of water per day, depending on climate and work load. Normally about one litre of water is provided by the daily food consumption.
The human body can survive without nutrition for some seven weeks with no lasting harm to its health, but going without drinking water is fatal after only a few days.
Water is also required for other functions such as personal hygiene, washing the dishes and cooking utensils, laundry, house cleaning etc.
The total water consumption per capita per day is determined by a great number of factors such as the availability of water, its quality, the cost of the water, the income and size of the family, cultural habits, standard of living, ways and means of water distribution, climate, etc.

The WHO (10) has published data on the average daily consumption per capita for rural areas in several continents. These data are given in table 2.1.

Table 2.1.   Range of average daily consumption per capita
               (litres per capita per day) in rural areas.

Africa	15-35	Latin America &	
South East Asia	30-70	Caribbean Area	70-190
Western Pacific	30-75	World average for	
Eastern Mediterranean	40-85	developing countries	35- 90

Source: WHO (10)

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The average domestic water consumption per capita per day
for various types of supplies in rural areas of developing
countries is summarized in table 2.2.
The first column contains figures quite suitable for design
purposes, whereas the second column shows what variations
may occur in the respective consumption-figures.

Table 2.2.　　　Average daily consumption and range of daily
　　　　　　　　consumption in litres per capita for various
　　　　　　　　types of rural water supplies.

type of supply	average daily consumption	range of daily consumption
unpiped supplies	15	5- 25
piped supplies with standpipes	30	10- 50
piped connections (single tap)	50	20-100

Source: Feachem et.al. (12)

2.2.　　　WATER QUALITY CRITERIA AND WATER RELATED DISEASES

Various national and international standards exist for
drinking water quality. Most developing countries have
adopted the WHO standards (see appendix 1) and are aiming to
meet these standards to the extent possible in their actual
water supply practice. The WHO standards include water
quality criteria for physical, chemical and bacteriological
aspects. The general characteristics of good drinking water
may be formulated as follows: it must be free of pathogenic
organisms, toxic substances and an overdose of minerals and
organic material; to make it pleasant it should be free of
colour, turbidity, taste and odour; moreover, it should
contain a high enough oxygen-content and it should have a
suitable temperature.

Due to relatively high temperatures which favour the survival
chances of pathogenic organisms in the natural waters of
many developing countries, the bacteriological quality of
the water is one of the main factors in determining whether
the drinking water is safe.

But some water-related diseases are not caused by poor
bacteriological quality of the water but by a shortage of
water, or by inadequate personal and domestic hygiene.

Table 2.3 shows a classification of water-related diseases,
with examples for each category and preventive strategies
against the occurence of such diseases.

Table 2.3.   Categories of infectious water-related diseases
              and preventive strategies.

Categories of transmission mechanisms	Examples	Preventive strategy
1. Water borne infections		improve water quality
- classical	typhoid, cholera	and prevent casual use
- non-classical	infective hepatitis	of other unimproved sources
2. Water washed infections		improve water quantity
- skin and eye infections	trachoma, scabies	and water accessibility,
- diarrhoeal diseases	bacillary dysentery	improve hygiene
3. Water based infections		decrease need for
- penetrating skin	schistosomiasis	water contact, control
- ingested	guinea worm	snail populations and improve water quality
4. Infections with water related insect-vectors		improve surface water management, destroy
- biting near water	sleeping sickness	breeding sites of insects
- breeding in water	yellow fever	and decrease need to visit breeding sites

Source: White et.al. (11)

The present knowledge of tropical epidemiology indicates
that low income groups in particular have high morbidity due
to non-waterborne faecal-oral or water-washed infections as
a result of lack of water for personal hygiene or of in-
sufficient hygienic practices. As is shown in table 2.3,
first the water quantity and the accessibility and reliability
of supplies should be improved, then efforts should be made
to improve the bacteriological quality of the water. This
may be done by measures aimed at the prevention of pollution
of raw water sources with faecal material or treatment of
the water with purification methods which allow for a
considerable improvement of the bacteriological quality,
such as slow sand filtration and other disinfection methods.

Recent surveys (12) show that improved village water supplies
often have measurable effects on health only if at the same
time programmes on health education are implemented which
are geared towards improved personal and domestic hygiene.

3.   PRINCIPLES OF SLOW SAND FILTRATION

3.1.   INTRODUCTION

Slow sand filtration is a purification process in which the
water to be treated is passed through a porous bed of filter
medium. During this passage the water quality improves
considerably by reduction of the number of micro-organisms
(bacteria, viruses, cysts), by removal of suspended and
colloïdal material, and by changes in its chemical compos-
ition. In a mature bed a thin layer called the Schmutzdecke
forms on the surface of the bed. This Schmutzdecke consists
of a great variety of biologically very active micro-organisms
which break down organic matter, while a great deal of
suspended inorganic matter is retained by straining.
The slow sand filtration process is essentially distinguished
from rapid sand filtration by the Schmutzdecke and the
purification processes which take place in this thin surface
layer. The main feature of rapid sand filters is the removal
of relatively large suspended particles by physical processes.
Moreover, rapid sand filters require cleaning by a rather
complicated backwashing operation, whereas slow sand filters
are cleaned by the relatively simple periodical removal of
the top of the filter bed, including the Schmutzdecke.

In principle, the porous substance of the filter bed may be
any stable material, but in the domestic water supply field
the normal practice is to use beds of granular material.
Sand in particular is used as it is cheap, inert, durable,
widely available and gives excellent results.

3.2. DESCRIPTION OF THE BASIC ELEMENTS OF A SLOW
SAND FILTER

Basically, a slow sand filtration unit consists of a box,
containing a supernatant raw water layer, a bed of filter
medium, a system of underdrains and a set of filter regulation
and control devices (see figure 3.1):
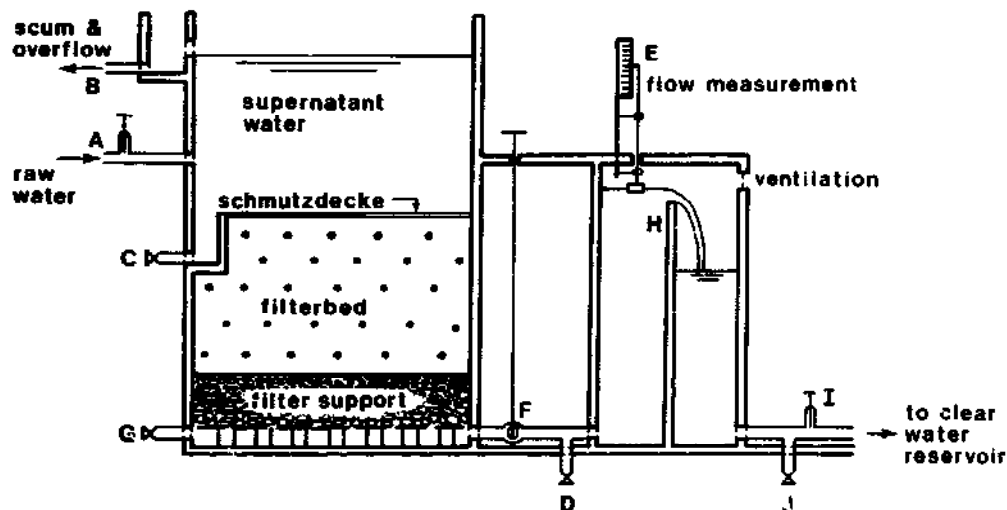
Figure 3.1.   Basic elements of a slow sand filter.

the supernatant water layer

The supernatant water layer serves two purposes:
first, it provides a head of water sufficient to make
the raw water pass through the bed of filter medium;
second, it creates a detention time of several hours for
the raw water to be treated, during which period particles
may settle and/or agglomerate or be subjected to other
physical or (bio)chemical processes. By no means,
however, should the supernatant water "reservoir" be
considered an ordinary sedimentation basin. If the raw
water contains a relatively high content of suspended
matter, a pre-treatment unit should be installed to
prevent rapid clogging of the slow sand filter (see
also paragraphs 3.4., 3.5. and 3.8.).

A suitable depth of the supernatant water layer is 1
metre (range 1-1.5 metres). Normal practice is to hold
the level of the supernatant water at a constant value,
but there are various modes of operation (e.g. declining
rate filtration[■1])).

The walls of the supernatant water reservoir must be
high enough to allow for a freeboard[■] of 0.2-0.3 m
above the water level.

For the removal of scum[■], the supernatant water reser-
voir may be equipped with a (manual) scum removal
device and a scum drain channel. The reservoir should
also contain an overflow weir which drains the surplus
water back to the raw water source.

the bed of filter medium

The filter medium should consist of inert and durable
grains. Normally, (washed) sand is chosen. It should be
free from clay and loam, and preferably free from
organic matter.

The filter medium is characterized by its effective
size[■] and uniformity coefficient[■]. Normally an effective
size in the range of 0.15-0.35 mm is selected. When no
natural sands with this characteristic are available,
the desired value of the effective size may be obtained
by mixing two types of sand. At last resort, screening
can be used.

The uniformity coefficient should preferably be less
than 2, although values up to 5 are acceptable. For a
proper functioning of the purification process a
minimum filter bed thickness of 0.6 metre should be
provided.

Since the top layer (10-20 mm) of the filter bed will
have to be removed regularly during operation (see
paragraph 3.3 and 3.7) a new filter should be

[1] ■: see glossary

provided with a filter bed 1 metre thick (range 1-1.4
metres) so that the bed will not have to be refilled
more than once every few years.

the system of underdrains

This drainage system serves two purposes; it provides
an unobstructed passage for the collection of treated
water and it supports the bed of filter medium, so that
a uniform filtration velocity over the entire filter
area is guaranteed.
The drainage system may have various configurations
such as a layer of coarse gravel or broken durable
stones, or structures of main and lateral drains, built
up from perforated or non-jointed pipes, concrete
blocks or bricks (see figure 5.12). This system of
underdrains is covered by layers of gravel.
The gravel is laid in layers commencing with large size
pieces at the bottom, reducing in size, progressively
to the top.
The gravel prevents filter bed grains from being carried
into the drainage system.
Including the gravel layers, the system of underdrains
should have a thickness of 0.5 metre (range 0.4-0.7 m),
see figure 5.12.

a set of filter regulation and control devices

The most important operations to be regulated and
controlled by valves, weirs and other devices are
mentioned below. A number of suitable appliances will
be described in paragraph 5.6.
-       delivery of raw water into the supernatant water
        reservoir up to a constant level in the filter
        box (A in figure 3.1.);

- drainage of surplus water and scum by means of an overflow weir (B in figure 3.1.);
- drainage of the supernatant water prior to filter cleaning (C in figure 3.1.);
- drainage of the water in the top layer of the filter bed (D in figure 3.1.);
- measurement of the flow rate of effluent[a] water by means of a calibrated flow rate measurement device (E in figure 3.1.);
- regulation of the filtration rate (F in figure 3.1.);
- backfilling of the filter bed with clean water after cleaning of the filter (G in figure 3.1.);
- prevention of negative pressure[a] in the filter bed (H in figure 3.1.);
- delivery of treated water to the clear water storage reservoir (I in figure 3.1.), or to waste (J in figure 3.1);

From the above description of the basic elements of a slow sand filter it can be gathered that, including the foundation (0.15 m), the total vertical height of the watertight box should be about 3 metres (range 2.8-3.5 m). Construction materials commonly used are mass or reinforced concrete, ferro-cement, natural stone or brickwork. The filter box, effluent channel and clear water storage reservoir should be watertight for two reasons: to prevent water loss and, in case of a high groundwater table, to prevent ingress of groundwater, which might contaminate the treated water.

3.3.   THE PRINCIPLE OF THE PURIFICATION PROCESS

The purification starts in the supernatant raw water layer where large particles will settle onto the filter bed and smaller particles may agglomerate to settleable flocks due to physical or (bio)chemical interactions.

Under the influence of sunlight, algae will grow, producing
oxygen which will be suitable for other purposes in the
supernatant water layer and in the filter bed.
The number of bacteria will decrease and there will be some
reduction of organic matter due to consumption by algae or
chemical oxidation.

The major part of the removal of impurities and the consider-
able improvement of the physical, chemical and bacteriological
quality of the raw water takes place in the filter bed and
especially in the Schmutzdecke at the top of the filter bed.
In this top layer abound micro-organisms such as algae,
plankton, diatoms and bacteria, which, through their tremendous
biological activity, break down organic matter.
A great deal of inorganic suspended matter is moreover
retained by straining.
As the water passes through the bed it is constantly changing
direction so that particles carried by the water come into
contact with the filter grains by various transport mechanisms.
The grains become covered with a sticky layer of mainly
organic material which in turn absorbs these particles by
various attachment mechanisms. At the same time the active
micro-organisms (bacteria, protozoa, bacteriophages) in the
sticky layer around the grain feed on the impurities caught
as well as on each other. In this way, degradable organic
matter, including bacteria and viruses of feacal origin, is
gradually broken down and converted into water, carbon
dioxide and harmless inorganic salts. The life-filled zone
where these purification mechanisms take place extends to
about 0.4-0.5 m down from the surface of the filter bed, but
it gradually decreases in activity downwards as the water is
purified and contains less organic matter and nutrients.
At greater depth in the filter bed the products of the
biological processes are further removed by physical processes
(adsorption) and chemical action (oxidation).

The transport, attachment and purification mechanisms described
will only function effectively for the water to be treated
if a sufficient detention time in the filter bed is allowed.
Especially, when slow sand filtration is the main treatment
process, the rate of filtration should be kept at a value of
0.1 and 0.2 metre/hour (or 0.1-0.2 m3/m2 bed area per hour).
Another important parameter for the purification process is
the oxygen content of the water. The activity of the bio-
mass will decrease considerably if the oxygen content of the
water in the filter medium falls below 0.5 mg/l. If anaerobic
conditions occur, various obnoxious impurities may be added
to the water by the bio-mass.
Such occurences may be prevented by aeration[a] of the raw
water (see paragraph 3.8), pre-sedimentation of the raw
water (see appendix 2) or a recycling of part of the aerated
effluent to the supernatant water reservoir.
An oxygen content of more than 3 mg/l in the filter effluent
is the normal goal. Since water with this oxygen content may
not be very suitable for public supplies, some additional
aeration of the filtered water is required.
For this purpose a simple overflow weir which suits a dual
purpose with respect to aeration is installed in the effluent
channel. The weir increases the oxygen content of the filtered
water and simultaneously decreases the content of carbon
dioxide and some other obnoxious dissolved gases which have
been added to the water as by-products of the bio-chemical
processes. For enhancement of this process, the weir chamber
must be provided with a ventilation shaft.

The effluent weir has two more important functions: it
prevents negative pressure in the filterbed by ensuring a
minimum overflow-level slightly above the top-level of the
filter bed, and it makes the operation of the filter bed
independent of fluctuations of the water level in the clear
water reservoir.

3.4. PERFORMANCE OF SLOW SAND FILTERS

The effect of the purification process on the water quality
depends on many factors, such as raw water quality, the rate
of filtration, grain size of the filter medium, the temperature
and the oxygen content of the water. For normal operational
conditions, the average performance of slow sand filters
with regard to the removal of certain impurities is summarized
in table 3.1.

Table 3.1.   Performance of slow sand filters.

parameter	purification effect
organic matter	slow sand filters produce a clear effluent, virtually free from organic matter
bacteria	between 99% and 99.99% of pathogenic bacteria may be removed; cercariae of schistosoma, cysts and ova are removed to an even higher degree; E.Coli[B] are reduced by 99-99.9 %
viruses	in a mature slow sand filter, viruses are virtually completely removed
colour	colour is significantly reduced
turbidity	raw water turbidities of 100-200 NTU[B] can be tolerated for a few days only; a turbidity more than 50 NTU is acceptable only for a few weeks; preferably the raw water turbidity should be less than 10 NTU; for a properly designed and operated filter the effluent turbidity will be less than 1 NTU

The performance of slow sand filters for any specific raw
water source may be tested by means of a small pilot plant,
e.g. consisting of oil vessels.

Algae may play a positive role in the performance of slow
sand filters. They are able to build up cell material from
simple minerals such as water, carbon dioxide, nitrates and
phosphates, thereby producing oxygen which in turn is
beneficial to other bio-chemical processes. Algae can also
consume organic matter and convert part of it into more
biodegradable cell-material; their presence may improve the
quality of the Schmutzdecke.

On the other hand, too high an algae content in the super-
natant raw water may disrupt the proper functioning of the
filter due to clogging or due to the emergence of anaerobic
conditions when large amounts of algae die off. Regular
harvesting of algae or shading of the filters are good
methods to cope with these problems.

Certain types of algae have a detrimental effect on the
filter performance, such as short filter run periods notwith-
standing proper design criteria. If such algae develop,
shading of the filters may be required.

Another consequence of the growth of algae is a daily
variation in the oxygen consumption and thus the effluent
oxygen content.

This is explained by the fact that in daylight algae
produce more oxygen than they consume, but at night the
reverse is the case.

Therefore the oxygen content of the effluent will be at a
minimum at daybreak, while it will be at a maximum at the
end of the afternoon.

3.5. APPLICABILITY AND LIMITATIONS OF SLOW SAND FILTERS

Slow sand filtration is an efficient method for the removal
of organic matter and pathogenic organisms.

It is therefore a particularly appropriate treatment method
for surface waters containing unwelcome quantities of such
impurities. The turbidity of surface waters may, however,

limit the performance of slow sand filters, so that quite
often some pre-treatment may have to be applied; see table
3.1 and the last two paragraphs of this chapter.

Slow sand filters have some limitations as they require a
large area and a large quantity of filter medium. Moreover
it may be necessary to install expensive roof structures to
prevent the entrance of sunlight, if the development of
unacceptable amounts or certain types of algae is expected.
Another limitation may be sudden changes in raw water
quality which can upset the performance of biological
filters, for example a high turbidity content during the
rainy season (or possibly toxic industrial wastes).
Apart from the availability of suitable filter medium and
the occurrence of high turbidities during certain periods,
the above mentioned limitations normally do not apply to
rural and urban fringe areas of developing countries or can
be obviated without serious constraints.

3.6.   ADVANTAGES OF SLOW SAND FILTERS

In comparison with various other treatment methods designed
for the removal of organic matter, pathogenic organisms,
turbidity and colour, slow sand filtration has many advantages.
It is the only known unit-operation which accomplishes such
a high degree of simultaneous improvement of the physical,
chemical and bacteriological quality of raw water.
In developing countries there are a number of special advantages,
such as:
-      the simplicity of design, construction and operation
       enables the application of locally available materials
       and skills with limited technical supervision; only
       common pipework and appliances are required and no
       special equipment or instrumentation is needed

- if sufficient filter bed materials are available the
  cost of construction is relatively low
- imports of material and equipment can be almost neglig-
  ible and, apart from a possible disinfection or safety
  chlorination of effluent, no chemicals are required (if
  for highly turbid waters advanced pre-treatment tech-
  niques such as flocculation/coagulation[8] are being
  used, considerable amounts of chemicals may be required)
- operation and maintenance can be carried out by semi-
  skilled labour; a slow sand filter does not require
  back-washing (as compared to a rapid sand filter)
- power may only be required to pump raw water to the
  supernatant water "reservoir"; the filtration process
  is carried out by gravity; no other power-driven
  mechanical parts are present
- fluctuations can be accommodated, provided turbidity
  does not become excessive for a long period
- no wash water is required for the cleaning of the
  filter, therefore some water is saved in comparison
  with other filtration systems
- sludge handling causes no problems; the sludge is small
  in quantity and has a very high dry matter content.

3.7.   OPERATION AND MAINTENANCE OF SLOW SAND FILTERS

Provided that a slow sand filtration unit has been well
designed and constructed, it requires only a simple routine
of operation and maintenance. Except for some of the physical,
chemical and bacteriological analyses of samples of the
effluent water, all activities of operation and maintenance
can be carried out by local manpower. These operation and
maintenance activities are comprehensively described in a
companion document (9).

Periodically, comprehensive analyses of water samples may be
carried out by the district medical authorities, although
the operator can be taught to carry out some simple standard
tests by himself. In this respect reference is made to the
WHO Monograph No 63 (13).

Some of the main operation and maintenance activities are
listed below:

—   *initial commissioning of a filter*

When the construction of the filter has been completed,
the filter bed is charged with clean water from the
bottom of the filter to drive out the air bubbles
present in the interstices of the sand.
When the level of the supernatant water reaches well
above the sand bed (0.1 m), raw water may be admitted
through the raw water inlet, in such a way that no
turbulence is caused in the supernatant water (see
paragraph 5.3.). By the time the supernatant water has
reached the design level, outlet valve D (see figure
3.1) is opened, and the effluent is run to waste or to
another filter at a rate (controlled by the filter
regulating valve F) of about one quarter of the normal
filtration rate.
The filter must now be run for a few weeks to enable
the formation of the Schmutzdecke and the sticky
layers around the filter bed grains, the so-called
"ripening process".
During this process the filtration rate is gradually
increased until it reaches the design filtration rate.
After comparative physical, chemical and bacteriological
analyses of the raw water and the filtered water have
shown that the filter is working properly, the drain
valve D may be closed and the effluent directed to the
clear water tank by opening valve I.

operation of the filter regulating valve

After a proper ripening process the filter will
operate sucessfully for several weeks with the regulating
valve F almost fully closed.

Then, as the Schmutzdecke becomes clogged, the valve
is gradually opened, a little each day, to compensate
for the head loss in the Schmutzdecke and to maintain
the flow rate at a constant value.

The flow rate may be measured by a venturi meter[B]
immediately upstream of the regulating valve or by a
floating indicator device in the upstream section of
the weir chamber (see figure 3.1 and paragraph 5.6.)

Floating effluent weir

A floating effluent weir (see figure 3.3), situated in
a weir chamber having the same height as the filter
box, may substitute both the flow rate measurement
device and the filter regulating valve as indicated in
figure 3.1.

The flow rate of a floating weir is determined by the
size of the inlet and the immersion depth of the
inlet. By adjusting the immersion depth of the inlet,
the floating weir will regulate the effluent flow rate
to a pre-set value, while the hydraulic resistance of
the filter regulating valve is substituted by a higher
level of the filtered water in the weir chamber.

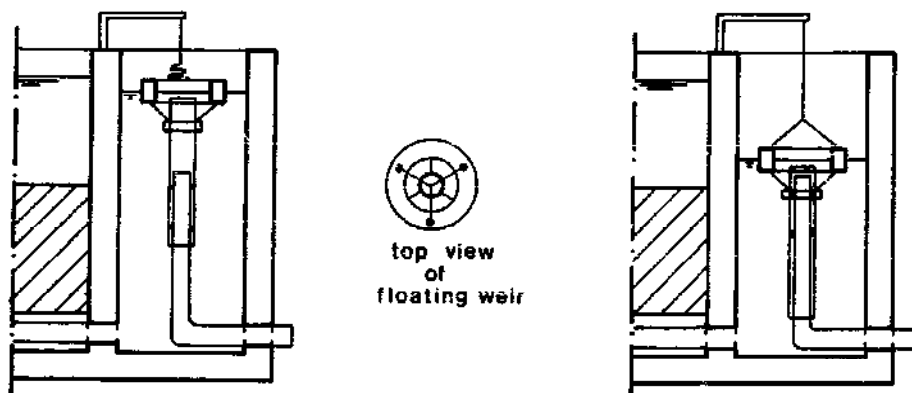top view
of
floating weir

Figure 3.3.   The functioning of a floating effluent
               weir.

Normally, the floating weir should be provided with a
small chain which prevents the weir from dropping
below a certain level (minimum level of the crest of
the effluent weir). The arrival at this level indicates
that a filter run period has come to its end. The
chain is also used to shut down the filter by pulling
the floating weir up to the top of the weir chamber.
To make this method of operation independent of the
level of the treated water in the clear water tank,
another effluent weir should be installed in the inlet
section of the clear water tank. Both the crest of
this effluent weir and the inlet of the floating weir,
at its minimum admitted level, should be situated some
distance (e.g. 0.2 m) above the top level of the
filter bed to prevent negative pressure.
The hydro-static head of water in the transport line
of the floating weir is determined by the level of the
crest of the effluent weir just mentioned. To enable
backfilling of a filter after a cleaning operation,
the length of the chain attached to the floating weir
should be extended by some 0.2 m. In this way, filtered
water from other filters will flow through the floating
weir in the reverse direction and flow into the filter
bed from the system of underdrains.

cleaning of the filter

When, after an operation period of several weeks or
months, the regulating valve is fully opened and the
rate of flow starts to decrease, the resistance of the
Schmutzdecke has become too high and the filter must
be cleaned. The raw water inlet valve A is closed and
the level of the supernatant water is allowed to drop
by continuing the filtration process for some hours.

The remaining supernatant water is drained by opening the
drain valve C. Finally the water level in the filter bed is
lowered to about 0.2 metre below the surface of the bed by
opening the drain valve D.
The Schmutzdecke is then carefully removed by using
flat-nosed shovels, the cleaning period being as short
as possible to prevent deterioration of the filter bed
and possible damage to the bed by scavenging birds.
The Schmutzdecke, and the sand removed with it, may be
tipped or be washed for re-use.
When a filter is being cleaned, the rate of filtration
through the remaining filters has to be suitably
increased to obtain the normal output from the plant.
The procedures to be followed for the start-up of a
cleaned filter ("re-ripening period") are similar to
those applied for the initial commissioning of a new
filter, although the periods required for both back-
filling (a few hours) and re-ripening (a few days) are
much shorter than the initial commissioning period.

regulation of the supernatant water level

Under normal operational conditions the level of the
supernatant water must be kept at a value as constant
as possible.
This may be done by a hand-controlled gate valve A, or
an overflow weir B which leads the surplus water back
to the raw water source. Preferably a combination of
the valve and the overflow weir is adopted.
If the raw water is fed to the filter unit by pumping,
the quantity of overflow water should be kept to a
minimum to save on energy costs.

level regulation of the effluent weir

The crest of the effluent weir H should not be below

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a level slightly above the surface of the filter bed
to prevent the build up of negative pressure in the
filter bed.
If the effluent weir consists of a rigid structure
(see figure 3.1), special attention is required during
the (re-)sanding of the filter to prevent the top
level of the filter bed from reaching above the crest
of this weir.

resanding of a filter

After several years of operation (approximately 3-4
years) and about 20-30 scrapings, the filter bed
reaches its minimum permissible thickness and new or
washed filter medium must be brought in to raise the
bed to its original depth. The new filter medium
should be placed under the top 0.3-0.5 m of old filter
medium by a so-called "throwing-over" process. See
figure 3.2.
By doing so, the top layer which is richest in micro-
biological life is replaced at the top of the filter
bed which will enable the re-sanded filter to become
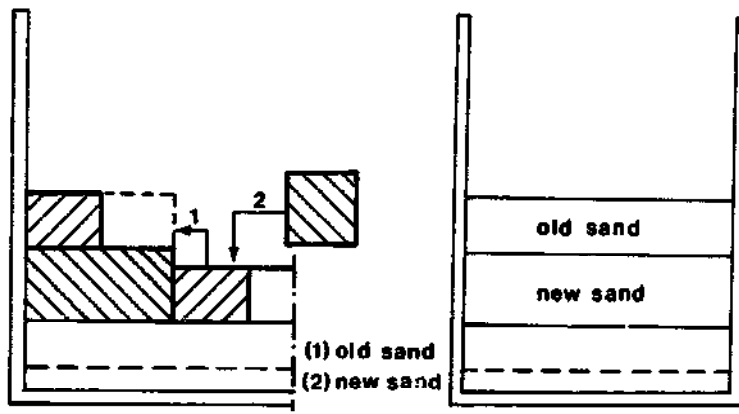operational with a minimum re-ripening period.

Figure 3.2.   Throwing-over process.

ALTERNATIVE MODES OF OPERATION

Declining rate filtration

Declining rate filtration will start as soon as the raw
water feedline to the supernatant water "reservoir" is
closed, while the filter regulating valve is kept at
the same position. The supernatant water will now
be filtered at a continuously declining filtration
rate due to a continuous reduction of the head of the
supernatant water.
This mode of operation may be applied during the night
and allows for savings on labour costs and capital
investment costs.
If declining rate filtration is applied, the minimum
level of the crest of the effluent weir should be
0.2 m above the top of the filter bed. Such a provision
prevents a too shallow depth of the supernatant water
at the end of a declining rate filtration period. If
this water depth should fall below 0.2 m, it could
cause unwelcome events such as damage to the Schmutzdecke
by scavenging birds, the filter bed running dry due
to evaporation, etc.
After a period of declining rate filtration, the
supernatant water reservoir will have to be refilled
to its normal level to allow for filtration at the
normal designed filtration rate. This refilling should
be done as quickly as possible (without disturbing the
Schmutzdecke!) to make maximum use of the production
capacity.
Normally a period of about one hour may be allocated
to realize this refilling operation. Raw water pumps
and possible pre-treatment units should be designed in
accordance with this mode of operation.

Intermittent operation

At intermittent operation the filtration process is
stopped completely during certain periods (e.g. night-
time). This means that not only the feedline to the
supernatant water reservoir is closed, but also the
effluent line to the weir chamber. For this purpose it
is recommended that an extra valve be installed in the
effluent line, so that the filter regulating valve may
be kept in its operating position and will function
properly as soon as the filtration process is restarted.

There are still some other methods of operation, but it is
beyond the scope of this manual to discuss all of them.

3.8.   PRE-TREATMENT AND POST-TREATMENT IN COMBINATION
WITH SLOW SAND FILTERS

Pre-treatment

For slow sand filters pre-treatment is indispensable if the
turbidity of the raw water has an average value of more
than 50 NTU for periods longer than a few weeks or values
above 100 NTU for periods longer than a few days.

The simplest and most appropriate pre-treatment systems are
river bed filtration, storage and plain sedimentation.
Other suitable pre-treatment techniques are rapid "roughing"
filtration and horizontal-flow coarse-material pre-filtration
(6, 7).
In this paragraph these pre-treatment systems will be
briefly discussed; more detailed information will be given
in appendix 2.

River bed filtration may be applied for the treatment of raw waters with rather low turbidities (10-20 NTU); turbidities up to 200 NTU can be tolerated for short periods. The purification principle is based on the removal of suspended solids in a bed of granular filter material, situated in the river bed.

Storage should be applied if the average annual turbidity is more than 1000 NTU. Suspended matter is removed by natural settlement and biological processes.

Plain sedimentation may be applied for average annual raw water turbidities of 20-100 NTU. For this treatment system turbidities up to 400 NTU for periods not longer than a few weeks are acceptable.

Rapid "roughing" filtration may be successfully applied as a pre-treatment method for raw waters with turbidities of 20-100 NTU, if suitable materials such as coconut fibre or coarse gravel are easily available.
Such a filtration can be carried out in a filter box similar to the slow sand filtration box. In this case the coconut fibre material or coarse gravel will function as filter medium.

Horizontal-flow coarse-material pre-filtration may be applied for raw water turbidities up to 150 NTU.
As filter media coarse gravel or crushed stones are applied; the filter box is comparable to the one used for plain sedimentation.

Aeration of the raw water, or re-cycling of oxygen enriched effluent water to the supernatant water reservoir, will be necessary if the oxygen consumption in the filter bed leads to anaerobic conditions. Aeration of the raw water by means of a simple overflow weir prior to entering the supernatant water reservoir may be sufficient.

Post-treatment

The only post-treatment which may be required for the effluent of a slow sand filter is safety chlorination, which is mainly aimed at the prevention of aftergrowth of bacteria in storage tanks or the distribution system. It should also be applied as a precaution if the raw water source is heavily polluted with organic matter of faecal origin, for instance for raw water with an E.Coli content of 10000/100 ml or more (disinfection).
An example of a suitable chlorination system is described in Appendix 3.

3.9. A GUIDE FOR THE SELECTION OF A WATER TREATMENT SYSTEM

In the previous paragraphs we have discussed topics such as the performance of slow sand filters, their advantages and limitations, and various techniques for pre-treatment and post-treatment. It may be concluded that slow sand filtration represents an excellent technique for a substantial improvement of the physical, chemical and bacteriological quality of most of the surface waters in tropical developing countries. On the other hand, it has been indicated that slow sand filters are sensitive to some raw water quality parameters. In this respect the turbidity of the raw water is of crucial importance to the design of the total treatment system (in particular choice of pre-treatment unit). Another important parameter for the total treatment system (in particular choice of post-treatment system) is the bacteriological quality of the raw water. In this respect, the E.Coli is used as an indicator-organism.
On the basis of the two mentioned parameters, turbidity and E.Coli content, table 3.2 gives a procedure for the selection of a water treatment system incorporating slow sand filtration.

Table 3.2.   Guide for the selection of a water treatment
                system, incorporating slow sand filtration.
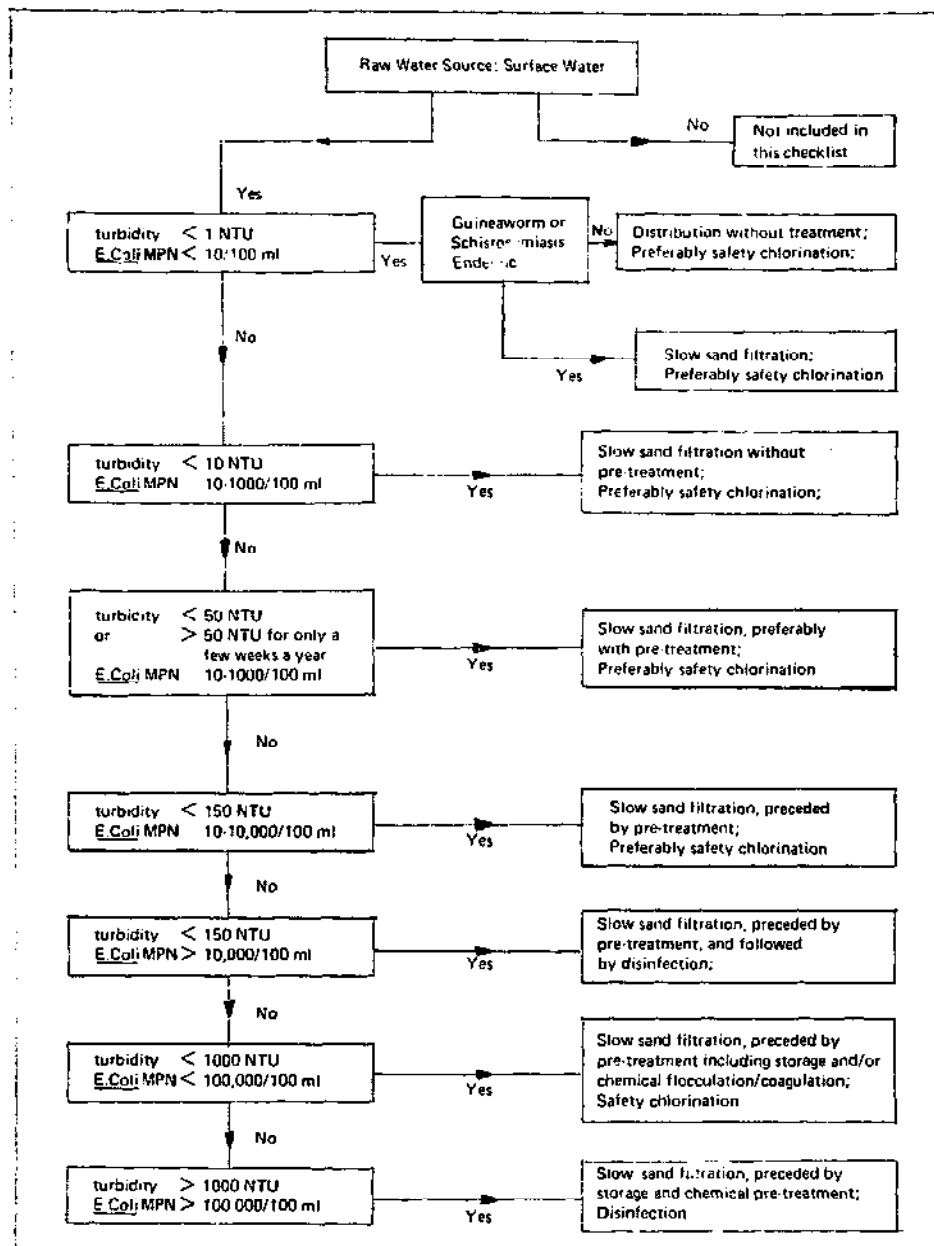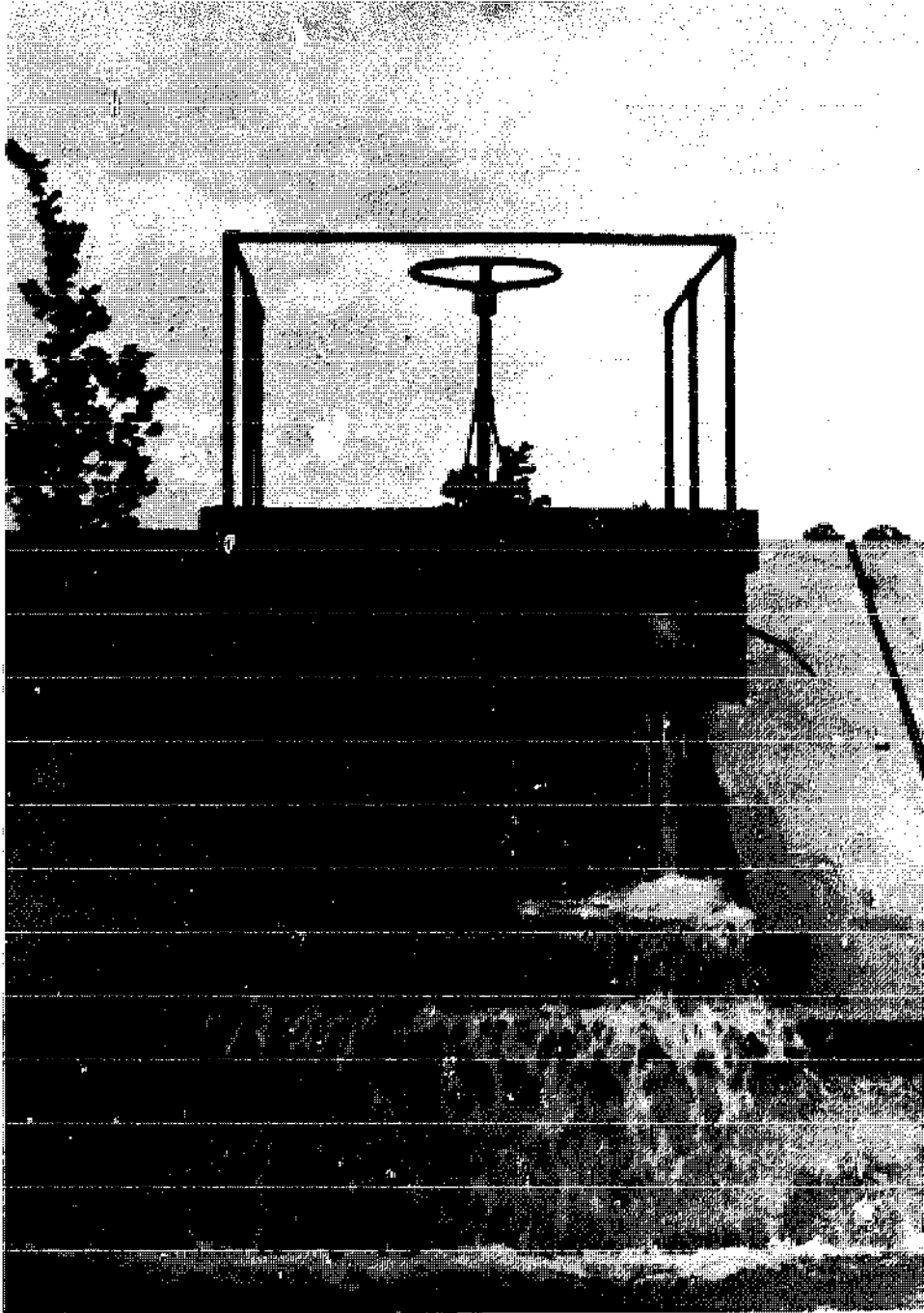
Inlet structure of a slow sand filter, Kranuan, Thailand.

4. THE DESIGN OF SLOW SAND FILTRATION PLANTS

4.1. INTRODUCTION

The primary objectives of a water supply system are, as
mentioned before, availability, quantity, quality and
reliability. A sound water supply system should provide the
population with water of good quality and in sufficient
quantities and with maximum reliability.

It is the designer's job to convert these theoretical
objectives into a realistic and economic design, taking
into account local circumstances and potentialities.

When working on this responsible job, the designer will
constantly have to make decisions on important items, most
of which are concerned with:

1. the set-up of the water supply system, i.e. the choice
   of raw water source, treatment method and distribution
   system

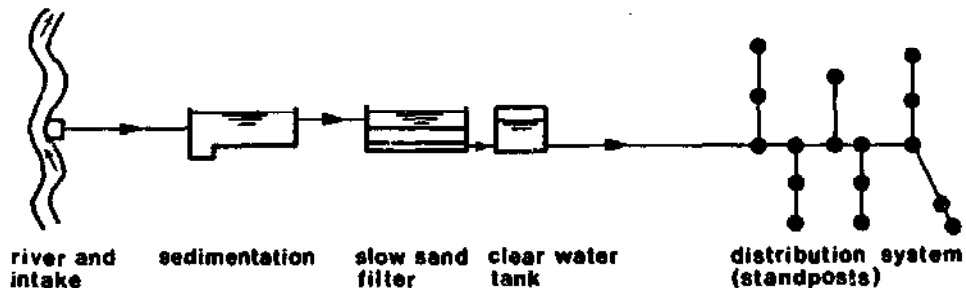| river and intake | sedimentation | slow sand filter | clear water tank | distribution system (standposts) |

Figure 4.1.   Set up of a water supply system

2. the dimensioning of the water supply system, i.e. the
   determination of the lay-out and size of the various
   elements and the plant as such.

Figure 4.2.   Dimensioning of slow sand filters

3. the specification of the elements; i.e. the detailed
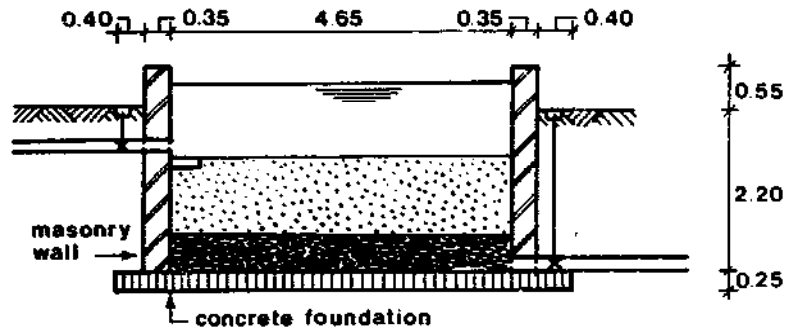   design of constructions and appurtenances

Figure 4.3. Specification of slow sand filter

In practice the set-up and dimensioning of a water supply
system usually form the preliminary design, which may be
used for raising funds and planning and organisational
purposes. These parts of the design will be dealt with in
this chapter. In the next chapter the specification of the
elements, which may eventually lead to the final design,
will be elucidated.

4.2. GENERAL DESIGN CRITERIA

The design of a slow sand filter and indeed of any element
of a water supply system is a complex matter. Huisman and
Wood (1) got to the root of the matter when stating "slow
sand filtration still is an art, more than a science". And
an art, unlike a science, cannot be taught by giving rules
and regulations.
Nevertheless it is possible to indicate an approach, which
may succesfully be followed when designing a water supply
system, incorporating slow sand filtration.
In general, the following criteria apply:

1. During the projected design period[a] the quality of the
   supplied water should under no circumstances deteriorate
   below certain limits, as indicated in chapter 3.
   This implies that provisions should be made to deal
   with a (possible) future deterioration of raw water

quality, breakdowns of critical elements in the
system and malfunctioning of the treatment system due
to operational failure or unfavourable conditions
(e.g. low temperatures). In this respect a slow sand
filter has favourable characteristics i.e. a rather
high flexibility with regard to variations in the raw
water quality and self-regulating operation.

2. The capacity of the water supply should be such that
at no time in the design period (serious) water shortages
occur. This is a less stringent condition than the
first, because whereas the deterioration of water
quality could immediately bring about the outbreak of
epidemic diseases, the consequences of shortage of
water would appear to be limited to some inconvenien-
ce. The population may, however, be tempted to draw
their water from unprotected sources, so the reduction
of water quantity should also be limited to the minimum.
This may lead to the incorporation of spare units,
water storage tanks and possibly high level service
reservoirs[■] etc.

3. The applied technology should be such that operation,
maintenance and preferably repair are within the
competence of the local population.
In developing countries this may mean the rejection of
advanced techniques and the incorporation and develop-
ment of appropriate technology. Vulnerable chemical
dosing equipment should be waived in favour of robust
hydraulic feeders[■] or (still better) be made superfluous
by a well-considered choice of raw water source and
treatment method.
Slow sand filtration is a very good example of a
reliable treatment method which falls within the
capabilities of the population of most villages in
developing countries.

4. The construction costs of the system should be minimal
   within the constraints of high quality and lifetime of
   the components.
   This means economical use of materials, particularly
   those which have to be imported.
   Although labour costs may of course influence the
   construction costs, it is felt that this item should
   be dealt with separately. In self help projects for
   instance, labour is provided without charge by the
   population that will benefit from the results.

5. Operating costs of the system should be minimal.
   This is another reason for omitting where possible
   dosing of chemicals. Furthermore an optimal hydraulic
   design will result in lower pumping costs. Operators'
   wages may put a heavy strain on the funds of small
   communities. It may therefore be decided to operate
   the intake and treatment works for only 8 or 16 hours
   per day (1 or 2 shifts, see also paragraph 4.3). In
   this case, a large service water reservoir, situated
   at sufficient height, will be necessary to ensure a
   continuous supply.

6. The mode of construction of the system should prefer-
   ably be such that it is within the competence of local
   contractors.
   Use of prefabricated construction elements and advanced
   construction expedients should be avoided, especially
   in small scale programmes.
   Appropriate standards for steadiness and accuracy
   should be imposed.

It will be clear that these conditions merely form a frame-
work, in which the designer may and must make many design
decisions.
A suitable approach to the design of water supply systems
is illustrated in the following paragraph.

4.3.   DESIGN EXAMPLE

Let us consider a village of say 1200 inhabitants with no
public water supply system. People fetch their water in
jars and buckets from the neighbouring river. As the river
is polluted with animal and human excreta, infectious
diseases occur frequently and the need for a safe water
supply system is expressed.
The first important factor to be determined when designing
the new water supply system is the design period. This is
the period during which the designed system must be able to
provide the population with water of adequate quality and
quantity. This period should not be too short (e.g. not
shorter than 10 years) for reasons of undisturbed operation
and not too long (e.g. not longer than 50 years) for reasons
of predictability and economy.
For our village the design period is set at 15 years, so
after a planning and construction period of 2-3 years the
plant's capacity will be adequate for at least 12-13
years.

   step 1: design period: 15 years

The design period may differ from the economic[a] or physical[a]
lifetime of the various elements of the construction. In
general, the following depreciation periods[a] are accepted,
although financing organizations may - for economic reasons -
demand much shorter capital-return periods[a]:

construction	elements	25 years
mechanical	elements	15 years
electrical	elements	15 years

Having established the design period, the design population
must be determined, where possible using population projection

studies. If demographical data are available, population
growth figures and projections for the design period can be
derived from them, taking into account socio-economic
factors such as family planning, migration, changes in
prosperity and changes in medical care. For our village no
such data are available, but on the basis of inquiries and
estimates of both birth and death rates and migration
figures, the design engineer arrived at a yearly growth
rate[B] of 3%.
From the following table the population growth factor[B] can
be determined as 1.56 (for a design period of 15 years).

Design period	Yearly growth rate (%)		
(years)	2	3	4
10	1.22	1.34	1.48
15	1.35	1.56	1.80
20	1.49	1.81	2.19

This means the population is likely to increase in 15 years
to 1.56 x 1200 = 1872, say 1900

step 2: design population: 1900

Next, the design water demand has to be established. In
chapter 2 the factors influencing the water demand have
already been discussed. A distribution system with various
standpipes is chosen for our village and the water consumption
is estimated at 30 1/cap per day (maximum day[B] in design
period). Including losses and wastage, estimated at 33%,
the water demand will be 40 1/cap per day. The design daily
water demand can now be calculated as follows:

1900 (cap) $*$ 40 (l/cap,d) = 76 m3/d

step 3a: design daily water demand: 76 m3/d

The design hourly water demand is estimated at 20% of the design daily water, i.e. 8 l/cap per hour (maximum hour[B] is design period). This figure is important with regard to the design of the clear water tank and distribution pipes. The design hourly water demand can be calculated at:

1900 (cap) $*$ 8 (l/cap,h) = 15.2 m3/h   say 15 m3/h

step 3b: design hourly water demand: 15 m3/h

For our village, on the basis of estimates of the water used for cooking, washing etc., the designer has come to the following daily pattern of water use.
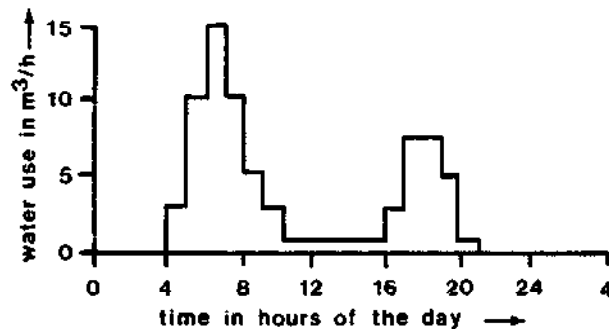

Figure 4.4.   Daily pattern of water use

Having established the design water demand, the set-up of the water supply system has to be further elaborated. A proper raw water source and suitable treatment methods have to be chosen in accordance with the given prerequisites. This procedure has already been outlined in chapter 3. From information concerning geological properties of the subsoil and a few test boreholes made with simple equipment

(see appendix 4) it was found that for our village no
groundwater was available at reasonable depths, so it is
decided to draw the water for the public supply system from
the neighbouring river.

The river takes its rises in the highlands and, although
hydrological readings are not available, it is estimated
that the minimum flow during dry season will not drop below
400 l/sec. The proposed maximum drawoff of 15 m3/h will
therefore be only 1% of the minimum flow, which is quite
acceptable.

step 4: water source: river

From information gathered from authorities upstream it is
found that the water quality parameters are all within
acceptable limits for human consumption (see appendix 1)
with the exception of turbidity (5-100 NTU) and microbiolo-
gical parameters (MPN[B] E.Coli 100-1000/100 ml), while the
Chemical Oxygen Demand[B] (COD) is also fairly high (4-8
mg/l). A number of samples taken at the site of the proposed
water intake (one at low flow and one at high flow) and
sent to the district water authorities for chemical and
microbiological analysis, confirm these findings.

On the basis of the checklist described in chapter 3.9, it
is decided to treat the riverwater by means of plain
sedimentation, followed by slow sand filtration. This type
of treatment is believed to lower the turbidity to less
than 1 NTU and the COD to 2-4 mg/l, while the microbiological
parameters will adhere to drinking water standards.

step 5: treatment system: plain sedimentation and
                          slow sand filtration

The site of the water intake will now be determined, taking
into account fluctuations in water quality due to the

occurrence of plug flows in the river and stability of the
river bank (a location on the inside of a river-bend will
be favourable, as flow velocities are low and suspended
particles will settle). A sufficient water depth should be
available at all times, which may restrict the possible
site locations. Taking into account the possible contamination
of the river water by excreta from the village, the intake
for the treatment unit will be located upstream from the
village.

step 6: intake location: upstream from the village

The location of the treatment works is the next thing to
consider. Factors which obviously influence this are the
location of the water intake and the distribution system.
However, availability of a suitable area and topography,
soil properties and ground water level are even more important
factors.
Compressibility and bearing capacity are the soil properties
which determine the mode of foundation. It will be clear
that foundation on piles and piers must be avoided if
possible.
In appendix 4 a description is given of some simple soil
investigation methods that may be used when designing a
water treatment plant.
A high ground water table (i.e. close to soil surface) will
make excavation difficult and drainage either in the open
or by means of filter wells will be necessary. Needless to
say this will add to the complexity and cost of the design.
Further, a high ground-water table has the disadvantage
that special provisions must be taken to prevent both
pollution of the treated water by ground water and forcing
up of the construction by water pressure. In the following
chapter the influence of soil properties and ground water
table on the design of the filter box and appurtenances is
elucidated further.

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Our village was fortunate enough to find a suitable area for the treatment plant near the water intake, so the plant operator(s) can also easily look after the raw water pumps.

step 7: site location: near intake

The layout of the treatment plant must now be considered. The most suitable layout depends on many factors, the most important being plant size, construction materials used and possibility of future extensions. Possible configurations are given in chapter 6.

The dimensioning of the filters is rather simple once the mode of operation and the design filtration rate, usually set at 0.1 m/h, are established.

Continuous operation for 24 hours per day will of course provide the maximum production per filter bed, but on the other hand 3 shifts will be necessary so the costs of the operators' wages will be relatively high. It is therefore recommended that the costs of extra filter bed area should be balanced against the costs of the operators' wages (in case no pumping is necessary, continuous operation with only 1 shift may be possible). Another item of importance in this respect is the consideration that the filters may be operated for part of the day at a so-called declining rate filtration. This is the case when the operator closes the raw water inlet valve at the end of his shift and shuts down the raw water pumps, but keeps the filter outlet valve open.
The supernatant water will drain through the filter at a continuously declining rate. Assuming a filtration rate of 0.1 m/h and a supernatant water level of 0.9 m above the crest of the effluent weir it can be calculated that after 8 hours the water level will have dropped by about 0.5 m and after 16 hours by about 0.7 m. This means an extra water production of 0.5 m3/m2 per day for 8 hours of declining rate filtration and 0.7 m3/m2 per day for 16 hours. The

required filter bed area can be reduced accordingly.
In the following table, the required filter bed area and
the number of operators are given for the design daily
water demand of 76 m3/d with various modes of operation.

Mode of operation	Required filter bed area	Number of operators
3 shifts (24 hours operation)	31.7 m2	3
2 shifts and declining rate filtration during night-time (8 h)	36.2 m2	2
2 shifts	47.5 m2	2
1 shift divided in four hours during morning and four hours during evening and declining rate filtration in between (16 h)	42.2 m2	1
1 shift and declining rate filtration during night-time (16 h)	50.7 m2	1
1 shift	95.0 m2	1

The filter bed area required may be calculated by the
following general formula:

$$X = \frac{Q}{0.1 \times a + b}$$

where: X =   required filter bed area (m2)

Q =   design daily water demand (m3/d)

a =   number of daily production hours at normal
operation (i.e. filtration rate of 0.1 m/h)

b =   0.5   if daily period of declining rate
filtration amounts to 8 consecutive
hours

= 0.7   if daily period of declining rate
         filtration amounts to 16 consecutive
         hours

= 0   if no declining rate filtration is
         applied

For our village, it is decided to operate the plant with 1
shift and declining rate filtration during the night. As a
rule of thumb it may be stated that for small plants (i.e.
smaller than 300 m3/d) this mode of operation will be most
appropriate. For plants with a capacity between 300 and
600 m3/d, 2 shifts followed by declining rate filtration may
be appropriate, whereas for larger plants 3 shifts will
probably be the best choice.

> step 8: mode of operation: 1 shift (8 h) and declining
>   rate filtration during the
>   night (16 h)

The filter bed area required may be read from the table
given above.

> step 9: net filter bed area: 50.7 m2 say 52 m2

The total filter bed area being known, the number of filters
still has to be determined. The most appropriate size for a
filter unit is influenced by many construction, technological
and operational aspects, as explained in chapter 5.
In the case of our village a good solution might be to
choose 2 filters, each with a net area of 26 m2. In this way
the shut down of one filter would mean an increase of the
load on the other to at the most 0.2 m/h, which is quite
acceptable. Further, it would be wise to reserve space for a
future third unit of 26 m2.

> step 10: dimensions of filters: 2 filters each 26 m2,
>   height 3 m.

The dimensions of the pre-treatment unit (plain sedimentation)
can be determined on the basis of the design criteria, set
forth in appendix 2.
For our village it is decided to construct a large sedimentation
pond by erecting a dam alongside the river bank.
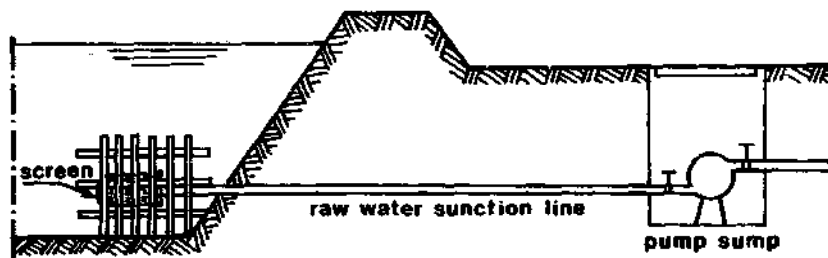The water is permitted to flow into the pond and suspended
matter will settle.

Figure 4.5.   Intake from a sedimentation pond

step 11: dimensions of sedimentation pond:
depth 6 m
area 1140 m2
detention time 3 months

The declining rate filtration of the filters calls for
special provisions in the supply of raw water. As the water
level in the filters drops by 0.7 m during the night, a
large flow of water will have to be supplied to the filters
in the morning. This means that either the pump capacity
will have to be raised or a high level raw water storage
tank has to be built. The advantage of the latter is that
also during the night water may be allowed to flow to the
filters, thereby further increasing the water production.

The dimensions of the clear water tank can be determined
from the daily pattern of water use and the water production

by the filters. Assuming that the operator's shift starts
at 7 a.m. and ends at 3 p.m., the daily water production
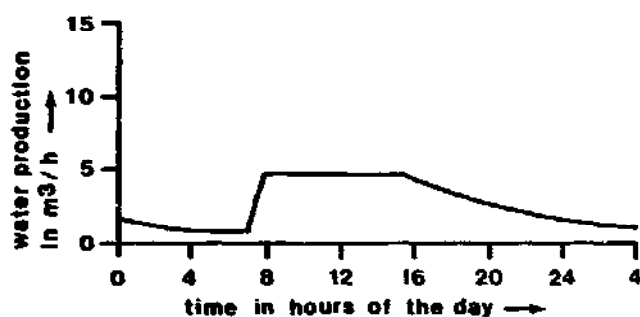can be represented by figure 4.6.

Figure 4.6.   Daily pattern of water production

The accumulated difference between water use (given in
figure 4.4.) and water production (given in figure 4.6.)
determines the size of the clear water tank. If no data are
available one may set the size of the clear water tank at
50% of the daily production (rule of thumb). From figure
4.6 it can be seen that for our village a net volume of 30%
of the daily production will be sufficient.
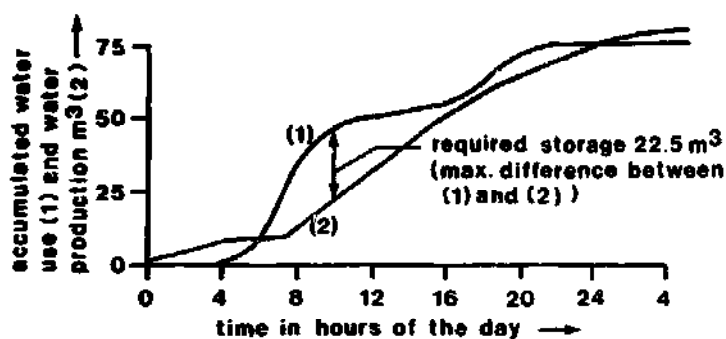
Figure 4.7.   Accumulated water production and water use

Therefore the net storage capacity of the tank will have to
amount to 0.3 $\times$ 76 = 22.5 m3. Assuming an acceptable variation
in water-level of 1.5 m, the net area will have to be 15 m2.

step 13: dimensions of clear water tank:

                area 15 m2 (circular 4.5 m)

                height 2.5 m

The mechanical design of the water supply system (raw water
pumps, clear water distribution) depends entirely on the
topographical characteristics of the area involved and on
the loss of head in the treatment units and piping arrangements.
The latter will be discussed in chapter 5; with regard to
the former, it is generally advisable to plan the treatment
plant at a sufficient height to allow for distribution by
gravity flow.
The lay-out of the treatment plant is mainly determined by
considerations of efficient operation and maintenance; a
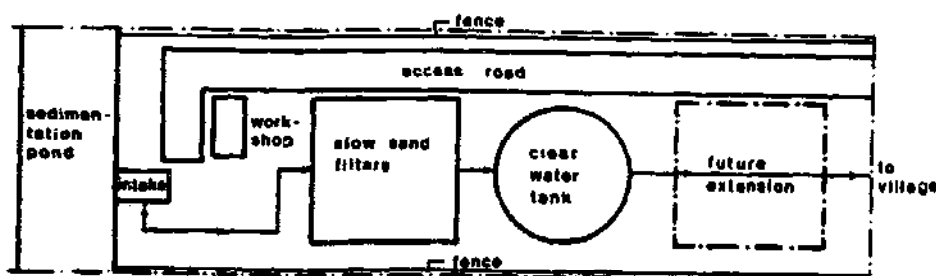typical lay-out for a water treatment plant can be seen in
figure 4.8.

Figure 4.8.   Typical lay-out of a water treatment plant

It will be clear that the design procedures discussed above
are for use during the preliminary planning (discussions
with authorities, raising of funds) and need to be detailed
at a later stage. The detailed design of slow sand filter
units and, to a limited extent, pre-treatment and post-
treatment units are elucidated in the following chapter. In
paragraph 4.4. the design criteria that may be used for the
design of water supply systems incorporating slow sand
filters in rural areas are summarized.

4.4.   DESIGN CRITERIA

---

1. design period

    15 years (range 10-25 years)

2. depreciation period

    construction elements   25 years (15-40 years)

    mechanical elements   15 years (15-25 years)

    electrical elements   15 years (15-25 years)

3. population growth

    entirely dependent on local conditions (birth
    rate, death rate, migration rate); moreover
    likely to change with time.
    In most cases the annual increase will be between
    2 and 4%

4. period of operation

    8-24 hours per day depending on number of shifts
    (1-3); declining rate filtration increases period
    of operation with 1 or 2 shifts

5. water demand

    dependent on local conditions (see chapter 2) and
    on water supply system installed:
    standpipes   30 l/cap,d (10-50 l/cap,d)
    private connections
    (1 tap)   50 l/cap,d (20-100 l/cap,d)

6. water quality

    the quality of the treated water should conform to
    drinking water standards (see appendix 1). The
    following maximum improvements in water quality
    may be expected by treatment methods:
    slow sand filtration: turbidity   max. 10 NTU
                          COD   2-5 mg/l
                          MPN E.Coli   100-1000/100 ml

sedimentation + slow

sand filtration : turbidity max. 100 NTU
COD 2-10 mg/l
MPN E.Coli 100-1000/100 ml

sedimentation + slow
sand filtration +
chlorination : turbidity max. 100 NTU
COD 2-10 mg/l
MPN E.Coli 1000-10000/100 ml

7. plain sedimentation tanks

|	
depth	1.5-2.5 m
detention time	4-12 hours
surface loading	2-10 m/d
weir overflow rate	3-10 m3/m/h
length/width ratio	4:1 to 6:1
length/depth ratio	5:1 to 20:1

8. rapid roughing filtration

|	
filtration velocity	0.5 m/h (0.5-1 m/h)
area per filter bed	10-100 m2
number of filter beds	minimum of 2
height of supernatant water	1 m (1-1.5 m)
initial depth of filter bed	1 m (1-1.4 m)
depth of system of underdrains	0.4 m (0.3-0.5 m)
specification of filter support	see figure 5.12

9. horizontal-flow prefiltration

filtration velocity
(horizontal)   C.6 m/h (0.4-1 m/h)
area per filter bed   10-100 m2
depth of the filter bed 1 m (0.8-1.5 m)
length   5 m (4-10 m)
specification of filter
bed   see drawing A.2.6

10. slow sand filters

filtration velocity   0.1 m/h (0.1-0.2 m/h)
area per filter bed   10-100 m2
number of filter beds   minimum of 2
height of supernatant
water   1 m (1-1.5 m)
depth of filter bed   1 m (1-1.4 m)
depth of system of
underdrains   0.4 m (0.3-0.5 m)
specification of filter
bed d_{eff} = 0.15-0.35 mm
                        UC = 2-5
specifications of
filter support   see figure 5.12

11. clear water reservoir

storage capacity   30-50% of daily water
                        production
height of tank   2.5-4 m
level variation of
clear water   1.5 m (1-2 m)
area   10-100 m2

12. water conduits

velocity of flow in in-
fluent*, effluent and
drainage mains   0.3-0.6 m/s

13.	chlorination system	
	maximum dosage	1.5 mg/l (1-5 mg/l)
	contact-period (dis-infection)	20-30 minutes
	maximum storage period of chemicals	1-6 months, depending on type
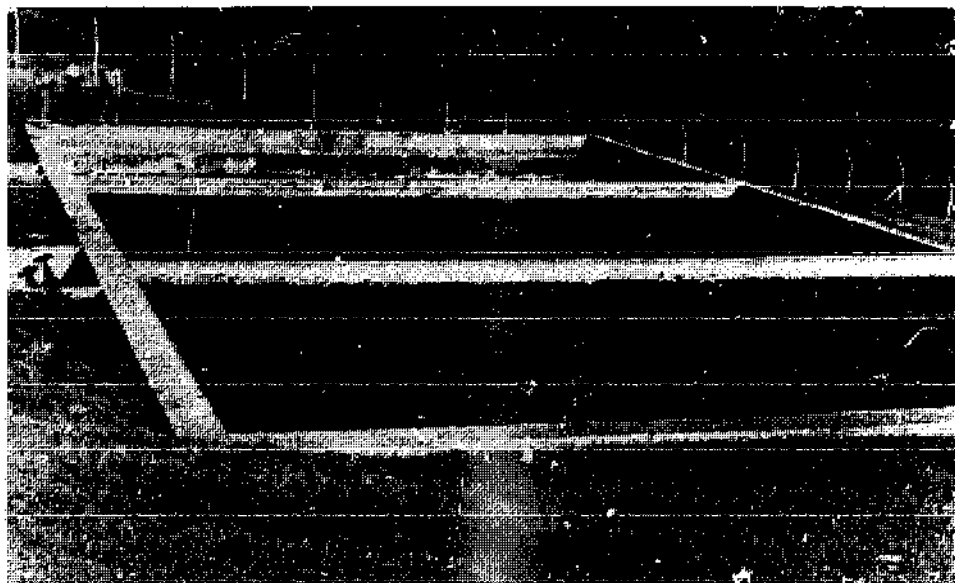
Rectangular reinforced concrete filters, West-
Karachuongo, Kenya.
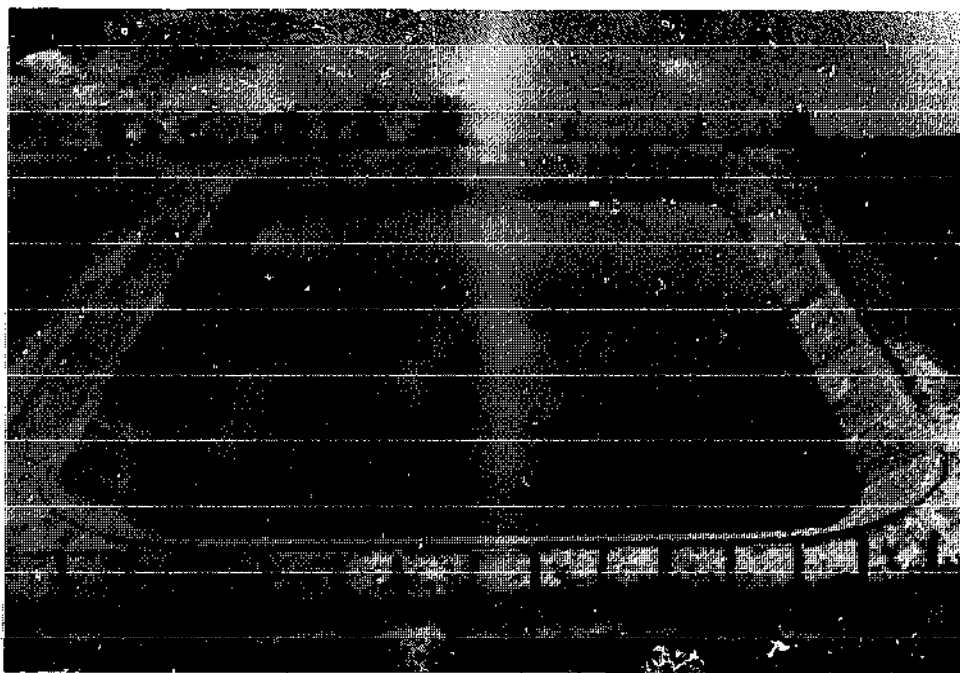
Protected sloping wall filters, Kranuan, Thailand
(background pre-sedimentation pond).

5. THE CONSTRUCTION AND SPECIFICATION OF ELEMENTS OF SLOW SAND FILTRATION PLANTS

This chapter deals with aspects of the detailed design and construction of slow sand filters. As a detailed design is greatly influenced by local circumstances it is not possible to provide a "standard design". The intent of this chapter (and indeed of this manual) is more to illustrate methods of design and construction rather than to give prescriptions to be followed under all circumstances.

For the sake of clarity, the detailed design will be explained on the basis of essential items, such as unit size and lay-out, construction of filter box, piping, pumping and filter regulation arrangements, system of underdrains, inlet structure, outlet structure, pre-treatment and post-treatment units and clear water storage.

Four typical designs for slow sand filtration plants are given in chapter 6.

5.1. SIZE AND LAYOUT OF FILTER UNITS

As already discussed in chapter 4, the minimum required area of filter bed A (m2) may be obtained by dividing the design capacity $^{\text{m}}$ Q (m3/h) by the design filtration rate v (m/h). However, the number of filter beds N and the area per filter bed F still have to be determined (the product of N $\ast$ F being at least equal to A).

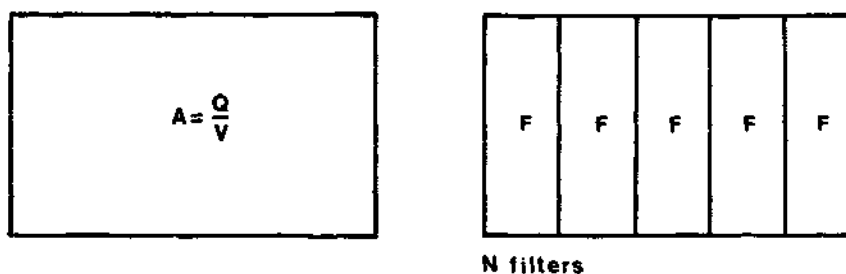$$A = \frac{Q}{V}$$

F   F   F   F   F

N filters

Figure 5.1.   Unit size of filter bed

Several considerations will determine the number of filter
beds required, for instance:

a.   to provide safe and uninterrupted operation at least
     two filters are needed (if there are two filter beds
     and one is being cleaned, the filtration rate of the
     other filter bed will not exceed 0.2 m/h, which is
     acceptable)

b.   the danger of short-circuiting and side effects are
     often mentioned as arguments against the use of small
     filter units. However, it is felt that these phenomena
     can easily be prevented by roughening the wall of the
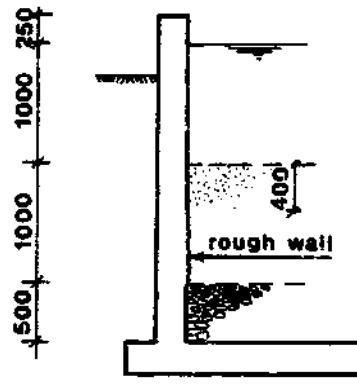   filter bed, as shown in figure 5.2.

Figure 5.2.   Measure to prevent short-circuiting in a
               slow sand filter

c.   in western countries, designs are directed towards
     large units, as the initial costs per m2 of filtering
     area tend to decrease with increasing size; however,
     this may not be the case in developing countries.
     Larger units generally require more advanced construct-
     ion techniques (e.g. use of reinforced or pre-stressed
     concrete) and better skilled labour, which may not be
     readily available in developing countries. Furthermore,
     larger units may need more construction materials to
     resist the larger loads. That is to say, the construct-
     ional advantages of the dividing wall in the rectangular

slow sand filter with length L, as shown below, result
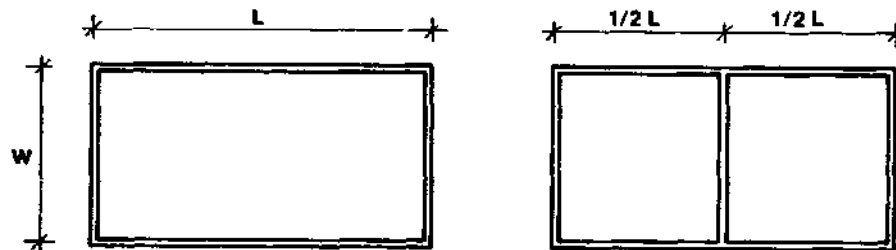in a less massive construction of the length wall.

Figure 5.3.   Dividing wall in rectangular filter

d.   watertight construction should be guaranteed, especially
      when the filter box is located below the ground water
      table. This means that special attention should be
      paid to shrinkage of concrete and masonry, differential
      settlements and temperature stresses.
      As these phenomena are all dependent on the span of
      the walls, relatively small filter boxes are favoured
      in this respect. Although there are other factors
      which influence these phenomena (e.g. concrete shrinkage
      is reduced by lowering the water-cement ratio and the
      quantity of cement and by improving the compression;
      subsidence is dependent on the properties of the
      subsoil and the mode of foundation; temperature
      stresses are climate-dependent), it is suggested here
      as a general principle that a maximum length of approxi-
      mately 20 m will not cause problems, whereas larger
      spans may call for special provisions (expansion
      joints, side-reinforcement etc.)

e.   the amount of materials needed is influenced by the
      plan and layout of the filter beds. Some arrangements
      for the layout of slow sand filter installations are
      given in figure 5.4.

circular filters

square filters
in excavation

square filters

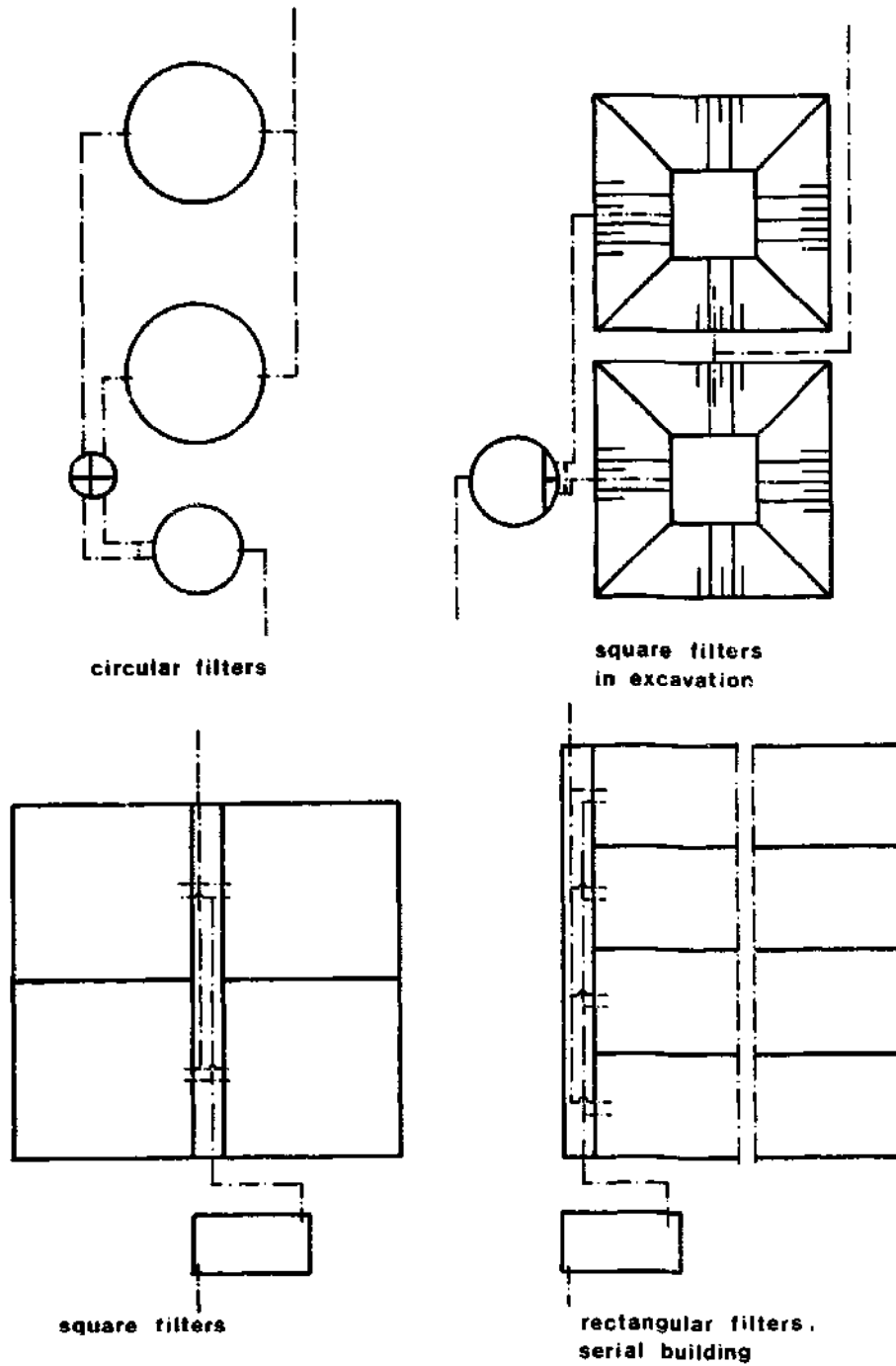rectangular filters,
serial building

Figure 5.4.   Lay-out of slow sand filters.

Circular filters have obvious structural advantages (universal
compressive or tensile stresses, no bending moments), which
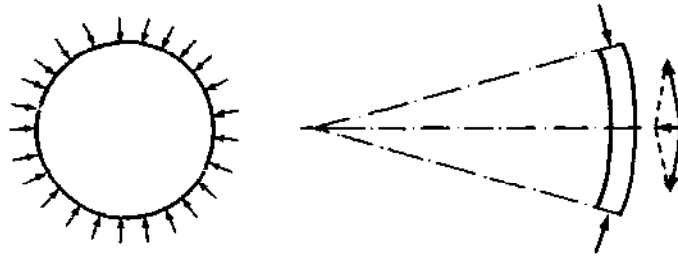result in economical use of materials.

Figure 5.5.   Principle of universal pressure

With increasing size of the treatment plant, their dis-
advantages (no serial building possible, no ready access to
piping and filter arrangements) tend to offset their ad-
vantages.
If for circular filters a maximum of two units is chosen,
with a maximum diameter of 10 metres and a filtration rate
of 0.1 m/h, such circular filters may be advantageous for
installations up to 20 m3/h.

Rectangular filters arranged along a common pipe gallery
are optimal for larger installations (3 or more filters).
Piping and filter regulating arrangements are easily
accessible, the installation is well-ordered and (future)
extensions can be incorporated without any problems. From a
structural point of view, rectangular plans have the ad-
vantage that all long sides, with the exception of those at
both ends, are symmetrically loaded, while the major part
of the forces is taken up by the short walls and the
supporting long walls. This advantage does not apply if,
for one reason or another, the sand bed of one of the
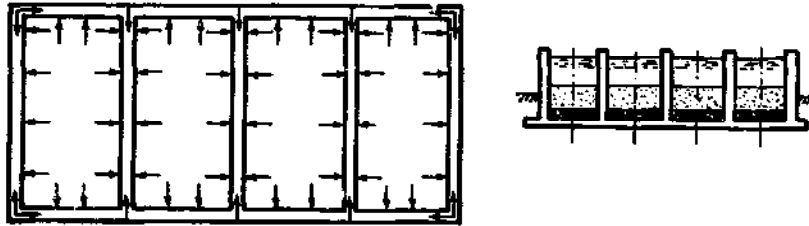filters is excavated.

Figure 5.6.   Pressure diagram for rectangular filters

Square filters have a shorter total length of walls for a
given filter bed area than do rectangular filters, but they
are less favourable with respect to the structural design.
In addition, a square plan has disadvantages with regard to
future extensions (a number of four filters can be considered
the maximum for square plans). If the filters are constructed
in an excavation, a square plan has the advantage of the
least earthwork.
This paragraph concludes with a table indicating the sizes
and plans of slow sand filters for different capacities.

Table 5.1.   Sizes and plans of slow sand filters for
              various capacities (for a filtration rate of
              0.1 m/h).

Capacity m3/h	Circular plan	Rectangular plan	Square plan
5	D = 5.66 m(2x)	-	5 x 5 m (2x)
10	D = 8 m (2x)	5 x 10 m(2x)	7.1 x 7.1 m(2x)
20	D = 9.25 m(3x)	6 x 11 m(3x)	8.2 x 8.2 m(3x)
50	-	6.5 x 20 m(4x)	11.2 x11.2 m(4x)
100	-	6.5 x 25 m(6x)	-

where: D   = diameter of circular filter
       (2x) = two filters

5.2.   CONSTRUCTION OF FILTER BOX

The construction of slow sand filters consists of either a
closed stiff box of reinforced concrete, a semi-closed
hinged structure of mass concrete, masonry, brickwork or
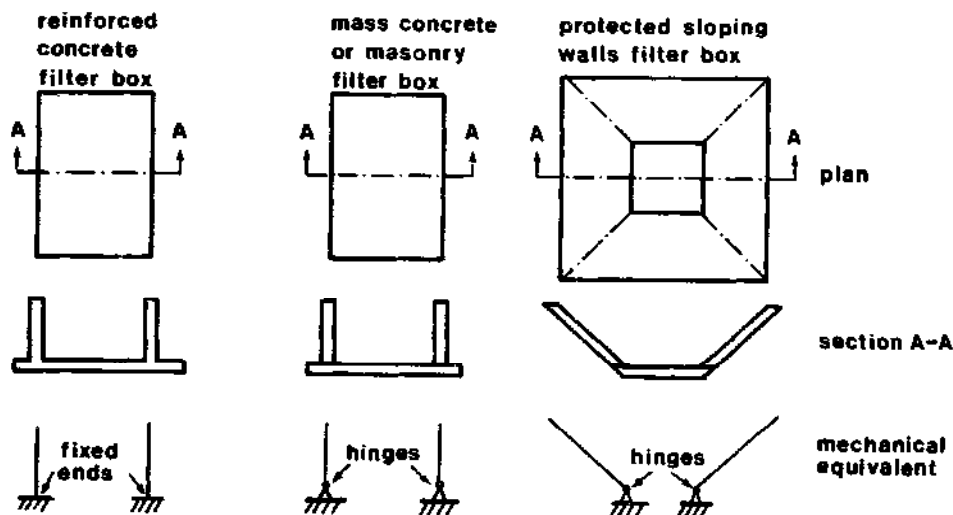ferrocement or an open, excavated structure with protected
sloping walls.

reinforced
concrete
filter box

mass concrete
or masonry
filter box

protected sloping
walls filter box

plan

section A-A

fixed
ends

hinges

hinges

mechanical
equivalent

**Figure 5.7.   Structural design of filter box and mechanical
equivalent**

- *Protected sloping wall filters*

A sloping wall filter has the advantage that construction
costs are lower than for closed and semi-closed filter-
boxes, while less skilled artisans are needed. Access to
the filters for cleaning is also somewhat simpler, while
there is less danger of short-circuiting along the walls as
the sand bed tends to get compacted against the sloping
walls by the overlying layers. As materials for the lining,
either masonry, riprap[a], puddled clay, mass concrete or
mixtures of sand-cement or bitumastic sand reinforced with
chicken wire can be chosen.

sand/cement
mixture with
chicken wire

mass concrete

impervious
clay

brickwork

chicken
wire

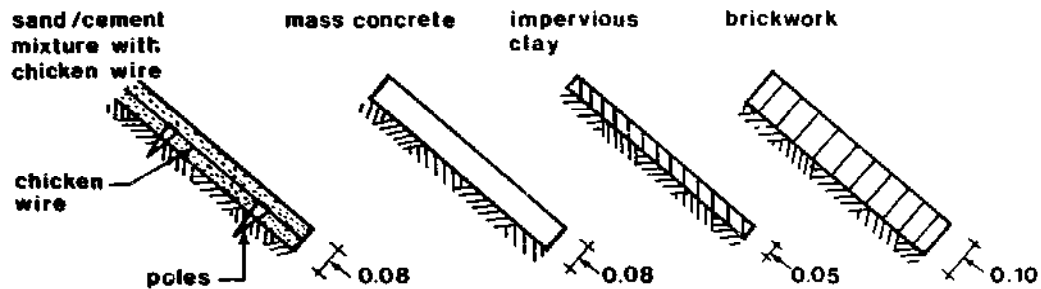poles

0.08

0.08

0.05

0.10

Figure 5.8.   Various linings for sloping wall filters

The slope of the walls of course depends on the stability
of the subsoil, but a 1:2 slope will generally be suitable.
As the filter is excavated in the subsoil, only small
settlements will occur even where there are soil layers
with high compressibility. Some disadvantages of protected
sloping wall filters may be:

1.   The land area required is larger than is the case with
      structures with vertical walls. (N.B. as design area
      for sloping wall filters should be chosen the net
      filter bed area at the minimum filter bed depth of
      0.6 m).
      This aspect need not present great difficulties for
      villages where sufficient land area is available.

2.   Piping and filter control facilities are less access-
      ible

3.   The watertightness of the construction can never be
      guaranteed. When the ground water table is low this
      may not be of great importance (except for losses),
      but at high ground water levels there is the danger of
      pollution of the filtered water

4.   When the filter excavation is dug in the natural soil,
      the filtered water level at the end of the filter run
      is more than 1 metre below ground level. This implies
      that the filter control structure and/or clear water
      tank may have to be located at great depth. (The clear
      water tank must of course be built with vertical walls
      and has to be covered)

5. Fouling of the sloping walls may occur due to growth
    of reed and other vegetation

A sloping wall filter may of course also be realized by
earthwork above ground level. This largely obviates the
disadvantages listed under 3 and 4, but also results in
higher pressures in the upper layer of the soil, which
may cause settlements and fissures.

— *Vertical wall filters*

The design of filters with vertical walls follows normal
structural design practice.
A very important structural design parameter is the depth
of the foundation relative to the ground level. Factors to
be borne in mind are:
1. The minimum depth of the foundation may be set at
    0.3 m in areas where is no danger of sub-zero
    temperatures
2. The minimum distance between the top of the filter and
    ground level should be 0.5 m in order to prevent the
    entrance of dust, animals, and even playing children.
3. A deep location of the filter bed has structural
    advantages.
    The load on the walls lessens because the outside soil
    pressure compensates for the inside pressure (see
    pressure diagram). In this regard a distance between
    the top of the filter box and the ground level of some
    0.5-1.0 m may be regarded as optimal
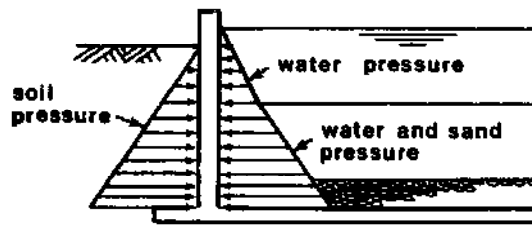
Figure 5.9.　　Pressure diagram for a wall of the
　　　　　　　　filter box

4.　a deep location of the filter bed is advantageous with
　　regard to the load on the soil.
　　The load on the soil is lower with a deep location and
　　so there will be less settlements and fissure development
5.　a high ground water table calls for either a high
　　location of the filter or the construction of a rein-
　　forced concrete filter box. In order to prevent pollution
　　of the filtered water, it is essential to guarantee
　　watertightness of the filter box in this case. Mass
　　concrete and masonry need additional protection and a
　　very careful design to guarantee watertightness, so it
　　is better to avoid their use.
6.　a high ground water table may also require special
　　provisions to prevent the construction being forced up
　　by water pressure. However, if the filter sand bed is
　　not lowered more than 0.4 m, as indicated in chapter
　　3, there is no danger of buoyancy of the construction.
　　Nevertheless a check on this and on the clear water
　　reservoir, which falls dry from time to time, is
　　always important. It may also be necessary to take special
　　precautions against forcing up (e.g. lowering the
　　ground water table by pumping) during the construction

of the filter and in repair situations, when the sand bed is completely excavated.

7. the water level desired in the treatment plant and the available head of the raw water may influence the depth of the filter; generally it is desirable to apply gravity flow through the entire treatment plant (sedimentation tank + slow sand filter + clear water tank)

In the case of reinforced concrete filter walls, the filter bottom will also be of reinforced concrete and a stiff joint between bottom and wall (by means of extended reinforcement) will allow side pressures to be transmitted to the foundation.

If the walls are of mass concrete, ferrocement, or masonry, a raft foundation (see figure 5.10) provides equal settlemen'. of the filter box, prevents loss of water through the joint between wall and foundatior. and simplifies execution. The joint between wall and ra:t may be considered a hinge in this case, through which only limited side pressures can be conveyed. A structure of mass concrete, ferrocement or masonry can therefore only be applied when inside and outside pressures do not differ greatly. The raft foundation may consist of 0.20 m of mass concrete of a 1:2:3 composition (see also appendix 5).

In this case an unequal loading will result in the development of cracks. It is therefore advisable to reduce the length of the tee of the foundation to the minimum, i.e. 0.10-0.20 m. A minimum reinforcement of e.g. $\emptyset$ 8-200 (i.e. steel bars of 8 mm diameter placed at 200 mm intervals) in both directions and both at the top and the bottom of the raft is quite suitable to prevent the development of cracks. The strength of the joint between foundation and filter wall may be increased by placing steel bars of e.g. 16 mm at large distances of some 500 mm (see also figure 5.10).
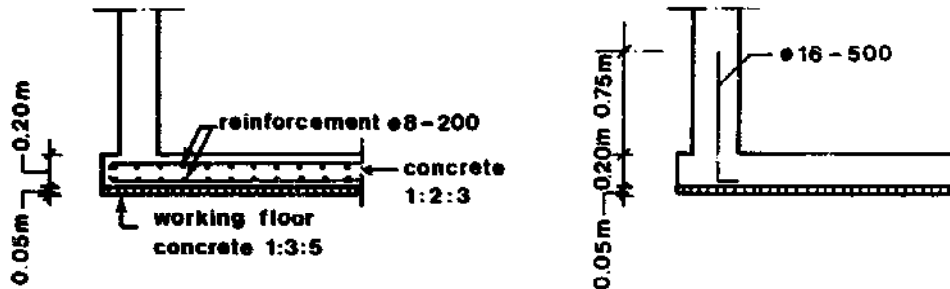
Figure 5.10. Raft foundation for vertical filter walls

Circular filters of mass concrete or masonry may be applied when the depth of foundation is relatively great. The resulting outside soil pressure is then transmitted by compressive forces in the walls of the filter box. However, if a high location of the filterbox is chosen, then the pressure of sand and water in the filterbox will result in tensile forces in the filter walls. The use of mass concrete or masonry is not possible in this case, but circular filters of ferrocement (for details on ferrocement building see appendix 5), reinforced with steel to transmit the tensile forces, can be used for small to medium-sized filters. Circular filters may also be constructed of reinforced concrete, in which case the depth of foundation may either be high or low.

Rectangular filters will generally be executed in reinforced concrete (except for small installations, that may consist of mass concrete or masonry). They are applicable for all sizes and depths of foundation. The thickness of the filter box walls and the amount of reinforcement used will depend on the size, the plan and the depth of the foundation of the filter box.

To conclude this paragraph a summary is given of the possible constructions of the filter box and their applicability. See table 5.2.

Table 5.2.   Various constructions of filter boxes and
             their applicability for slow sand filtration.

1. protected sloping wall filter;
   applicable for small to medium sized square filters
       Size   2 - 20 m in length and width
       Thickness of walls 0.05 - 0.10 m
   attractive when very low finances are available

2. mass concrete or masonry filter;
   applicable for circular filters with deep foundation
       Size   1 - 10 m in diameter
       Thickness of wall   0.2 - 0.3 m
   for non-circular filters only limited applicability
   (small filters, low ground water table, careful
   structural design)

3. ferro-cement filter;
   applicable for small circular filters with deep or
   high foundation (universal pressure or tensile hoop
   principle)
       Size   1 - 5 m in diameter
       Thickness of wall   0.06 - 0.12 m
   some deformation of the filter wall will occur and the
   construction is not completely watertight, but this
   may be acceptable

4. reinforced concrete filter;
   applicable for all sizes, plans and topographical
   conditions;
   circular filters will have a somewhat smaller thickness
   of wall than rectangular filters (i.e. 0.15 - 0.20 m
   instead of 0.25 m);
   attractive when finances and skills are more readily
   available.

5.3.   INLET STRUCTURE

The functions of the inlet structure may include:

1.   to ensure an equal distribution of the raw water over
     the filter bed area. This is generally achieved if the
     entrance velocity of the incoming water is low, say in
     the order of 0.1 m/s.

2.   to reduce the energy of the incoming water, so as to
     prevent turbulence in the supernatant water layer and
     damage to the Schmutzdecke. This function also requires
     a low entrance velocity. Furthermore, the inlet structure
     may be located just above the filter bed, in order to
     prevent jets of water pouring down onto the filter
     bed. A rupture of the Schmutzdecke may also be prevented
     by placing slabs of concrete or natural stone on the
     filterbed at the point of entrance of the raw water.
     The minimum total width of the inlet structure may be
     determined by dividing the design flow (m3/h) by 20.
     In this way the height of the overflowing water will
     be a few centimetres only, so a gentle flow is obtained

3.   to drain the supernatant water when the filter needs
     to be cleaned.
     This may be another reason for situating the inlet
     structure just above the filter bed. However, after
     the filter bed has been scraped several times, its
     level sinks up to 0.4 m. This means that the supernatant
     water cannot be drained fully through the inlet structure,
     unless a solution by means of removable weir beams
     (e.g. concrete slabs or wooden planks of 0.05 x 0.10 m)
     is chosen. Otherwise, the only way to remove the water
     in the top 0.4 m above the filter bed, is by opening
     the outlet valve. However, as the filter resistance
     will then be very high, the drainage time can be
     expected to be very long.

4. to provide means of adjusting the height of the super-
    natant water. This can be done either by means of a
    float-controlled butterfly valve, a manually operated
    gate valve or by drainage through an overflow weir.
5. to provide a means of shutting down the raw water
    flow. This is generally done by a hand-operated gate
    valve

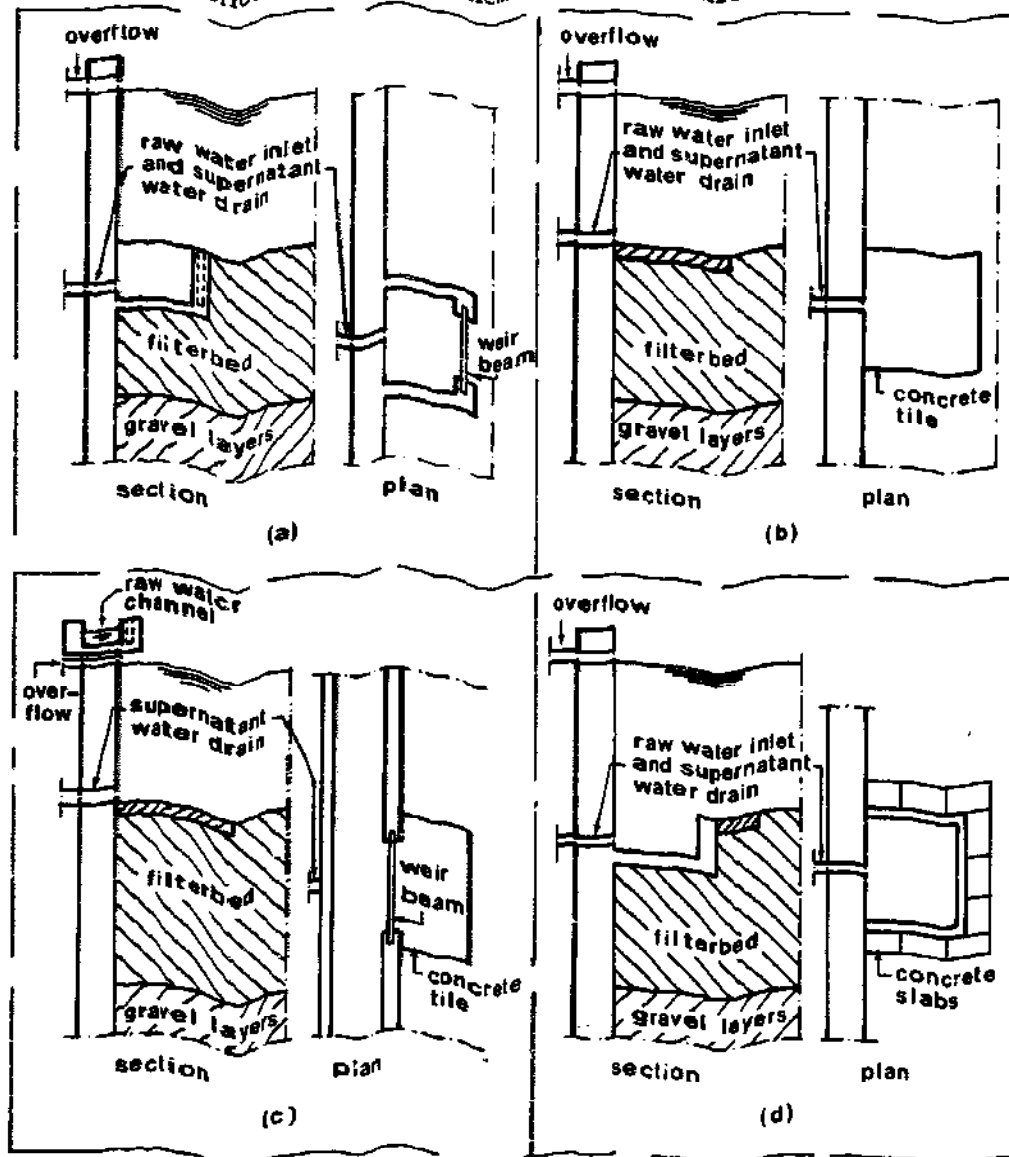Figure 5.11 shows possible schemes for the inlet structure.

(a)

(b)

(c)

(d)

Figure 5.11.   Inlet structures

5.4.   OUTLET STRUCTURE

The functions of the outlet structure may include:

1.   to guarantee exclusion of the occurrence of negative
      pressures in the filter bed. To this end a simple
      overflow weir in the effluent line with its crest
      slightly above the top of the sand bed is usually
      used. Other possibilities include a vertical outlet
      pipe or transport pipe with its inlet just above the
      top level of the sand bed.

2.   to provide means of measuring the flow through the
      filter bed. The above mentioned weir may also be used
      for this purpose by means of a calibrated float (to
      increase the accuracy of this reading a V-notch weir
      may be used). The flow through the filter may also be
      adjusted to a pre-set value by means of floating
      weirs.

3.   to provide means of adjusting the filtration rate. The
      simplest way of doing this is by manual adjustment of
      a butterfly value.

      In case a floating weir is applied which also fulfills
      the function as described under item 2 above, then the
      minimum allowable level of its inlet should be adapted
      in accordance with the top level of the sand bed. If
      one of the filters is being cleaned, the filtration
      rate and thus the capacity of the floating weirs of the
      remaining filters should be increased (by increasing
      the immersion depth of the inlet of the floating-weir).

4.   to provide means of shutting down and draining the
      filter. The structures using vertical outlet pipes
      will therefore have to be equipped with separate drain
      pipes. To shut down the filter a gate valve may be
      used.

5.   to provide means of re-filling a filter with clean
     water through the system of underdrains after it has
     been scraped

Although not absolutely necessary, it is a great advantage
when the filtered water is aerated by means of an overflow
weir. To this end, the outlet structure should be well
ventilated.
A manhole is desirable in order to facilitate control of
weirs and valves.
The relation between flow and height of water in a V-notch
weir[a] is further explained in appendix 6.
Figure 5.12 gives some suitable schemes for the filter
outlet structure.
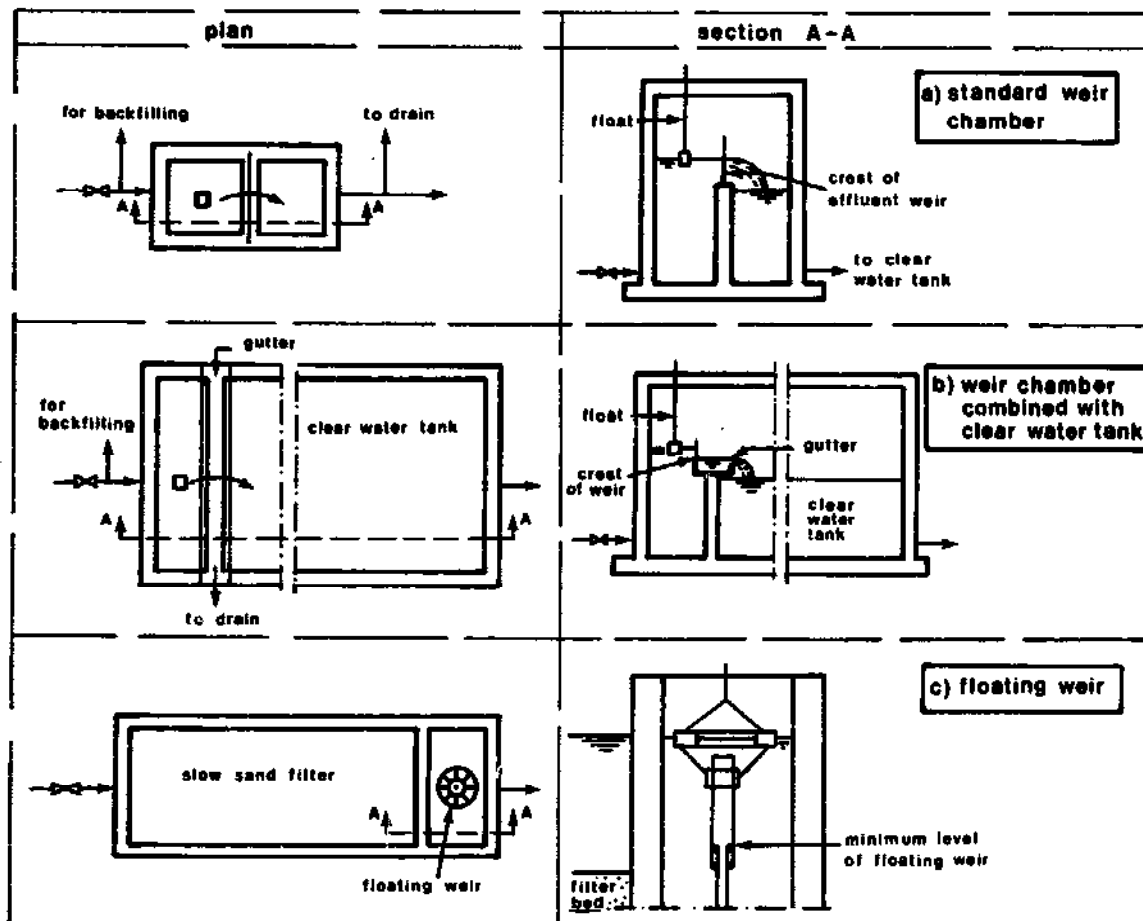
Figure 5.12.   Outlet structures

5.5. SYSTEM OF UNDERDRAINS

The function of the system of underdrains is twofold:

1. to support the filter medium and to prevent the filter medium from being carried into the drainage system
2. to ensure a uniform filtration rate over the entire filter area

In order to prevent loss of filter medium a number of gravel layers with increasing grain size are located between the filter medium and the actual underdrain system. The use of three layers of gravel with sizes ranging from 1-1.4, 4-6, 16-23 mm will generally be practical. The thickness of these layers should be about 100-150 mm each.

For the actual system of underdrains (see figure 5.13), it may be stated that in general the hydraulic characteristics of the systems using pre-fabricated concrete slabs, bricks and porous concrete, can be relied upon without further calculation. For these systems the area in which the water flows freely is relatively large. The systems using perforated pipes and gravel or broken stones may be dimensioned on the basis of the following criteria:

perforated pipes			
maximum velocity in manifold	0.3	m/s	
maximum velocity in laterals	0.3	m/s	
spacing of laterals	1.5	m	(1-2 m)
size of holes in laterals	3	mm	(2-4 mm)
spacing of holes in laterals	0.15	m	(0.1-0.3 m)

gravel or broken stones		
height of layer	0.15	m
size of gravel	25-50	mm
maximum area of filter bed	25	m2
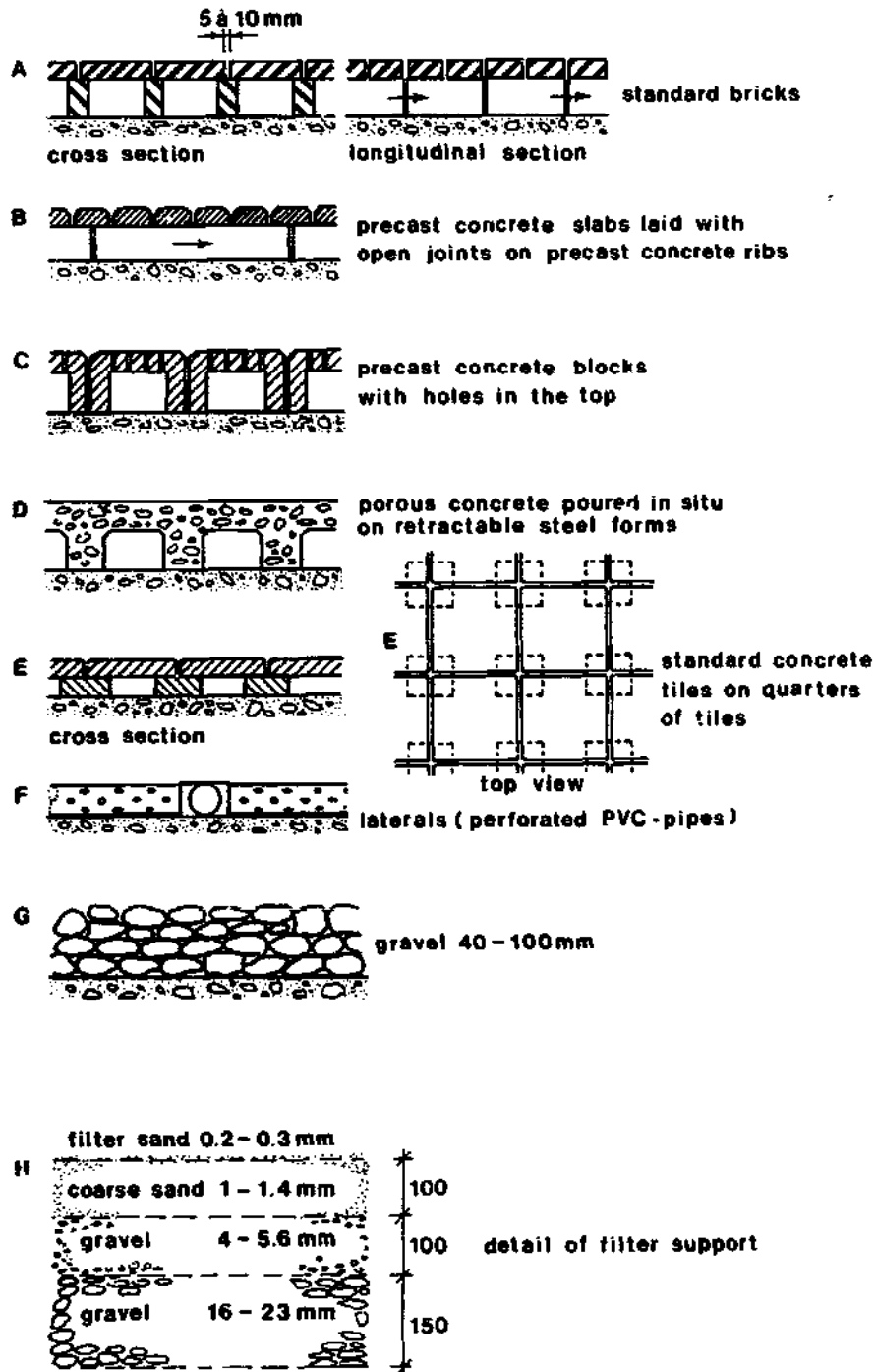
Fig. 5.13.   System of underdrains

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5.6.   FILTER CONTROL ARRANGEMENTS

A flowsheet of a typical slow sand filter installation is
given in figure 5.14.

LEGEND:
- flow rate measuring device with indicator
- valve
- weir chamber
- overflow
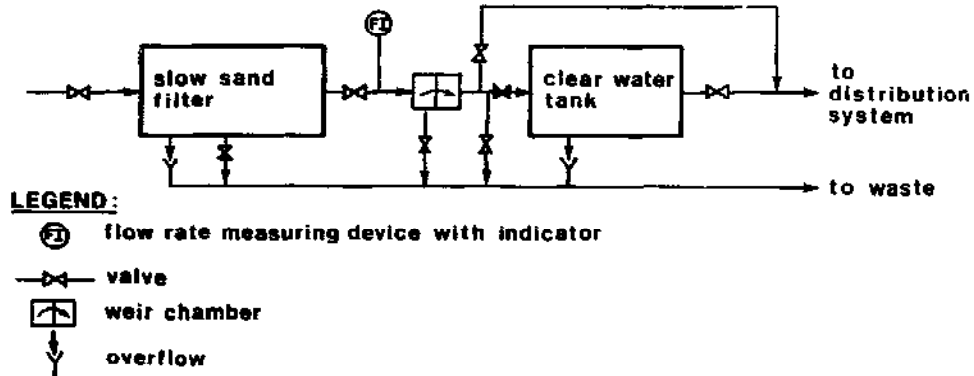
Figure 5.14.   Flowsheet of a typical slow sand filter
installation

The simplest shut-down arrangement in a pipeline is a gate
valve (figure 5.14a), whereas in open conduits removable
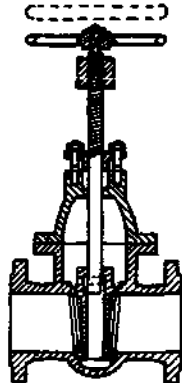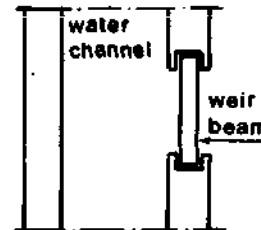weir beams may be used (figure 5.14b).

Figure 5.15a. Gate valve   Figure 5.15b. Weir beam

The flow control arrangements both at the inlet and outlet
structure have already been discussed in chapter 5.3 and
5.4 respectively. A suitable flow-control arrangement in a
pipeline is a butterfly valve, as shown in figure 5.16.a
and b.

Although a gate valve may also be used to control the
flow in a pipeline, a butterfly valve enables a more
convenient and more accurate control. The reason is that
the flow characteristics of a gate valve are such that
the flow through the valve is relatively independent of
the position of the valve. Only when the valve is closed
for more than 90%, the flow starts decreasing considerably.
This means that an accurate adjustment of the flow is
rather troublesome.

However, the butterfly valve is characterized
by a more even relation between the percentage of opening
and the flow rate.
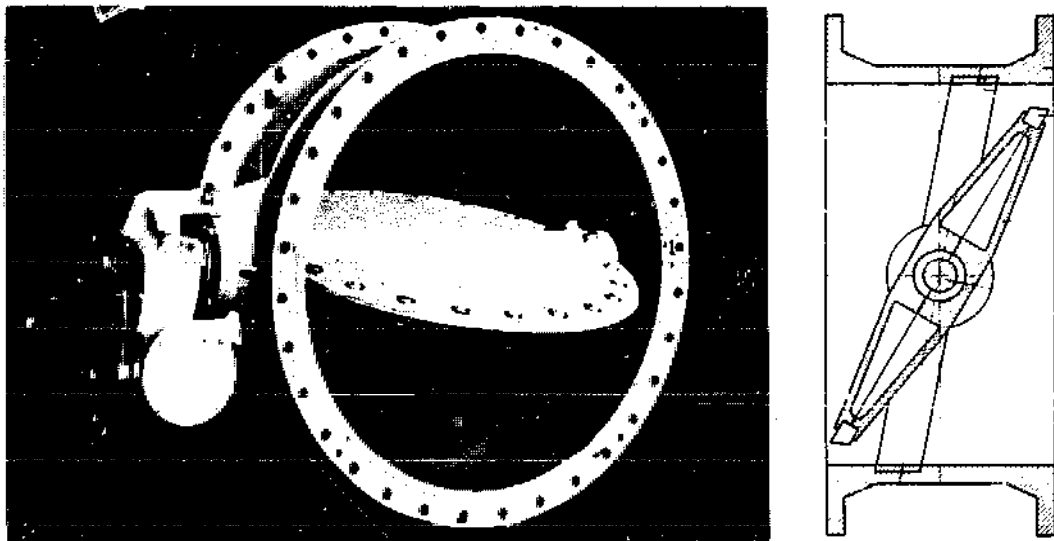
Figure 5.16a and b.   Butterfly valve

The filter control arrangement determines the flow and
head of the water through the plant. An important parameter
in this respect is the hydraulic line, which gives the
head of the water when flowing through the plant. In
figure 5.17 the hydraulic line[H] for a typical installation
is given. The head loss over the entire plant is kept at
a constant value during the various operational conditions
by adjustment of the control valves.
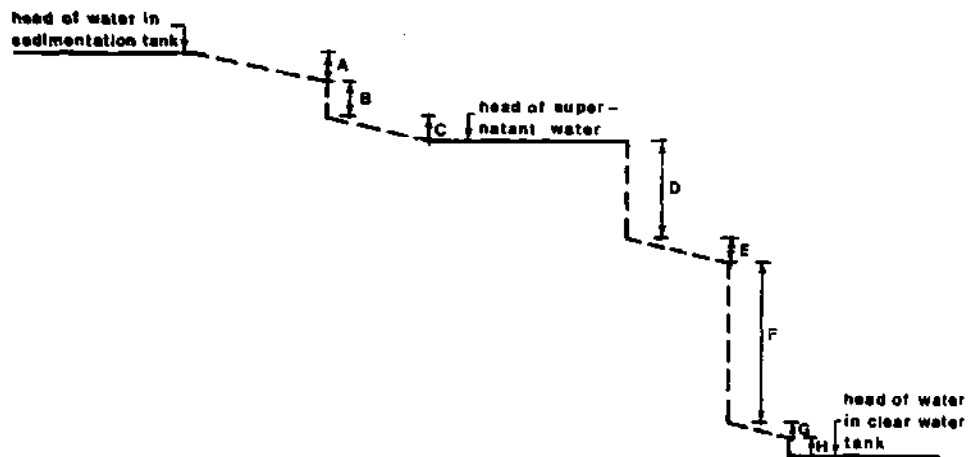
A = head loss in pipe between sedimentation tank and valve 1

B = head loss over valve 1

C = head loss in pipe between valve 1 and slow sand filter

D = head loss over slow sand filter;(increases during filter run)

E = head loss in pipe between slow sand filter and valve 2

F = head loss over filter-regulating valve 2 ; (to be decreased during filter run in order to keep D + F constant)

G = head loss in pipe between valve 2 and clear water tank

H = head loss over effluent weir

Figure 5.17.   Hydraulic line in a slow sand filtration plant (gravity flow)

5.7. PRE-TREATMENT AND POST-TREATMENT UNITS

Design criteria for the design of pre-sedimentation basins
and safety-chlorination systems are given in chapter 4.3
and in appendices 2 and 3. The aspects concerning layout,
unit size, construction of box etc. described for slow sand
filters are essentially the same for the detailed structural
design of sedimentation tanks. Of course, the head of the
water in the sedimentation tank should be somewhat (e.g.
0.10 m) higher than in the slow sand filter (see figure
5.17), so the top level of the sedimentation tank should be
higher accordingly. Furthermore, provisions are necessary
for the removal of sludge (sloping bottom, sludge removal
device or manual sludge removal) and for inlet and outlet
of water.

With regard to the detailed design of chlorination dosing
equipment (see appendix 3), for larger plants it may be
convenient to build a small chlorine house on top of the
clear water tank. Bleaching powder and high-test-hypochlorite
both need protection from sunlight, humidity and high
temperatures so they are best stored in a closed, well
ventilated room.

In a separate room the chlorine solution may be prepared by
adding a fixed amount of bleaching powder or hypochlorite
to a volume of water. The chlorine solution then flows to
the dosing tank, from which a dosing apparatus and pipeline
conveys it to the underflowing clear water. A weir is a
suitable point to mix the chlorine solution with the clear
water.

The chlorine house, which may include an operator's room,
may be built of any material locally available, as long as
the stored chlorine cannot be affected by humidity. The
structural consequences of the chlorine house for the
underlying clear water storage are limited to a somewhat
higher load on the cover of the storage tank and on the
subsoil.

5.8.   CLEAR WATER STORAGE

The structural design of the clear water tank differs
from that of the slow sand filters in two ways. In the
first place the clear water tank will have to be covered,
which allows side pressures to be transmitted to the
cover. When the joint between cover and wall is stiffened
by means of extended reinforcement bars, the strength of
the structure increases, and the thickness of the walls
may be reduced.

The second difference between the design of slow sand
filters and that of a clear water reservoir is that the
downward load on the bottom of the clear water reservoir,
unlike that on a slow sand filter, may be reduced to nil
at some periods. This means that the structure will have
to be dimensioned for large outside pressures and the
possibility of the construction being forced up by water
pressure must also be considered.

Taking both factors into consideration, it may be said
that the dimensions of filter walls and reservoirs walls
can generally be of the same magnitude. If there is a
chance of the construction being forced up, then the
walls of the reservoir will have to be somewhat more
massive than those of the filter, especially for reservoirs
with larger capacities. For small installations the cover
of the clear water tank can consist of a simple wooden
structure, but for larger tanks a concrete cover of some
0.25 m thickness having a minimum reinforcement of ∅ 8-
150 (in both directions and both at the top and bottom of
the slab) will generally be advisable.

The foundation for the clear water tanks will of necessity
have to be deep, because the loss of head through the
filter amounts to 1 m (see chapter 5.6) and some level
variation in the clear water tank has to be permitted in
order to balance production and demand. If the net level
variation is taken a. 1.5 m, the depth of foundation for
the clear water tank will be the same as is the case with

the slow sand filter.

The clear water tank will have to be provided with ventilation pipes and a manhole for inspection.

If the clear water tank also serves as a chlorine contact chamber, then the clear water outlet pipe should be located at such a height above floor level that a minimum detention time of 30 minutes is obtained.

The net volume of the clear water tank depends on several considerations. As has been set out in chapter 4.3, storage of clear water is necessary in order to balance water production and water demand. On the other hand, it is not necessary to build the clear water storage tank at the treatment plant itself; construction somewhere in the village has the advantage that the production capacity of the transport pipe between treatment plant and village is better utilized.

It is also possible to build more than one clear water tank, the total net volume being at least equal to the calculated required storage volume. The use of 2 or 3 tanks may be advantageous with respect to the reliability of the water supply system (if one tank is out of order, then the other tank(s) can still supply water to the population) and with respect to the costs of the clear water storage, as the construction of large clear water tanks is relatively difficult and expensive.

5.9.   PIPING AND PUMPING ARRANGEMENTS

In water supply engineering it has always been good practice to design the major hydraulic elements of a treatment plant to a capacity of at least 1.5 times the design water demand. When at a later stage an extension of the treatment works proves to be necessary it would be very inconvenient to find out that cross-connections are not possible without replacing pipes, valves and other appurtenances. Design velocities as low as 0.3 m/s in major pipes are advisable.

Gate valves and filter control valves should be arranged in
such a fashion that future extensions may easily be connected.
Valves, control floats and other vulnerable mechanical
parts should preferably be easily accessible for control
and repair. The use of a pipe gallery or a filter control
structure should in any case be given serious consideration.
Filter influent and drain conduits should be strictly
separated from clear water pipes.

Assuming that the treatment system is based on gravity flow
the head losses through pipes and treatment units have to
be determined (see also chapter 5.6) for the design of raw
water pumps. For the loss through pipes see figure 5.18.
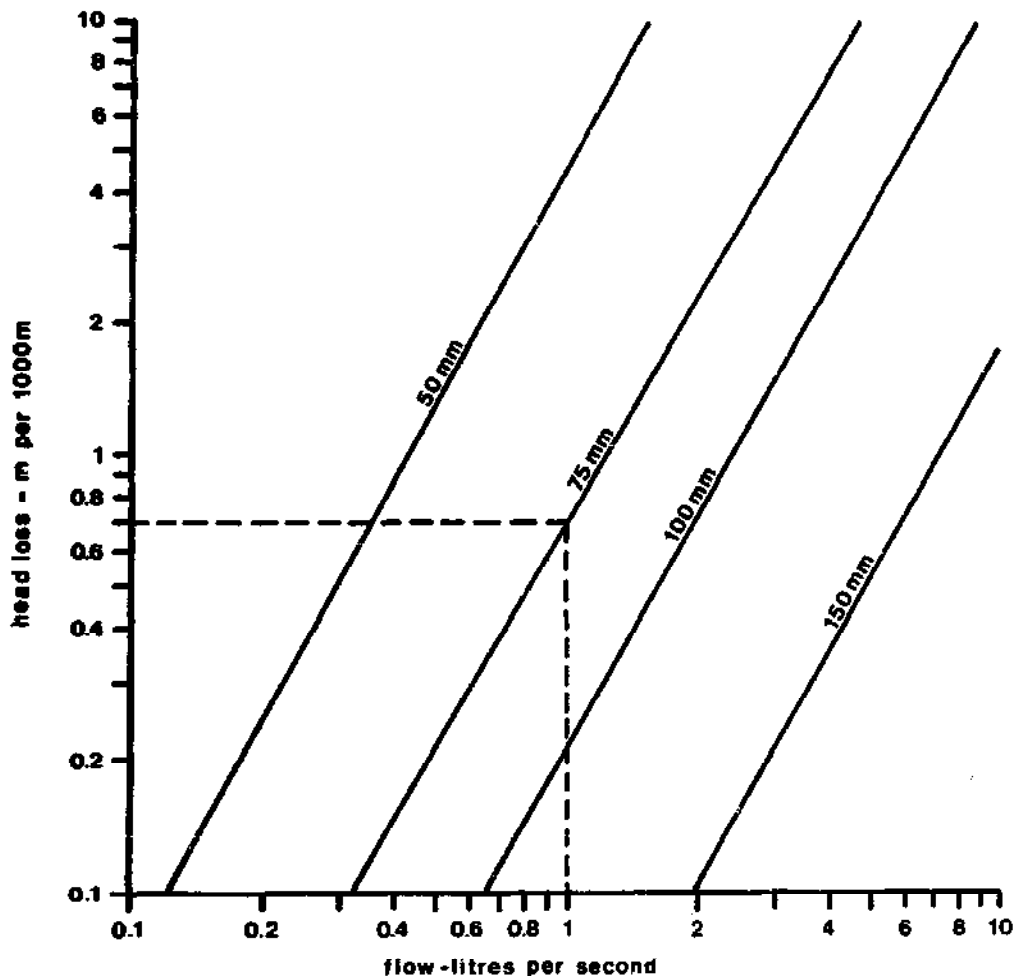
Figure 5.18. Head losses through friction in PVC-pipes

For example, it can be seen that a flow of 1 litre per
second (3.6 m3 per hour) will cause a head loss of 0.7 m
water column per 1000 m pipeline for a pipeline with a
diameter of 75 mm.

The head loss in the slow sand filters amounts to 1 m
watercolumn and the head loss in pre-sedimentation tanks
will be in the order of 0.05-0.10 m watercolumn. The
design flow and the design head for the raw water pumps
can thus be specified. Other important specifications of
the raw water pumps, such as suction head and pressure
head, depend entirely on local circumstances.

In water treatment plants, centrifugal pumps are usually
applied. The power required for the pump engine in kW may
be estimated by means of the figure below.

The source of power for the engine, i.e. diesel oil,
electricity or even water or wind power, will depend on
local availability.
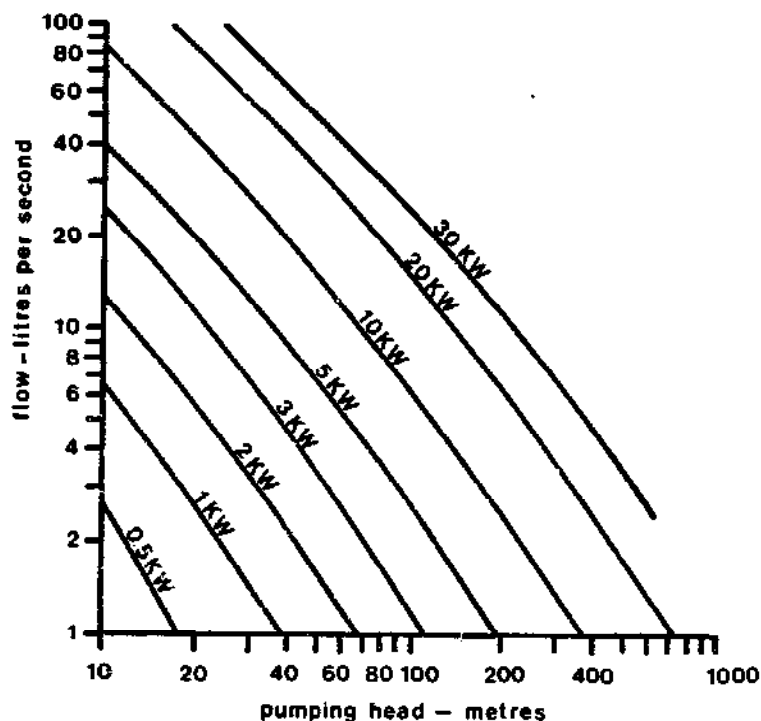
Figure 5.19.   Power requirements for a raw water pump (kW)

System of underdrains and supporting gravel layers,
Amsterdam Waterworks, the Netherlands.

6.   TYPICAL DESIGNS FOR SLOW SAND FILTERS

To illustrate the outlined approach to the design of slow
sand filtration plants, 4 typical designs have been prepared
(see figures 6.1-6.4). It should always be borne in mind
that these designs apply to specific conditions and may not
be suitable under different circumstances. The authors
therefore refer once again to the statements made in chapter
1 concerning the use of the information given in this manual.
In the paragraphs 6.1-6.4 the four typical designs are
described and in the following paragraphs some information
is given about suitable lay-outs of treatment plants incor-
porating these four typical designs, the production capacity
of the typical designs, the amount of building materials
required and the costs of slow sand filtration.
It should be noted here that in the typical designs no
provisions have been made for a pre-treatment of the raw
water. The designs therefore can only be applied to relativ-
ely pure surface water (turbidity preferably less than
10 NTU, but certainly less than 50 NTU). If the turbidity of
the raw water has higher values, a pre-treatment system has
to be designed (see paragraph 3.9 and appendix 2).

6.1.   PROTECTED SLOPING WALL FILTER

In chapter 5, it is stated that sloping wall filters are in
particular applicable for low income villages. However true
this may be, it should not lead to the misconception that
their purification effect is necessarily inferior to the
other conceptions of the slow sand filter principle.
If well designed and constructed with care, a sloping wall
filter will prove to be a major step forward in the hygienic
and public health conditions of villages.

The design No. I (figure 6.1) is set up as a protected sloping wall filter.

The hourly production can be calculated from the net area of filter bed (i.e. area remaining after the top 0.4 meter of the filter bed has been scraped; in the design 8.4 x 8.4 m) and the filtration rate (0.1 m/h). For the two filters together, this amounts to 2 x 8.4 x 8.4 x 0.1 m3/h = 14.1 m3/h. If an operation period of 8 hours is selected with declining rate filtration during the night (16 hours), then the daily production will amount to 8 x 14.1 + 141 x 0.7 = 211.7 m3/d (see chapter 4). With a domestic daily water demand of 40 l/cap.d this unit can serve about 5300 people.

The walls of the filters have been protected with an 0.08 m lining of mass concrete. If due attention is paid to a good execution of the concrete work (see instructions in chapter 7.4 and appendix 5), then the watertightness of walls and bottom will be reasonable. However the structure is not absolutely watertight, so the design can only be applied for locations where the highest ground water table is preferably below the filter bottom and in any case below the top of the sand bed. Instead of mass concrete other linings may be used (see figure 5.8).

For the design of water conduits and filter control facilities, simplicity has been striven after. The raw water flows to the filters through an open, mass concrete channel. The flow to the filters can be shut down by means of simple, removable weir beams, whereas the water level in the filter is controlled by the overflow pipe.

The effluent from the filters flows through PVC-pipes to the clear water tank, which has a storage capacity of about $\frac{1}{4}$ x π x 6^2 x 1.5 m3 = 43 m3 (20% of daily production). This storage capacity is rather small because the designer has planned another storage tank in the supply area.

The clear water tank is executed in masonry, with a mass concrete raft foundation.

To prevent pollution of the clear water, a hardwood cover has been provided for the clear water tank.

The filter control is done by manual adjustment of the butterfly valve in the effluent pipes, after inspection of the calibrated floats in the clear water tank. As an alternative to the weir chamber described in paragraph 3.2, this typical design comprises a weir chamber which is part of the clear water tank. The second section of the standard weir chamber is reduced to a simple gutter on top of the weir. During the re-ripening period of a filter the filtered water flowing into the gutter is directly drained, whereas during normal operation the drain valve of this gutter is closed and the water will flow over the crest of the gutter into the clear water tank.

Drains for the supernatant water, filter-to-waste pipes, and a by-pass of the clear water tank (in order to provide the possibility of inspection and repair of the clear water tank) have been provided.

As an example of the operation of the various valves, in paragraph 6.3 a scheme is given for the positioning of the valves during normal operation and backfilling. This scheme applies to design No. III.

6.2.   CIRCULAR FERRO-CEMENT FILTER

Circular filters of ferro-cement are very suitable for small villages. They can be built both abo' . and below ground level, depending on the ground water level. The maximum diameter of ferro-cement filters is limited to some 5 metres for reasons of deformation and non-universal loading.

In design No. II, circular filters of ferro-cement have been applied which are placed above ground level so they

are subjected to tensile forces. The hourly production
capacity of the two filters together can be calculated at
$\frac{1}{4} \times \pi \times 4,5^2 \times 0.1 \times 2$ m3/h = 3.2 m3/h.

With an 8-hour shift and declining rate filtration at night
(16 hours), the total daily production amounts to 48 m3/d.
If the daily water demand is set at 40 l/cap,d, this produc-
tion will serve a population of 1200 people.
The clear water tank has a storage volume of about $\frac{1}{4} \times \pi \times$
$4^2 \times 1.5$ m3 = 19 m3 (39% of daily production).
The raw water flows through PVC-pipes in which a gate valve
is provided to permit shutting down of the filters. The
effluent lines and filter control facilities are designed in
accordance with the description given in paragraph 3.2.
For details on the technique of ferro-cement construction
the reader is referred to appendix 5.

6.3.   CIRCULAR MASONRY FILTER

The use of masonry for the construction of slow sand filters
is particularly suitable when circular filters below ground
level are planned. As building materials natural stones,
quarry stones, concrete blocks or bricks may be applied.
These filters are subjected to pressure forces only. Ground-
water level should preferably be low.
The design No. III, has been prepared for the same village
as that of the ferro-cement filters, so the net filter bed
area and storage volume are the same as above.
The piping and filter control arrangements are similar to
those of design No. I.
When a filter is cleaned, the filtration rate of the other
filter should be doubled by opening the filter regulating
valve (valve No. 1 or 2 in figure 6.3) slowly until the flow
rate measurement device indicates a double flow (3.2 m3/h).
After the cleaning operation, the cleaned filter is backfilled
by means of filtered water from the other filter.

For instance if filter 1 requires backfilling, part of the
filtered water of filter 2 is allowed to flow through the
valves Nos. 3 and 4 (which are normally closed) and valve
No. 1 (which should be completely open for that purpose). If
the water level in filter 1 has reached some 0.1-0.2 m above
the top of the filter bed, the valves Nos. 3 and 4 are
closed, and the raw water inlet to filter 1 is re-opened.
When the supernatant water has reached its normal level, the
re-ripening period can start (see paragraph 3.7). During
this period the effluent water of filter 1 can be drained by
opening the valve No. 7.
As a further illustration of the operation of the valves, a
scheme for the positioning of the various valves during
normal operation and backfilling is given in table 6.1 (see
also figure 6.3.).

Table 6.1:   Positioning of valves for design No. III.

Valve No.	Normal operation filter 1 & 2	Backfilling filter 1 & 2	Scraping filter 1
1	open	open	closed
2	open	open	open
3	closed	open	closed
4	closed	open	closed
5	closed	closed	closed
6	closed	closed	closed
7	closed	closed	closed
8	closed	closed	closed
9	closed	closed	closed
10	open	open	open

6.4.   RECTANGULAR REINFORCED CONCRETE FILTER

Reinforced concrete filters will generally be used for small

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towns or somewhat larger villages, whose financial means are
not too limited. Furthermore, the skill to construct reinforced
concrete has to be available.

The design No. IV has a design capacity of 4 * 100 *
0.1 m3/h = 40 m3/h and a production capacity of 960 m3/d (at
a continuous operation).

It could serve a small town of some 12,000 inhabitants with
a daily water demand of 80 l/cap,d. In case of supply to a
group of villages with a daily water demand of 40 l/cap,d
some 24,000 people may be served.

Filter inlet and outlet structures are designed in a more
advanced way and the accessibility of piping and control
facilities is optimal as a piping gallery alongside the
filter units has been provided. Provisions for safety
chlorination or disinfection by means of bleaching powder or
high-test hypochlorite have been included and an operator's
building is placed on top of the clear water reservoir. The
piping gallery is covered with a concrete cover with recessed
handles for the filter controlling valves.

6.5. LAY-OUT OF THE TREATMENT PLANTS OF THE FOUR TYPICAL DESIGNS

In addition to the designs of the slow sand filters dealt
with in paragraphs 6.1 to 6.4, possible lay-outs of
treatment plants incorporating these filters are given in
this paragraph.

In order to give a general picture of water treatment
plants incorporating slow sand filters, on these lay-outs
some area is allocated to possible pre-treatment units.
Moreover, attention is paid to future extensions to the
treatment unit and basic services such as an operator's
workshop, store, sanitary services and site roads.
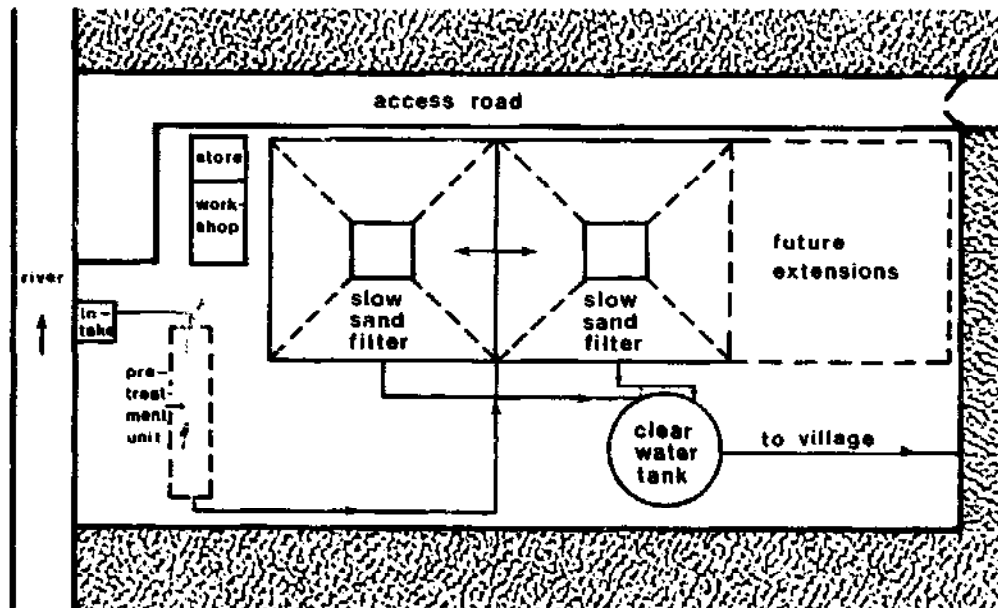
Figure 6.5.   Lay-out of a treatment plant, incorporating
typical design No. I.
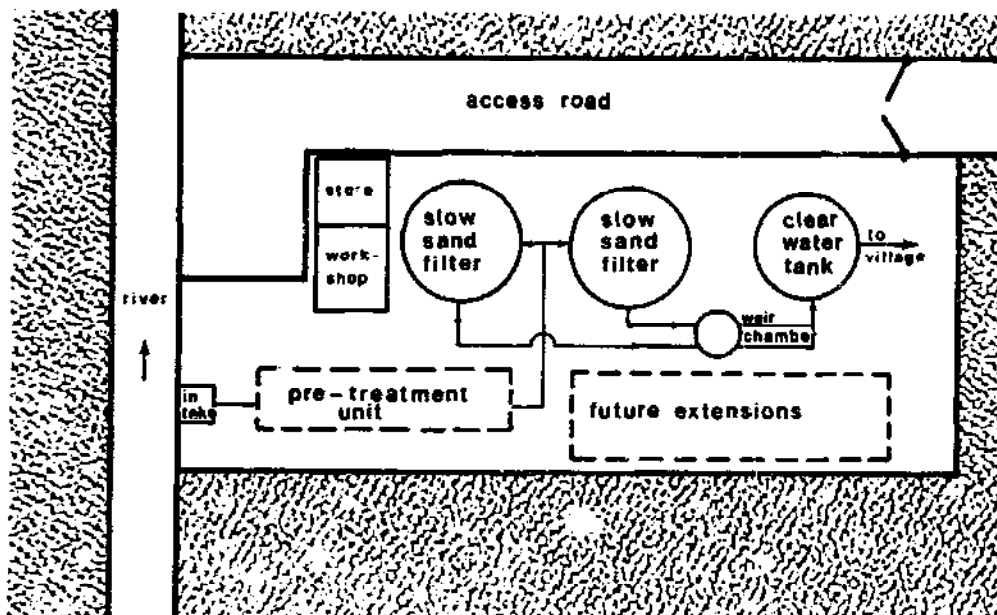
Figure 6.6.   Lay-out of a treatment plant, incorporating
typical design No. II.
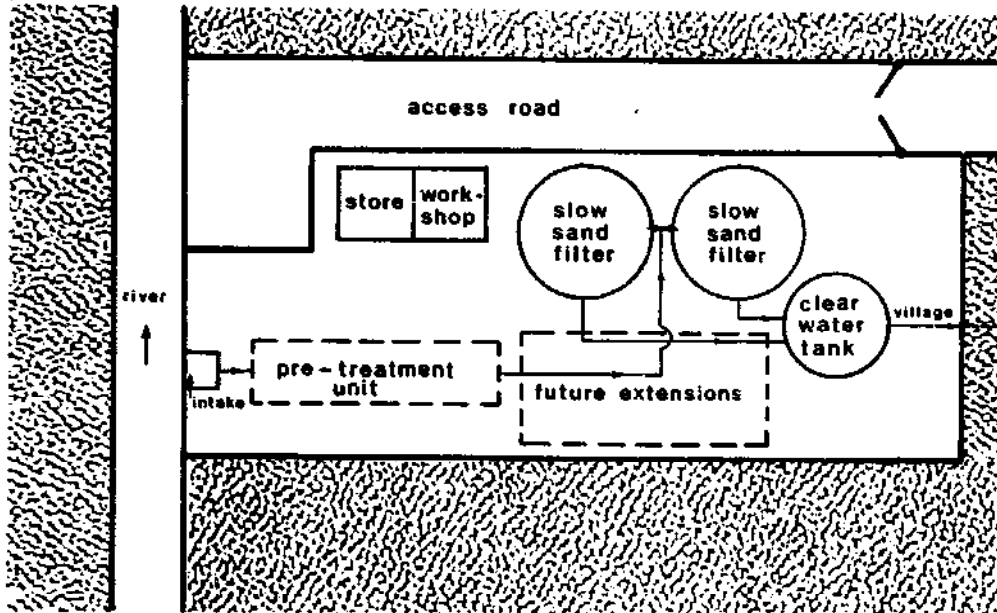
Figure 6.7.   Lay-out of a treatment plant, incorporating
                typical design No. III.
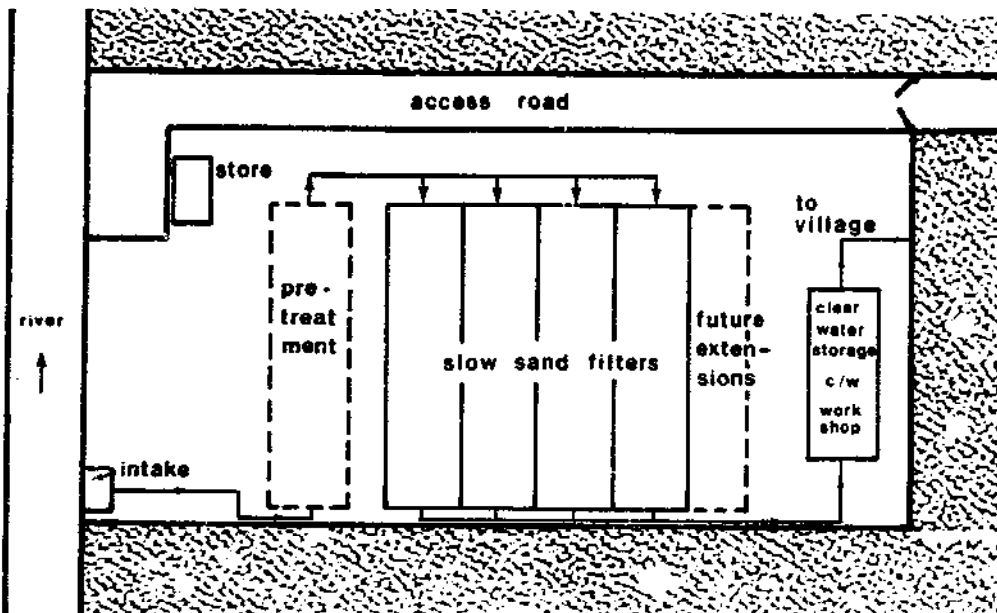
Figure 6.8.   Lay-out of a treatment plant, incorporating
                typical design No. IV

6.6. THE PRODUCTION CAPACITY OF THE FOUR TYPICAL DESIGNS

The hourly production capacity of the four typical designs
is determined by the total filter bed area and the filtration
rate, which is set at 0.1 m3/m2,h.
The daily production capacity is dependent on the mode of
operation: number of shifts, continuous operation, declining
rate filtration or intermittent operation.
Table 6.1. summarizes the daily production capacities of the
four typical designs for various modes of operation.

Table 6.2.   Daily production capacities of the four
               typical designs (I-IV) for various modes
               of operation.

Daily operation schedule			Daily production capacity (m3/d)			
NF(h)	DRF(h)	FC(h)	I	II	III	IV
8	-	16	112.9	25.5	25.5	320
8	16	-	211.7	47.8	47.8	600
16	-	8	254	50.9	50.9	640
16	8	-	324.6	66.8	66.8	840
24	-	-	338.7	76.3	76.3	960

where: NF = normal filtration
       DRF = declining rate filtration
       FC = filters closed

The number of people which may be served by the four typical
designs depends again on the mode of operation, the daily
water consumption per capita, losses, wastage etc. If the
water demand per capita (including losses and wastage) is
set at 40 l/cap d, the number of people serviceable is given
in table 6.2.

Table 6.3.   Number of people which may be served by the
               four typical designs at a water demand of
               40 1/cap d (for various modes of operation)

Daily operation schedule			Number of people serviceable			
NF(h)	DRF(h)	FC(h)	I	II	III	IV
8	-	16	2822	636	636	8000
8	16	-	5292	1195	1195	15000
16	-	8	6350	1272	1272	16000
16	8	-	8115	1670	1670	21000
24	-	-	8467	1908	1908	24000

where: NF = normal filtration
       DRF = declining rate filtration
       FC = filters closed

6.7.   QUANTITY OF BUILDING MATERIALS REQUIRED FOR THE FOUR TYPICAL DESIGNS

On the basis of the typical designs mentioned before, a
graphical representation has been made of the relationship
between construction materials required to build a slow sand
filtration plant and the capacity of such a plant (in m3/h,
as well as m3/d for one mode of operation). Figure 6.9 which
shows this relationship, may be used for a rough estimation
of the building materials that are required to build a slow
sand filtration plant. The graph does not include construction
materials required for pre-treatment or post-treatment.
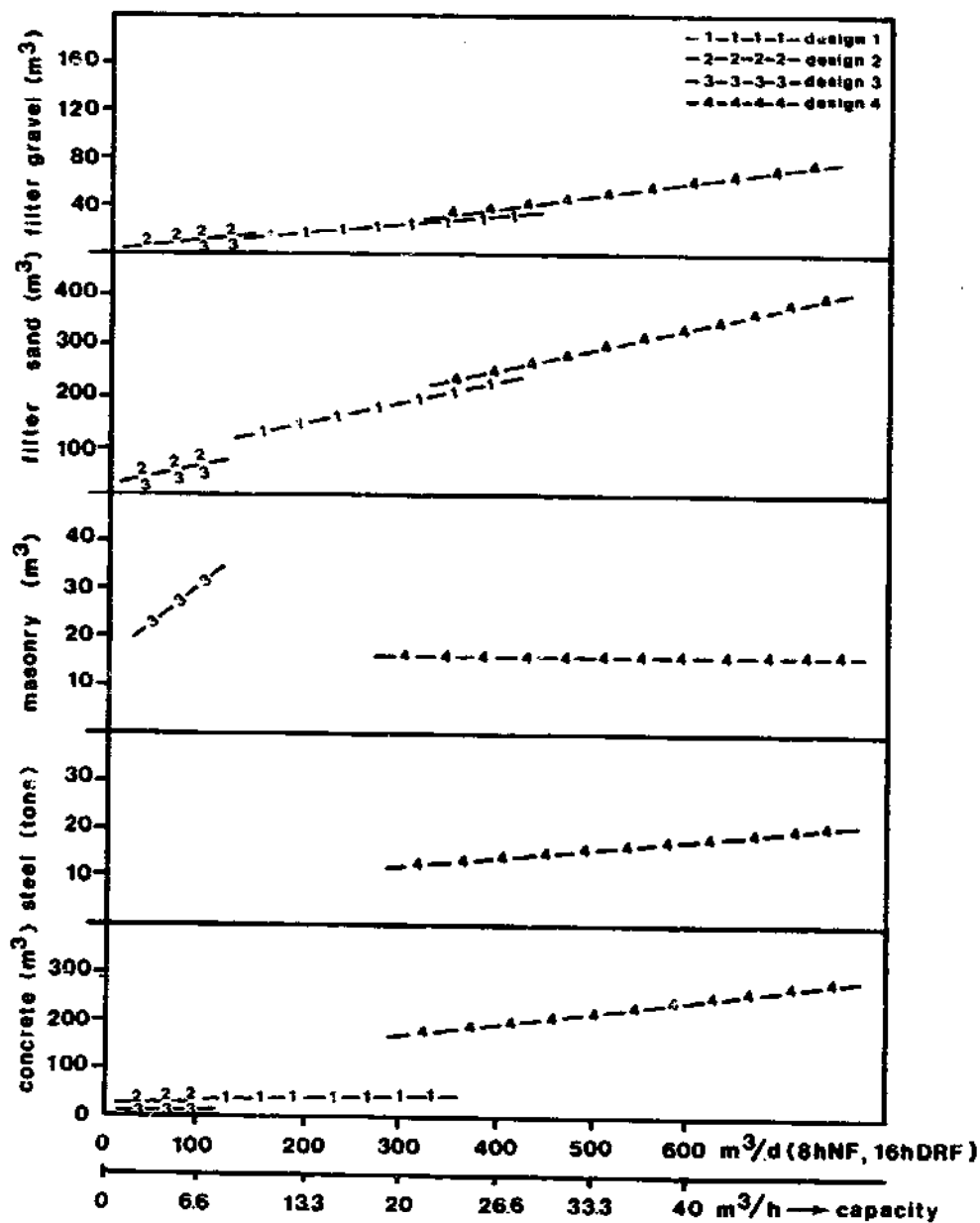
Figure 6.9. Quantity of building materials required for the four typical designs.

6.8 THE COSTS OF SLOW SAND FILTERS

The investment costs of slow sand filters are mainly determined
by the costs of materials such as cement, gravel, reinforce-
ment steel, filter sand, pipes, valves and the like. The
bills of quantity of the typical designs should be costed,
using local prices of materials. Prices for these materials
may vary within a broad range depending on various regional
and local circumstances. Therefore, in principle, efforts
to calculate fairly accurate unit prices (e.g. costs per
m3/h of production) are bound to fail. However, as a first
estimate of the costs of slow sand filters may be useful
for planning purposes, table 6.3 gives an estimate of the
costs of materials per unit of production for the 4 typical
designs. It should be borne in mind that this table, which
is based on information gathered in the slow sand filtration
project, does not include costs of construction, such as
labour costs and contractors' fees.

Furthermore it is noted that - within the range of filters
covered by this manual - economics of scale are included in
the table. Nevertheless, deviations from the figures given,
may occur in extreme situations, e.g. high costs of transport
of materials.

Table 6.4.   Estimated range of costs (in US$) of materials
               for slow sand filters per unit of production
               (m3/h), based on the four typical designs.

protected sloping wall filter	1000 - 4000	US$ per m3/h
ferro-cement filter	1500 - 6000	US$ per m3/h
masonry filter	1500 - 6000	US$ per m3/h
reinforced concrete filter	3000 - 12000	US$ per m3/h

If the total water availability is set at 2 1/cap h (or
48 1/cap d) the figures given in table 6.3 may be transfer-
red to costs per capita. See table 6.4.

Table 6.5.   Estimated range of costs (in US$) of materials
              for slow sand filters per capita served
              (based on the four typical designs).

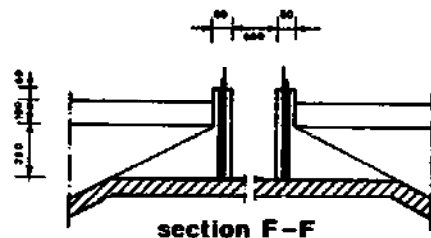|	
protected sloping wall filter	2 - 8 US$/cap
ferro-cement filter	3 - 12 US$/cap
masonry filter	3 - 12 US$/cap
reinforced concrete filter	6 - 24 US$/cap

100

plan

OVERFLOW P.V.C. ⌀100
DRAIN
C
B
RAW WATER
A
A
G
F F
FILTER 1
FILTER 2
G
EFFLUENT LINE PVC ⌀100
EFFLUENT LINE PVC ⌀100
DRAIN ⌀100
OVERFLOW ⌀100
DRAIN ⌀100
CLEAR WATER RESERVOIR
BYPASS ⌀100
MANHOLE
DRAIN ⌀100
B
SUPPLY LINE PVC ⌀100 TO VILLAGE

detail D (weir and gutter)
300
DESIGN W.L.
WATERTIGHT JOINT
220

section E-E
MEASURING DEVICES
OVERFLOW ⌀100
V-NOTCH
2750
330   6000   330

section B-B
E
HARDWOOD COVER
V-NOTCH
DESIGN W.L.
VALVE
2750
1500
D
MINIMUM REINF. ⌀8 -150
6000   750
EFFLUENT LINE PVC ⌀100
PERFORATED PVC ⌀100
DRAIN ⌀100
OVERFLOW ⌀100
E
5500   4000   5500

section A-A
NATURAL GROUND LEVEL
FREE BOARD
SUPERNATANT WATER
REINFORCEMENT ⌀8
FILTER SAND
CONCRETE FLOOR 1:2:3
FILTER GRAVEL - BROKEN STONES
REINFORCEMENT ⌀8
HIGHEST GROUNDWATER LEVEL
2750
5500   4000   5500   5500   4000   5500
760

section F-F

section C
OVERFLOW PVC ⌀100

section G-G
400

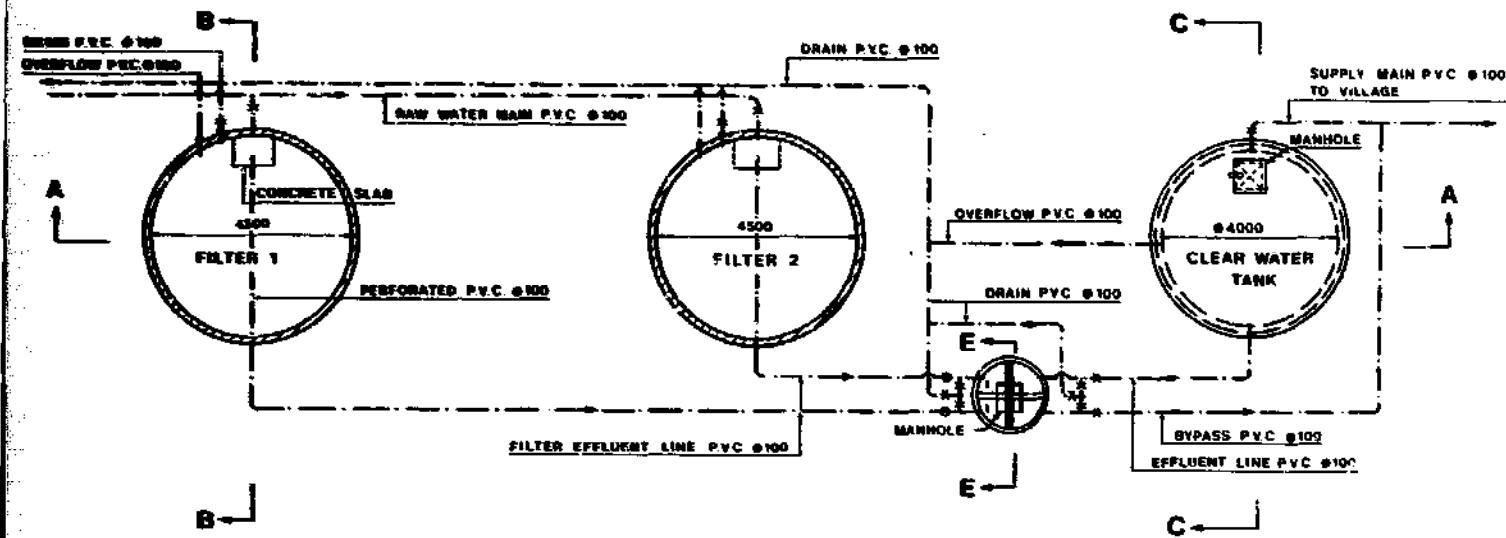| BILL OF QUANTITIES	
MATERIAL	QUANTITIES
CONCRETE 1:2:3	75 m³
REINFORCEMENT STEEL	1000 kg
MASONRY	10 m³
FILTER SAND 0.15 - 0.35 mm ; 1000 mm	200 m³
COARSE SAND 1.00 - 1.40 mm ; 100 mm	
GRAVEL 4.00 - 5.60 mm ; 100 mm	
GRAVEL 16 - 43 mm ; 150 mm	50 m³
BROKEN STONES 50 - 100 mm ; 150 mm	
GATE VALVES	10
BUTTERFLY VALVES	2
P.V.C. PIPES ⌀100	250 m
90° BENDS	15
T-JOINTS	15

— ⋈ — GATE VALVE
— ⊕ — BUTTERFLY VALVE
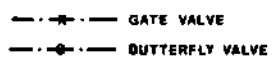
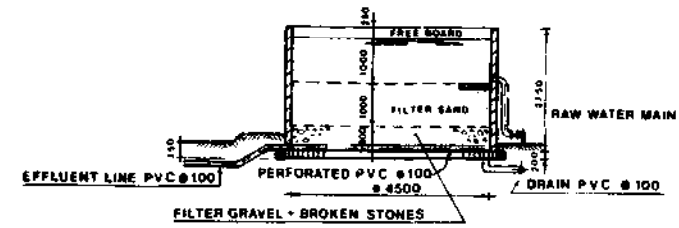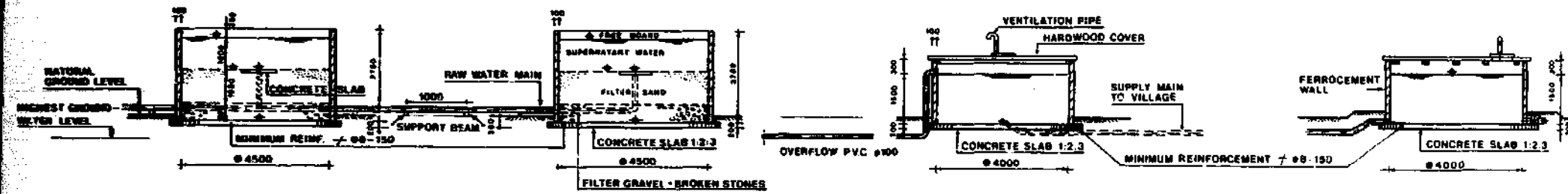| SLOW SAND FILTRATION		
TYPICAL DESIGN No I	Measures in mm	
PROTECTED SLOPING WALL FILTERS	date 780530	
CAPACITY 14.1 m³/h (113 - 338 m³/day).	T.W.O	FIG. 6.1
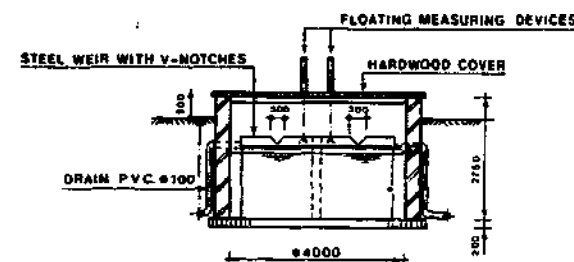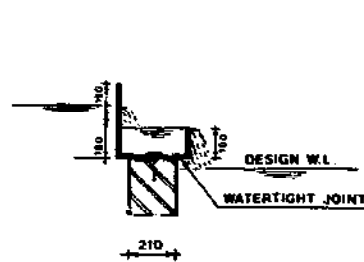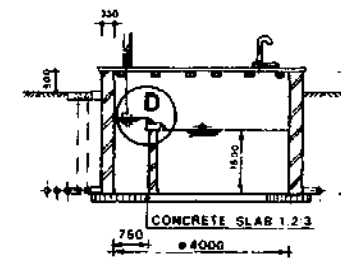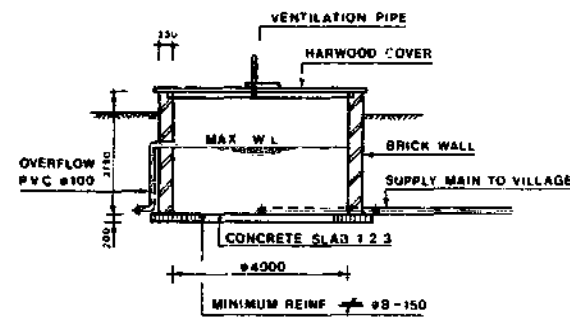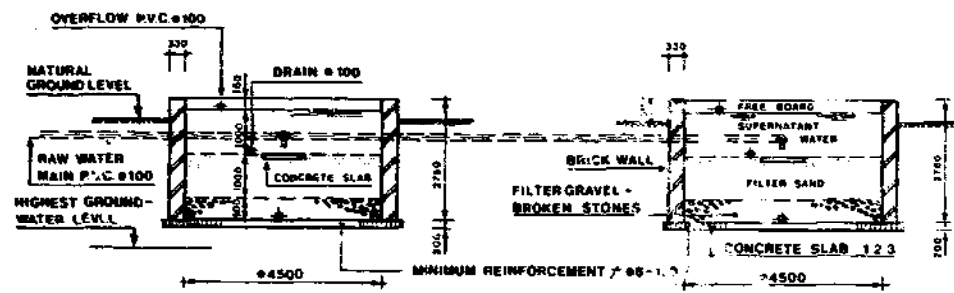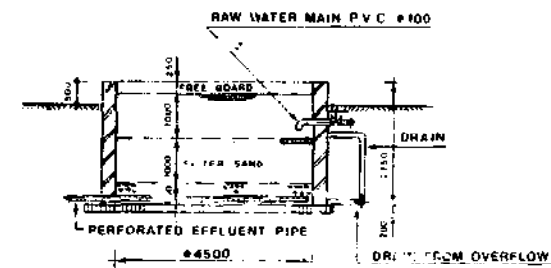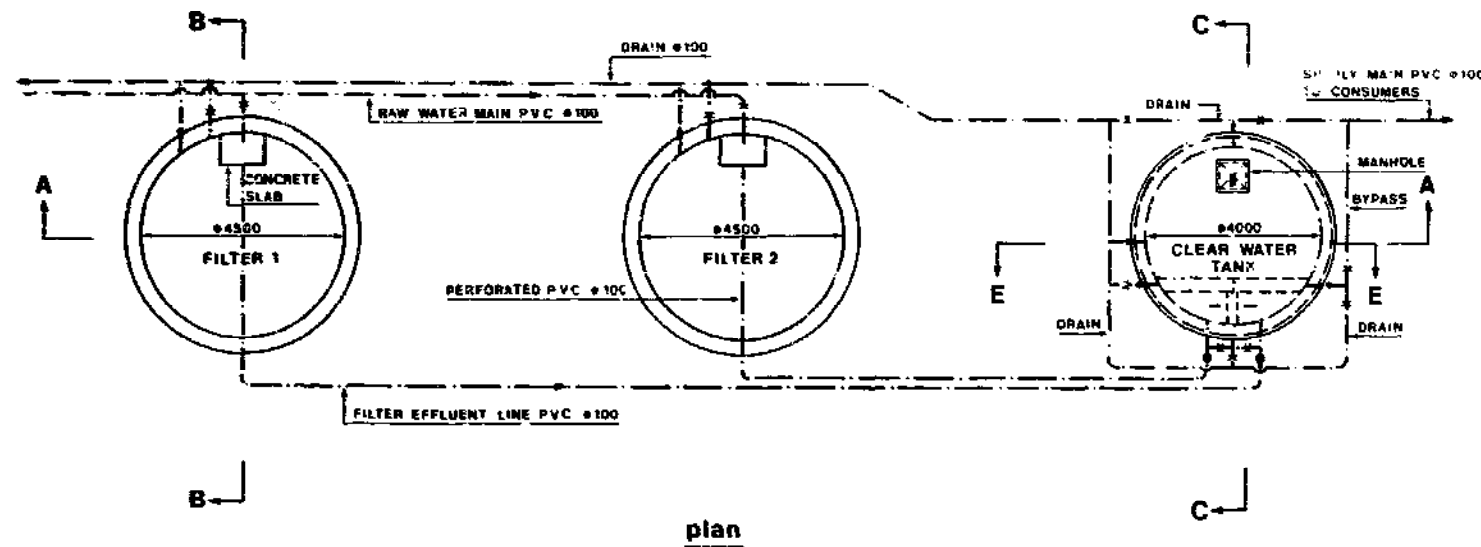
plan

section B-B

section A-A

section C-C

detail D

section E-E

BILL OF QUANTITIES	
MATERIAL	**QUANTITIES**
CONCRETE 1 2 3	10 m³
REINFORCEMENT STEEL	1000 kg
MASONRY	40 m³
FILTER SAND 0.15 – 0.35 mm; 1000 mm	32 m³
COARSE SAND 1.00 – 1.10 mm; 100 mm	
GRAVEL 4.00 – 5.60 mm; 100 mm	
GRAVEL 16 – 23 mm; 150 mm } 500 mm	16 m³
BROKEN STONES 50 – 100 mm; 150 mm	
GATE VALVES	12
BUTTERFLY	2
PVC PIPES	150 m¹
90° BENDS	26
T – JOINTS	15

— · — ⊗ — · — GATE VALVE

— · — ⊙ — · — BUTTERFLY VALVE
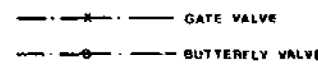
SLOW SAND FILTRATION

TYPICAL DESIGN no II	Measures in mm
MASONRY FILTERS	date 780530

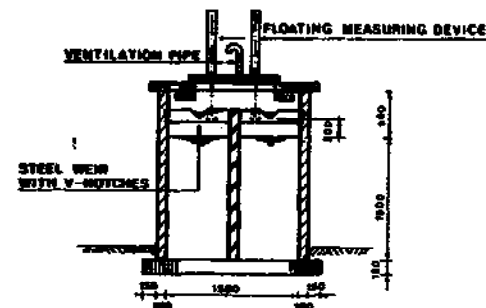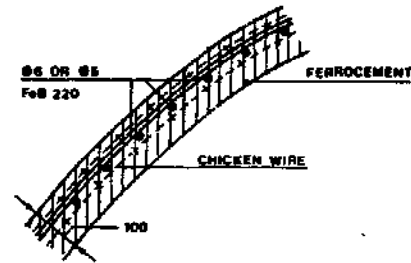| CAPACITY 3.2 m³/h (25.6 – 76.8 m³/day) | T.W.O | FIG. 6.2 |

Plan

plan

- SERIE P.V.C. ⌀ 100
- OVERFLOW PVC ⌀ 100
- B
- DRAIN PVC ⌀ 100
- RAW WATER MAIN PVC ⌀ 100
- C
- SUPPLY MAIN PVC ⌀ 100 TO VILLAGE
- CONCRETE SLAB
- MANHOLE
- A
- 4500
- FILTER 1
- PERFORATED P.V.C. ⌀ 100
- 4500
- FILTER 2
- OVERFLOW PVC ⌀ 100
- DRAIN PVC ⌀ 100
- ⌀ 4000
- CLEAR WATER TANK
- A
- E
- MANHOLE
- E
- BYPASS PVC ⌀ 100
- EFFLUENT LINE PVC ⌀ 100
- FILTER EFFLUENT LINE PVC ⌀ 100
- B
- C

section B-B

- FREE BOARD
- FILTER SAND
- RAW WATER MAIN
- EFFLUENT LINE PVC ⌀ 100
- PERFORATED PVC ⌀ 100
- ⌀ 4500
- DRAIN PVC ⌀ 100
- FILTER GRAVEL + BROKEN STONES

section A-A

- NATURAL GROUND LEVEL
- HIGHEST GROUND WATER LEVEL
- MINIMUM REINF. ⌀ 8-150
- SUPPORT BEAM
- ⌀ 4500
- CONCRETE SLAB
- RAW WATER MAIN
- FREE BOARD
- SUPERNATANT WATER
- FILTER SAND
- CONCRETE SLAB 1:2:3
- ⌀ 4500
- FILTER GRAVEL + BROKEN STONES

section C-C

- VENTILATION PIPE
- HARDWOOD COVER
- SUPPLY MAIN TO VILLAGE
- OVERFLOW PVC ⌀ 100
- CONCRETE SLAB 1:2:3
- ⌀ 4000
- MINIMUM REINFORCEMENT ⌀ 8-150
- FERROCEMENT WALL
- CONCRETE SLAB 1:2:3
- ⌀ 4000

section E-E

- VENTILATION PIPE
- FLOATING MEASURING DEVICE
- STEEL WEIR WITH V-NOTCHES

wall section

- ⌀6 OR ⌀5 FeB 220
- FERROCEMENT
- CHICKEN WIRE
- 100

BILL OF QUANTITIES

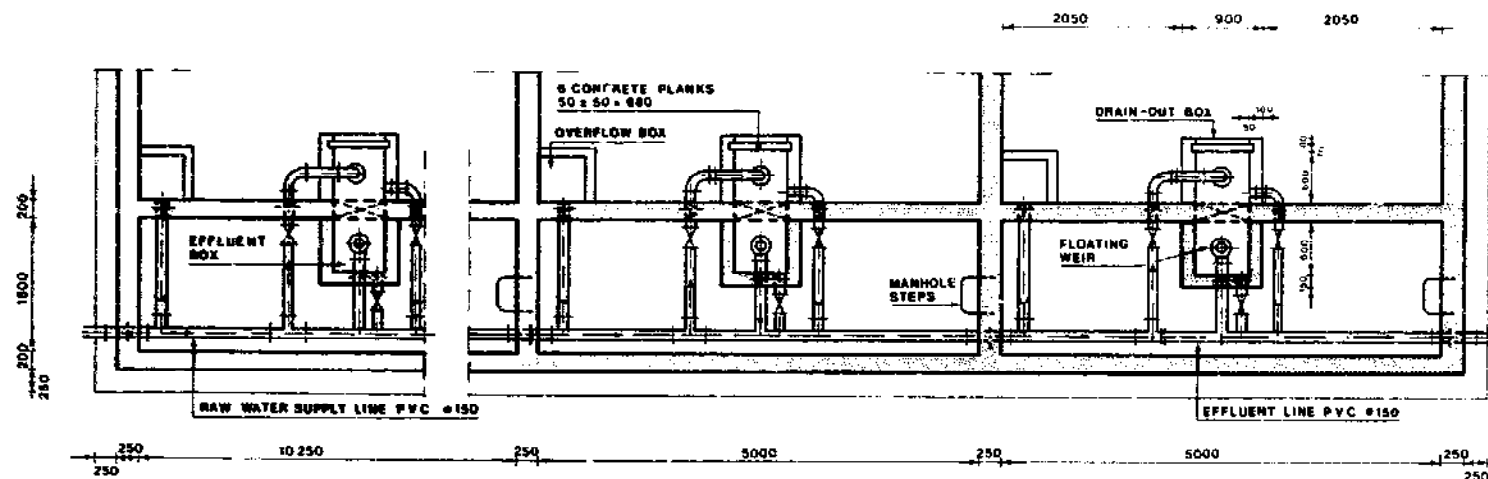| MATERIAL		QUANTITIES
CONCRETE 1:2:3		10 m³
REINFORCEMENT STEEL		2600 kg
FERROCEMENT		12 m³
FILTER SAND	0.15 - 0.35 mm : 1000 mm	32 m³
COARSE SAND	1.00 - 1.40 mm : 100 mm	
GRAVEL	4.00 - 6.60 mm : 100 mm	
GRAVEL	16 - 23 mm : 150 mm	16 m³
BROKEN STONES	50 - 100 mm : 150 mm	
GATE VALVES		13
BUTTERFLY VALVES		2
P.V.C. PIPES ⌀ 100		150 m¹
90° BENDS		32
T - JOINTS		14
CHICKEN WIRE		300 m²

(500 mm for the three gravel/coarse sand layers)

- ⊢ GATE VALVE
- ⊢ BUTTERFLY VALVE

SLOW SAND FILTRATION

TYPICAL DESIGN no III	Measures in mm date 780530
FERROCEMENT FILTERS	

| CAPACITY 3.2 m³/h (25.6 - 76.8 m³/day) | T.W.O | FIG. 6.3 |
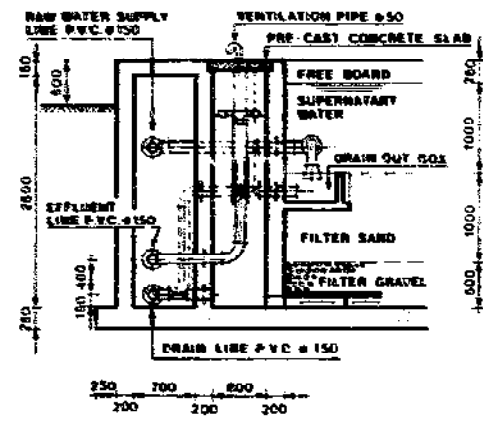
section A-A
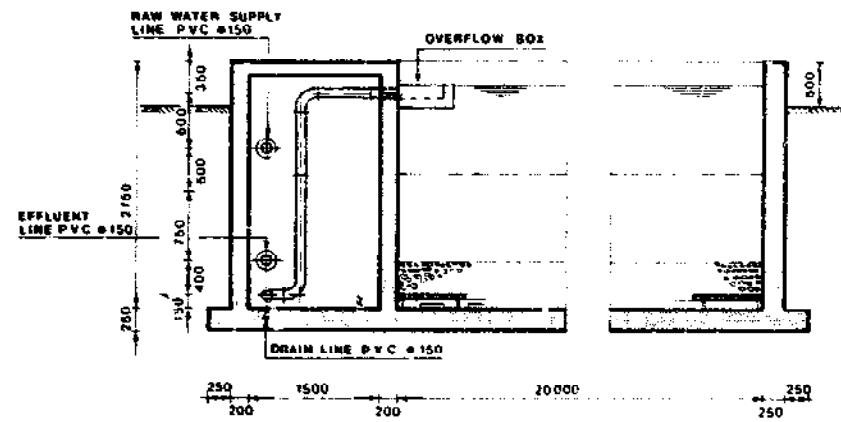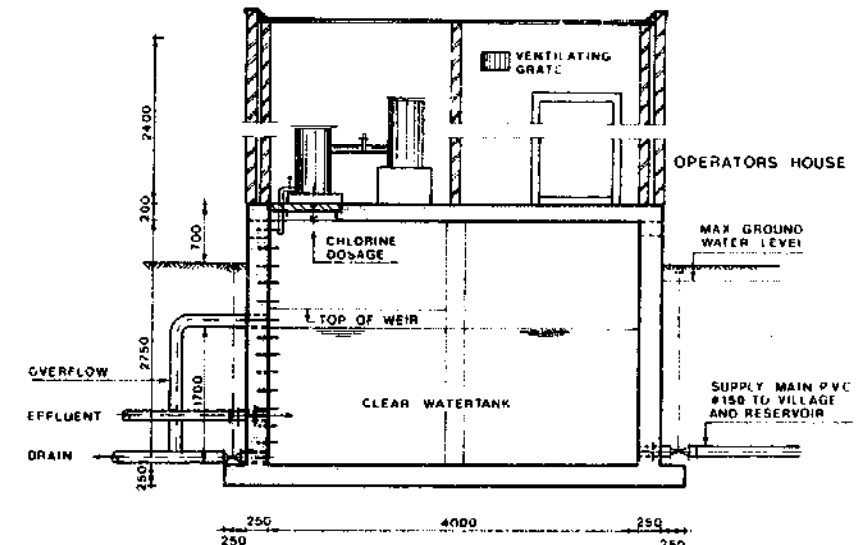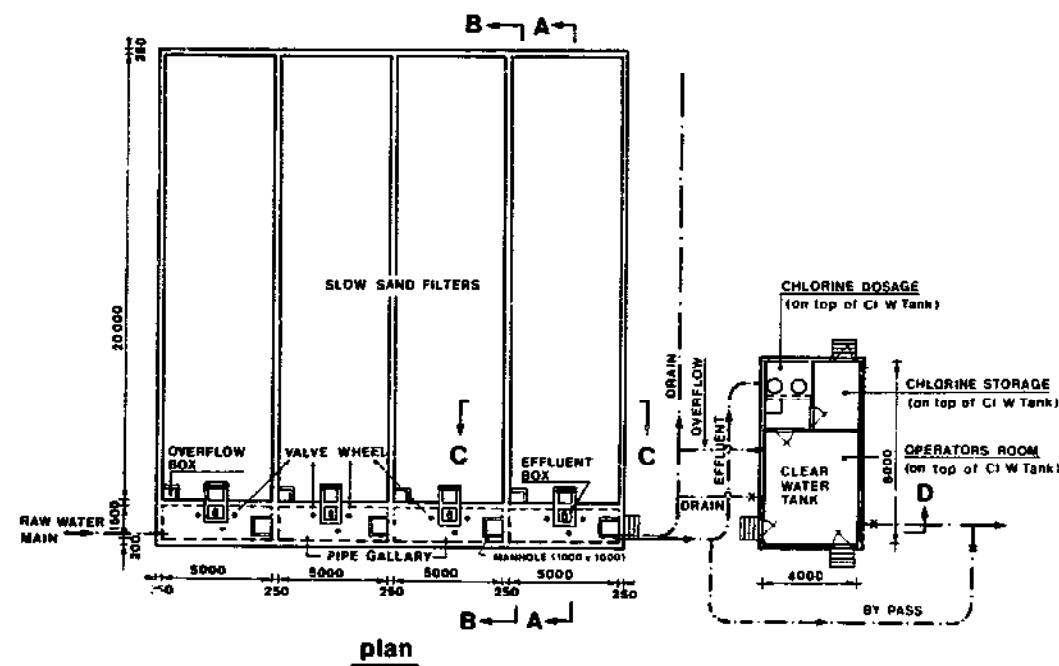
section B-B
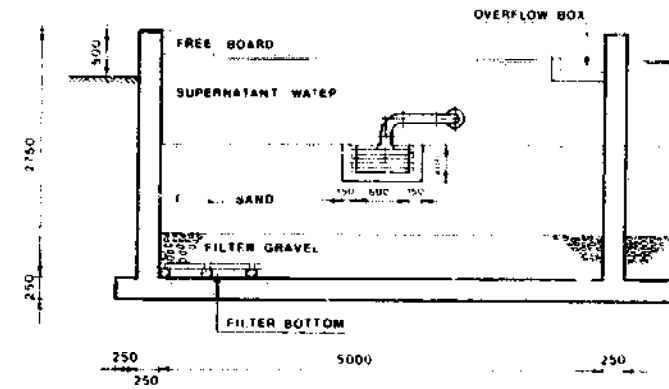
section C-C

horizontal section of pipe gallery

section D

plan

BILL OF QUANTITIES		
MATERIAL		QUANTITIES
CONCRETE 1 2 3		260 m³
REINFORCEMENT STEEL		16000 kg
MASONRY		18 m³
FILTER SAND	0.15 – 0.35 mm. 1000 mm	400 m³
COARSE SAND	1.00 – 1.40 mm. 100 mm	
GRAVEL	4.00 – 5.60 mm. 100 mm	
GRAVEL	16 – 23 mm. 150 mm	500 mm 140 m³
GRAVEL	50 – 100 mm. 150 mm	
GATE VALVES		15
P.V.C PIPES ø 150mm		150 m¹
90° BENDS		40
T – JOINTS		25

SLOW SAND FILTRATION		
TYPICAL DESIGN no IV	Measures in mm date 780530	
REINFORCED CONCRETE FILTERS		
CAPACITY 40 m³ (320 – 960 m³/day)	T.W.O	FIG. 6.4

7. THE IMPLEMENTATION OF SLOW SAND FILTRATION PLANTS

7.1. INTRODUCTION

The task of the designer does not usually end when the detailed design of a water treatment plant is completed. Now comes the time for fund-raising, administrative (tender documents and working schedules) and, most of all, coordinating activities.

Of course the design engineer will not have the sole responsibility for the progress of the project, but in any case he should stimulate the other participants in their task. Generally, two different approaches may be distinguished for the implementation of a water supply scheme, i.e. realisation by means of paid contractors or by means of the participation of the benefitting population. The task of the designer will also differ greatly in these two cases. In the first case, the design engineer will act on behalf of the client (probably a governmental or semi-governmental organization) and after the tender documents are drawn up his contribution will be limited to supervision. However, in self help projects the designer may act as a field engineer coordinating the project, the work of the participating population and the activities of suppliers, officials and other people involved. He will have to make reservations for material supply, plan activities ahead and coordinate the daily supervision.

In order to gain insight into these matters, some aspects of tendering, organization and supervision are further discussed below. In the last two paragraphs of this chapter some important aspects related to the building process are dealt with.

7.2. TENDERING

If the works (or parts of them) are carried out by contractors, appropriate tender documents have to be drawn up.

Tender documents comprise:

1. Form of tender
2. Form of contract
3. General conditions of contract
4. Particular conditions of contract
5. Technical specifications for the execution of the works
6. Bills of quantities

Furthermore a list of prequalification data to be furnished by the contractor and instructions to tenderers, general information, list of equipment, tender and performance guaranties, etc., may be included if desired.

The form of tender, the form of contract and the general conditions of contract contain legal and administrative regulations, which have been internationally standarized in the "Conditions of contract (international) for works of civil engineering construction" (15).

Copies from these elaborate documents may be obtained from the addresses, mentioned in appendix 9.

The specific conditions of contract relate to administrative and legal regulations that are particularly applicable for the specific country or work involved, e.g. conditions of payment, overnight labour etc. These can be drawn up on the basis of the general conditions, mentioned above.

The technical specifications, including drawings and the bills of quantities are the "heart" of the tender. They should include an accurate and complete description of the works to be carried out, the way they should be carried out and the materials to be used.The materials to be used may be fixed by referring to national or international standardized quality parameters (see also appendix 5) and the description of the way the works have to be carried out should contain standards of accuracy, bending of shuttering etc. These standards are also frequently described in nationally or internationally used instruction manuals (see bibliography).

National engineering institutes may also be able to furnish
instructions for use in tender documents. It should always
be remembered that the functions of the tender documents
are:
1.   Transfer of knowledge and intentions
2.   Guide for the execution of the works
3.   Legal contract documents
4.   Basis for the estimate of the contractor
5.   Guide to duties and responsibilities for people involved
      in the execution
6.   Means to inspect and to test the execution of the
      works

The tendering may be public or by private contract, depending
on local circumstances (familiariaty with contractor,
expected effect on price and quality of work).
Once the contract documents are signed, the implementation
of the works may start. The design engineer's job is then
usually limited to:
1.   co-ordination of the works, if more than one contractor
      is at the site
2.   co-ordination of the activities between contractor and
      client
3.   supervision and control of the performance of the
      contract
4.   control and approval of expenditures

7.3.   PLANNING AND ORGANIZATION

Especially in self help projects, a certain knowledge of
organization and planning techniques is indispensable for
the designer acting as a field engineer.
Wastage of materials and time frequently occur at building
plots and are the result of inefficient organization of the
works. The effects of delayed ordering of essential materials
or tools need no further argument.

It may be stated that a good organization of the work is
obtained when the efficiency of the operations of the
labourers is at the highest possible level. Inefficiency of
course cannot be entirely excluded, as, for example, the
labourers themselves may not have enough skill to use the
most efficient technique for a certain job. In general, the
following organizational measures may improve efficiency:

1. making plans; determining means, sequence of operations,
   required time and place
2. dividing of tasks; motivation of labourers by describing
   tasks clearly
3. co-ordinating; keying communication to tasks, improving
   cooperation
4. control; check results with plans
5. correction; change plans in order to reach goal

It may be clear from the above that planning is an important
part of organization. The need for planning can be illustrated
by the consequences of its absence; occurence of bottlenecks,
lack of equipment or labour and wastage.

Many techniques for the planning of works have been developed,
some of which are so complicated that computer programmes
are required to use them. In the scope of this manual only
simple planning techniques for the relation between the
amount of work, the sequence of unit operations and the
required time are discussed.

Time-schedules are usually executed as bar-charts and give
a systematic projection of the planned progress of the
project.

By comparing the actual progress with the one planned,
differences may be registered and corrective measures
taken.

To make a time-schedule, the field engineer will have to
record:

1. What is to be done?

2. In what amounts is it to be done?

3. When is it to be done?

4. By whom is it to be done?

5. What means are necessary to do it?

Of course, it will not be necessary to make detailed plans
far in advance; rough plans may suffice in the first instance,
while more detailed plans can be drawn up in a later stage.
Besides the time-schedule of the work at the site, sub-
schedules will have to be made for preparatory activities
(e.g. hiring of personnel, ordering of tools and materials).
An important feature of time-schedules is the sequence of
operations; for a reinforced concrete foundation for instance,
this schedule is:

1. stake out trench

2. excavate

3. make shuttering

4. pour working floor

5. bend and fix reinforcement

6. pour foundation

These operations can be reproduced by means of a bar-chart,
for which time periods are given, horizontally divided by
so-called plan strokes. For each plan stroke the number of
planned operations can be given, as well as the cumulative
number of operations. This gives a simple check on the
progress of the work.

As an example, the work on the foundations of four reinforced
concrete filters could be visualized as in figure 7.1.

month		month 1				month 2				month 3		
week	1	2	3	4	5	6	7	8	9	10	11	
operations												
stake out trench	(2)	(2)										
excavate			(1)	(1)	(1)	(1)						
make shuttering							(4)					
pour working floor								(4)				
mesh rein- forcement										(4)		
pour foundation											(4)	

reserve

where: number between brackets indicates the number of
         filters involved

Figure 7.1.   Working-schedule for construction of the
              foundations of 4 reinforced concrete filters.

7.4.   BUILDING INSTRUCTIONS

In self help projects, the designer will generally have to act
as leader of the construction team. This implies that he will
now be actively engaged in construction

and supervision, more than is the case when the works are carried out by contractors. The designer must therefore necessarily have constructional experience. However, there are certain aids and appliances, which he can use to advantage when organizing the work and instructing the labourers. Regional and national authorities will probably have standardized building instructions, but textbooks on construction such as the "Manual of Concrete Practice" (19) and the "A manual on building construction" (20) may also be used.

In countries with a large labour-potential, the designer should concentrate on labour-intensive building, and omit the use of mechanized equipment. An important factor in labour-intensive building is the motivation and interest of the labourers in the project. If the labourers themselves benefit from the works, then there need be no problem, but if this is not the case it may be necessary to promote the interest of the labourers by paying piece-wages.

For information on properties and processing of the building materials used, the reader is referred to appendix 5.

The most important aspect of the execution of the works is to pay the utmost attention to the watertightness of the filter box and clear water mains. This means cleaning of pouring seams, good compaction of concrete in order to prevent the occurrence of gravel spots and using as little water as possible for the processing. Furthermore it is necessary to keep the shuttering and the construction wet for a few weeks after the pouring in order to limit temperature stresses and evaporation of the process water. Fences may also be used to protect the fresh concrete against sun and wind.

The pouring and compaction should be done as quickly as possible; tardiness and delay during pouring should never occur.

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Another matter of importance is that the filter sand should
not be placed until the excavated soil of the building-pit
has been refilled; this is to limit tensile stresses.
Furthermore it is important to pay utmost attention to a
good compaction of the subsoil (before the building is
started) in order to limit differential settlements and
tensile forces in the raft foundation.
With respect to further details on the execution of the
building process, the reader is referred to the textbooks on
building and construction given in the bibliography.
As an example, aspects of the concrete shuttering of construc-
tional elements for slow sand filtration plants will be
discussed below.

Example: Shuttering of concrete works

Asbestos cement and steel may be used for the shuttering,
but wood is the most usual material. The minimum size of
wooden planks for use in shuttering is 25 x 150 mm for
girders and shores; battens of at least 65 x 165 mm are
used. The wood has to be dried for some time, as uncured
wood shrinks.
Of course the shuttering has to be able to transmit the
weight of the concrete mortar without horizontal or vertical
displacement or bending. Vertical walls have to be adequately
supported. During the construction of the shuttering some
openings have to be provided to allow the removal of dirt,
wire and sawdust. It is important to see to it that the
shuttering is plumb.
The loosening of the shuttering can be promoted by coating
the inside of the shuttering with shuttering oil or some
other fatty substance.

Shuttering of floor

The floor can be poured direct onto the natural soil or onto
a working floor of 50 mm 1:3:5 concrete (see appendix 5).
The sides to the floor are lined by means of pickets and
shuttering boards (2.5 x 150 mm). The pickets have to be
hammered firmly into the soil in order to be able to with-
stand deformations. The floor of the filter is usually
extended 0.10 to 0.20 m in order to provide space for the
wall-shuttering (see figure 7.2).
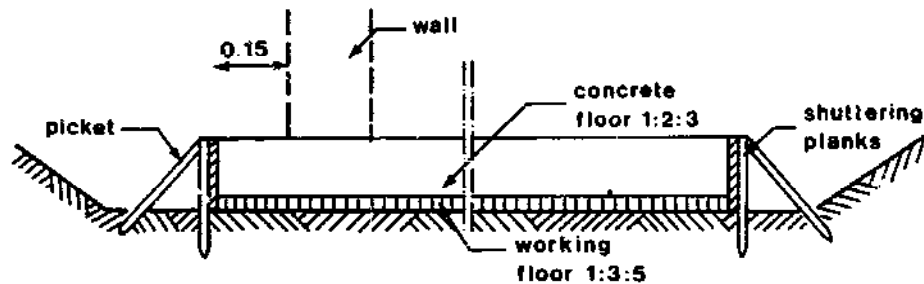
Figure 7.2.   Shuttering of floor

Shuttering of walls

The shuttering-boards of the filter walls can be nailed onto
vertical battens, placed at 0.75 m intervals. As the horizon-
tal pressure of the concrete mortar is large, the shuttering
has to be supported by shores. The battens can be joined
together by means of centrepins (see figure 7.3). Loosening
of the centrepins soon after the hardening of the concrete
has the disadvantage that large holes and cracks in the
concrete result. After sufficient hardening the pins only
leave small sound holes, which can then be filled up with
mortar.
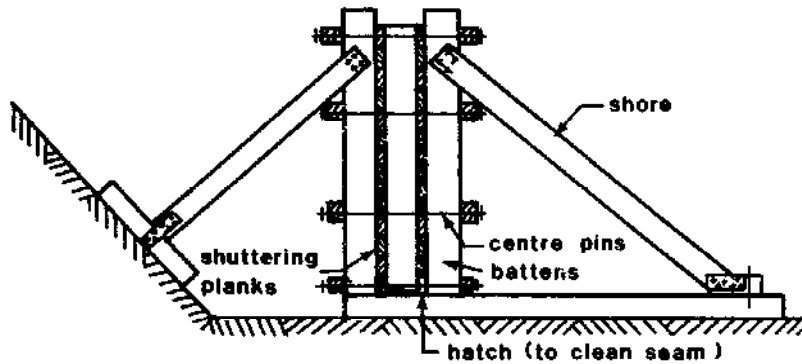
Figure 7.3.   Shuttering of walls

Shuttering of cover (clear water tank)

The shuttering can consist of boards (2.5 x 150 mm) which
are supported by beams (65 x 165 mm) laid on edge. The beams
are supported by cross-beams. The connection between battens
and beams is made by nailing short planks of 0.4 m length
on both sides. The battens rest on planks with wedges in
between for the removal of the shuttering.
The battens are connected by shores to stiffen the shuttering
(see figure 7.4).
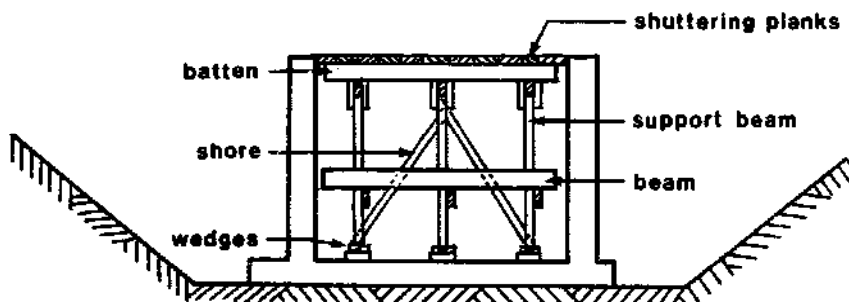
Figure 7.4.   Shuttering of cover

7.5. A CHECKLIST FOR THE SEQUENCE OF OPERATIONS IN THE CONSTRUCTION OF SLOW SAND FILTERS

The building of slow sand filters is done in accordance
with the normal principles of construction. Amongst others
this means that certain operations can only be executed
when others are finished, i.e. there is a sequence of
operations which is determined by the process of construction
and the physical characteristics of the construction
materials. In this paragraph a simple checklist is given,
in which the sequence of operations in the construction of
slow sand filters is summarized:

- site clearance
- setting out
- (drainage of building pit)
- excavation
- concrete work of the foundation
- i.e. placing of shuttering
      fixing of the reinforcement
      preparation of concrete
      pouring of concrete
      curing of concrete
      removal of shuttering
- concrete work of the filter walls
      analogous to the work on the foundation
- installation of pipelines and transits
- finishing of concrete work
- placing of system of underdrains
- placing of gravel layers
- placing of filter sand
- (shutting down of drainage provisions)
- completion of all appurtenances
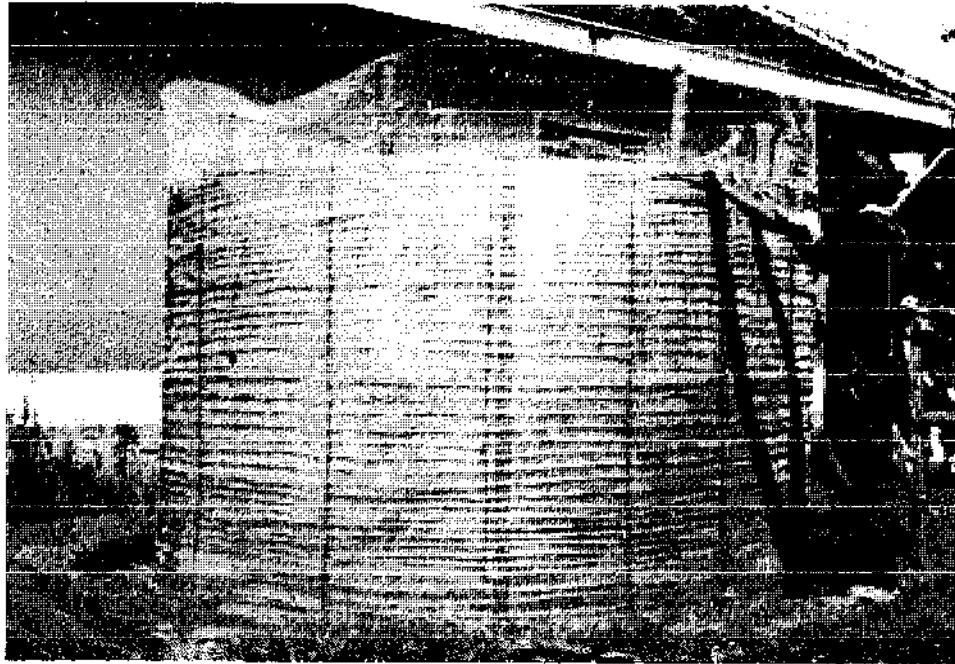
Construction of a ferro-cement water tank, Lombok, Indonesia.
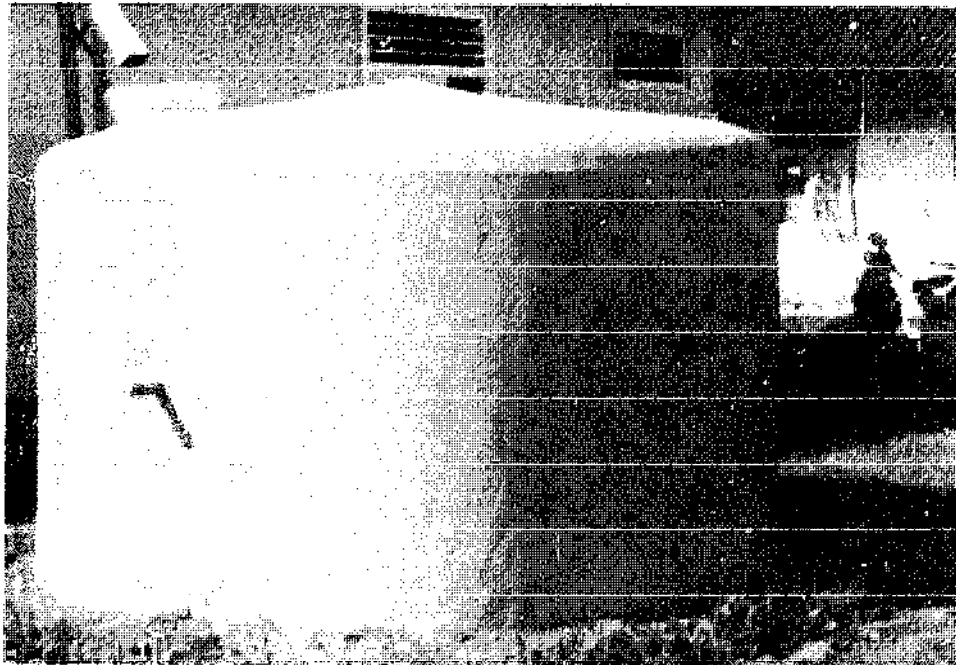
Water tank completed. At top left, inflow pipe and simple filter (containing palm fibre) can be seen.
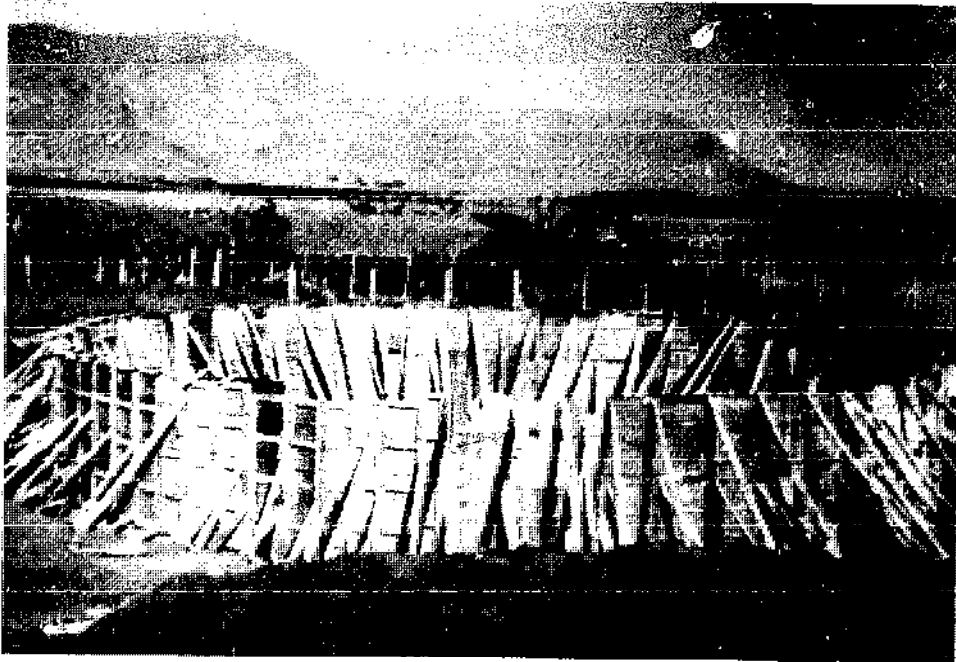
Circular reinforced concrete filter under construction, Tamil Nadu, India.

Filter completed.

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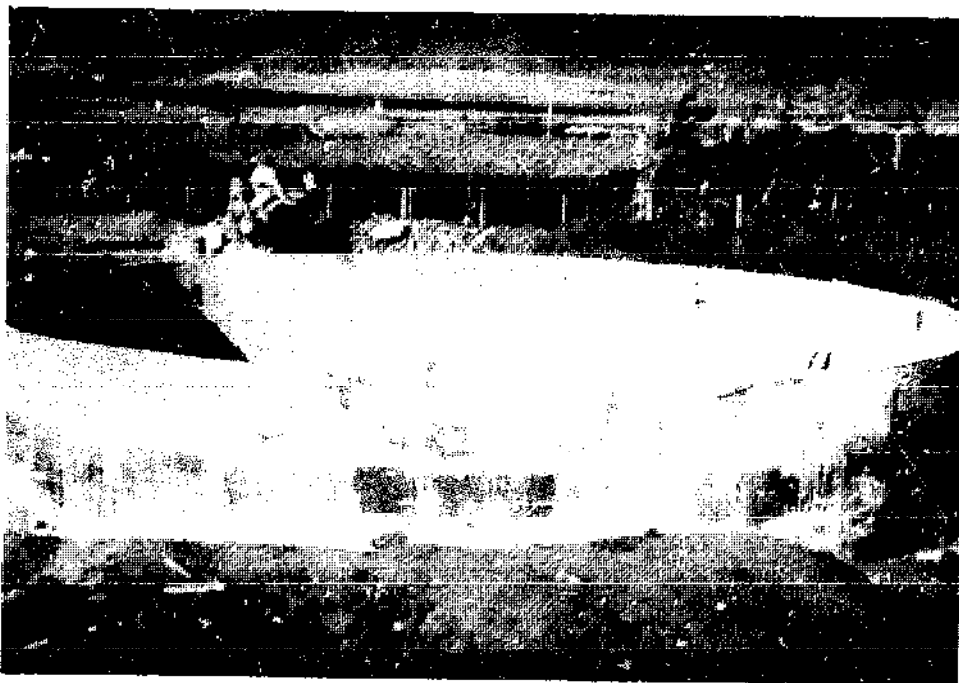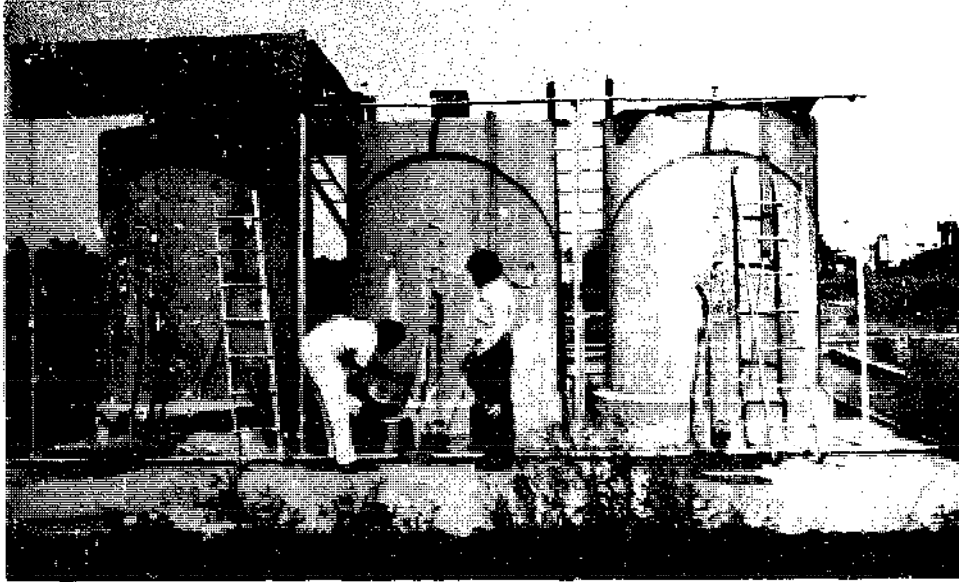
Slow sand filtration pilot unit, Nagpur, India
(National Environmental Engineering Research
Institute).

Slow sand filtration pilot unit, Owabi Waterworks,
Ghana (Ghana Water and Sewerage Corporation,
University of Science and Technology, Kumasi).

APPENDIX 1

WATER QUALITY CRITERIA

This appendix summarizes the WHO International Standards for Drinking Water (16).

a. Standards for the bacteriological quality of drinking water:

1. Throughout any year, 95% of samples should not contain any coliform organisms in 100 ml.

2. No sample should contain E.Coli in 100 ml.

3. No sample should contain more than 10 coliform organisms per 100 ml.

4. Coliform organisms should not be detectable in 100 ml of any two consecutive samples.

b. Substances and characteristics affecting the acceptibility of water for domestic use:

Substance or characteristic	Undesirable effect that may be produced	Highest desirable level	Maximum permissible level
Substances causing discoloration	Discoloration	5 units[a]	50 units[a]
Substances causing odours	Odours	Unobjectionable	Unobjectionable
Substances causing tastes	Tastes	Unobjectionable	Unobjectionable

Substance or characteristic	Undesirable effect that may be produced	Highest desirable level	Maximum permissible level
Suspended matter	Turbidity Possible gastrointestinal irritation	5 units[b]	25 units[b]
Total solids	Gastrointestinal irritation	500 mg/l	1500 mg/l
pH range	Taste Corrosion	7.0 to 8.5	6.5 to 9.2
Anionic detergents[c]	Taste and foaming	0.2 mg/l	1.0 mg/l
Mineral oil	Taste and odour after chlorination	01 mg/l	0.30 mg/l
Phenolic compounds (as phenol)	Taste, particularly in chlorinated water	mg/l	0.002 mg/l
Total hardness	Excessive scale formation	2mEq/l e (100 mg/l CaCO3)	10mEq/l (500 mg/l CaCO3)
Calcium (as Ca)	Excessive scale formation	75 mg/l	200 mg/l
Chloride (as Cl)	Taste; corrosion in hot-water systems	200 mg/l	600 mg/l

Substance or characteristic	Undesirable effect that may be produced	Highest desirable level	Maximum permissible level
Copper (as Cu)	Astringent taste; discoloration and corrosion of pipes, fittings and utensils	0.05 mg/l	1.5 mg/l
Iron (total as Fe)	Taste, discoloration; deposits and growth of iron bacteria; turbidity	0.1 mg/l	1.0 mg/l
Magnesium (as Mg)	Hardness; taste; gastrointestinal irritation in the presence of sulfate	Not more than 30 mg/l if there are 250 mg/l of sulfate; if there is less sulfate, magnesium up to 150 mg/l may be allowed	150 mg/l
Manganese (as Mn)	Taste; discoloration; deposits in pipes; turbidity	0.05 mg/l	0.5 mg/l

Substance or characteristic	Undesirable effect that may be produced	Highest desirable level	Maximum permissible level
Sulfate (as SO4)	Gastrointestinal irritation when magnesium or sodium are present	200 mg/l	400 mg/l
Zinc (as Zn)	Astringent taste; opalescence and sand-like deposits	5.0 mg/l	15 mg/l

a. On the platinum-cobalt scale.

b. Turbidity units.

c. Different reference substances are used in different countries.

d. If the hardness is much less than this, other undesirable effects may be caused; for example, heavy metals may be dissolved out of pipes.

e. 1 meq/l of hardness-producing ion = 50 mg CaCO3/l = 5.0 French degrees of hardness = 2.8 (approx) German degrees of hardness = 3.5 (approx) English degrees of hardness.

c. Tentative limits for toxic substances in drinking
    water:

Substance	Upper limit of concentration
Arsenic (as As)	0.05 mg/l
Cadmium (as Cd)	0.01 mg/l
Cyanide (as CN)	0.05 mg/l
Lead (as Pb)	0.1 mg/l
Mercury (total as Hg)	0.001 mg/l
Selenium (as Se)	0.001 mg/l

APPENDIX 2

SIMPLE PRE-TREATMENT SYSTEMS

Slow sand filters do not function properly if the raw water has a high turbidity. If the average daily turbidity of raw water is more than 10 NTU pre-treatment is recommended.

Storage

A storage basin (see figure A.2.1) may serve a threefold purpose; it may improve the reliability of the water supply during periods of short supply of raw water, it reduces turbidity by sedimentation and finally it improves the quality of the water because a substantial reduction of pathogenic bacteria may be achieved through the activity of algae, protozoa and other predatory organisms on the one hand and the germicidal effect of ultraviolet rays in sunlight on the other hand.

A storage basin may be constructed by erecting a simple earth dam up to a height of about 6 metres (range 6-10 metres). Allowance should be made for storage of the deposited silt which may amount to 100 ml per litre raw water in arid areas, and for losses due to evaporation and seepage. The dead storage should amount to about 2 metres. Evaporation may be up to about 2 metres a year, and losses by evaporation and seepage of 15 - 25 mm/day are not uncommon. The detention time will be in the order of several weeks to a few months.
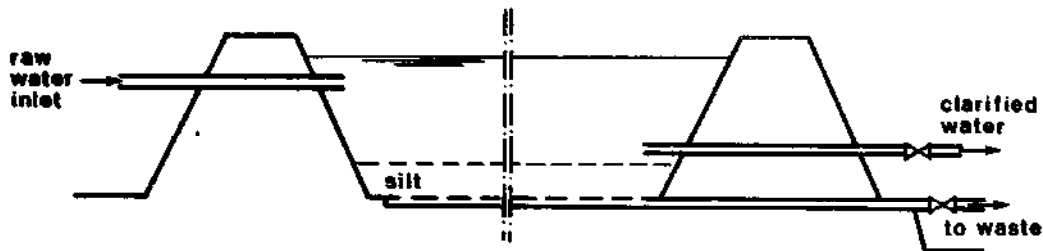
Figure A. 2.1 Storage basin

Small storage reservoirs may be lined with stabilized soil, concrete or masonry to decrease seepage. The silt may be removed by the raw water source itself during flood-flow or by manual labour. In the first case waste drains should be installed, whereas in the second case bottom drains should be provided to improve the removal of the water from the silt. Access to a storage basin should be restricted to a minimum to limit pollution of the water in the basin. Routine maintenance of storage basins should include the removal of vegetation and weeds.

Plain sedimentation

A plain sedimentation basin (see figure A.2.2) mainly serves the purpose of reduction of turbidity and removal of suspended matter. The detention time (maximum of 2 days) is short in comparison with that of a storage reservoir, but should be long enough to allow the suspended solids to settle (particles with a density higher than water) or to float (particles with a density lower than water). The designed detention time should be based on samples typical of all regimes of the river. A sedimentation tank may have a batchwise or a continuous operation. The most common configuration of a continuously operated sedimentation basin is a rectangular box made of concrete or masonry, or a dug basin with protected sloping walls.
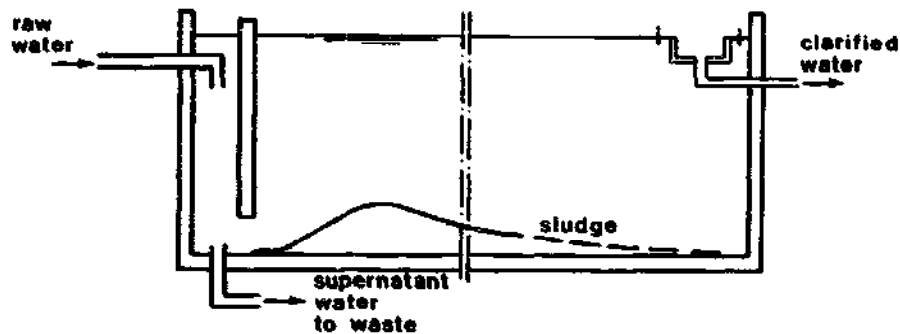
Figure A.2.2   Plain sedimentation basin

The raw water inlet is situated at the one short side of
the box, the outlet at the other short side. Inlet and
outlet structures (see figure A.2.3) are essential to a
proper functioning of the basin. The incoming flow should
be distributed as evenly as possible over the whole width
of the basin to reduce currents and short-circuiting.
The outlet structure usually consists of one or more weirs
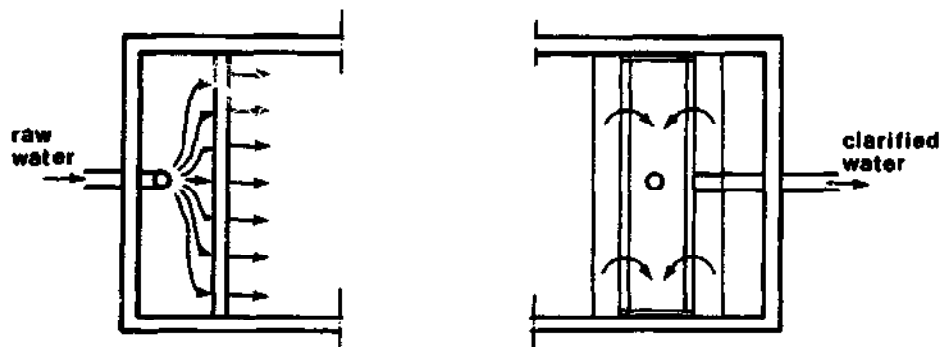extending across the whole width of the basin.

**Figure A.2.3   Inlet and outlet structures of a plain
sedimentation basin**

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If there is a high concentration of algae at the water surface, the outlet may be situated some distance below the surface (see Figure A.2.4).
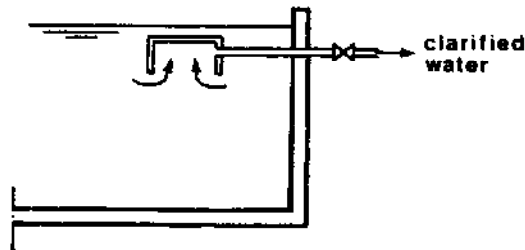
Figure A.2.4   Outlet-structure in submerged position.

Design criteria for rectangular sedimentation basins are summarized in Table A.2.1. It is remarked that the figures mentioned are not universally applicable but may serve as rules of thumb.

Table A.2.1   Design criteria for rectangular sedimentation basins.

parameter	symbol	range of values
detention-time	V/Q	4 - 12 hours
surface loading	Q/A	2 metre/day - 10 metre/day
depth of the basin	H	1.5 - 2.5 metre
weir overflow rate[x] (outlet)	Q/R	3 - 10 m3/metre per hour
length/width ratio	L/W	4:1 up to 6:1
length/depth ratio	L/H	25:1 up to 35:1 or 5:1 up to 20:1 for small basins

where:

H = depth (in metres)

L = length (metres)

W = width (metres)

V = volume of the basin : L $\times$ W $\times$ H   (m3)

Q = raw water feed flow (m3/hour)

A = bottom-area of the basin : L $\times$ W (m2)

R = total length of overflow of the outlet weir (metres)

For the methods of construction of a sedimentation tank the reader is referred to the Chapters 4 and 5 of this manual. Sludge removal may be carried out by a continuous mechanical operation or by a batchwise operation. If the operation is to be carried out manually, which is a very appropriate method for smaller rural water supply systems, the tank should be provided with bottom-drains to remove the supernatant water.

Sludge may be removed by shovels and buckets or wheelbarrows. In case a sedimentation tank will regularly have to be taken out of operation for sludge removal, two sedimentation tanks should be constructed to enable a continuous operation of the water treatment plant.

River bed filtration

A possible lay-out for a pre-treatment by means of river bed filtration is given in figure A.2.5.
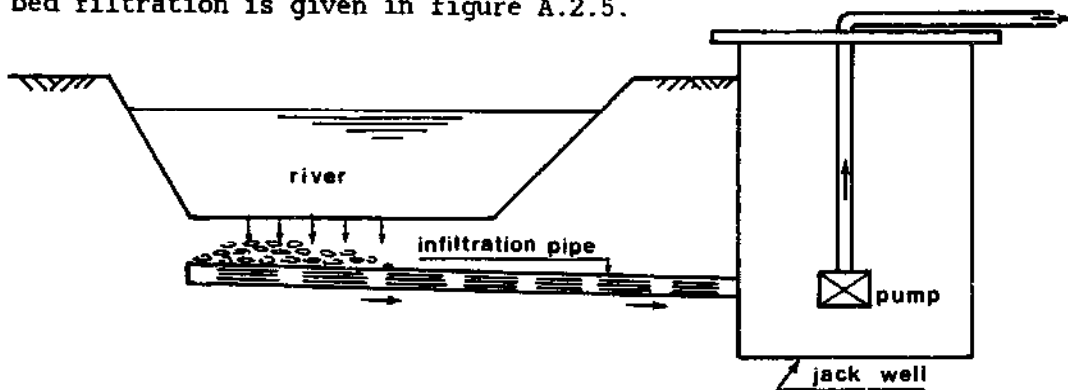
Figure A.2.5.   Pre-treatment by means of river bed filtration

Whether such a river bed filtration will operate successfully
or not depends on the degree of clogging of the river bed.
In the river bed filtration unit, filtration rates of 5-
10 m/h may be applied. The filter bed should be built up
from various layers of gravel and coarse sand. The effective
size of the filter bed material should decrease from the
bottom to the top of the filter bed.

Rapid roughing filtration

The filter box of a rapid roughing filtration unit is
similar to the filter box for a slow sand filter.
The supernatant water layer and the filter bed (e.g. coconut
fibres) should have a thickness of about 1 metre and the
design filtration rate should be about 0.5 m/h (range 0.5-
1 m/h). To clean the filter bed of a roughing filter, water
should be drained off completely from the filter box and the
coconut fibres should be removed and discarded. To repack
the filter, new coconut fibre stock, previously soaked in
water for 24 hours to remove organic matter (colour), should
be used. Experiments of Thanh and Pescod (8) show that the
behaviour of the coconut fibre filters is remarkably consist-
ent, exhibiting considerable potential to absorb turbidity
"shock loading" and produce an effluent relatively constant
and satisfactory for subsequent slow sand filtration. The
overall turbidity removal varies between 60-75%.
Other filter materials, such as coarse gravel, can also be
used for roughing filtration.

Horizontal-flow coarse-material prefiltration

Horizontal flow prefiltration may be carried out in a
rectangular box similar to a basin used for plain sediment-
ation. The raw water inlet is situated at one side of the
box, the outlet at the opposite side. In the main direction
of flow the water passes through various layers of graded

coarse material (in the sequence coarse-fine-coarse). The
vertical depth of the filter bed may be designed at about
1 m (range 0.8-1.5 m) and suitable filtration rates are in
the range of 0.4-1 m/h (horizontal flow).
The total length of the filter bed, run through by the
water, may vary between 4 and 10 metres. A typical lay-out
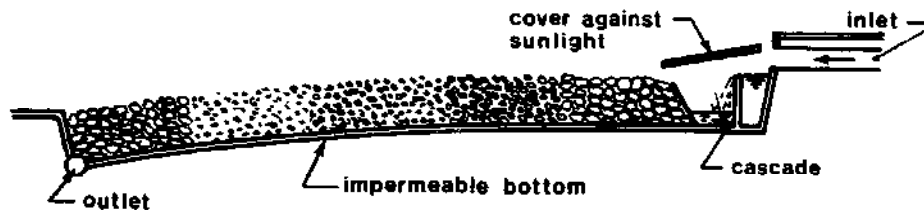of a horizontal flow prefiltration unit is given in figure
A.2.6.

Figure A.2.6.   Typical lay-out of a horizontal flow pre-
                filtration unit.

Thanh and Ouano (7) describe investigations on laboratory
scale and pilot scale. The experimental results show that
these pre-filtration units, after a maturation period of a
few weeks, are quite suitable to remove part of the suspended
matter of raw waters having a turbidity content up to about
150 NTU. Turbidity removal of 60-70% is reported.

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APPENDIX 3

SAFETY CHLORINATION AND DISINFECTION

Introduction

Disinfection serves to destroy pathogenic organisms which
may cause various types of waterborne diseases (see chapter
2). Safety chlorination provides a precautionary measure
against future contamination of bacteriologically safe water
(e.g. in a distribution system).If the risks of such an
event are considered to be acceptable, it may be decided to
rely upon the disinfecting properties of the slow sand
filter itself.

For rural areas in developing countries the most suitable
chemicals for these processes are bleaching powder and high-
test-hypochlorite materials, the choice being determined
mainly by availability and costs in the particular country
or area.

These chemicals are characterised by a certain content of
"available chlorine" which is the active disinfecting
component.

Chemical disinfectants

Bleaching powder (sometimes called chlorinated lime) consists
of calcium hydroxide, calcium chloride and calcium hypochlorite
and when fresh it contains between 20% and 35% of available
chlorine, i.e. 20-35 parts by weight of chlorine per 100 parts
by weight of bleaching powder.

Bleaching powder is easy to handle, although it is bulky and
comparatively unstable. When stored in a container that is
opened once a day for 10 minutes, it loses some 5% of its
initial available chlorine over a span of 40 days, but if
left open all the time for the same period, the loss may be
up to about 18%. In chlorine solutions made from bleaching

powder and stored in a container in the dark, the loss of
chlorine over a 10-day period is not significant, but
considerable loss will result in the same period if the
solution is exposed to light. Both the powder and the
solution should be stored in a dark, cool and dry place in
a closed container that is resistant to corrosion. Containers
made of wood, ceramic, or plastics are suitable. The concen-
tration of the solution should not be greater than 2.5% as
in higher concentration some chlorine may be lost in the
sediment. As bleaching powder contains excess lime which is
insoluble in water, an aqueous mixture will contain some
suspended solids. In preparing a solution it is thus necessary
to mix the material with water in one tank and, after allowing
the insoluble solids to settle, to decant the clear super-
natant liquid into a storage tank. If the insoluble material
is not removed in this manner it will soon cause clogging of
metering valves and feed lines. If 2 kg of bleaching powder
with 25% available chlorine is mixed with 20 litres of water
it will give a 2.5% solution of chlorine.

High-Test-Hypochlorite Materials (HTH) contain 60-70%
available chlorine. Different brands are available in
granular form; these are much more stable than bleaching
powder and deteriorate much less during storage. HTH materials
are quite soluble in water and relatively clear solutions
may be prepared if the concentration of the solution is kept
below 5%. The strength of the solution should preferably be
between 2% and 4%. If 0.84 kg HTH with 60% available chlorine
is mixed with 20 litres of water it will give a 2.5% solution
of chlorine.
Similarly to bleaching powder, HTH should be stored in a
dark, cool and dry place in a closed container that is
resistant to corrosion, otherwise fire or explosions may
occur due to exothermic chemical reactions.

Dosing equipment

There are several methods of hypochlorite chlorination
which are essentially based on non-mechanical appliances to
suit small water supplies. The so-called "solution hypo-
chlorinators" are quite suitable for the treatment units
discussed in this manual.

A good example of a solution-type hypochlorinator is the
Floating-platform Hypochlorinator (see figure A.3.1.).
A glass tube inlet fixed below a float allows for a constant
flow of solution to the dosing point while the liquid level
falls in the container.
The glass dripper introduced below the stopcock helps to
keep the drip outlet free from being blocked by the format-
ion of calcium carbonate. The arrangement is useful to feed
chlorine solution into a water supply at a constant rate
and therefore it is particularly applicable in combination
with slow sand filters which have themselves a constant
effluent flow.
The container should hold enough chlorine solution for 3-5
days operation; for larger treatment plants several contain-
ers may be placed in parallel position.
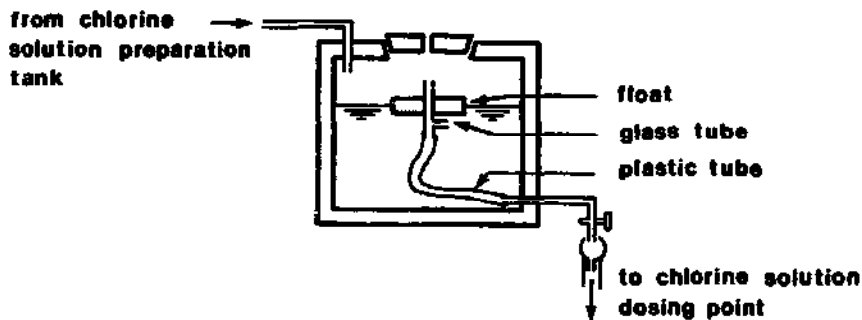
Figure A.3.1. Floating-platform hypochlorinator

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Disinfection process

Depending on the quality of the water to be disinfected,
between 0.5 and 2 mg available chlorine are added to each
litre of water.
For an optimal disinfection the hypochlorite solution
should be mixed with the water to be treated as quickly and
as thoroughly as possible. This may be realised by situating
the dosing point of the chlorine solution just after an
overflow weir (see figure A.3.2.).
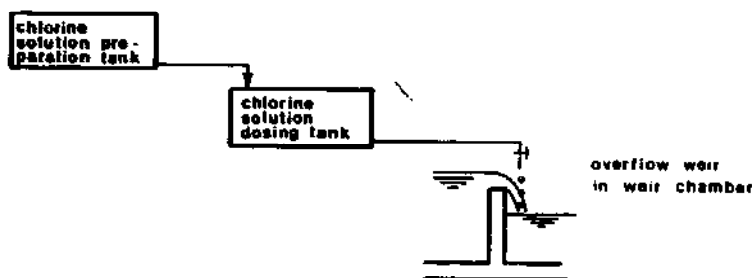
Figure A.3.2. Chlorine mixing system

Because chlorine is an oxidizing agent, part of the chlorine
applied will be used by other constituents of the water .
Enough chlorine must therefore be applied for reaction with
such constituents and the pathogenic organisms. The chlorine
requires some time to act on these constituents and the
micro-organisms, a period which is called the "contact
time".
The effectiveness of the disinfection process is therefore
expressed as the chlorine content ("residual chlorine")
which remains after a certain contact-time.
In general a residual chlorine content of 0.5 mg/l after
30 minutes contact is recommended for rural supplies (12).
If for instance 2 mg available chlorine per litre of water
need to be added to reach a residual chlorine content of
0.5 mg/l and a bleaching powder or HTH solution with a
strength of 2.5% is being used, 1000 litres of water will
require 80 ml of such a hypochlorite solution.

APPENDIX 4

SOIL INVESTIGATIONS

A good knowledge of the composition and properties of soils is of utmost importance to the design engineer, as in any structure, irrespective of its design and the other construction materials used, the weight of the structure and its load will ultimately have to be transmitted to the natural soil.

The behaviour of natural soils is very complex and even highly advanced laboratory experiments cannot supply complete information on the reaction of the soil to the load of the proposed structure. This obviously calls for a large factor of safety in the design. Furthermore, within the scope of rural water supply only simple tests that may be carried out at low cost are justifiable, calling for an even more conservative design.

The site investigations for a treatment plant will generally comprise the following items.

1. Gathering and review of all available information on geological and subsurface conditions of the area involved. Information may be obtained from government institutes keeping records of geological data as well as from the experience of institutes and individuals, e.g. local contractors who have been involved with subsoil exploration in the area. A visual inspection of buildings in the neighbourhood of the plant may also prove useful (cracks in walls and settlements indicate that soil layers with high compressibility are present).

2. Exploratory borings.
   In addition to the information mentioned under 1 it may be necessary to drill holes through which samples of the subsoil may be obtained for direct observation.

Shallow holes up to a depth of about 5 m are commonly made with augers. Deeper borings, for which wash borings and rotary borings may be used, will not be discussed here.

Hand drills and augers are easy to construct and operation is not difficult, especially when drilling in sand and clay. Harder layers such as laterite or calcite demand the use of a tripod. To increase the pressure a number of people may sit on the cross handle, while two men rotate the drill.

Holes in non-cohesive soils and holes below ground water level need a casing to prevent the hole from caving in. In cohesive soils, samples of the subsoil can be taken from the contents of the auger, and in non-cohesive soils, with bailers or special sample spoons.

A very important property of the soil is its resistance to penetration of the drill. To measure the degree of compactness of the soil, a standard penetration test has been developed.

This consists of counting the number of blows of a standard weight at a standard height of fall to drive a standard sampling spoon into the soil to a distance of 0.3 m. The standard penetration test gives vital information as the results give an indication of the relative density of the soil and its bearing capacity. From the samples, taken at regular distances and collected in a sample box, information on the physical properties and composition of the soil may be obtained. A number of tests that are useful for discriminating between different kinds of soils are given below:

a.   Grain size, and grading.
The coarse and very coarse fractions of the soils are the grains with diameters larger than

approximately 0.06 mm, which can still be inspected with the naked eye. It is customary to classify the 0.06 - 2 mm fraction as sand and the 2 - 300 mm as gravel. Even larger fragments are known as boulders. The grading of the larger fractions can be determined by sieve-analysis, but may also be classified with experience as "well-graded" or "poorly-graded".

Grains smaller than 0.06 mm cannot be investigated with the naked eye, but can be separated from the larger fractions by washing with water. The finer fractions are washed off and the coarse fractions remain.

The fraction from 0.06-0.002 mm is generally called silt, while the even smaller fractions are called clay. These grains can be examined only under a microscope, but a simple discriminating test may be performed by kneading a ball of the soil under water. A silt ball will fall apart while a clay ball will keep its consistency.

b. Dilatancy.

The shaking test gives information on the dilatancy of the soil. A pat of soil is shaken in the palm of the hand and the appearance of its surface is noted.

If the surface appears glossy, the results are described as conspicious or weak, depending on the intensity of the phenomena observed. This provides another possibility of distinguishing clay and silt. Silt will, unlike clay, react positively.

c. Consistency.

The degree of cohesion between the soil particles and the resistance against deformation is described as hard, stiff, plastic and soft.

These terms correspond with certain values for the
unconfined compressive strength; the load per unit area
at which unconfined cylindrical samples fail in a simple
compression test.

Furthermore the ground water level may be determined
from the water content of the samples, while it can be
measured with a rope when a casing is installed.

3.   Soundings and other field tests

Soundings provide information on the resistance of the
soil against penetration. They may be used to make
sure that the subsoil does not contain any soft spots
between drill holes and to investigate the relative
density of non-cohesive layers. One of the most widely
used procedures for measuring resistance to penetration
is the standard penetration test, mentioned above.
Whereas the standard penetration test only furnishes
one value of resistance for approximately each metre,
many other types of subsurface soundings yield continu-
ous penetration records.
In its most simple form a sounding consists of a rod,
pipe or railroad rail which is driven into the ground
by a drop weight. Records of the penetration by each
blow can give very useful results, especially in
combination with a few exploratory borings. Next to
these so-called dynamic sounding methods, there are
also static sounding methods.
These consist of a standard cone pushed into the
ground at a standard rate by means of manual or mechanic-
al power. The pressure exerted on the rod has to be
registered by a Bourdon gauge.

APPENDIX 5

BUILDING MATERIALS

The most common building materials used for slow sand
filtration plants are mass concrete, reinforced concrete,
masonry and ferrocement.
The quality and characteristics of these building materials
will vary from place to place and time to time, depending
on such items as the nature and quality of the raw materials,
climatic conditions and the attention paid to handling,
processing and finishing of the materials. In this appendix
consideration is given to some aspects of these building
materials.

Concrete

Concrete consists of a mixture of sand, gravel, cement and
water. It is important to see to it that all the components
of concrete are tested. International standard testing
methods exist for this purpose. The testing need not to be
done at the building site itself; samples may be taken at
the site and examined in a laboratory.
The quality of cement is usually locally known and therefore
it need not necessarily be tested. Care should be taken that
the cement is not stored for too long a period and that it
is stored in a dry place.
Sand and gravel have to be tested for their organic matter
content (Abram-Harder or fulvic acid test). Furthermore the
grain size distribution of the sand and gravel has to
fulfil certain (locally differing) conditions.
The water to be used has to be clean, fresh and clear.
The proportion of the components in the concrete mixture
will depend on the characteristics of the components, but a
mixture of 1 litre cement to 2 litres of sand to 3 litres
of gravel will usually give good results.

Some 120-160 litres of water per m3 concrete have to be
added to this mixture (¾ litres of water to 1 litre of
cement).

In order to guarantee watertightness of the concrete the
following measures are important.

1. Attention must be paid to the grain size distribution
   and especially the content of fine materials. The
   content of "fines" consists of the cement and the
   fraction of sand particles smaller than 0.3 mm.
   Recommended contents of fines are:

Table A.5.1. Recommended contents of fines for
             concrete.

	Largest grain size (mm)	Content of fines (kg/m3)
	10	500-550
"Normal concrete"	20	425-475
	30	375-425
"Large aggregate	50	300-350
concrete"	80	250-300

2. The water-cement ratio, i.e. the ratio of weight of
   water used and weight of cement used, has to be kept
   as low as possible. A value of 0.5 will generally be
   satisfactory. It is advisable to keep the water content
   down to the lowest workable value.

3. Use as little cement as possible. It may be advisable
   to increase the largest grain size of the gravel to,
   for example, 50 mm (instead of the usual 30 mm), so
   that the content of cement can be decreased

4. Pay due attention to finishing of the concrete. It is important to keep the shuttering and the surface of the poured concrete wet (by spraying with water of a temperature not above 20-25°C) and to prevent high temperatures and strong evaporation. This may be done by erecting a temporary cover.

With regard to steel reinforcement of concrete, it is necessary to have information on the quality of the steel that is locally available. Some details on reinforcement schemes are given in appendix 8.

Ferro-cement

Ferro-cement consists of a heavily reinforced (reinforcement percentage by weight 0.9-2.1) sand-cement mortar. The reinforcement is built up of vertically and horizontally placed rods of small diameter ($\emptyset$ 5 - 6 mm). The rods are embedded in chicken wire.

Ferro-cement is particularly suited for curved construction elements (14).

It may be applied in circular slow sand filters because bending moments do not occur and small deformations are acceptable.

Favourable properties of ferro-cement are its simplicity in construction and its durability. The construction process is labour-intensive, which need not cause serious problems.

There are two ways of constructing a slow sand filter:

1. use of built-in frame
2. use of inside or outside mold

The second possibility seems most promising.
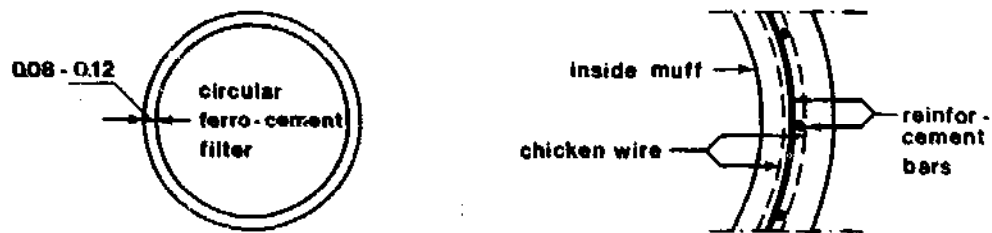
Figure A.5.1. Ferro-cement wall

In figure A.5.1. the design with inside mold is given. The
reinforcement consists of vertically and horizontally
placed 5 or 6 mm steel bars, at distances of 50 to 120 mm.
For the wire mesh, chicken wire with a mesh width of 20 mm
is quite suitable.

The building process is as follows: from the outside of the
reinforcement structure, the mortar is spread onto the
reinforcement with a trowel up to the inside mold. The
thickness of the wall is usually between 60 and 120 mm. The
composition of the mortar is 1 part cement and 2 parts sand.
The sand should not be too coarse. Part of the cement (for
instance 10%) may be replaced by puzzilanos, if available,
to prevent a high water uptake.

To protect the structure against weather and to obtain a
high degree of watertightness, it may be finished with a
coating layer of tar epoxy or natural rubber.

Masonry

The quality of the masonry and the mortar should be high in
order to obtain a watertight structure. The wall thickness
will be in the order of 0.30-0.40 m for circular filters
with a diameter of some 5-10 m. Important points in the
preparation of the bond for the wall are:

1. vertical joints should never be placed above each other
2. vertical joints should go all over the width of the wall, if possible
3. the bricks should not be split in pieces smaller than half the standard size locally available

Mortars for masonry consist of cement or lime, sand and water.

A mixture of 1 part cement and 2-2.5 parts of sand will be suitable. If the bricks are of low quality, then the quality of the mortar should also be lowered (for instance to 1:4.5) in order to prevent the occurrence of differences in shrinkage between brickwork and mortar.

It should be remembered, however, that this will lead to a less rigid and certainly less watertight construction.

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APPENDIX 6

FLOW MEASUREMENT DEVICES

In slow sand filtration plants, it is necessary to measure
the flow through the filters in order to adjust the filtration
rate to a preset value.

Flow measurements can be carried out in closed pipelines by
means of venturi meters or other devices, but they are best
done in open channels with measuring weirs. Weirs provide a
sound and simple way of measuring the flow. They are based
on the principle that the flow over a weir in an open
channel is related to the depth of the water above the
crest of the weir. In figure A.6.1. some possible types of
weirs are given, together with their discharge equations.

$$Q = 1.42 * H^{5/2} \qquad Q = 0.84 * H^{5/2} \qquad Q = 1.91 * B * H^{3/2}$$
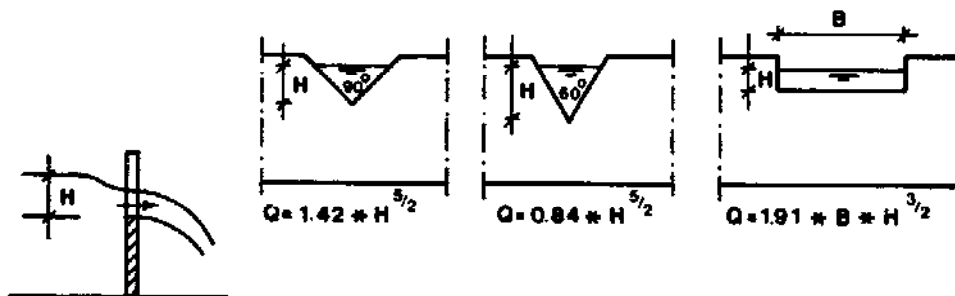
Figure A.6.1. Weirs and discharge equations

In figure A.6.2. the relationship flow versus depth of
water for rectangular weirs, 90°- triangular weirs and 60°-
triangular weirs is given graphically. Once the level of
the water above the lowest point of the weir is known the
flow can be determined quite simply on the basis of this
figure.

Weirs can be made of wood, but a concrete structure with a
steel plate will give more accurate readings. A 90°- weir

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is very suitable for accurate readings at low flows. The
water level over the crest of the weir must be measured
some 0.3 m back from the crest (see typical designs).
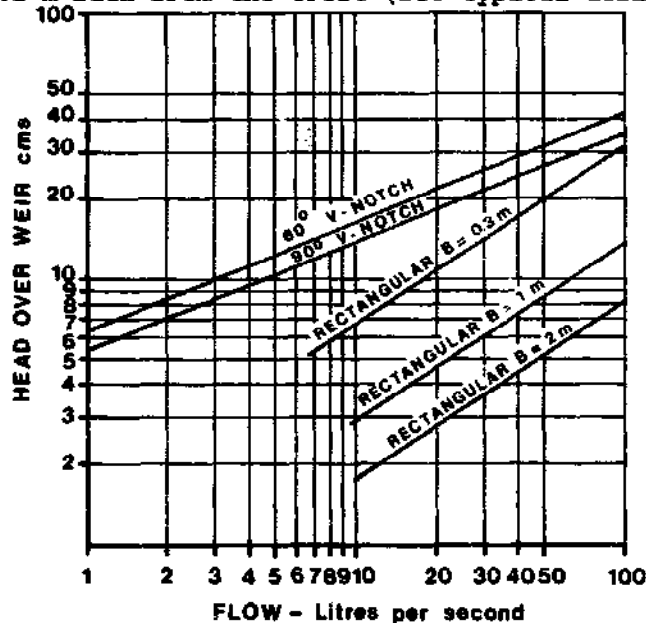
Figure A.6.2. Discharge charts for three types of weirs.

The discharge through floating weirs, discussed in paragraph
5.4., depends on the diameter of the effluent pipe and the
distance d between the water level and the crest of the
effluent pipe. This distance has to be adjusted to the flow
desired. Figure A.6.3. gives an indication of the flow
through floating weirs for different pipe diameters and
various values of d.
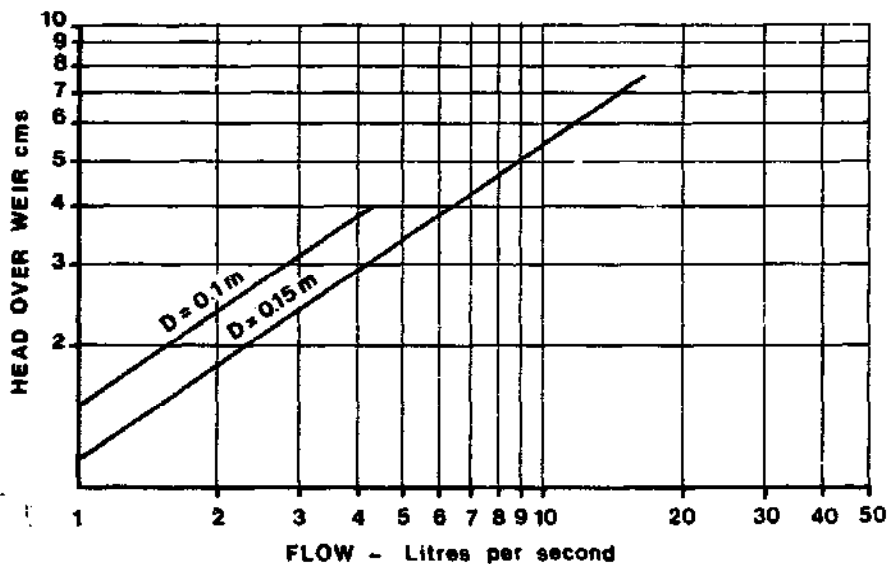
Figure A.6.3. Discharge through floating weirs.

It should be borne in mind that the accuracy of flow measurements is always limited and that a regular calibration of the measuring weir (e.g. by means of vessels and a watch) is advisable.

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APPENDIX 7

WATER QUALITY ANALYSIS

In the case of domestic water supply, water quality tests
are required, regularly or periodically, for the following
purposes:
- selection of a water source
- examination and control of the water source or the
  performance of a water treatment system

General

Water quality tests may include comprehensive analyses of
the physical, bacteriological and chemical constituents of
a water sample or an examination of just a few crucial
water quality parameters (see also appendix 1).
Comprehensive water analyses require well trained and
skilled laboratory workers, who have sufficient suitable
laboratory equipment and chemicals at their disposal.
Therefore, such analyses should preferably be carried out
in a laboratory of the district or regional authorities.
If river water is chosen as the source for a slow sand
filtration unit, data should be collected during the planning
stage on the variations of the water quality of the river
for a complete hydrological year[a]. In other words, one
should have sufficient data on the river water quality
during the dry as well as the wet season. The turbidity of
the raw water is a crucial parameter for a slow sand filtration
unit, and special attention should be paid to the values of
this parameter during the early stages of the rainy season,
when the run-off water is likely to carry transportable
debris and sediments from the river-basin and the river bed
itself is being "cleaned up" by the rapidly increasing
surge of water. The data required may be available from the

water authorities; otherwise samples for testing and analysis should be taken and sent to an adequately equipped laboratory. Clean glass or plastic bottles sealed with a rubber or plastic stopper must be used for such samples. The bottle
* should be washed out at least three times with a small quantity of the water to be sampled and then filled and labelled immediately with time, date and place. The bottle should be plunged in at a point a short distance from the river-bank and care should be taken to prevent gross floating debris or mud disturbed from the bottom from entering the bottle. Samples taken in this way are suitable for physical and chemical examination but not for bacteriological tests. The samples should be not less than 2 litres and should be sent for analysis without delay.

If the data regarding the physical and chemical composition of the samples have shown that the water source can produce water suitable for human consumption by means of slow sand filtration (with or without pre-treatment), further comprehensive tests are only required periodically (i.e. once every 1-3 months). They then serve to check whether the water source remains acceptable and whether the slow sand filtration unit is functioning properly, so that a clean water suitable for human consumption is produced.

Bacteriological examination

One of the parameters which requires a more regular examination (once a week or at least once a month) is the bacteriological quality of the raw and the treated water. The bacteriological quality of the water is a main concern, owing to the risk of epidemics of waterborne diseases (see chapter 2). Such tests have to be carried out on site at the treatment unit, as any delay in analysing a sample will lead to incorrect results due to continuing biological activity in the sampling bottle.

One of the limitations of the various bacteriological
testing methods is the length of time required to produce
results.
The multiple-tube fermentation test for coliform bacteria
needs 48-96 hours from sample collection to results, the
membrane filter test 18-22 hours. Furthermore, bacteriological
testing requires certain laboratory skills and equipment
that are often not available. The tests are also fairly
expensive.

A suitable bacteriological test method for developing
countries is the membrane filtration technique. The membrane
filters used in water bacteriology are flat, porous, flexible
plastic discs about 0.15 mm thick and usually 47-50 mm in
diameter. Pore size is rigidly controlled; for water
bacteriology the pore diameter is usually 0.5 micrometre.
A water sample is filtered through the membrane filter, the
filter is then placed on agar bacteriological culture
medium or on a paper pad impregnated with moist culture
medium, and the preparation is incubated for a specified
time under prescribed conditions of temperature and humidity.
The resulting bacterial culture is then examined and inter-
preted.
As a more detailed discussion of the various bacteriological
test methods is beyond the scope of this manual, the
reader is referred to "Surveillance of drinking-water
quality" (13) and other publications (23, 24).

Field equipment

In recent years, some field kits have been made available
which enable trained laboratory workers to carry out tests
at different places during field trips.
For instance, the Hach Chemical Company (21) has developed
several field kits which include instruments and chemicals

to determine most of the water quality parameters mentioned
in appendix 1, item b. Some of the Hach field kits are
equipped to examine 10-20 parameters, while others have
been especially developed to examine one specific parameter.
A very suitable portable test kit for bacteriological
surveys has been developed by Millipore (22). This test kit
is based on the membrane filtration technique described
above.

Some simple tests, which may provide much useful information,
can be carried out by the operator of the slow sand filtration
plant, i.e. observation of a sample from the raw water
drawn in a glass cylinder. Turbidity can be noted and may
be measured by comparison with other samples or with prepared
standards. The usefulness of quiescent settlement can be
observed and also the nature of suspended matter, whether
animal, vegetable, or mineral, can be estimated. If dis-
infection in a treatment plant is effected by means of
chlorine compounds, the tests for residual chlorine can
also be carried out by the plant operator. At larger plants
an elementary laboratory training for plant operators may
be considered, to enable them to use some of the field test
kits mentioned above.

APPENDIX 8

STRUCTURAL CALCULATIONS OF A REINFORCED CONCRETE FILTER BOX

For the convenience of the reader, some details of the structural calculations of a reinforced concrete filter box are given below. More elaborate information on this subject can be found in the textbooks, mentioned in the bibliography.

Data :

1. Concrete compressive strength[a]   17.5 N/mm2
2. Steel tensile strength[a]   220   N/mm2
3. Ground level 0.50 m below top filter level
4. Groundwater level 0.70 m below top filter level
5. Specific gravity of natural soil 1.9
6. Specific gravity of concrete 2.4
7. Specific gravity of sand and gravel 1.6

Diagram
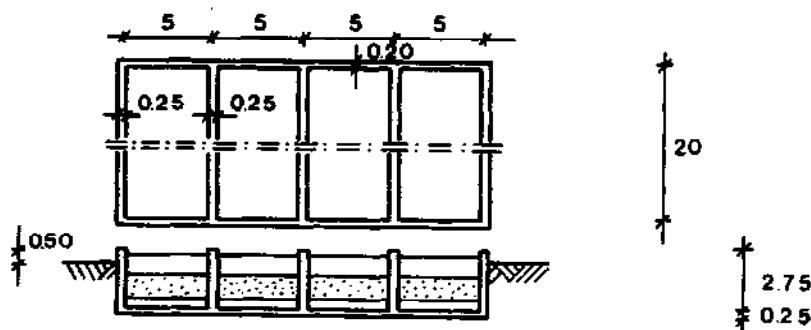
Calculation of filter bottom

Forcing up of the construction by water pressure has to be checked:

1. Weight of the structure:
    (length $\times$ height $\times$ thickness $\times$ gravity)

```
walls  2 * 20 * 2.75 * 0.2 * 24      =   528 kN
       5 * 20 * 2.75 * 0.25 * 24     =  1650 kN
floor  20 * 20 * 0.25 * 24           =  2400 kN
                                       ─────────
                                        4578 kN
```

2. Water pressure (water head * length * width * gravity)

   2.3 * 20 * 20 * 10 = 9200 kN

It follows from the calculations that if the filter box is empty, buoyancy will occur. However, the filter gravel and part of the filter sand will remain in the filter, so their weight can be added to the weight of the structure.

```
(length * width * height * gravity)
Weight of gravel    20 * 20 * 0.5 * 16      = 3200 kN
Weight of sand      20 * 20 * 0.6 * 16      = 3840 kN
```

As the total weight of the structure and the filter bed is more than 1.15 (safety factor) times the water pressure, forcing up need not be feared (during construction drainage of the building pit will of course have to be provided).

As no large bending moments occur in the floor of the filter, a minimum reinforcement of Ø 10-200 will suffice.

Calculation of filter walls

- <u>Long wall</u>

Diagram
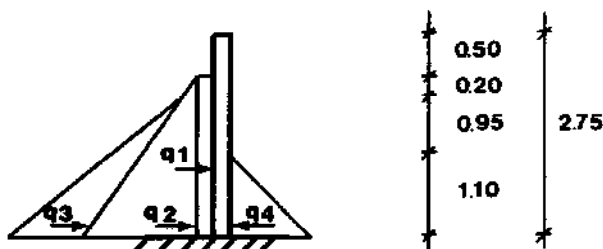
q_1 = surface load = 0.67 kN/m' (i.e. 0.67 kN per metre
of wall length)

q_2 = soil load   = 1/3 $*$ 9 $*$ 2.25 = 6.75 kN/m'

q_3 = water load = 10 $*$ 2.05   = 20.50 kN/m'

q_4 = gravel and = 1/3 $*$ 1.1 $*$ 16 = 5.9 kN/m'
sand

The entry moment at the filter bottom will amount to:

M_A = $\frac{1}{2}$ $*$ 0.67 $*$ 2.25^2 + 1/6 $*$ 6.75 $*$ 2.25^2 + 1/6 $*$ 20.50
$*$ 2.05^2 - 1/6 $*$ 5.9 $*$ 1.1^2 = 20.57 kNm

Thickness of the wall is set at 0.25 m, so the inner lever
arm is 0.8 $*$ 0.25 = 0.20 m

reinforced
concrete wall

stress
diagram
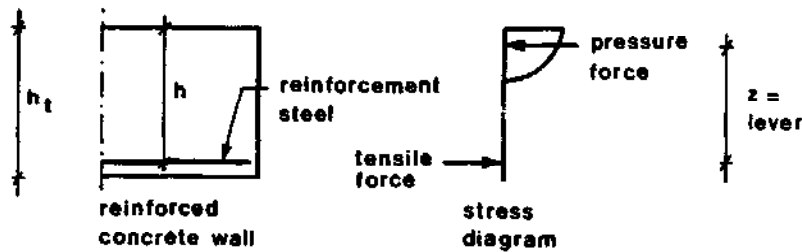
The reinforcement A can be calculated as the entry moment
$*$ a safety factor devided by the inner lever arm times the
steel tensile strength, in this case therefore

$A = \dfrac{M_A * 1,8}{0,2 * 220}$ = 841 mm^2/m^1, or $\emptyset$ 16-200 (see figure A 8.1.).

- <u>Short wall</u>

Diagram
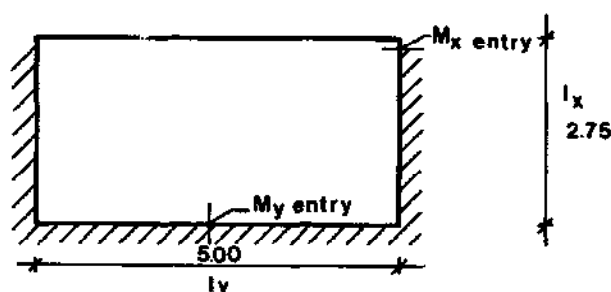
The short wall can be calculated as a three sided fixed plate. The entry moments follow from the ly/lx ratio and can be read from tables (lit. 17, 18).

$$M_{x\ entry} = \frac{0.67 \times 2.75^2}{6} + \frac{27.25 \times 2.75^2}{13} = 16.7 \text{ kNm,}$$

so A = 853 mm2 ($\emptyset$ 16-200)

$$M_{y\ entry} = \frac{0.67 \times 2.75^2}{4} + \frac{27.25 \times 2.75^2}{18} = 12.72 \text{ kNm,}$$

so A = 650 mm2 ($\emptyset$ 16-250)

The influence of the small inside load q_4 has been neglected.

In figure A.8.1. the reinforcement schemes are given, both for the filter boxes and the clear water tank of typical design No. IV (paragraph 6.4).

detail long wall

detail short wall

detail clear water tank
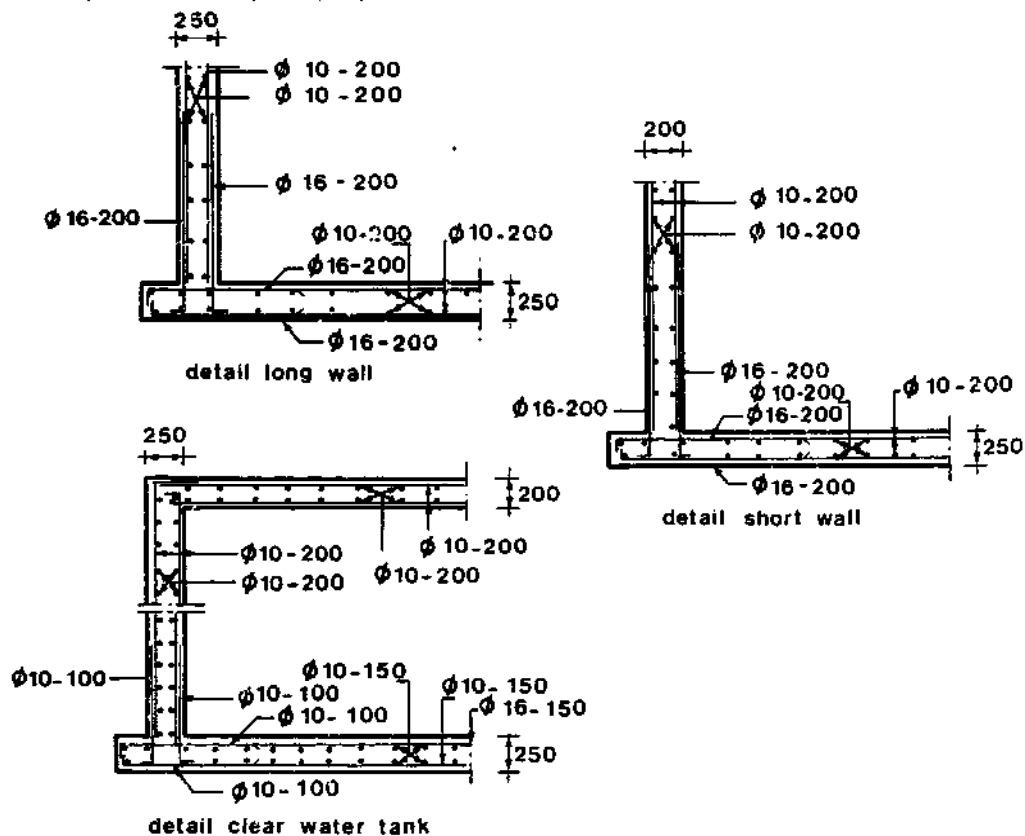
Figure A. 8.1. Reinforcement schemes of filter box and clear water tank.

APPENDIX 9

ADDRESSES OF MEMBER ORGANIZATIONS OF FIDIC

The FIDIC (Fédération Internationale des Ingénieurs-Conseils)
is an international organization, from which information
regarding contract documents, tendering etc. may be obtained.
Member organizations in countries in the developing world
include:

ARGENTINA
Cámara Argentina de la
Construcción,
Av. Paseo Colón 823,
BUENOS AIRES

BANGLADESH
Bangladesh Thikadar Samity,
23 Bangabandhu Avenue,
DACCA 2

BOLIVIA
Cámara Boliviana de la
Construcción
Casila de Correo 3215,
LA PAZ

BRAZIL
Cámara Brasilera de la
Construcción
Rua Do Senado 213,
RÍO DE JANEIRO

COLOMBIA
Cámara Colombiana de la
Construcción
A.P.T. Aereo 28588
BOGOTA

COSTA RICA
Cámara Costarricense de la
Construcción
Apt. 5260
SAN JOSE

DOMINICA
Cámara Dominicana de la
Construcción
Calle No. 9,
Reparto Vista Mar,
Zone 7,
SANTA DOMINGO

ECUADOR
Federación Ecuatoriana de
Cámaras de la Construcción
Block Centro Commercial,
Ciudadela Bolivariana,
Casilla 8955
GUAYAQUIL

EL SALVADOR
Cámara Salvadoreña de la
Industria de la Construcción
Avenida Olimpica,
Pasase 3
No. 130
SAN SALVADOR

GUATEMALA
Cámara Guatamalteca de la
Construcción
Apt. Postal 2083,
GUATAMALA CITY

HONDURAS
Cámara Hondurena de la
Construcción
Apartado Postal 905,
TEGUCIGALPA

HONG KONG
The Building Contractors
Association
Ltd., Hong Kong
180-182 Henessy Road, 3rd Floor,
HONG KONG

INDIA
Builders Association of India
G-1/G-20 Commerce Centre,
7th Floor
J. Dadajee (Tardeo)
Main Road, Tardeo
BOMBAY 400034

INDONESIA
Asosiasi Kontraktor Indonesia
(Indonesia Contractors'
Association)
JI.M.H. Thamrin 57,
P.P. Building, 2nd Floor,
JAKARTA

KOREA
Construction Association of
Korea Construction
Building,
32-23, 1-Ka, Taepyung-Ro
Joong-Ku,
SEOUL

MALAYSIA
Master Builders' Association,
Federation of Malaya,
13 Jalan Gereja, 3rd Floor,
KUALA LUMPUR

MEXICO
Cámara Nacional de la
Industria de la Construcción
Colima 254,
MEXICO 7 D.F.

NICARAGUA
Cámara Nicaraguense de la
Construcción
Apartado Postal 3016
MANAGUA

PANAMA
Cámara Panomeña de la
Construcción
Apartado Postal 6793,
PANAMA 5

PARAGUAY
Cámara Paraguaya de la
Construcción
Yegros 242,
ASUNCION

PERU
Cámara Peruana de la
Construcción
Paseo de la Republica
Cuadra SA,
Edificio Caêso Piso 12,
LIMA

PHILIPPINES
Philippine Contractors'
Association Inc.
3rd Floor, Padilla,
Cond. off. Bldg.,
Ortigas Commercial Cenrte,
Pasig, Rizal,
MANILLA

SINGAPORE
Singapore Contractors'
Association
150 Neil Road,
SINGAPORE

THAILAND
Thai Contractors' Association
110 Vidhuya Road,
BANGKOK

URUGUAY
Uruguay
Cámara de la Construcción
de Uruguay
Av. Agraciada 1670,
ler piso
MONTEVIDEO

VENEZUELA
Cámara Venezolana de la
Construcción
Calle Villaflor,
Centro Professional del Este,
CARACAS

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        .

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GLOSSARY

Aeration	A process for continuously creating new air/liquid interfaces to increase the oxygen content of the water. This may be achieved by:

a.   allowing the liquid to flow in thin films over a weir or plate
b.   spraying the liquid in the air
c.   bubbling air through the liquid
d.   agitating the liquid

Capital return period
The period elapsing between a capital expenditure and the reimbursement of this capital expenditure by means of recurrent income from the fixed assets.

Chemical Oxygen Demand (COD)
The amount of oxygen consumed from a specified oxidizing agent in the oxidation of the matter present in a (water)sample. As normally determined, i.e. from silver-catalysed dichromate, it approximates to the oxygen theoretically required for complete oxidation of the carbonaceous matter to carbon dioxide and water. This term is now restricted to the standard test employing oxidation by a boiling solution of acid potassium dichromate.

Concrete compressive strength
The maximum allowable compressive force per unit of area without the occurrence of shear (deformation).

Declining rate filtration	A specific mode of operation of slow sand filters. If the raw water inlet to the supernatant water is closed and the filtration regulating valve is kept in its normal operating position, the supernatant water will be filtered at a continuously declining filtration rate. Such an operation may be applied during the night to save labour costs and capital investment costs.
Depreciation period	An estimated period (on the bases of experience) after which equipment should be replaced due to wear and tear.
Design capacity	The treatment capacity (in m3/h) of a newly designed water purification unit.
Design period	The period a treatment unit or water supply system is designed for, or the period during which under normal circumstances no extension of the treatment unit is required to provide the consumers with an unobstructed water supply.
<u>**E.Coli**</u>	Escherichia Coli: a bacterium living in the alimentary tract of man and other mammals. As it is passed out with faeces in large numbers its presence in water is indicative of faecal contamination and the possible presence of pathogenic organisms of enteric origin; normally it is not itself pathogenic.

Economic lifetime   The period during which equipment
creates an income which more than
offsets costs of capital expenditure
(interest of loans) and costs of operation
and maintenance.

Effective diameter   The size of the sieve opening through
which 10% of the filter bed material
will just pass (symbol: d_{10}). Also
indicated by "effective size".

Effluent   Water (or other liquid), treated to a
greater or lesser extent, flowing out of
a section of the treatment plant.

Flocculation/   The process by which colloïdal and
Coagulation   finely-divided suspended matter is
caused to coalesce, leading to the
formation of flocs and agglomeration of
the flocculated matter.
Flocculation/coagulation may be effected
by adding a suitable chemical or chemicals,
or it may be a biological process.

Freeboard   The vertical distance between the
maximum water level in a tank and the
top of the side walls, provided to
prevent the contents of the tank from
being blown over the walls in a high
wind.

Yearly growth rate   The yearly rate of multiplication,
expressed as the rate of increase in
population per unit of population
present (in percentage).

Hydraulic feeder Chemical dosing equipment consisting of non-mechanical appliances. A chemical solution is fed to the water to be treated by means of gravity-forces (see also figure A.3.1.).

Hydraulic line A graph showing the subsequent hydraulic gradients in the various sections of a treatment unit passed through by the water to be treated.
A hydraulic gradient represents the loss of head in a liquid flowing in a pipe or channel, through a filter bed or a valve, expressed as a ratio, the slope of a curve, or as a fractional drop (m/km).
When the liquid is flowing under pressure in a pipe line, the hydraulic gradient is the slope of the line joining the elevations to which the liquid would rise in pipes freely vented and under atmospheric pressure.

Hydrological year A period in the lifetime of a river (8-12 months) which covers all variations in its hydrological characteristics due to rainfall, run off, evaporation, artificial (man-made) withdrawals or discharges etc.

Influent Water (or other liquid), untreated or partially treated, flowing into a section of the treatment plant.

Maximum day   The maximum water demand during one
single day (24 hours).

Maximum hour   The maximum water demand during one
single hour.

MPN   Most Probable Number:
a statistical estimate of the numbers of
viable bacteria obtained in a dilution
count, such as the presumptive coliform
count, in which a series of tubes
containing a selective growth medium is
inoculated with specified volumes of
sample, and incubated. The most probable
number is obtained by examining the
tubes for a positive growth response
(such as the production of acid and gas
for coliforms) and referring the pattern
of such responses to statistical tables.

N;kN   Newton: kiloNewton
the unit of force; $1\ N = g\ kg\ m/s^2 \approx$
$9.8\ kg\ m/s^2$; $1\ kN \approx 9800\ kg\ m/s^2$; $g =$
acceleration due to gravity ($\approx 9.8\ m/s^2$).
(10N = approx. 1 kgwt)

Negative pressure If the head loss in a filter bed were
more than the available head of the
supernatant water layer, then the
filtered water could drain away from the
supernatant water, leaving a partial
vacuum. Under such conditions "air
binding" may occur: release of air in
the low-pressure region below the
filter-skin which forms bubbles in the
filter bed pores.

Air-binding may lead to overloading of part of the filterbed and subsequent deterioration of the effluent quality.

NTU   Nephelomatric Turbidity Unit:
The turbidity is measured by the interference with the passage of light rays through a liquid caused by the presence of fine suspended matter.
(1 NTU = 1 FTU (Formazin Turbidity Unit) $\sim$ 1 mg SiO_2/l).

Physical lifetime   The physical lifetime of equipment is the period (months/years) it keeps on functioning as long as maintenance and repairs are carried out.

Population growth factor   The total increase in population per unit of population present, during a certain number of years. The population growth factor is determined by the yearly growth rate and the number of years considered (design period).

Riprap   Coarse and durable natural material, e.g. murram.

Scum   A layer of fats, oils and grease together with particles of plastics, floating wrapping materials, remains of vegetation and algae which rises to the surface of the supernatant water layer due to a specific gravity lower than that of water.

Service reservoir	A clear water storage tank, within the distribution system, which provides sufficient storage to overcome periods of higher demand and sufficient head to deliver the water to all planned withdrawal points.
Specific gravity	The ratio of the mass of a given volume of a substance to the mass of an equal volume of water at a temperature of $4^{o}C$.
Surface loading	The maximum rate of flow to be treated per day per unit area, or: surface loading (m3/m2 d) =

$$\frac{maximum\ flow\ (m3/d)}{surface\ area\ (m2)}$$

The surface loading may also be expressed as m3/m2 h (or m/h).

Tensile strength	The maximum allowable tensile force per unit of area without the occurrence of strain (deformation).
Turbidity	Interference with the passage of light rays through a liquid, caused by the presence of fine suspended matter.
Uniformity coefficient	The coefficient of uniformity (U.C.) is the ratio d_{60}/d_{10} (see effective diameter).
Venturi meter	A device used for measuring the flow of liquid in a pipeline, in which there is a gradual contraction to a throat followed by an expansion to normal diameter.

The pressure is measured at the throat where the pressure is reduced and up-stream where the diameter is normal, by means of small pipes leading to gauges. The velocity and therefore the rate of flow is related to the pressure difference between these points.

V-notch weir

A measuring weir of V-shape with the angle at the apex usually 90°, used for measuring small discharges (see "weir" and appendix 6).

Weir

A structure over which water flows, the downstream level of the water usually being lower than the crest of the weir. When used for measuring flows the weir may be rectangular, notched or trapezoidal and the rate of flow will be related to be upstream height of the water above the crest and to the geometry of the weir opening.

Weir overflow rate

The volume of liquid passing over the outlet weir of a tank per unit length of weir at maximum flow, calculated as follows:

weir overflow rate (m3/m h) =

$$\frac{\text{maximum rate of flow (m3/h)}}{\text{total length of outlet weirs (m)}}$$

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