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HORIZONTAL-FLOW ROUGHING FILTRATION (HRF)

A Design, Construction and Operation Manual

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FOREWORD

The present manual is a state-of-the-art review of Horizontal-flow Roughing Filtration (HRF). It covers design, construction, operation and maintenance aspects of this technology. The manual addresses primarily the design engineer, the construction foreman and the trainer of treatment plant caretakers.

Horizontal-flow Roughing Filtration is used as pretreatment process prior to Slow Sand Filtration for the reduction of the raw water turbidity. The treatment combination is based on natural purification processes and therefore does not depend on any chemical supply. However, the filter units are relatively large but usually constructed with local resources. The technology is primarily meant for rural and small urban water supplies.

The method has been tested in the laboratory of the University of Dar es Salaam. The purification potential of such filters was confirmed by subsequent field tests carried out in Tanzania. Thanks to the support of the Swiss Development Cooperation and the Swiss Federal Institute for Water Resources and Water Pollution Control (EAWAG), the International Reference Centre for Waste Disposal (IRCWD) had the opportunity to test intensively the HRF process on a laboratory scale. These investigations lead to a better understanding of the mechanims taking place in the HRF and to practical design criteria. This manual is the outcome of these investigations and represents the present state-of-knowledge of the HRF technology.

Grateful acknowledgment is made for the review of the manual to:

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Dr M. Boller, EAWAG, Duebendorf/Switzerland
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The Horizontal-flow Roughing Filtration technology is still under development. The filter efficiency for different raw water characteristics has to be established. Practical experience reveals that reasonable filter operation can be expected with average raw water turbidities between 50 and 200 turbidity units. Nevertheless, preliminary field tests indicated that for a few weeks the same filters can also handle turbidity peaks of 1000 turbidity units. Filter regeneration and cleaning is another aspect currently under investigation.

Therefore, the present manual provides tentative guidelines to allow people to introduce this filter technique and to collect more information on operation and maintenance. We hope to receive your valuable comments on this manual as well as your practical experience with Horizontal-flow Roughing Filtration, in order to publish a revised version in approx. 1-2 years.

I should like to take this opportunity to also express my gratitude to the people who have been strongly supporting our HRF project, particularly to Prof. E. Trüeb, Dr M. Boller and Mr A. Hartmann.

Roland Schertenleib
Director IRCWD

CONTENTS

Part A:

EXECUTIVE SUMMARY

THE SCOPE OF THE PROBLEM AND ITS POSSIBLE SOLUTION

Slow Sand Filtration is commonly considered an appropriate water treatment process most suitable for developing countries. The ability to significantly improve the bacteriological quality of the water without the use of any chemicals speaks in favour of this process. However, the slow sand filters are frequently overloaded with suspended solids thereby causing unacceptable short filter runs. Hence, pretreatment of the raw water is almost a necessity.

Plain sedimentation and even prolonged storage are usually not able to reduce the suspended solids concentration to the required level for successful slow sand filter operation. Destabilization of the suspension by chemical flocculation creates many operational and practical problems for a reliable application of this process in developing countries. Finally, conventional types of rapid sand filters require complicated backwash systems of a higher technical standard than that of slow sand filters. Therefore, all these processes are often inappropriate in combination with slow sand filters.

Horizontal-flow Roughing Filtration might close this gap. The filter is composed of a simple box filled with gravel of different sizes (from coarse to fine) as can be seen in Fig. 1. Horizontal-flow roughing filters have long operational times due to their large silt storage capacity, i.e. in the order of months, similar to efficiently operating slow sand filters.

This manual addresses design engineers, construction foremen and trainers of plant caretakers. It is meant as a practical tool for the implementation of Horizontal-flow Roughing Filters. Through this sturdy and self-reliant pretreatment method, it is possible to achieve a sound and efficient application of the slow sand filter process.

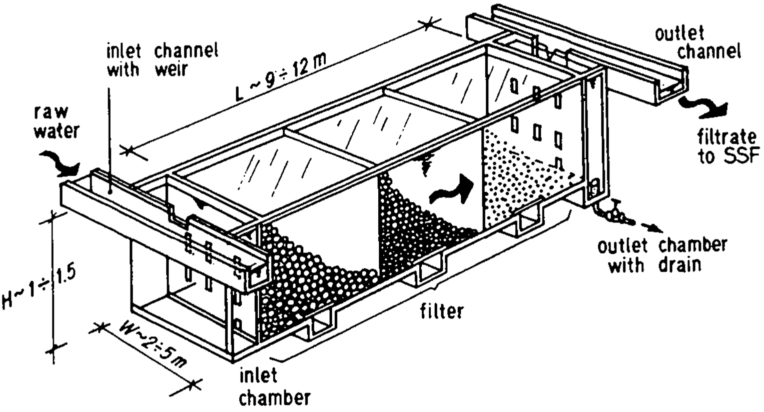
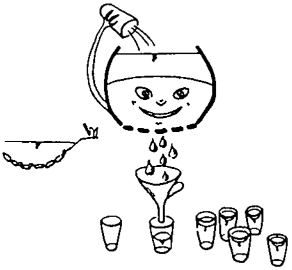


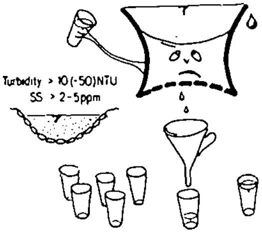
Fig. 1 Main Features of a Horizontal-flow Roughing Filter

for the fans of cartoons:

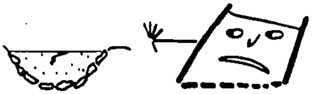
A SERIOUS PROBLEM AND ITS POSSIBLE HAPPY END

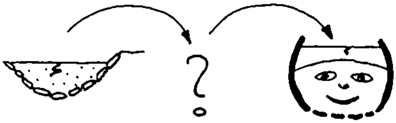


Hello, I'm Miss Slow Sand Filter. How are you? I'm fine because people admire me. Why? Because of my quality to produce clean drinking water and perhaps also because of my modesty which is highly appreciated by men ....

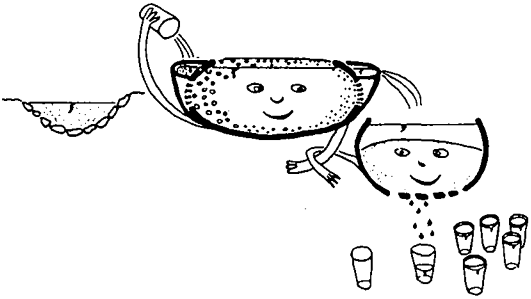


However, I'm not as modest and quiet as most people think. I can get quite upset, especially if I'm fed nasty turbid water. Then I get dizzy because the water pressure almost blocks and bursts my head, and I am no longer able to produce water.





Some people have become aware of my difficult condition and tried to help me by adding chemicals. Aluminum sulfate was thrown into the turbid water to improve my condition. However, quite often I felt no improvement because either the flocs bothered me or the chemicals ran out - so, I had a new attack! The only remedy to restore my health is: no turbid water! But how can it be achieved ?



Well, I found what I was looking for: a nice clean-cut boyfriend whose name is Mister Horizontal-flow Roughing Filter - a somewhat strange name so, I nicknamed him "HORFI". Anyhow, he behaves like a real gentleman and protects me from turbid water with his mighty strength. I'm really looking forward to our honeymoon which I hope will never

END

Part B: why opt for a HRF ?

(HRF = Horizontal-flow Roughing Filtration / Filter)

1. INTRODUCTION AND PROBLEM IDENTIFICATION

Ground and springwater are generally safe for consumption. The water drawn from such sources undergoes natural purification when percolating and flowing through the pore system of the soil. Especially the harmful bacteria, viruses, protozoas, eggs and worms - known as pathogens - are most effectively removed to a level which will no longer endanger human health.

Surface water, however, is unprotected and permanently exposed to possible faecal contamination. The natural purification processes in a free water body are less pronounced due to a smaller interface between water and solid material. Furthermore, flowing water which acts as a transport vehicle can spread the pathogens to consumers located downstream of a polluted site.

A large part of mankind is forced to use surface water, water drawn from polluted rivers, irrigation canals, ponds and lakes. Where no alternative water sources are available, treatment of such water, especially with respect to its bacteriological improvement, is necessary if contamination by man and/or animals is significant (e.g. if it contains more than 100 E.coli/100ml).

Slow Sand Filtration/Filter (SSF) copies the natural purification processes which take place in an aquifer. When flowing through a sand layer, the unsafe surface water is converted into a water whose quality can be compared with a safe "groundwater". Last century, under the menace of cholera epidemics, European waterworks discovered the benefits of SSF. The technique proved to be efficient against water-borne diseases and, in combination with other sanitation improvements, these epidemics were eradicated from Europe. Even today, numerous water supplies in industrialized countries are still using SSF as part of their water purification system.

The main features of a SSF are shown in Fig. 2. A SSF consists of an open box containing a sand layer of approx. 1 m depth. The upper part of the filter box is filled with water to be filtered. This water which flows by gravity through the sand bed is then collected by an underdrain system and conveyed through flow control devices to a clear water tank. An area of 1 m^2 sand has a daily water output of 2.5 to 5 m^3.

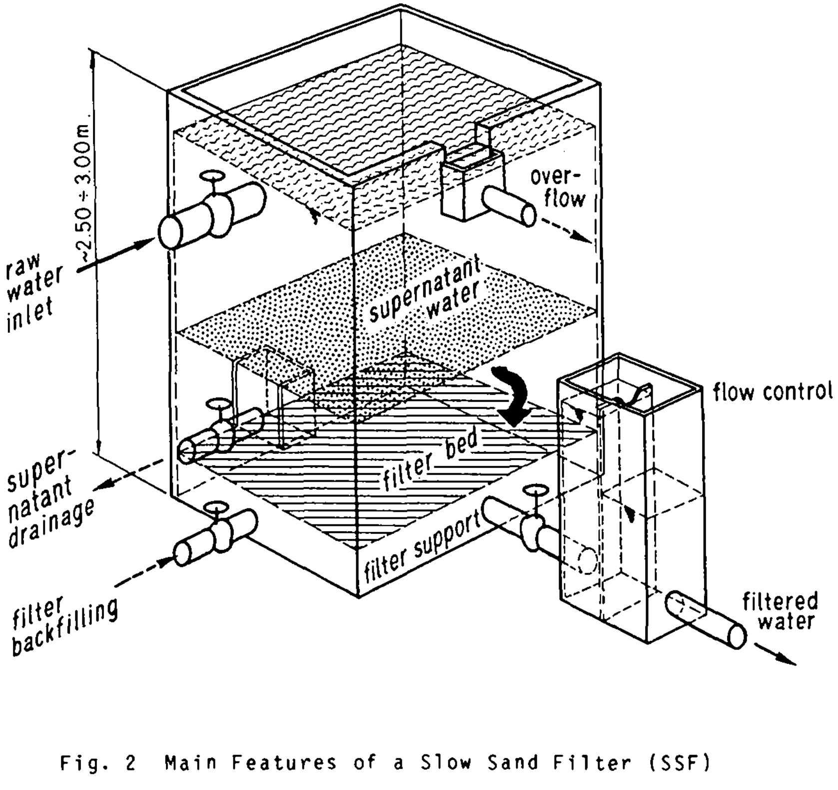


Fig. 2 Main Features of a Slow Sand Filter (SSF)

SSF offers the great advantage of being safe and stable, simple and reliable and can therefore be considered a most appropriate water treatment technology for developing countries. Filter construction makes extensive use of local material and skills. Construction, operation and maintenance of the filters are easy and require only limited professional skills. Neither mechanical parts nor chemicals are necessary for SSF. If the water fed to the SSF does not contain more than 5000-10000 E.coli/ 100ml, then the quality of the treated water is good since it is virtually pathogen-free.

The purification processes of a SSF are located mainly in the top part of the sand bed. A biologically active layer, on which filter performance greatly depends, reaches its required efficiency after a ripening period of 2-4 weeks at the initial start of operation. Later on, after subsequent cleanings, a period of a few days to 1 week might be sufficient for the redevelopment of this layer.

Accumulation of solid matter and gradual growth of the biological layer at the filter surface increase filter resistance. The filter has to be cleaned when the filter resistance attains a maximum permissible filter resistance of approx. 1 m. The filter bed is drained and a few cm of sand from the filter top are removed.

SSF should run for at least 1-2 months between two cleanings to ensure economic and reasonable operation. Large concentrations of solid matter in the raw water will rapidly clog the filter and impair the development of the biological layer. Therefore, a sound SSF application is questionable with operation times of a few days or weeks only.

More information on SSF is compiled in a design and construction manual published by IRC, The Hague/The Netherlands (1).

However, *practical experience with SSF* in developing countries reveals that many installations are facing operational problems or are even out of operation. One major reason for the existing situation is the poor raw water quality fed to the filters. SSF is very sensitive to high suspended solids concentrations since they will block the filter after a short time. SSF will therefore only operate satisfactorily with raw water of low turbidity (lower than 10 NTU). Filtration of raw waters with higher turbidities will cause a rapid increase of the filter resistance. Short filter runs and frequent cleaning are the consequence of a poor raw water quality.

Throughout or during part of the year, most flowing surface waters in the tropics are of a higher turbidity than the standard required by SSF. Therefore, in order to achieve a reasonable SSF operation, raw water pretreatment is generally a necessity since it will reduce turbidity or, more specifically, it will separate the suspended solids responsible for most of the turbidity.

Conventional Pretreatment

The solid matter in the water is usually either removed by *sedimentation tanks*, possibly supported by *flocculators* or, alternatively, by *rapid sand filters*. Conventional settling tanks are able to separate solids larger than about 20 µm. However, finer material, which might represent a large part of the solids found in river water, will only partially be retained by sedimentation tanks and cause premature clogging of the SSF. Consequently, plain sedimentation will hardly meet the high standard required by SSF. The settling rate of the fine matter can be accelerated by the addition of chemicals (such as aluminum sulfate or ferric chloride). These salts destabilize the suspension as the small particles can come together to form flocs. However, the flocculation process is an advanced treatment technique which requires highly qualified personnel and well equipped facilities; both hardly available in rural areas. Due to the great difficulties encountered with the supply of chemicals, the correct dosage of flocculants and flocculant aids and the lack of qualified staff to operate the installations, a reliable and successful application of this process is rather doubtfull in small water supply schemes. Finally, rapid sand filters are often applied to remove fine solids from the water. Conventional filters must be frequently cleaned by a backwash process requiring rather complicated mechanical equipment. The technical level of rapid sand filters stands in discrepancy to the relatively simple SSF process. Rapid sand filters are thereby generally not combined with SSF.

It can be concluded that the conventional pretreatment techniques for the removal of fine particles from the water are either not efficient enough or too sophisticated for rural and small urban water supplies.

HRF as Alternative Pretreatment

Since gravel and sand layers of aquifers significantly improve the water quality of infiltrated surface water, why ignore such an excellent process just because nature has not provided the specific hydrogeological conditions at the site? An artificial aquifer might act in the same way and produce a hygienically safe drinking water.

Horizontal-flow Roughing Filtration copies nature. The main characteristics of the process are its horizontal flow direction and the graduation of the filter material. This specific flow direction enables to construct a shallow and structurally simple filter of unrestricted length. Three to four subsequent gravel packs, ranging from coarse to fine material, effect a gradual removal of the solids from the water. The coarse filter material, contained in the first part of the filter, retains all the larger particles and some of the finer matter, while the last filter part with the finest filter material has to cope with the remaining smallest particles. Since the effluent of a HRF is virtually free from any solids, the standards required by SSF are easily met.

HRF is very similar to SSF. Since both filter techniques make use of natural purification processes, no chemicals are necessary to assist the treatment process. The installation of such filters requires only local resources such as construction material and manpower. Furthermore, no mechanical parts are required to operate or clean the filters. A well-designed filter combination will work for several months between two subsequent cleanings.

Hence, why not *use HRF in combination with SSF*? As pretreatment process, HRF acts mainly as physical filter and retains the solid matter. As main treatment process, SSF is a biological filter which substantially improves the bacteriological water quality. The thereby treated water is similar to a good groundwater and safe for consumption. Therefore, let's copy nature where no suitable aquifer is available to supply safe and reliable drinking water.

Historical Background of HRF

Last century already, coarse media filters were used in England and France for raw water pretreatment prior to SSF. For the past 25 years, gravel prefilters have been used in combination with sand beds for artificial groundwater recharge in Germany, Switzerland and Austria (2). More recently, investigations on coarse media prefilters were carried out at the Asian Institute of Technology in Bangkok/Thailand (3, 4) and at the University of Dar es Salaam/Tanzania (5, 6), to examine the treatment efficiency of these filters with highly turbid water. Five years ago, the International Reference Centre for Waste Disposal (IRCWD), attached to the Swiss Federal Institute for Water Resources and Water Pollution Control (EAWAG) in Duebendorf/Switzerland, started extensive laboratory investigations on HRF (7). A demonstration project, sponsored by the Swiss Development Cooperation, is in progress. Its objective is to introduce the HRF technology in different developing countries and to gain more practical experience with this process.

Note:

- *groundwater and springs should be used whenever possible. Surface water is often of poorer quality*
- *SSF makes the most use of local resources and is hence independent of imported supplies such as chemicals, mechanical spare parts etc*
- *SSF is able to produce hygienically safe water*
- *since SSF is very sensitive to solid matter in the water, pretreatment is in most cases a necessity*
- *Conventional pretreatment (sedimentation tanks, flocculation, rapid sand filter) is not efficient enough or often fails due to operational reasons*
- *HRF uses the purification potential of nature and is on the same technical level as SSF*
- *HRF and SSF complement each other, and their application is a very valuable and reliable option*

2. MAIN FEATURES AND LAY-OUT OF A HRF

The schematic lay-out of a HRF is illustrated in Fig. 3. The filter is divided into three parts: *the inlet structure, the filter bed and the outlet structure*. In and outlet structures are flow control installations required to maintain a certain water level and flow along the filter as well as to establish an even flow distribution across the filter. The main part of a HRF consists of the filter bed composed of 3 to 4 gravel packs of different sizes.

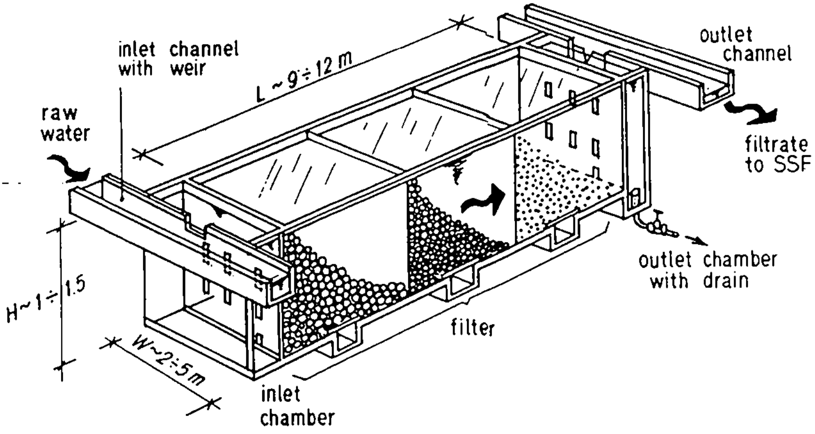
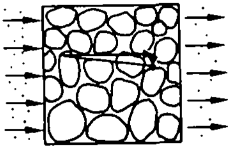


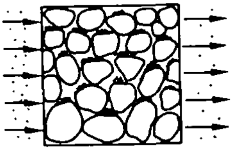
Fig. 3 Main Features of a Horizontal-flow Roughing Filter (HRF)

The raw water falls over a weir into an inlet chamber where coarse solids settle and floating material is retained by a separation wall. The water passes through the perforated separation wall and flows in horizontal direction through a sequence of coarse, medium and fine filter material. The pretreated water is collected at the filter end by an outlet chamber, discharged for flow measurements over a weir and conveyed to the SSF.

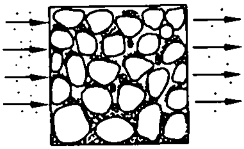
Sedimentation is the main process in HRF responsible for the separation of the solid matter from the water as observed in laboratory tests conducted at EAWAG (2, 7). The filter acts as a multi-store sedimentation basin, thus providing a large surface area for the accumulation of settleable solids. The solids accumulate on top of the collectors and grow into dome-shaped aggregates with advanced filtration time. Part of the small heaps drifts towards the filter bottom once the heaps reach instability. This drift regenerates the filter efficiency of the the upper gravel layers and enables accumulation of a considerable amount of retained material. Fig. 4 schematizes the different mechanisms of sedimentation taking place in a HRF. Depending on the organic characteristics of the raw water, other processes such as biological oxidation or adsorption of solid matter at the slimy filter surface might also occur.



HRF acts as a multistore sedimentation tank



Accumulation of solids on the upper collector surface



Drift of separated solids to the filter bottom

Fig. 4 Mechanism of HRF

Design Variables

The objective of a HRF design is the reduction of the suspended solids in the raw water from a certain, in many cases unknown concentration and hence assumed value, to a standard required by SSF. The characteristics of the raw water determine filter lay-out and its operation, whereas the required capacity only determines the cross-section area of the filter bed.

The following *four design criteria* have to be considered for HRF design:

1) the required effluent quality for a specific raw water quality in terms of separated suspended solids concentration ΔC in mg/l
2) the required daily output Q in terms of m^3/d
3) the required filter run period T_r in terms of weeks
4) the maximum allowable filter resistance ΔH in terms of cm

The following *four design variables* determine the HRF lay-out:

1) the filtration rate v_F in m/h, which is the hydraulic load in m^3/h on the filter's cross-section area in m^2
2) the individual sizes d_{gi} of the filter material in mm
3) the individual lengths l_{fi} of each filter material in m
4) the cross-section area A of the filter in m^2

For a constant suspended solids concentration in the raw water, the design criteria and variables are correlated to each other according to the following matrix:

variables criteria	v_f	d_{g_i}	l_{f_i}	A
ΔC	x	x	x	
Q	x			x
T_r	x	x	x	
ΔH	x	x	x	

Table 1: Interdependencies of design criteria and variables

Raw Water Characteristics

The suspended solids concentration in the raw water is usually not constant as it is subjected to seasonal fluctuations. Extremely high peaks might be observed at the start of the rainy season, followed by moderately high values during the remaining part of the wet season. During the dry season, however, the suspended solids concentration might reach quite low levels. In addition, particle size distribution and colloidal stability of the suspension might differ considerably in both seasons. Larger particles due to higher flow velocities might be expected in the rainy season, and the stability of highly concentrated suspensions might be lower due to flocculation caused by Brownian diffusion. Additional remarks on water quality control can be found in Chapter 5 and in Appendices 2 and 8.

Design Aspects

HRF has to be dimensioned for extreme situations, i.e. for maximum suspended solids concentration in the raw water. As filter efficiency decreases with increasing filter load σ (g/l) defined as dry weight of accumulated solids (in g) per unit of filter volume (in l), peak loads in the raw water should preferably be treated with a recently cleaned filter. The annual operational plan should therefore consider seasonal quality fluctuations of the raw water. Details in this respect are given in Chapter 5.

In order to guarantee an economic lay-out of HRF, moderately higher effluent concentrations of suspended solids might be permitted during extreme situations. Furthermore, the filtration velocity v_F can normally be increased when the mean suspended solids concentrations of the river water is moderate or low. Higher filtration rates permit smaller filter cross-sections although the filter length l_f may, as a consequence, have to be increased. The three design variables v_F, A and l_f are interrelated. An economic optimization of the filter bed volume by a variation of these three variables is possible within narrow limits only. The detention time of the water in the filter is one major operational filter characteristic since sedimentation remains the main process in HRF. However, a reduction of the filter run period T_r will not only reduce the required filter length l_f but also the filter bed volume. Thus, economic filter optimization can more readily be achieved by a variation of T_r and l_f.

With respect to the grain size d_g of the filter medium, one would primarily tend to use finer material as coarser filter aggregates have a lower efficiency. However, besides efficiency in the separation of suspended solids, other criteria such as final headloss ΔH, filter run period T_r and filter cleaning aspects have to be considered. With the use of only one fine filter material, it might be possible to pretreat the raw water sufficiently but at the expense of high head losses, short filter runs and difficulties in filter cleaning. Such problems arise with filter material of less than 4 mm in size. A graded filter bed with differently sized fractions overcomes the aforementioned difficulties.

Design Guidelines

The suspended solids concentration in the raw water and the particle size distribution of these solids mainly determine the lay-out of a HRF. The following *tentative design guidelines* in Table 2 might be used if this information is not available or,

maximum suspended solids concentration in presettled water	C_o (mg/l)	>300 high	300-100 medium	<100 low
filtration rate	v_F (m/h)	0.5	0.75 - 1	1 - 1.5
filter length for d_g = 20 mm	l_i (m)	3 - 5	3 *)	3 *)
15 mm		2 - 5	2 - 4	2 - 3
10 mm		2 - 4	2 - 3	2
5 mm		1 - 2	1 - 2	1
maximum suspended solids concentration in HRF effluent	C_e (mg/l)	5	2 - 3	2

*) this gravel fraction can possibly be omitted

Table 2: Tentative Design Guidelines

alternatively, as a baseline for preliminary design considerations. To reduce the solids load on the HRF, coarse, settleable matter is separated preferably by a small settling tank prior to filtration. Therefore, the values in Table 2 apply to presettled raw water (detention time less than 3 hours).

The tentative design guidelines are listed for 3 different maximum suspended solids concentrations in presettled water. Table 2 suggests the use of a HRF with 4 differently sized filter materials, i.e. filter media of 20, 15, 10 and 5 mm average sizes. The total filter length amounts to 8 - 16 m for highly turbid water and can possibly be reduced to 5 m if a lower filtration rate is used for raw water of medium or low suspended solids concentration.

A nomogram presented in Appendix 1 might be used for further design evaluations or for the development of an individual filter configuration. This nomogram is based on laboratory filtration tests carried out with a suspension of kaolin (7). The raw water characteristics of a specific river might not necessarily coincide with the ones of the tested suspension. Further specifications and the design procedure are explained in Appendix 1.

Finally, *a computer programme* for dynamic HRF modelling is available at EAWAG. This programme considers the filter efficiency reduction caused by the filter load. The fluctuation of the suspended solids concentration in the raw water can thereby be simulated and the design will consequently no longer be based on a specific maximum concentration. The development of the HRF effluent quality, in terms of suspended solids concentration, can be examined for different filter configurations to achieve best filter operation. However, detailed information on the raw water characteristics is required to attain optimum benefits. Details on the required input and the conditions for a computerized HRF design are available from EAWAG at special request.

Height and Width

Neither the height H nor the width W of a HRF are dependent on the raw water characteristics but are influenced by structural and operational criteria. The following aspects were taken into account for the recommendation of the respective dimensions:

- although the efficiency of a HRF can partly be restored by intermittent drainage, the filter media has to be taken out and cleaned manually to remove the sticky sludge which will have accumulated in the lower part of the filter after longer operational periods. Therefore, a convenient side walls height will allow for easier removal and refilling of gravel from and into the filter box respectively. In addition, a shallow height will also enable the construction of non-reinforced side walls and thus effectively reduce construction costs. On the other hand, too small structures require extensive land. Therefore, the height of the side walls should lie between 1.0 and 1.5 m.

  $H_{max.} = 1.5$ m
  $H_{recommended} = 1 - 1.5$ m

- the width W of a HRF depends on the required capacity of the treatment plant. In general, at least 2 HRF units should be provided in order to allow for treatment continuity during maintenance of any one unit. For hydraulic reasons and in order to limit the interruption period necessary for manual filter cleaning, the maximum width should not exceed 5 m, whereas the minimum width should be at least 1 m to ease cleaning.

  $W_{max.} = 5$ m
  $W_{recommended} = 1 - 4$ m

Flow and Headloss Control

The hydraulic conditions in a HRF are determined by the hydraulic load and by the water depth in the filter. These conditions are controlled by certain installations such as weirs and valves. Filter control is essential to maintain specific flow conditions and to detect leakages.

A distributor box or channel divides the flow to the different HRF units into equal parts. The simplest control device is a V-notch weir. Maximum flow through the treatment plant can be limited by an overflow located in the distributor box or channel.

The water level in the HRF is influenced by the outlet control system. In general, either a fixed or a variable water level in the outlet chamber is possible. The simplest option here is also the installation of a weir or an effluent pipe which maintains the effluent water level at a fixed height.

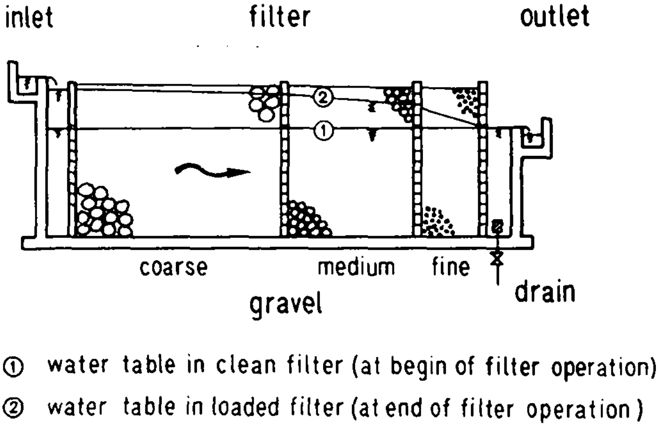


Fig. 5 Fixed Water Level Filter Control (recommended)

The filter resistance increases with progressive filter operation. Since the water flows through coarse material at low velocities, the final headloss in a HRF will usually be in the range of 10 to 20 cm, but should not exceed 30 cm. The headloss variation in the filter is accommodated in the top part of the filter material. Therefore, filter material should be filled to approx. 30 to 40 cm above the effluent's weir level. Fig. 5 illustrates the general lay-out of this option. More details on discharge measurements are given in Appendix 3.

A variable water level at the effluent side is achieved by the installation of either a manually operated valve, a self-regulating floating weir or a constant flow device. The general lay-out of the variable water level system is illustrated in Fig. 6, and details of self-regulating devices are given in Fig. 7. The filter resistance can be compensated by a variable water level system which will enable higher headlosses (8). However, since the final headlosses for the discussed HRF are relatively small, the use of variable effluent and mechanical flow rate devices are not advisable for flow control of HRF.

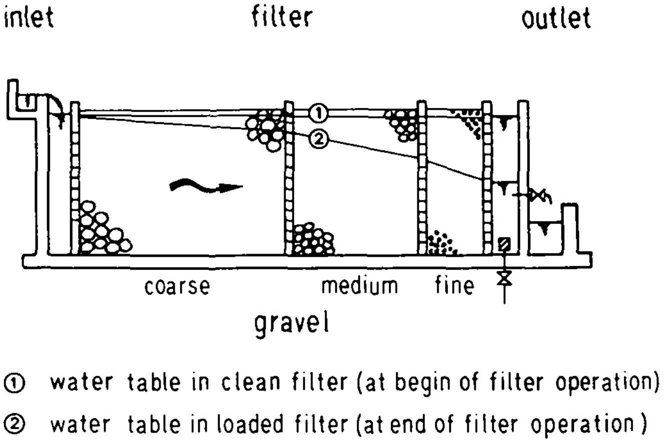


Fig. 6 Variable Water Level Filter Control
(not recommended)

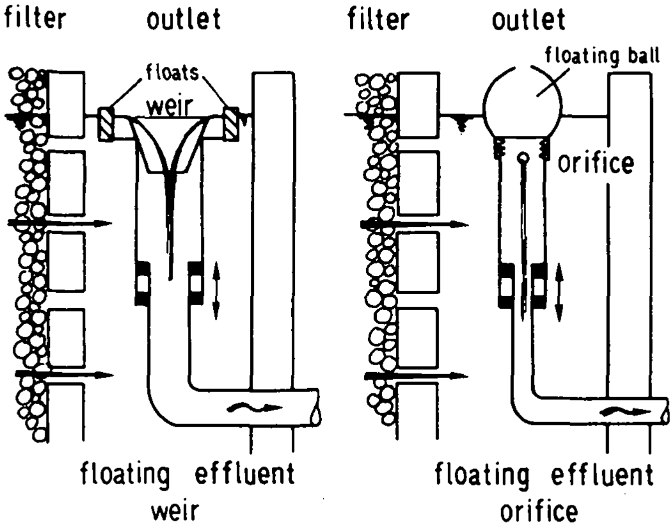


Fig. 7 Mechanical Flow Rate Devices (1), (9)

Further information on the dimensioning and lay-out of a HRF can be found in Chapter 7. An example illustrates the HRF design procedure.

Note:

- *a HRF is composed of an in and outlet structure and a main part consisting of the filter bed filled with 3 to 4 differently sized filter fractions*

- *sedimentation is the main process in a HRF*

- *the objective of HRF application is the separation of the solids from the water for a safe SSF operation*

- *4 design criteria (suspended solids removal, daily output, running period, maximum headloss) determine the dimensions of 4 design variables (filtration rate, size of filter material, length of filter bed, filter cross-section)*

- *HRF must be designed to cope with peak loads*

- *tentative design guidelines, a nomogram and computer programme are available for HRF design* *where to integrate a HRF ?*

3. LAY-OUT OF WATER TREATMENT PLANTS

General Considerations

Surface water has to be collected, treated and stored before it is distributed to the consumers. These activities are achieved by different treatment processes. Table 3 lists the processes and the required specific installations.

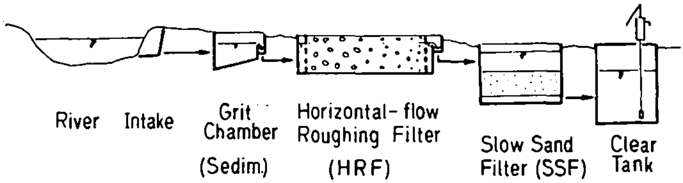
Process	Collection	Pretreatment	Main Treatment	Storage
Installation	Intake	Grit Chamber HRF	SSF	Reservoir
	or			
	Infiltration Gallery		SSF	Reservoir
Process Scheme				

Table 3: General lay-out of a treatment plant

Under special local conditions, collection and pretreatment of the raw water may be combined in a single installation such as an infiltration gallery.

All the installations work at free water tables. The total headloss through the treatment plant, schematized in Table 3, will be in the order of 2 or 3 m. *Gravity flow* through the system can therefore be achieved and pumping steps avoided. In general, all water lifting devices, apart from handpumps, should be avoided in order not to depend on energy supplies and sophisticated spare parts which, in most cases, increase the unreliability of a system. If water has to be lifted due to topographical reasons, a 1-stage pumping scheme should be chosen to pump the raw water to an elevated site where the treatment plant and the reservoir are located. A 1-stage pumping scheme is more advantageous than a 2-stage scheme as it increases the reliability of the scheme by a factor of 2. In addition, the risk of flooding in the lowland area may often not be completely avoided. A high-lift pumping station is more easily protected from floods than a full-size treatment plant. The two discussed schemes are illustrated in Fig. 8. However, the installation of a 2-stage pumping system cannot be avoided for a piped system in a flat area devoid of natural elevation.

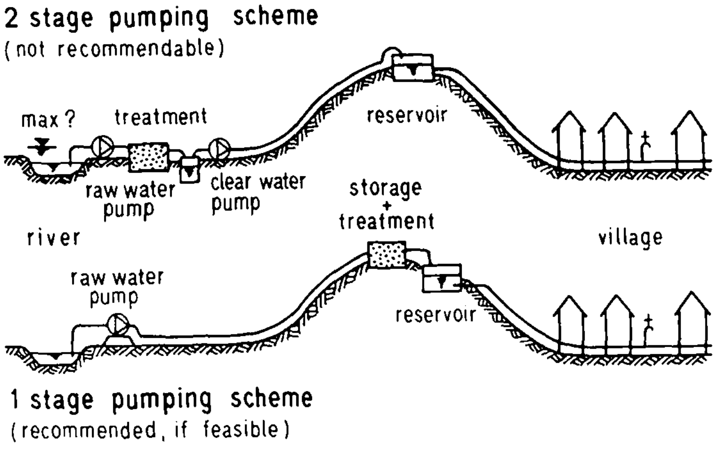


Fig. 8 Longitudinal Profiles of Water Supply Schemes

Infiltration Gallery or Trench

Intake and pretreatment can be combined in a single installation either by an infiltration gallery or by an infiltration trench. As shown in Fig. 9, the set-up differs with respect to the river. The gallery is placed under the river bed, whereas the trench is located along the river's embankment.

The construction of an infiltration gallery creates some problems especially with perennial rivers. The water course has to be deviated temporarily from the construction site, where an approx. 2-3 m-deep ditch is excavated. Different layers of gravel ranging from coarse to fine fractions are placed around a drainage pipe and the ditch refilled with clean sand. Coarser material may be placed on the river bed to prevent erosion. According to the literature (1), filtration rates of 5 to 10 m/h may be used. Such high hydraulic loads, however, might quickly clog the infiltration ditch, especially in the case of silty river water. Configuration of the filter material with e.g. fine sand at the infiltration side and coarse material at the drainage side, enhances clogging even further. Since most

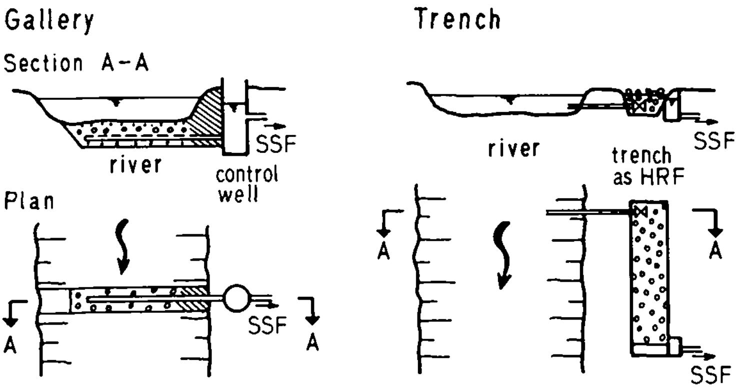


Fig. 9 Infiltration Gallery and Trench

infiltration galleries are not accessible, cleaning and maintenance operations are hardly possible. The installation of manholes might allow flushing of the collection pipe but not efficient cleaning of the filter packages. Such galleries are therefore not recommended for common application and should only be used in special cases.

Infiltration trenches installed along or across the river embankment create less structural and operational problems. Most of the construction work can be carried out under dry conditions. The excavated trench is filled with filter material and operated according to the guidelines valid for HRF. One drawback might be the variable water level communicating between river and trench, although smaller filtration rates are of advantage at flood periods with correspondingly high silt loads. During cleaning and maintenance operations, the water flow to the infiltration trench must be stopped either by water-tight stop logs, in the case of a river intake structure, or by a valve if the raw water is conveyed to the trench by a pipe. A regeneration of the filter efficiency by drainage of the infiltration trench will, however, require additional installations and equipment such as a drainage well equipped with a high-discharge pump.

Finally, pretreated water can also be collected from a river if a small scale proprietary filtration unit is burried into the river bed and the water pumped to the SSF. Practical experience (10) with such installations reveal the main drawbacks. The need of a relatively powerful pump and fairly frequent maintenance in the form of backwashings are the main disadvantages of this system. The use of such small filter boxes should be limited to exceptional circumstances, e.g. emergency water supply for a refugee camp.

Removal of Coarse Material

Floating matter might block and damage the water supply installations. Therefore, this undesirable material is retained right at the beginning either by screens or by a scum-board. The latter is applicable only at a constant water level intake. Screens, as illustrated in Fig. 10, are therefore commonly used for the removal of coarse floating matter. Water abstraction below the water surface by a floating intake is another alternative.

Flowing surface water might also carry *solids of different sizes*, varying from coarse sand and silt to fine clay. By sound location of the intake structure or installation of a guide dam, as sketched in Fig. 11, coarse and fine solids are separated to a certain degree. Since silt accumulation at the intake causes operational difficulties, the intake should be located at a rivier bend's erosion side.

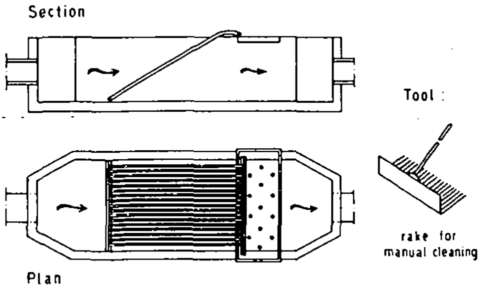


Fig. 10 Screen

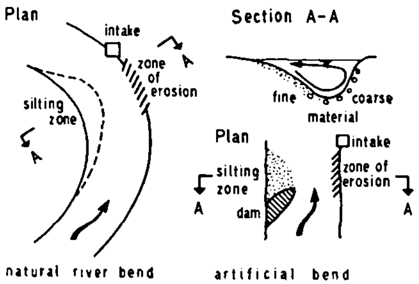
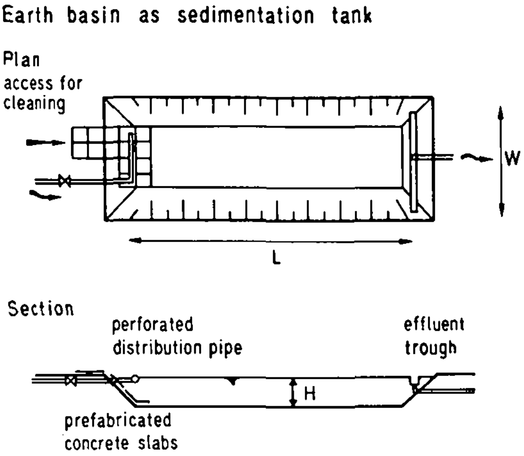


Fig. 11 Location of Intake

The separation of coarse solids from the water is carried out preferably by a *high-load sedimentation tank* since sludge removal from such a tank is less troublesome than from HRF. The design values listed in Fig. 12 are applicable for the removal of coarse solid particles larger than approx. 50 µm, or 20 µm respectively.



$\rho_{particle} \sim 2.6$

removal of particles > 50 µm:
surface load s_0 = 6 m/h
detention time T_d = 15 Min

removal of particles > 20 µm:
surface load s_0 = 0.6 m/h
detention time T_d = $2^1/2$ h

H ~ 1.5 m
L/W ~ 5 ÷ 10

Fig. 12 Simple Sedimentation Tank

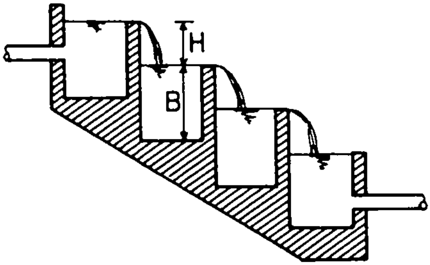
One sedimentation tank should be enough for a small-scale water supply scheme. The accumulated sludge can be removed during periods of low silt load. A by-pass is required in order not to interrupt operation of the treatment plant during cleaning periods. Two or more sedimentation units should be provided for larger schemes.

Aeration

The *oxygen* content of the water plays an important role in the biology of the SSF process. The activity of the aerobic biomass decreases considerably if the oxygen concentration of the water falls below 0.5 mg/l. Physical processes are the major mechanisms in HRF. Nevertheless, biochemical reactions do also occur in the prefilter, especially with water containing a high organic load.

There is usually sufficient oxygen content in turbulent surface water. Standing water, however, can exhibit low oxygen contents and therefore requires to be aerated.

Cross - Section



weir load :
10 l/s · m
$H < 70$ cm
$B > {}^{2}/_{3} H$

Fig. 13 Cascade

Cascades are simple but efficient aeration devices. The installation of a submerged cascade aerator as described in Fig. 13 should be constructed whenever the natural gravity allows for such a provision. It should preferably be placed prior to the HRF in order to cope with a possible oxygen demand of this filter.

The different weirs used for filter control are an additional source of oxygen supply.

HRF as Pretreatment

HRF separates the fine solids which are not retained by the preceding sedimentation tank. The effluent of HRF should not contain more than 2-3 mg/l filterable matter in order to meet the SSF raw water quality requirements. When the required HRF effluent quality is exceeded, the filter will have to be cleaned to restore filter efficiency.

HRF mainly improves the physical water quality by removing suspended solids and reducing the turbidity. Additionally, *bacteriological improvement* of the water can also be expected since bacteria and viruses are solids too, ranging in size from approx. 10 to 20 µm or 0.4 to 0.02 µm, respectively. Furthermore, the specific literature states that these organisms are frequently attached to the surface of other solids found in water. Hence, a removal of the solids also means a reduction of the pathogens (disease-causing microorganisms). HRF efficiency in reducing microorganisms might hypothetically be of the same order of magnitude as that for suspended solids, e.g. an inlet concentration of 100 mg/l can be reduced by a HRF to say 1 mg/l. The removal ratio for this example amounts to 99% or to a 2 log reduction. Pathogens of a larger size (eggs, worms) might be removed even further. These hypothetic considerations, however, need to be verified in the field since little practical information is available so far.

HRF is meant as pretreatment step prior to SSF. SSF might be omitted if the bacteriological pollution of the water to be treated is absent or minimal. This may be the case with surface water draining an unpopulated catchment area, or where contamination of the water by human waste is prevented by controlled sanitation. Permanent or periodic high silt loads in the surface water, however, might call for physical improvement of the water. Excessive amounts of solids in the water result in a silting-up of pipes and reservoirs. In view of such technical considerations, HRF may be used without SSF if the bacteriological water quality level is acceptable, i.e. containing less than 100 E.coli/100 ml.

Operational aspects call for at least 2 HRF units to be installed in a treatment plant. Manual cleaning and maintenance work may take some time during which the remaining HRF unit(s) is (are) operated at higher hydraulic loads. A single HRF unit might be appropriate for small water supply schemes treating water of periodically low turbidity.

SSF as Main Treatment

SSF is supposed to remove the finest impurities found in the water and is therefore placed at the end of the treatment line. The filters act as strainers since the small suspended solids are retained at the top of the filter in the pore system of the fine sand. However, the biological activities of the filter are more important than this physical process. Solid and dissolved organic matter causes oxygen depletion when decomposing. The SSF biology turns the organic material into stable inorganic products. Even more important from the hygienic point of view is the *substantial reduction of bacteria and viruses by the SSF*. Oxidation of the organics as well as separation of the pathogens is mainly performed by the biological layer located on top of the filter bed, the so-called "Schmutzdecke", and in the additional 30-40 cm of the sand bed. A SSF will produce hygienically safe water once this layer is fully developed.

Unlike HRF, the time for SSF cleaning is not determined by the deterioration of the effluent quality but by the achievement of the maximum available headloss. This is of some advantage as the determination of a hydraulic criteria is easier than that of a quality parameter.

Additional information on SSF is summarized in Appendix 5. However, details concerning the design and construction of a SSF are referred to in a special manual (1).

Water Disinfection

A SSF with a well-developed biological layer produces hygienically safe drinking water. Any further treatment such as disinfection of the water is therefore unnecessary. Apart from the water quality aspect, numerous examples from many developing countries reveal that a reliable disinfection is practically impossible in small water supply schemes. An uninterrupted supply of mostly imported chemicals and the accurate dosage of the disinfectant are the main practical problems encountered in developing countries.

If water is disinfected, it is also possible to use the water produced in the initial operation phase of a SSF. Furthermore, the chlorine acts as a safe-guard against pathogens introduced by secondary contamination, i.e. either in the distribution system or at the consumer's side. Bleaching powder or a sodium hypochlorite solution are commonly used as disinfectants.

A more judicious measure than preventive disinfection is the production of an acceptable water quality level and the implementation of a general health education programme including special training in water handling.

Water Storage

SSF is either operated at a constant filtration rate for 24 hours/day or at a declining filtration rate at night. Smaller filter units and a continuous supply of nutrients and oxygen to the biological layer are, besides water quality aspects, the main reasons why SSF should not run intermittently. HRF is less sensitive to such operational variations, although careful restarting of filtration should be observed in order not to resuspend the solids accumulated in the filter. As daily water demand is more or less concentrated in 2 peaks, a storage volume of approx. 30 to 50% of the daily treatment capacity has to be provided to compensate for this uneven demand.

Water Distribution

For the water to reach the consumers, installation of a piped gravity system might be considered if the economic conditions and local topography are favourable. However, an increased water demand resulting in a possible overload of the treatment plant and in serious drainage problems in the housing area of the community might be the consequence of such a distribution system.

In many situations, however, the economic as well as the topographic conditions do not enable a piped gravity system. Difference in altitude can be overcome by water lifting. However, pumps require additional investment and operation costs but energy in particular - an aspect which will gain increasing importance in the future. Pumped systems should therefore be limited to special situations.

The walking distance between house and water source is more important to the water consumer than the water quality. Consequently, a new water source has to compete with the traditional source and bring the water nearer to the users. Treated river water as a new source will be accepted for instance if the original walking distance to the river is significantly reduced.

A semi-piped system equipped with handpumps is a judicious choice and best combination of the different aspects discussed. The treated water could be distributed by gravity to different water cisterns placed between treatment plant and village. The cisterns would not only act as reservoirs but also as water points. The energy supplied by the consumers operating the handpump keeps the system running and greatly contributes towards reducing the operation costs.

Fig. 14 illustrates a possible water treatment plant lay-out independent of any foreign chemicals or energy supply.

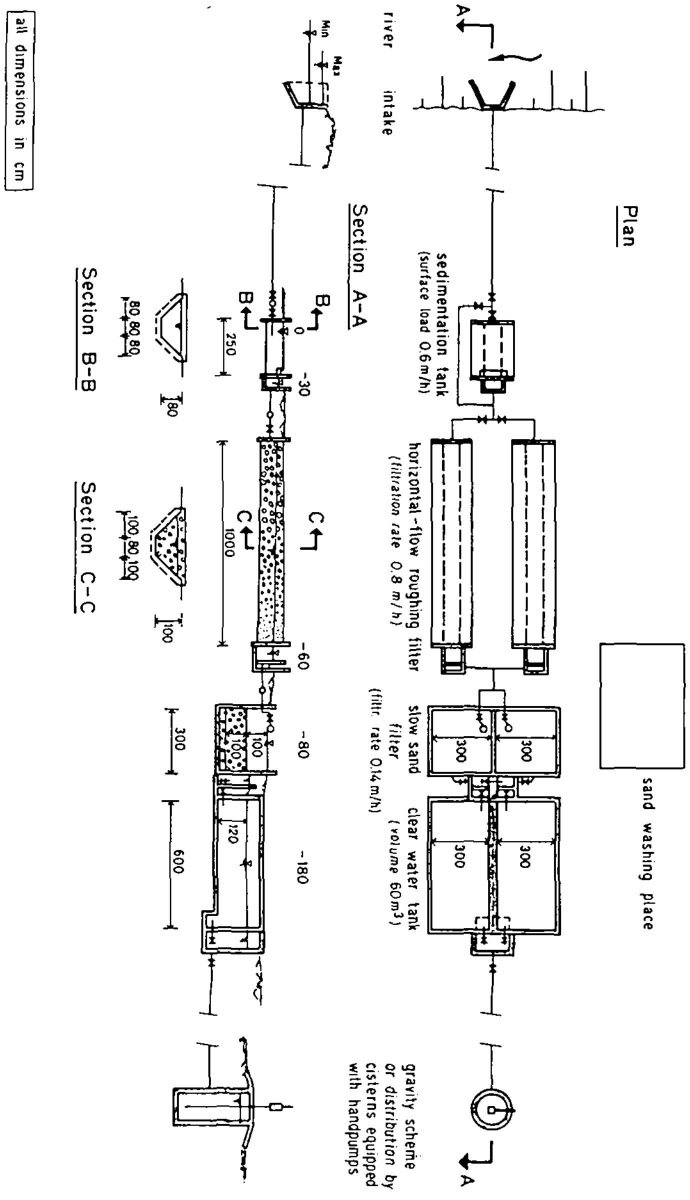


Fig. 14 Lay-out of a Water Treatment Plant for 60 m^3/d (2000 people at 30 l/c·d)

Note:

- design your treatment plant for gravity flow
- avoid whenever possible any pumping
- if pumping is unavoidable, install a semi-piped system equipped with handpumps or at most a one-stage pumping and distribution scheme
- trenches excavated along the embankment are more suitable for river water infiltration than infiltration galleries
- coarse material is separated by screens, scum-boards and high-load sedimentation tanks
- cascades should be introduced in front of the filters to aerate in particular standing surface water
- HRF is a physical filter which mainly removes the solid matter
- SSF is a biological filter which reduces organics, bacteria and viruses

how to construct a HRF ?

4. HRF CONSTRUCTION

As a matter of principle, local material, manpower and community participation should be used whenever possible in the construction of any water supply scheme. The installations should be simple, sturdy and of good finish, as well as maintainable with local means. The lay-out should facilitate both operation and maintenance.

Filter Box Location

HRF can generally be located below or above ground level as illustrated in Fig. 15. The choice of the HRF type depends on the hydraulic profile, soil characteristics and available construction material. In a flat topography, gravity flow often requires the structures to be placed below ground level. A partially buried HRF has the advantages of requiring less excavation work, of providing support to the side walls by the back-filled soil and of presenting greater protection against dust and sand.

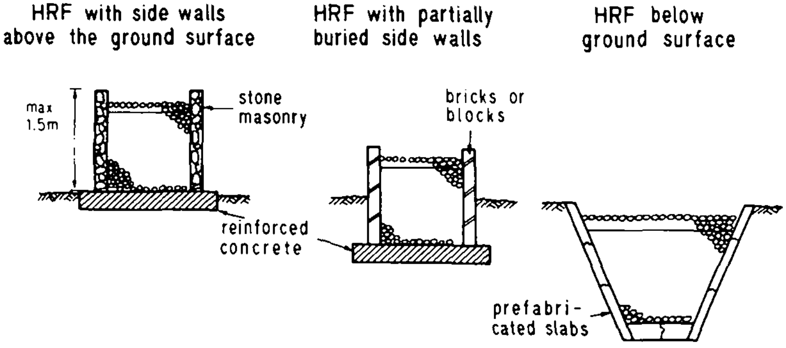


Fig. 15 Location and Materials of HRF Boxes

Filter Box Material

The most modest box consists of a trench excavated in an impervious soil such as clay, silt or laterite. The ditch has inclined side walls not exceeding the slope stability of the water-saturated soil (slope approx. 1:1).

Lining of the base and the side walls of such a basin prevents the mixing of clean filter material with the underground. The type of lining depends on the degree of soil impermeability and stability to be investigated in the design phase. A layer of sand, prefabricated slabs, in-situ applied coatings (concrete lining, ferrocement, lime mortar) or, in emergency cases (e.g. refugee camps), prefabricated plastic can be used as lining material. *A watertight box has to be constructed if the underground* is permeable or if the filter is installed above the ground surface. In such cases, vertical side walls are recommended. Burnt clay bricks with a cement mortar lining, concrete bricks or reinforced concrete are the filter box's building materials.

In order to avoid cracks in the box resulting from uneven settling of the soil, construction of the foundation and the floor of the box require special attention. Finally, dilatable joints will eventually be necessary in long filter boxes constructed with material prone to shrinking or the HRF can alternatively be divided into two interconnecting compartments. Another alternative to reduce the total length of the filter box is the design of a U-shaped unit. In and outlet are on the same filter side and the filter box is divided by a longitudinal separation wall into two equal parts.

The filter box should be tested for watertightness, preferably before it is filled with filter material, as leakages are more easily detected and repaired in empty structures.

Filter Material

The filter material should have a large specific surface in order to enhance the sedimentation process taking place in the HRF. Furthermore, it should provide high porosity necessary for the accumulation of the separated solids. Generally speaking, any inert, clean, insoluble and mechanically resistant material fulfilling the above two criteria can be used as filter medium. Filtration tests revealed that neither the surface roughness nor the shape or structure of the filter material have an appreciable influence on filter efficiency.

The following filter material can for instance be used:

- *gravel* from a river bed or present in soils
- *broken stones or rocks* from a quarry
- *broken burnt bricks* made of clay
- *plastic material* either as chips or as modules, e.g. used in trickling filters (self-reliance as regards the use of locally-available material is no longer considered here; attention should be paid to the uplift forces of the water)
- possibly *burnt charcoal* (risk of disintegration when cleaning the filter material)
- possibly *coconut fibre* (risk of odour nuisance during longer filter operation periods)

A HRF is composed of 3 to 4 differently sized filter fractions which range from coarse to fine. The coarse and most of the finer suspended solids are removed by the first filter pack. A large pore volume should therefore be provided in this part of the filter. This is best achieved by locating a coarse filter material along a substantial part of the filter length. The subsequent filter material is of finer size and the packs of shorter length. The last filter fraction should only resume polishing functions as it is supposed to remove the last traces of the finest suspended solids found in the water.

Table 4 lists some *general guidelines* for the size and length of the different filter fractions. These guidelines should not be too rigidly applied. However, the average size of the aggregates should not be smaller than 4 mm to enable regeneration of the filter efficiency as described in Chapter 5.

filter fraction	approx. size of filter material	approx. length of filter fraction
first *)	15 - 25 mm	3 - 5 m
second	10 - 20 mm	2 - 5 m
third	5 - 15 mm	2 - 4 m
fourth	3 - 8 mm	1 - 3 m

*) can possibly be omitted

Table 4: Size and Length of Filter Material

The Asian Institute of Technology (AIT) in Bangkok has also carried out some investigations on HRF. The authors of (3,4) recommend the installation of 6-8 small gravel layers. The gravel size should subsequently be reduced from 20 to 2.5 mm, and thereafter increased again to 25 mm. No advantage can be gained by locating the smallest gravel fraction in the centre of the filter bed since the following gravel packs have by nature a lower removal efficiency.

When choosing filter material size, practical aspects such as the availability of specifically sized material from a quarry is also an important criteria. Fig. 16 illustrates 2 simple possibilities of on-site sieving installations if graded filter material is not available.

In order to remove all loose and dirty material from the surface of the filter, the aggregates should be washed thoroughly. If this recommendation is not observed, the HRF's initial effluent quality will be poor and result in a rapid clogging of the SSF.

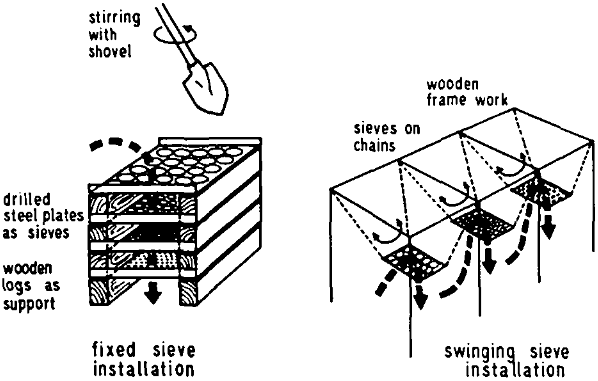


Fig. 16 On-site Sieving Installations

Separation Walls

The different filter fractions should be separated from each other in order to avoid mixing of the aggregates during manual cleaning of the filter. Burnt brick or cement block walls with open vertical joints are best suited for such a separation. The total area of the open joints should idealy cover 10 to 20% of the total filter cross-section area, and be equally distributed over the entire cross-section in order to maintain even flow throughout the HRF. Prefabricated perforated bricks or blocks (e.g. holes Ø 3 cm, spacing 5 x 5 cm) or loose rubble could be installed as an alternative to the open joints. Finally, wooden boards might be used to separate the different gravel fractions. In loose or weak separation wall structures, the filter material should be filled simultaneously on both sides of the wall.

In and Outlet Structures

Even distribution of the raw water and abstraction of the treated water, flow regulation and water level control as well as separation of coarse settleable and floating matter at the filter inlet are the objectives of the in and outlet structures. Examples are illustrated in Fig. 17.

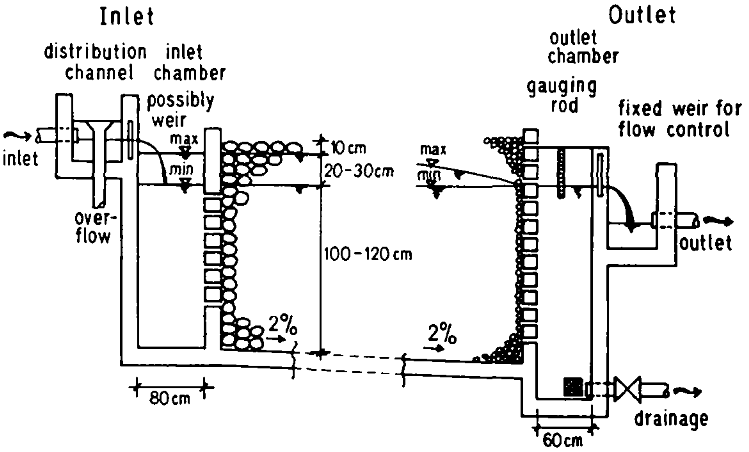


Fig. 17 In and Outlet Structures of HRF

If weirs overflow of approx. 30 cm headloss can be installed in the hydraulic profile of the treatment plant, the in and outlet are preferably equipped with V-notch weirs for flow control. The V-notch weir at the outlet can be replaced by a fixed effluent pipe in treatment plants with minimum available hydraulic heads.

Even distribution of the flow over the full filter's cross-section area is achieved by an inlet chamber. The separation wall between this compartment and the first filter package should contain openings in its middle part as shown in Fig. 17. A solid wall at the bottom and at the top respectively, hinders penetration of coarse settled solids or floating matter into the filter. The minimum width of the inlet chamber should not be smaller than 80 cm to ease cleaning.

A similar outlet chamber is installed at the effluent side. However, the openings in the separation wall located after the last filter package are distributed all over the filter's cross-section.

A weir or an effluent pipe maintains the water table of the filter outlet zone at a specific level. The progressively increasing filter resistance must be accommodated within the filter bed. For this reason and to avoid mosquito breeding, it is necessary to fill filter material up to approx. 30 to 40 cm above the weir's level.

Drainage System

Drainage facilities, as illustrated in Fig. 18, are required for filter cleaning and filter efficiency regeneration (see Chapter 5). For *manual cleaning* of the filter medium, a drain, placed in the outlet chamber, enables complete drainage of the filter box. The filter bottom should thereby be slightly inclined by 1 to 2 % in the direction of flow. A side effect of this proposed slope is the saving of some filter material.

Hydraulic cleaning consists of a fast filter drainage and a slow refilling of the filter with water. Drainage facilities such as perforated pipes, troughs or culverts enable hydraulic cleaning of the filter medium. The system is placed perpendicular to the direction of flow at the filter bottom. The spacing between the drains should amount to about 1-2 m. The hydraulic capacity of these installations should permit an initial vertical filter drainage velocity of 60-90 m/h necessary for efficient cleaning. Valves, slide gates or flexible hose pipes can be used to operate the drainage system. Each drain should discharge into an open channel to allow visual supervision of any drainage operation. Facilities for safe washwater disposal are necessary to prevent erosion and water ponding.

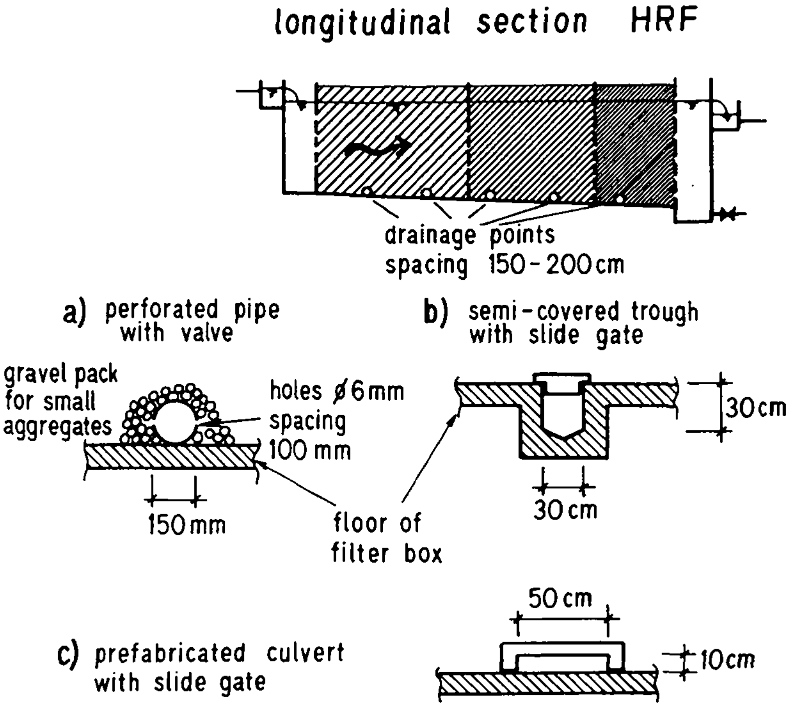


Fig. 18 Drainage Systems

Note:

- *construct your water supply scheme as much as possible with locally available material and manpower*
- *any inert material can be used as filter medium*
- *3 to 4 differently sized filter fractions ranging from approx. 25 mm down to 4 mm are required*
- *avoid filter material smaller than 4 mm since it hinders filter regeneration by drainage*
- *install only thoroughly washed filter material*
- *V-notch weirs are necessary for flow control. Place at least one weir at the inlet of HRF*
- *include drainage facilities necessary for manual cleaning and filter regeneration*

how to operate and maintain a HRF ?

5. HRF OPERATION AND MAINTENANCE

HRF can easily be operated and maintained by trained local caretakers. It does not depend on external inputs provided the necessary materials and tools are available. The daily activities of the caretaker are preferably supported by occasional visits of a supervisor attached to the operation and maintenance section of the governmental institution responsible for the water supply sytem. Important maintenance work should be carried out at the time when village participation can be involved. This is of particular importance as regards manual cleaning of the HRF.

Commissioning of the Filter

Filter operation should only start when construction work is totally completed. The efficiency of a HRF filled only partially with gravel will be poor as the unit will not act as a filter but as an inadequate sedimentation tank. Emphasis should therefore be placed on a good finish of the construction work including the installation of proper flow control and drainage facilities as well as a full supply of filter material. Before starting filter operation, it is recommended to wash the installed filter material by drainage. The filter unit should be filled with water up to the effluent's weir level at low flow rates of 0.5-1 m/h. Thereafter, the water should be drained off through the first drainage installation located next to the inlet. Any dust on the surface of the filter material is rinsed to the filter bottom. The impurities accumulated around the drainage system will be flushed out of the filter. This procedure should be repeated if necessary 2 to 3 times by changing the point of drainage from filter inlet to filter outlet side. Filter cleaning will prevent dust from penetrating into the fine gravel fraction which would otherwise increase the initial filter resistance. Operational check of the complete drainage system is a positive side effect of the described cleaning procedure.

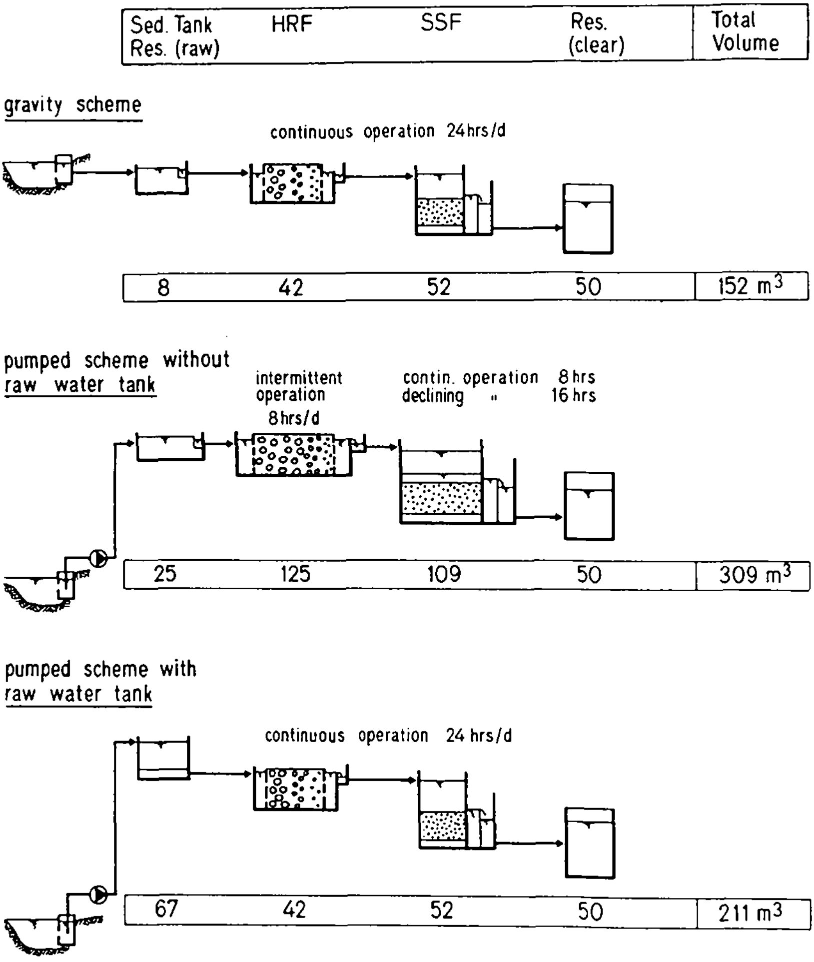
Flow Pattern

A 24 hours (per day) continuous filter operation makes the best use of the installations, provides maximum production and a constant flow pattern. However, full gravity flow will be required for such an ideal situation.

If pumping is necessary, the treatment plant can be staffed for 8 or 16 hours a day, depending whether 1 or 2 shifts are available. For quality reasons it is not recommended to operate SSF intermittently. In order not to affect the biological activities in the SSF, this filter can be operated at declining filtration rate during the unstaffed period of the day. This means in practice that at night the stock of supernatant water is drained through the filter at continuously declining flow rate. During the morning hours, the filter has to be refilled with pretreated water to resume normal operation. Such an operation calls for special provisions since water must be supplied intermittently and at higher rates during the day.

HRF acts as physical filter and therefore does not depend like SSF on a continuous supply of nutrients. Hence, intermittent operation is possible without a marked deterioration of the filtrate, provided smooth restarting of filter operation is observed. Due to the relatively small water volume stored in the HRF, it is not reasonable to operate HRF at a declining filtration rate just for the sake of maintaining the SSF at a constant filtration rate. The most favourable option in a pumped scheme is the introduction of a raw water balancing tank which allows continuous filter operation. The different possibilities as regards the design of the required volume of a 100 m^3/d plant are illustrated in Fig. 19.

It can be concluded that for operational and economic reasons, it is recommended to continuously operate a HRF-SSF plant at constant filtration rates for 24 hours/day. In case of a pumped scheme, a raw water balancing tank is required. Removal of the coarse solids is a positive side effect of such a tank.



	Sed. Tank Res. (raw)	HRF	SSF	Res. (clear)	Total Volume
gravity scheme	8	42	52	50	152 m^3
pumped scheme without raw water tank	25	125	109	50	309 m^3
pumped scheme with raw water tank	67	42	52	50	211 m^3

assumptions: Sed. Tank $T_d = 2$ hrs

HRF $v_F = 1$ m/h, $L_{tot} = 10$m

SSF $v_F = 0.2$ m/h, $H_{tot} = 2.5$ m

Fig. 19 Flow Pattern and Required Volume of a 100 m^3/d Plant

Flow Control

Unlike SSF, which requires gradual opening of the valve at the effluent line to compensate for progressive headloss, HRF is hydraulically controlled by a flow control device at the inlet and by a fixed weir at the outlet as illustrated and recommended in Fig. 5. In gravity schemes, constant feeding is maintained by a more or less fixed position of the valve in the supply pipe and a subsequent overflow in the distributor box. In pumped schemes with a raw water tank, the flow to the HRF is regulated by a mechanical flow rate device as shown in Fig. 7. These two main possibilities are illustrated in Fig. 20.

The discharge is measured either by fixed installations such as V-notch weirs or by transportable equipment as described in Appendix 3. The flow rate through each HRF should be controlled daily if V-notch weirs are provided, or at least twice a week in the case of transportable equipment.

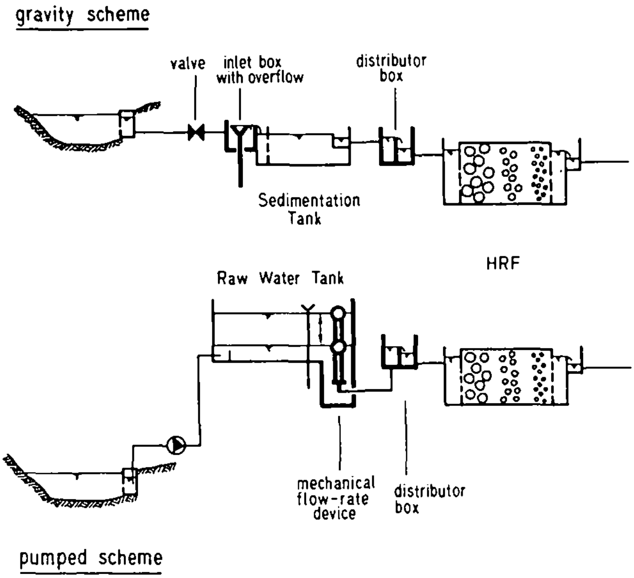


Fig. 20 Raw Water Flow Control and Distribution

Water Quality Control

The degree of bacteriological contamination is the most important quality criteria for drinking water. However, improvement of the bacteriological water quality greatly depends on the turbidity of the water. Turbidity and bacteriological contamination of the water are therefore the main parameters for the characterization of a rural surface water. As a consequence, the first objective of any basic treatment method is the improvement of these two parameters.

The treatment combination HRF-SSF meets this objective since HRF is mainly used to separate the suspended solids or to reduce raw water turbidity. The pretreated water is subsequently treated by SSF which significantly improves the bacteriological water quality. While turbidity measurements play a major role in HRF monitoring, the SSF efficiency is mainly established by bacteriological tests.

Bacteriological water quality control requires special equipment and generally also the infrastructure of a laboratory. Well-trained and experienced staff are essential for a reliable analysis. Routine bacteriological water quality control of rural water supply schemes is in many cases far beyond the capacity of the responsible institution and therefore mostly restricted to random tests. A well-operated SSF is a stable and reliable water treatment unit not requiring frequent bacteriological tests. In practice, the frequency of these tests can be reduced to a minimum once the bacteriological efficiency of the SSF is established.

Turbidity measurements are simpler and can therefore be handled by the local caretaker of the treatment plant. Weekly records and, at periods of high turbidity, daily measurements enable

- to characterize the raw water quality

- to establish and monitor the HRF (and SSF) performance
- to develop operational criteria for HRF (i.e. schedule for filter regeneration/cleaning)
- to optimize the HRF lay-out (i.e. replacing of filter material)

Turbidity measurements, although theoretically simple, might be difficult to carry out in rural areas on a regular basis. Transport and communication problems, the fragility of delicate instruments and the difficulties in commodities supply (i.e. batteries, standards) are aspects leading to possible failures in the execution of even a simple turbidity monitoring programme.

Sturdy, simple field test methods for the characterization of mainly physical properties have therefore been developed to meet the actual field conditions. The different methods described in Appendix 2 do not produce absolute but relative values which are, however, a useful tool for water quality description of any specific treatment plant.

A simple *turbidity test tube* developed by DelAgua (10) replaces the common turbidity meters which are usually dependent on power supply. The visual method depends on the sensitivity of the eye and hence, is not as accurate as electronic systems, especially in the high turbidity range. The lower practical limit of the tube amounts to 5 TU (Turbidity Units) and therefore covers the turbidity range required by SSF.

The *filtrability test* roughly indicates the amount of suspended solids in the water and can therefore be used in place of the standard method for the determination of the suspended solids concentration which requires a highly accurate balance, a vacuum pump and a drying furnace in an air-conditioned room. Furthermore, modified Imhoff cones are used for the determination of the settleable solids volume.

The *stability test* gives some information on the settling characteristics of the colloidal matter and on the stability of the suspension. The results of this test not only reflect the size and surface properties of the solids but also the chemical and organic composition of the water. Adsorption of Ca^{2+} and Mg^{2+} ions on suspended solids surfaces may destabilize a suspension, while humic substances have been reported to increase, in many instances, the stability of a suspension.

Water samples should be drawn from the raw water and from the in and outlets of the filters as indicated in Fig. 21. Additional sampling points are required to optimize by a possible exchange of gravel size the HRF lay-out already in operation. Sampling tubes installed at the end of the different filter layers as illustrated in Fig. 22, enable to examine the efficiency of the individual filter layers. Water sampling from these tubes should be carried out with special care in order not to resuspend the deposits around the sampling point which would otherwise lead to inaccurate results. Dropwise sampling is recommended, however, the first tube of sampled water volume must be discarded before starting the actual sampling.

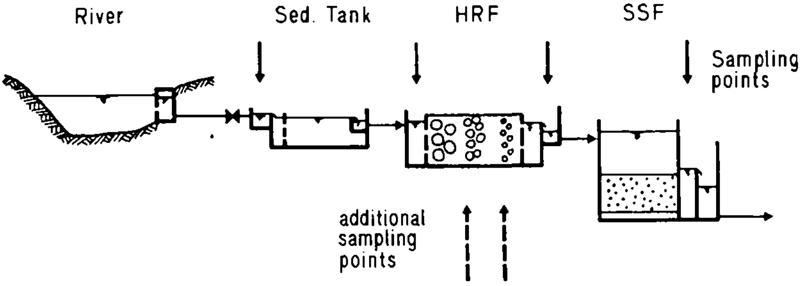


Fig. 21 Location of Sampling Points

Simple field test equipment should be allocated to each treatment plant. The caretaker must be properly trained in order to carry out the different water quality tests and the monitoring programme for his treatment plant. An example of such a monitoring programme is summarized in Table 5. The local caretaker should be assisted and guided by a supervisor attached to the operation and maintenance section of the governmental institution responsible for the water supply (i.e. district or regional water administration). The supervisor will initially carry out monthly and later biannual visits to the treatment plant in order to support the caretaker's daily activities and create a feedback useful for the design and operation of other treatment plants.

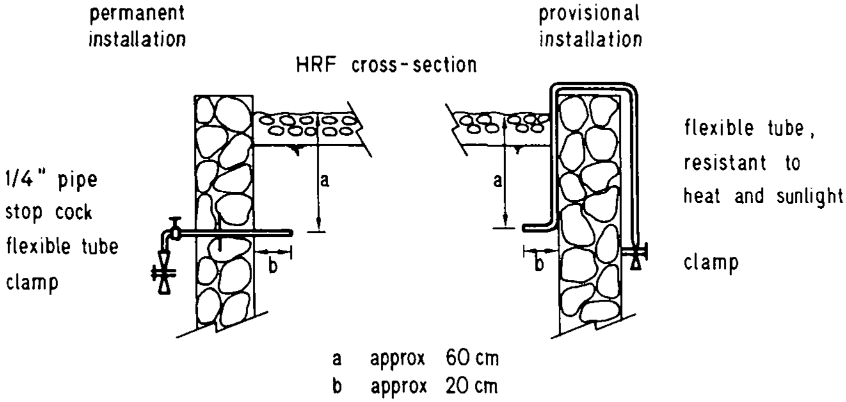


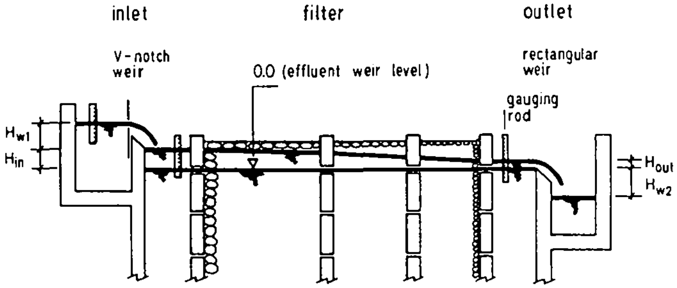
Fig. 22 Water Sampling Installations

Filter Resistance Determination

Headloss in HRF is normally only within a few centimeters and therefore of minor importance for filter operation. Its measurement, however, can give some valuable information about the changes in the filter bed. The suspended solids accumulation in the filter will decrease filter bed porosity and increase flow velocity and filter resistance. The degree of filter regeneration can be established by comparing the headloss before and after hydraulic filter cleaning. A continuous headloss increase in one part of the filter bed indicates premature clogging of the respective fraction and consequently the need for manual cleaning.

Total filter resistance can easily be determined by measuring the free water surfaces in the in and outlet chamber of the HRF. The effluent's weir crest level might be used as reference (0-level). Gauging rods fixed to the walls of these two chambers will facilitate the respective measurements. Attention must be paid when calculating the real filter resistance, i.e. the difference in level of the two gauging rods. The outlet gauging rod also indicates the flow height over the V-notch weir and can therefore be used as flow control. Fig. 23 illustrates the different headlosses of a HRF.

Fig. 23 Headloss Recording System



filter resistance $\Delta H = H_{in} - H_{out}$

flow rate (effluent weir discharge) H_{out}

total headloss in HRF $\Delta H_{tot} = H_{in} + H_{w1} + H_{w2}$

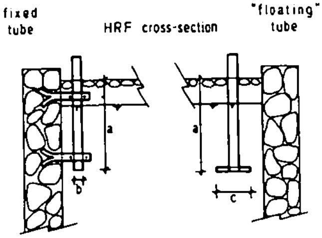


Fig. 24 Piezometers

a approx 60 cm
b approx 1-2"
c approx 20 cm

The installation of additional recording points at the end of each filter fraction is recommended for additional control of the HRF. As already mentioned, the headloss data recorded at these additional points are used to determine the regeneration efficiency and detect premature clogging. The piezometers illustrated in Fig. 24 are utilized for this purpose. Careful recording of the water table is important since the difference in head between the subsequent filter layers is usually only within a few millimeters or centimeters. Hence, firmly fixed tubes should be chosen to avoid subsequent changes in level which could lead to inaccurate measurements.

Filter resistance might become the decisive criteria for hydraulic or manual cleaning if the water level reaches the top of the filter material. A free water surface on top of the HRF can never be tolerated since filter efficiency will dramatically drop due to short-circuiting of the water.

Table 5 Field Monitoring Programme

record/parameter		frequency
flow rate HRF + SSF		every 2 days
filter resistance HRF		1 x / week
filter resistance SSF		every 2 days
turbidity filtrability	of raw water and effluents of HRF and SSF (at high turbidity filtrate of each HRF gravel pack)	2 x / week (daily at periods of high turbidity)
settleable solids	raw water	1 x / week

Filter Cleaning

Filter efficiency decreases with progressive accumulation of solid matter in the filter. Hence, periodic removal of this accumulated matter restores filter efficiency and keeps the filter in good running condition. A HRF can be cleaned in two ways, either hydraulically or manually.

Hydraulic cleaning assists the mechanisms of self-regeneration already discussed and illustrated in Fig. 4. The natural drift of accumulated matter towards the filter bottom can be enhanced by filter drainage. The retained solids are washed down when the water level in the filter is lowered. The upper part of the filter bed is thereby cleaned and regenerated while an additional accumulation of solid matter takes place at the filter bottom. These solids can be flushed out of the filter by an adequate drainage system (examples are given in Fig. 18) at initial drainage velocities ranging preferably between 60 and 90 m/h.

It is very important to *start the cleaning procedure at the inlet side* as most of the solids are retained in this part of the filter. An initially vigorous drainage at the rear of the filter would wash the bulk of solids towards this drainage point and enhance the risk of clogging of the fine filter part.

Furthermore, *full drainage of the HRF* at one single point is equally important as it flushes out the accumulated matter in the vicinity of the drainage point. The drained HRF is thereafter refilled with water and redrained at the same drainage point if the solids have not been completely washed out in this filter part. This is visible by the high turbidity of the drained water. At low washwater turbidities, the next point should be drained using the same procedure.

When *refilling the HRF*, attention must also be paid not to drag to the fine filter part the solids accumulated at the filter bottom. Moderate flow rates must therefore be applied and may be increased during refilling. If an efficient drainage system is available for complete wash-out of solids, the HRF can be filled only partially with water as most of the solid matter will be rinsed towards the filter bottom after 2 or 3 full drainages.

In case a special drainage system is not installed, partial filter efficiency regeneration can still be achieved when the ordinary drain, preferably at the inlet chamber, is used. If only a single drain is provided at the HRF outlet, lower drainage velocities in the range of 10 to 20 m/h should be observed to prevent blockage of the fine filter material.

Filter cleaning frequency greatly depends on the raw water characteristics, filter lay-out and operation. Most of the solid matter (80-90%) of tropical surface water usually consists of stable inorganic material. Since this type of material does not change the chemical properties of the water passing through the filter, it can therefore be stored in the HRF without negative effects. However, high levels of organic matter call for frequent and regular cleaning to avoid decomposition of the organics in the filter and prevent water quality deterioration in terms of taste and odour. Nevertheless, regular hydraulic cleaning is advisable since it enhances filter efficiency and reduces sludge compaction and frequency of manual filter cleaning.

The annual hydraulic cleaning schedule has to be adapted to the annual fluctuation of the raw water quality. High turbidity loads are preferably treated by relatively clean filters to prevent a breakthrough of the solid matter which would otherwise affect SSF operation. It is therefore recommended to thoroughly clean the HRF before peak loads (e.g. before the start of the rainy season). Hydraulic cleaning can be handled by the caretaker and does not normally require external assistance (e.g. community participation). Therefore, the annual working plan of the community does not influence the hydraulic cleaning schedule.

The time interval between two hydraulic cleanings can also be estimated by a mass balance of the solid matter. The amount of retained solids is the difference in mass between in and outlet. HRF should be cleaned hydraulically at a filter load of 10 g per liter filter volume as filter efficiency decreases progressively thereafter. The suspended solids concentration strongly influences the turbidity, and these two figures are frequently of the same order of magnitude. Since the bulk of the suspended solids is retained by the first filter fraction, the load on this filter section becomes the decisive criteria for hydraulic cleaning. In order to determine the running time, the following equation was established on the basis of the above mentioned assumptions:

$$T_{run} = 1'000 \cdot \frac{\sigma \cdot L_1}{(C_o - C_e) \cdot v_F} \sim 10'000 \cdot \frac{L_1}{(T_o - T_e) \cdot v_F}$$

T_{run}	(h)	time interval between two cleanings	
σ	(g/l)	average filter load	
L_1	(m)	filter length of the first filter fraction	
C_o, C_e	(mg/l)	susp. solids conc.	at the beginning and at the end of the first filter fraction
T_o, T_e	(TU)	turbidity	
v_F	(m/h)	filtration rate	

For example, a 10 m-long HRF operated for example at 0.5 m/h with a turbidity reduction of 300 TU in the 4 m of the first filter fraction needs to be hydraulically cleaned every 11 days during the rainy season. At dry periods of low turbidity, when turbidity reduction in the first filter part might amount to 50 TU, the first 4 m of the same filter have to be cleaned after 2 months operation.

The general approach for hydraulic filter cleaning is illustrated in Fig. 25. However, details regarding the procedure greatly depend on the specific situation. Each caretaker will therefore have to establish through practical experience the optimal procedure and cleaning frequency required by his own treatment plant. He will certainly be most interested in an efficient hydraulic cleaning since manual cleaning is time-consuming and labour intensive.

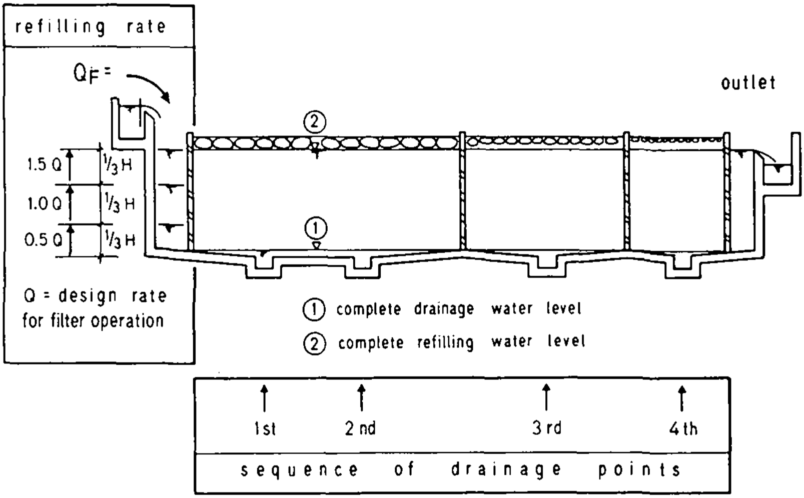
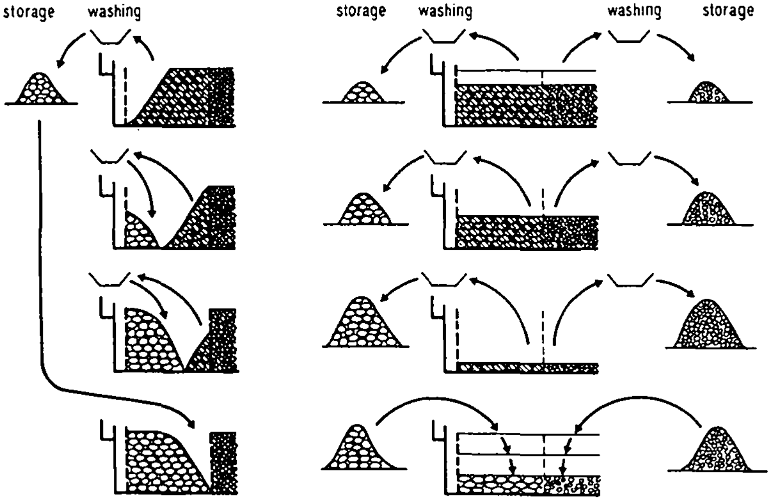


Fig. 25 Procedure for Hydraulic Cleaning

Manual cleaning must be applied when the solids accumulated at the filter bottom or, at worst, all over the filter, can no longer be removed hydraulically. This occurs if a drainage system is absent under the filter bed, if proper hydraulic cleaning has been neglected or if solid matter has cohered to the filter material or at the bottom. A slimy layer might cover the filter material if there is biological activity in the filter caused by high loads of dissolved organic matter in the water. This biological layer will most probably increase the filter's efficiency at the beginning, but will subsequently hinder the drift of deposited matter towards the filter bottom. Accumulated cohesive matter might also hinder self-regeneration of the filter.

Finally, retained material in silted but drained filter beds will also dry up and form a skin around the filter material. Thus, *HRF should never be kept dry* unless the filters are properly cleaned in advance.

The manual cleaning procedure mainly consists in excavation, washing and re-installation of the filter material. The filter material is excavated from a drained filter. The coarsest filter material is normally removed first, cleaned and thereafter refilled into the filter section. The first part of the filter material may be stored for awhile, whereas the remaining material can be washed and directly re-installed in order to save storage space and reduce work. As regards HRF



HRF with strong separation walls

HRF with weak separation walls

Fig. 26 Manual Cleaning Procedure

with strong separation walls, each filter fraction is generally handled separately to avoid mixing of material. Simultaneous excavation of the filter material is necessary if the HRF separation structures are weak, or where these walls are completely missing. The different procedures are illustrated in Fig. 26.

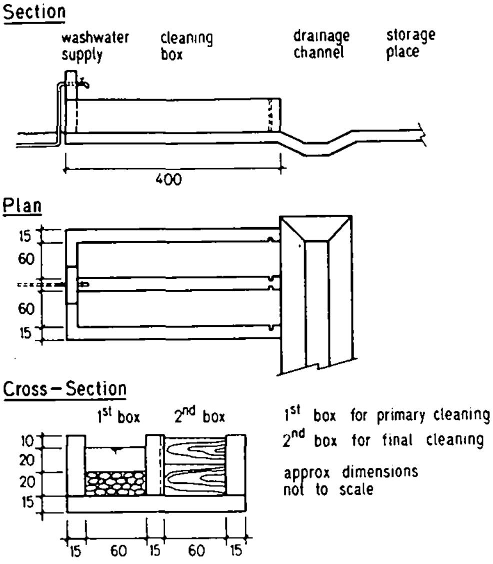


Fig. 27 Gravel Washing Installation

The *washing* of the filter material is best achieved by mechanical stirring of the aggregates in a washwater basin as mechanical friction rubs the impurities off the aggregates' surface. Washwater can be saved and a good efficiency achieved if small filter material loads are stirred with a shovel in a first tank to remove gross impurities before they are transferred to a second tank for final washing. Such a washing installation is sketched in Fig. 27. However, centralized cleaning involves transportation of the filter material. Use of the open drainage channel located along the HRF is an alternative to the washing place since it requires less efforts as regards gravel movement.

Resieving of the filter material is necessary if mixing of the different fractions occurred or if the filter medium has been broken up into smaller pieces due to excavation and mechanical cleaning. A well specified, uniform size for each filter fraction is essential to maintain high porosity of the filter bed. In this context, it is obviously advantageous to install a mechanically-resistant filter material right at the beginning.

Re-installation of the filter material should not create any difficulties. However, the material should preferably be brought into the filter right after having been washed in order to avoid any contamination with dust or other impurities. Disintegrated material must be replaced in order to refill the HRF up to its original level. A stock of additional filter material should therefore be kept at the treatment plant.

Manual filter cleaning involves a great deal of manual work which is often beyond the caretaker's capacity. Additional manpower must be mobilized either by contracting local casual labourers or by involving the community. Careful planning and organizing is necessary when manual filter cleaning is carried out with village participation. The cleaning schedule should for instance not coincide with a period of intensive agricultural work.

Adequate material and tools must be provided to enable efficient filter cleaning, otherwise maintenance work will become too tedious and might never be done. Manual filter cleaning requires shovels, sieves, preferably 2-3 sturdy wheel-barrows, some wooden boards and buckets. The same material already used for construction should therefore remain at the treatment plant or in the care of the local operator at the end of construction.

Filter Maintenance

Great events often come from little causes. This saying also applies to HRF maintenance. HRF maintenance is not very demanding as the filter does not contain any mechanical parts. Nevertheless, *maintenance should aim at maintaining the plant in* good condition right from the beginning. External assistance for maintenance work can usually be avoided if the following work is carried out properly by the local caretaker:

- periodic upkeep of the treatment plant's premise (grass cutting; removal of small bushes and trees which could impair the structures by their roots; removal of refuse)
- soil protection against erosion (especially surface water intake structures, the washwater drainage channels and surface runoff)
- repairing fissures in the walls of the different structures and replacing the chipped plastering
- application of anti-corrosive agents to exposed metal parts (V-notch weirs, gauging rods, pipes)
- checking the different valves and drainage systems and occasionally lubricating their moving parts
- weeding out the filter material
- *scumming off floating material from the free water* surface
- washing out coarse settled material (distribution box, HRF inlet)
- controlling the ancillaries and replacing defective parts (tools and test equipment)

The term *"periodic"* does not only apply to the first point in this check list but to all of them. Proper maintenance of the treatment plant guarantees long-term use of the installations at low running costs.

Note:

- *start filter operation only when construction is entirely completed*
- *check the drainage system before starting operation and wash out any impurities remaining in the filter*
- *operate the treatment plant whenever possible for 24 h/d*
- *control daily the flow rate through the filters and adjust it if necessary*
- *record the filter resistance development*
- *check the quality of the raw water and filter effluents*
- *apply frequently hydraulic cleaning to restore filter efficiency*
- *start hydraulic cleaning at the inlet side and drain the HRF completely*
- *refill the HRF with water at low flow rates*
- *carry out manual cleaning when the retained solids can no longer be flushed out from the HRF*
- *back up maintenance efficiency by a supply of adequate tools*

what are the costs of a HRF ?

6. ECONOMIC CONSIDERATIONS

That costs depend on locally prevailing conditions, and the fact that generally valid information on economic aspects can hardly be assessed, is a very pertinent remark. Filter design, availability of construction material and type of constructor (construction by private contractor, national institution or by community participation in a self-help project) strongly influence the construction costs. Generally applicable, absolute values are therefore not possible. However, economic aspects of HRF construction and operation can be compared with other elements of a water supply system. In addition, the different costs might be subdivided into local and foreign currency demand.

HRF Construction Cost Structure and Specific Costs

An evaluation of the construction cost structure for different HRF projects with a design capacity ranging from 70 to 750 m^3/dd and located in Tanzania, Kenya, Indonesia and Australia reveale rather similar results:

- earthwork and structure	approx. 70%	of	total	costs
- filter medium	approx. 20%	"	"	"
- piping and accessories	approx. 10%	"	"	"

Topography and soil conditions (required excavation work and type of foundation) as well as type of structure (reinforced concrete or brickwork) are cost decisive factors for earthwork and structure. Local availability of filter material in the required sizes strongly influences the purchase price, i.e. the supply. These first two cost components have only a little economy of scale, however, the relative costs for piping and accessories will decrease with increasing plant size.

The specific HRF construction costs per m^3 of installed filter volume range between US $ 100 and 175 for the evaluated plants in Tanzania, Kenya and Indonesia. These specific costs are exceeded by US $ 600 for the plant in Australia. It is, however, not only the smallest in capacity and made of reinforced concrete but also reflects the prices of a private contractor in an industrialized country. In developing countries, specific costs ranging from US $ 150 to 200 /m^3 will most probably cover the HRF construction costs. The construction costs might be reduced up to 50% in self-help projects where only construction material has to be paid for.

The specific HRF construction costs per daily m^3 water output depend on the filter length and the applied filtration rate. For an assumed total filter length of 10 m and a filtration rate of 1 m/h for 24 h/d, the specific costs per daily capacity are the following:

total construction costs	approx. US $ 60-80 /m^3/d
material costs only (e.g. in self-help projects)	approx. US $ 30-40 /m^3/d

HRF and SSF Specific Cost Comparison

A SSF cost study made in India (11) and based on 1979 prices revealed specific construction costs of approx. US $ 25-40 /m^3/d for the considered design range of 70 to 750 m^3 daily capacity.

A material cost estimate in the SSF Manual (1) revealed higher specific costs. For the less expensive SSF options with protected sloping walls or a masonry structure, the material costs were estimated between US $ 40-60 /m^3/d and US $ 160-240 /m^3/d, respectively. However, the cost estimate for these plants of a design capacity between 70 and 350 m^3/d also includes the material costs for small clear water tanks of 20 to 40 m^3 volume.

The two studies also reveal the difficulty in obtaining a generally valid cost indication due to the variable construction material and labour costs. Therefore, a HRF and SSF-specific cost comparison might be more appropriate on a bill of quantity basis. Even such a comparison is greatly affected by the filter lay-out, i.e filter length and applied filtration rates.

As regards HRF and SSF average filter characteristics, the volume of the filter medium is of the same order of magnitude. A capacity of for instance 1 m^3/h requires about 10 m^3 HRF filter material (if total filter length is 10 m and filtration rate 1 m/h), and about 8.7 m^3 sand and gravel for the SSF (if sand depth is 1 m, gravel depth 0.3 m and filtration rate 0.15 m/h). The filter boxes are also similar in size. Based on the above assumptions, a HRF box of about 16.8 m^3 (if total height of the structure is 1.5 m and length of in and outlet chamber is 0.6 m each), and a SSF box of approx. 16.7 m^3 (if total height of the structure is 2.5 m) is required.

On the basis of such considerations it can be concluded that *the HRF and SSF construction costs are of the same order of magnitude*. Hence, the addition of HRF will roughly double the investment costs of a SSF plant.

Treatment Plant Investments Versus Pipeline Costs

The construction costs of a water treatment plant might represent a high percentage of the total investment costs of a water supply scheme. Economic criteria besides technical and operational aspects therefore need to be carefully considered before selecting a water source.

The installation of for example a transport pipeline for clean water which does not require treatment, might be an economic alternative to the construction of a treatment plant. On the basis of equivalent costs, the economic pipeline length increases with increasing design capacity. This means that due to economic aspects, small water supply schemes are limited to the use of local water sources, whereas larger schemes are more likely in a position to transport water from a remote place for the same investment costs as required for a treatment plant.

For correct economic evaluation, the annual operation and maintenance costs have to be added to the annual capital recovery costs. However, operation and maintenance costs are highly variable and a general estimate is therefore difficult.

In general, the installation of a transport pipeline for the supply of larger water quantities of untreated but safe water might be an economic alternative to the construction of a treatment plant, especially when gravity flow is available.

Cost Comparison between HRF and Flocculation/Sedimentation

Destabilization of a suspension by chemical flocculation and subsequent separation of the solids in a sedimentation tank is an alternative pretreatment method which is usually inappropriate for rural water supply schemes in developing countries. Nevertheless, a cost comparison between this process and HRF has been established for Tanzania (6). The construction costs of a pretreatment unit with a daily capacity of 440 m^3/d, composed of a baffled tank (detention time 20 min.) used as flocculator, and a horizontal-flow sedimentation tank (overflow rate 1 m/h, detention time 2 hrs) were estimated at approx. US $ 20000. This results in relative costs of about US $ 46 /m^3/d. Construction costs of a chemical storage building are not included in these figures. The total investment costs for such a chemical pretreatment process would be lower than the construction costs of a HRF.

However, the annual operation costs for chemical flocculation might well amount between 5 and 10% of the initial investment necessary for construction work. The costs for the purchase of chemicals which, in most cases, have to be imported, represent the major part of the operation cost.

When considering the annual equivalent costs, which comprise capital recovery and operational costs, the construction of HRF on a long-term basis is clearly more advantageous since this type of pretreatment runs at low operational costs.

Operational Costs of a HRF

A HRF is operated without the use of chemicals. The costs for filter cleaning are the only operational costs of a HRF. Hydraulic cleaning of the filters can be carried out by the caretaker and therefore does not create additional expenditures, possible costs for energy excluded. Manual cleaning, however, usually requires additional labour.

Manual cleaning might be required every 3 to 5 years or may even be avoided by the installation of an efficient drainage system. Assuming a cleaning capacity of 1.5 m^3 gravel per man-day, the required specific labour input per m^3/d filter capacity of a 10 m-long HRF run at 1 m/h filtration rate will amount to approx. 0.3 man-days/m^3/d. Hence, HRF units with the same specifications and for instance a 200 m^3/d capacity, will require a total labour input of 56 man-days for manual cleaning.

Since only labour is involved in the use of a HRF, any community with a strong interest in treated water can afford the operation of these filters. The running costs can be reduced to a minimum if the community participates in filter cleaning. The fully self-reliant treatment process therefore does not depend on any external financial and technical support. Hence, large operation and maintenance expenditures, often not sufficiently available, can be reduced to an absolute minimum by the installation of self-reliant treatment processes such as HRF and SSF. This is one criteria for long-term operation of any water supply scheme.

Local and Foreign Currency Cost Component

HRF is essentially a self-reliant technology largely reproducible with local means. According to the construction cost structure, 90% of the investment costs are expenditures for construction material such as gravel, sand, cement, bricks and stones, and for labour, both readily available in the country. The remaining 10% are costs for the purchase of pipes, valves and accessories (V-notch weirs, gauging rods) which may partly have to be imported. Hence, none or a very small amount of the construction costs require foreign currency.

HRF operation and maintenance basically require manpower but no additional material. HRF is a system operated at village level, and thereby run and maintained entirely by the local community. Hence, the absolute self-reliant process demands local input only.

Note:

- *approx. 90% of the construction costs are expenditures for locally available construction material and labour. The remaining 10% are required for the purchase of pipe fittings*

- *the construction costs of HRF and SSF are of the same order of magnitude. The specific costs per m^3 daily capacity might be in the range of US \$ 60-80 /m^3/d*

- *economic, technical and operational considerations are necessary for the selection of a water source*

- *conventional pretreatment (flocculation/sedimentation) requires less investment costs than HRF but it is less economical in the long run due to high operational costs*

- *operational costs of HRF are essentially labour costs which can be avoided by community participation*

- *none or hardly any foreign currency is required for the construction of a HRF, and its operation is absolutely self-reliant* *how to dimension a HRF ?*

7. DESIGN EXAMPLE

The implementation of a HRF shall be illustrated by a small design example. It is obvious that a treatment plant, and particularly prefilters constitute only one part of a water supply scheme. Proper operation of the system depends on the reliability of all its different elements. Therefore, the following design example also includes some general remarks on the layout of the other components of a water supply system. Such a system may be divided into 3 main parts, namely in a raw water supply, in a treatment and in a distribution part as illustrated in Fig. 28. General aspects are only outlined for the raw water and for the distribution part, since the design example will mainly focus on the treatment part and, specifically, on the HRF design.

Water Demand

Larger communities in rural areas of developing countries usually number between 2000-5000 inhabitants. Let us therefore consider a village of at present 2200 inhabitants. Since there is no other water source (spring, ground nor rainwater) available, people are forced to collect their water from a neighbouring river which is polluted because people wash, defecate and water their animals at the same place where they collect their water. Only a small amount (approx. 5 to 10 l/c.d) of water is carried to the village. This greatly affects personal and domestic hygiene and increases the risk of infection from water-borne and water-washed diseases. An increased water availability, preferably combined with improved sanitation facilities, will increase the health standard of the population.

The water demand depends on the type of distribution system. A water demand of 30 l/c.d is frequently used as design value for a supply with public standposts. The actual consumption with such a system is often lower and may range between 12 and 20 l/c.d. A design value of 30 l/c.d therefore provides a certain spare capacity to cover wastage and losses.

1st assumption: daily water demand per capita 30 l/c·d.

Since the number of village inhabitants will most probably increase, the scheme must be designed so as to meet the future water demand. This is best achieved by a phased construction of the installations which is usually more economical and flexible.

A design period of 15 years for phase 1 is quite reasonable to enable an adequate provision of water for 12-13 years after a planning and construction period of 2-3 years. Annual population growth rates of 2-4% are common in rural areas of developing countries. Let us therefore assume for our design example an annual growth rate of 3%.

The quantification of the long-term water demand is difficult since it depends on different factors such as population growth, standard of living, type of infrastructure etc. Let us therefore assume a general water demand increase of 50% to meet the additional requirements of phase 2.

2nd assumption: daily water demand development

- present population 2200 people
  - phase 1:
    population in 15 years: 2200 x 1.5 = 3300 people
    water demand: 3300 x 30 l/c·d = 99 m^3/d, say 100 m^3/d
  - phase 2:
    water demand: 100 m^3/d x 150% = 150 m^3/d

General Lay-out of the Water Supply Scheme

A basic decision in the planning of a water supply scheme is the selection of its hydraulic profile. First priority must be given to gravity supply since it does not require any water lifting. Schemes in which handpumps can be installed have second priority. The last option of mechanically-driven pumps should be chosen only in special cases where a reliable and affordable energy supply is guaranteed and the infrastructure for pump maintenance available. Hydraulic rams might be an appropriate option but require surface water with sufficient fall and discharge.

Fig. 28 illustrates different hydraulic lay-out possibilites. On the raw water side, the water flows by gravity directly to the treatment plant or, if pumped, preferably first in a raw water balancing tank. The water passes through the treatment plant and is then stored. The treated water is brought to the consumers either by a piped system next to their houses, or it is pumped by hand from a system of cisterns located between treatment plant and village. An additional pumping stage should be avoided (see also Fig. 8) but might be necessary for a piped system in a flat area.

Raw Water Supply

The economic and physical lifetime of structures and pipelines lies around 25 years or more. The one of mechanical and electric components might reach, if carefully maintained, a period of 15 years. Hence, in our design example, the intake, the pipelines and possibly a required pump house and a raw water balancing tank should be designed for a capacity of 150 m^3/d. The pumps, however, would need a capacity of 100 m^3/d to serve the demand of phase 1.

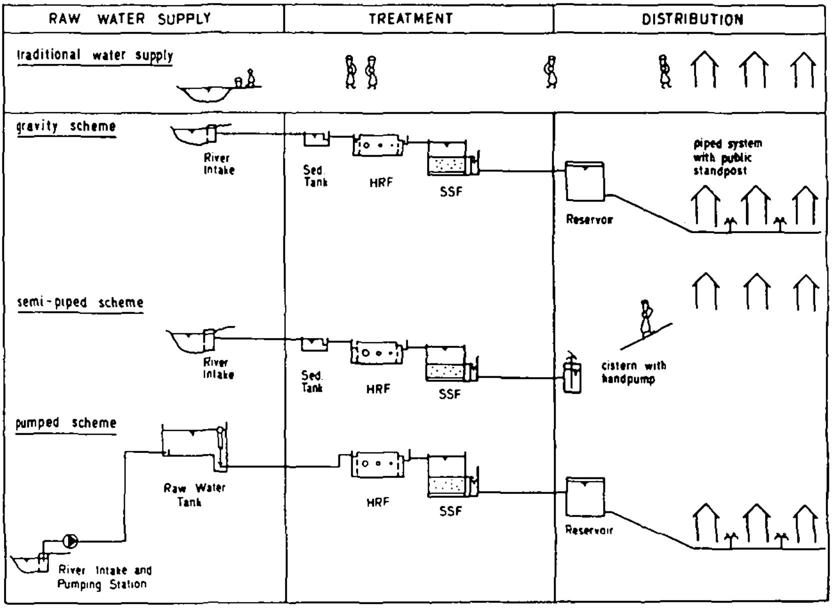


Fig. 28 Water Supply Systems

The size of the pipeline depends on the required discharge and the available hydraulic gradient. Generally, a flow velocity of about 1 m/s is economical. To avoid operational problems and high friction losses, it should not exceed 1.5-2 m/h.

In case of a pumped system operating 8 hours/day, 2 pumps with a capacity of 3.5 l/s or 3 pumps with a 1.75 l/s discharge each should be selected in order to provide one spare unit for phase 1. Finally, a raw water tank volume of 100 m^3 is required to allow continuous treatment plant operation in the considered 8 h/d pumped scheme. An additional 20 m^3 must be provided to avoid complete drainage of the tank which would scour the settled coarse solids and flush them into the HRF. A low turbulence inlet structure, similar to that of a sedimentation tank, is equally important to improve the hydraulic flow conditions and to avoid resuspension of the solids. The flow rate at the raw water tank outlet is preferably controlled by a mechanical flow rate device (see Fig. 7) which maintains continuous and constant water supply to the filters independent of the water level in the reservoir.

Water Treatment

The river catchment area upstream of the intake might be extensively used as farmland and be rather densely populated. Due to land shortage and charcoal production, deforestation is in progress. All these factors will be reflected in the river water quality which might exhibit the following characteristics:

raw water quality	dry season	rainy season	
turbidity	30 - 50	300 - 500	units
filtrability	100 - 150	20 - 50	ml/3 min
suspended solids conc. *)	20 - 50	200 - 500	mg/l
dissolved organic carbon *)	4 - 6	2 - 4	mg C/l
E.coli	500 - 10000		/100 ml

*) this information might not be available. However, the suspended solids concentration might possibly be of the same magnitude as the turbidity.

Hence, the turbid river water carries a relatively high concentration of solid matter (soil erosion) and a moderate organic load. The fairly hight bacteriological counts indicate a contamination of the river water by human excreta.

Such river water needs to be physically and bacteriologically improved to meet the drinking water standards. While HRF reduces turbidity and suspended solids concentration, SSF will decrease the chemical oxygen demand and the bacteriological contamination of the water. A small sedimentation tank or possibly a required raw water balancing reservoir placed in front of the filter will separate the settleable coarse solids. The treatment will therefore comprise the following processes:

sedimentation	-	prefiltration	-	main filration
by		by		by
sedimentation tank or raw water reservoir		HRF		SSF

Phase 2 design capacity of 150 m^3/d is used for the lay-out of the treatment plant. Different single installations such as sedimentation tank or distribution boxes are designed for this final capacity. The filters, however, which are the main structures, will be constructed in 2 phases with an initial 100 m^3/d capacity.

Sedimentation Tank

The river can carry a considerable amount of settleable solids, especially at periods of high discharges during the rainy season. Therefore, a sedimentation unit is preferably placed before the filters for the separation of these solids as it is easier to clean a tank than a filter. The single sedimentation unit will be cleaned during periods of low raw water turbidity. A by-pass enables continuous operation of the treatment plant during such cleaning periods.

In order to separate a large part of the settleable matter, the sedimentation tank is dimensioned to remove all mineral particles larger than 20 μm (see also Fig. 12). It will therefore have the following design criteria and dimensions:

design capacity $Q = 150\ m^3/d = 6.25\ m^3/h$
surface load $s_0 = 0.6\ m/h$
detention time $T_d = 2\ ^1/_2\ h$

required surface area $A = 6.25 : 0.6 = 10.4\ m^2$
assumed length $L = 8\ m$
width $W = 1.5\ m$
depth $H = 1.5\ m$

designed surface load
$$s_0 = \frac{6.25}{8 \times 1.5} = 0.5\ m/h$$

designed detention time
$$T_d = \frac{8 \times 1.5 \times 1.5}{6.25} \sim 3\ h$$

The raw water balancing reservoir required in a pumped raw water system should preferably also be of rectangular shape. A tank with a storage volume of 120 m^3 and an assumed depth of 2.5 m will efficiently remove the settleable solids.

HRF Design

Raw water which is presettled for 2-3 hours will probably exhibit only half of its original turbidity. This turbidity reduction depends on the stability of the suspension, on the solid particles concentration and particle size distribution. The efficiency of a sedimentation tank can be determined by the suspension stability test. The information gained from such a test should, however, be interpreted with care since the test is run with quiescent, standing water and not under flow conditions.

HRF has to be designed for turbidity peaks. In our design example, the turbidity and the suspended solids concentration can possibly be reduced by the sedimentation tank from 500 to 300 turbidity units, or from 500 to 300 mg/l respectively.

According to Table 2 on page 17, the presettled raw water is of medium turbidity and the applied filtration rates should range between 0.75 and 1 m/h. For this relatively high turbidity, our design example foresees a filtration rate of 0.75 m/h.

The HRF units are of the following dimensions:

final design capacity	$Q = 150\ m^3/d = 6.25\ m^3/h$
design capacity phase 1	$Q = 100\ m^3/d = 4.2\ m^3/h$
filtration rate	$v_F = 0.75\ m/h$
required cross-section area for 6.25 m^3/h	$A = 6.25 : 0.75 = 8.33\ m^2$

assumption 3 HRF units

filter depth	$H = 1.2\ m$	
filter width	$W = 2.4\ m$	
filter length/gravel size	$L_1 = 4\ m$	$d_g = 15\ mm$
	$L_2 = 2\ m$	$d_g = 10\ mm$
	$L_3 = 1\ m$	$d_g = 5\ mm$
total filter length	$L = 7\ m$	

phase 1	2 HRF units
phase 2	3 HRF units in total

designed filtration rate $$v_F = \frac{6.25}{3 \times 1.2 \times 2.4} = 0.72 m/h$$

Economy in the filter design is mainly achieved by a reduction of the filter length. The assumed filter length of the different gravel fractions is within the lower limit. This minimum filter design can be compensated by the installation of an efficient hydraulic cleaning system. By periodically cleaning the filter hydraulically, the amount of accumulated solids in the HRF (filter load) will remain small (e.g. less than 10 g/l).

The HRF efficiency can be determined by the E-value presented in Appendix 1. The suspended solids concentration in the HRF effluent is determined graphically by the nomogram, or analytically by multiplication of the E-values with the inlet concentration. The table in Appendix 1 gives the following E-values for our design example:

filtration rate v_F = 0.75 m/h	E-value (%)
gravel size 15 mm, filter length 4 m	15.2
" " 10 mm, " " 2 m	25.7
" " 5 mm, " " 1 m	28.3

Hence, for an assumed maximum suspended solids concentration of 300 mg/l in the presettled raw water, the respective concentration in the HRF amounts to:

$$C_e = 300 \times 0.152 \times 0.257 \times 0.283 = 3.3 \text{ mg/l}.$$

The graphical solution illustrated in Fig. 29 gives a similar value. According to this estimation, the chosen HRF design just meets the standard required by SSF. However, it must be stressed that the above considerations are only valid for a relatively clean filter and for suspensions with a similar characteristic as the kaolin suspension described in Appendix 1.

The periodic intervals between two filter cleanings are determined by the equation described on page 58. With an assumed average suspended solids concentration of 200 mg/l in the presettled water and a maximum allowable filter load of 10 g/l in the first gravel pack, the filter running time between two hydraulic cleanings amounts to:

$$T_{run} = 1000 \times \frac{10 \times 4}{(200 - 30) \times 0.75} = 310 \text{ hrs} \sim 13 \text{ days}$$

with $C_e = 200 \cdot 0.152 = 30$ mg/l (susp. solids conc. after
the first gravel pack)

During the dry season and with an assumed suspended solids concentration of 30 mg/l in the presettled water, a cleaning interval of approx. 90 days should be observed.

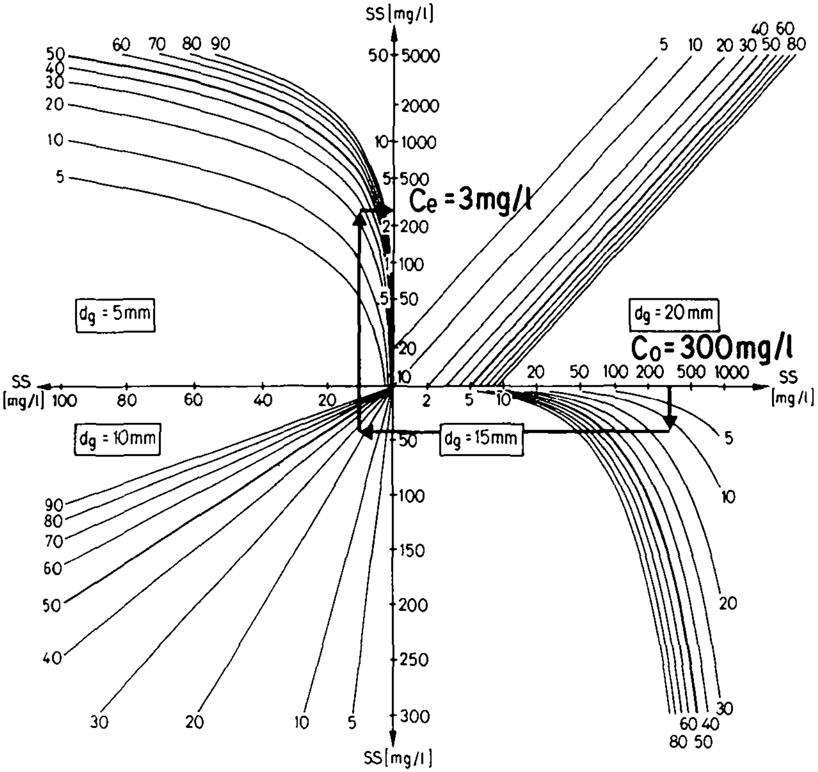


Fig. 29 Nomogram for Filter Efficiency Estimation

The lay-out characteristics of our HRF design example were also used in EAWAG's computer programme for dynamic HRF modelling. Some results of this filter run simulation are graphed in Figs. 30 and 31.

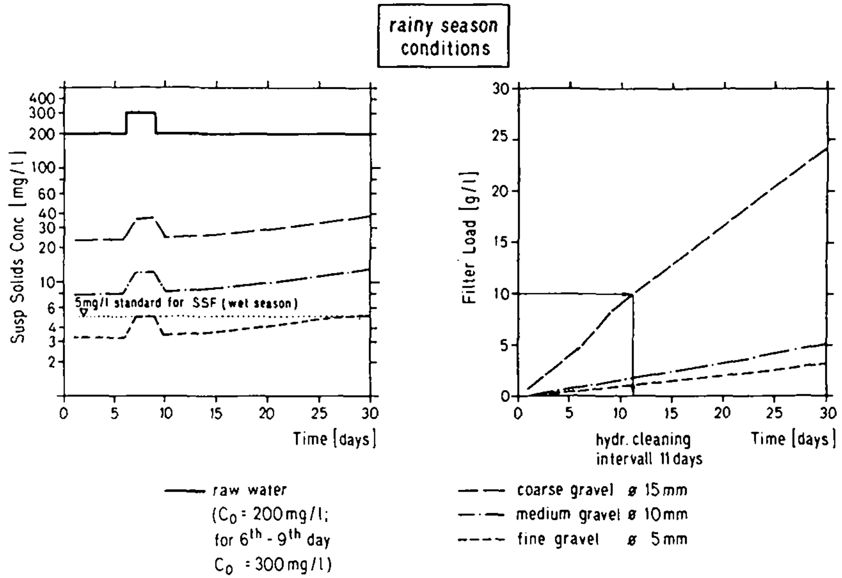


Fig. 30 Suspended Solids and Filter Load during the Rainy Season

Fig. 30 illustrates the suspended solids concentration in the effluent and the filter load during the rainy season. As shown in the graph on the left, the assumed suspended solids concentration of the presettled water amounts to 200 mg/l, with a peak load of 300 mg/l during the 6th and 9th day. The calculated suspended solids concentration in the HRF effluent increases from 3 to 5 mg/l during the simulated period. It is hence slightly higher than the estimation determined with the E-value. The graph on the right clearly demonstrates that the bulk of the solids is retained in the first gravel pack. Compared to the medium and fine gravel fraction, the filter load in this coarse gravel section increases considerably. The coarse filter medium has to be cleaned at intervals of approx. 11 days if the permissible filter load of 10 mg/l is to be met.

Fig. 31 illustrates the dry season conditions where a suspended solids concentration in a presettled water was maintained constant at 30 mg/l. The respective HRF effluent concentration is less than 1 mg/l. Most of the solids are retained in the first filter pack, which should be cleaned hydraulically approx. every 85 days during the dry season period.

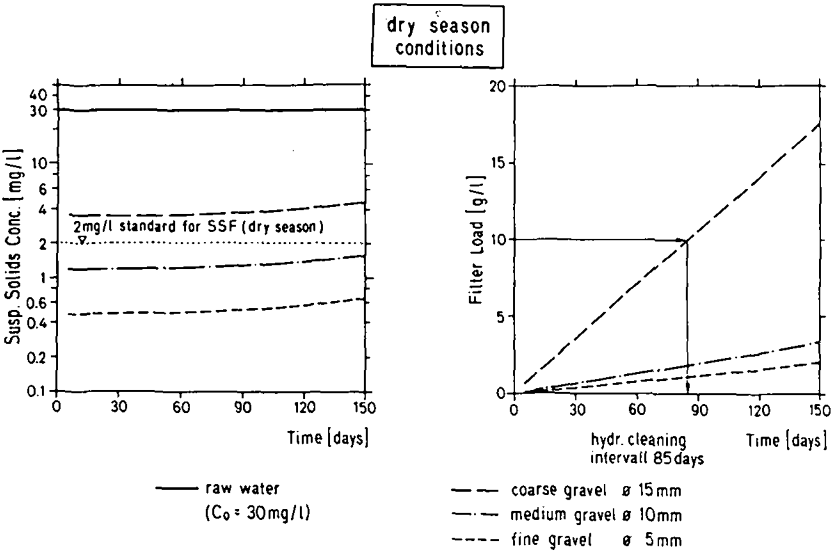


Fig. 31 Suspended Solids and Filter Load during the Dry Season

As already indicated by the different calculations, the proposed HRF design of minimum filter length requires an efficient hydraulic cleaning system. This is best achieved by a false filter bottom installed in the first gravel pack of the HRF. Prefabricated culverts could be used as an alternative drainage system. Such culverts simplify the construction of the filter box but might be less efficient in hydraulic filter cleaning. Flow control and in and outlet structures of the HRF do not need to be discussed further. The drawings of the discussed HRF design example are presented in Appendix 4.

SSF Design

In our design example we used the described design values and obtained the following dimensions:

final design capacity	$Q = 150\ m^3/d = 6.25\ m^3/h$
design capacity phase 1	$Q = 100\ m^3/d = 4.2\ m^3/h$
filtration rate	$v_F = 0.1$ m/h
required filter bed area for 6.5 m^3/h	$A = 6.25 : 0.1 = 62.5\ m^2$
assumption 3 SSF units	
length of filter bed	L = 4.6 m
width " " "	W = 4.6 m
phase 1	2 SSF units
phase 2	3 SSF units in total

designed filtration rate

$$v_F = \frac{6.25}{3 \times 4.6 \times 4.6} = 0.1\ m/h$$

filtration rate during cleaning of 1 SSF unit

phase 1	$v_F = 0.2$ m/h
phase 2	$v_F = 0.15$ m/h

The flow through the SSF is controlled by the V-notch weir of the distribution box. The filter which operates at a variable water level of the supernatant therefore acts as a self-regulating system, i.e. the water level increases with progressive filter resistance. Since the effluent weir crest is at the same level as the top of the sand bed, it prevents negative pressure in the filter. Finally, a cross-connection between the effluent pipes of the different SSF units enables a refilling of the sand bed with water from bottom to top. This important operation drives the air out of the sand bed, reduces the initial filter resistance and produces an equally distributed filter load. The main features of the discussed SSF are illustrated in Appendix 5.

Distributor Box

The total flow through the treatment plant is concentrated, controlled and distributed to the different filter units by distributor boxes. Two boxes are required for our design example, one before and one after the HRF. More structural details of a distributor box are given in Appendix 3.

Treatment Plant Lay-out

The general treatment plant lay-out for our design example is illustrated in Fig. 32. An area of approx. 25 x 25 m is required for the plant. It should preferably have a slight slope of 1:5-1:10 since it would facilitate gravity flow installation and also reduce excavation work.

The water flows by gravity through the treatment plant. The total headloss amounts to approx. 2.5 m. A maximum filter resistance of 30 cm for the HRF and 100 cm for the SSF is included in this value. The remaining 1.2 m are required for the overfalls of the 4 weirs and for the friction losses in the piping system.

A washing place for gravel and sand cleaning and a small building for the storage of tools and test equipment are necessary as subsidiary installations. Finally, a sufficient drainage system must be provided for the discharge of the washwater.

Distribution Scheme

Most of the treated water produced at a constant rate over the full day is generally only used at some peak hours in the morning and late afternoon. Storage capacity must therefore be provided prior to distribution. The treated water is distributed to the consumers either by a full or by a semi-piped system.

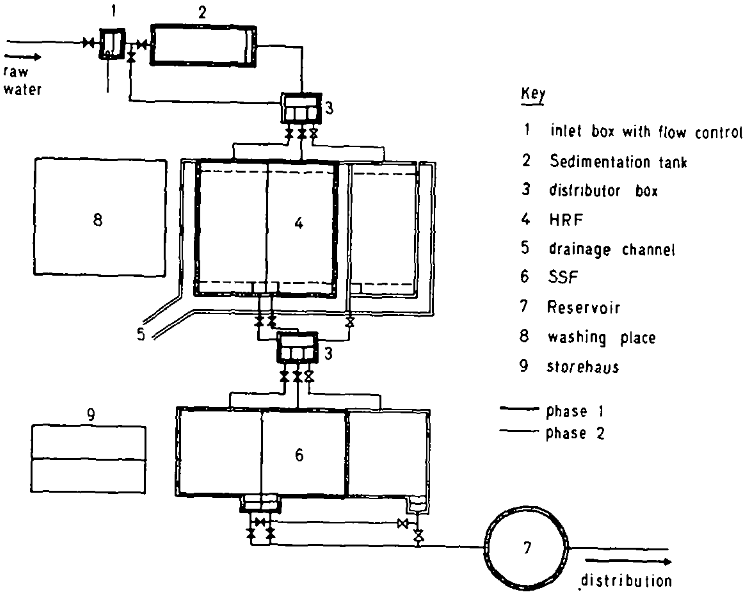


Fig. 32 Treatment Plant Lay-out

Clear Water Reservoir

The required reservoir volume depends on the daily pattern of water use. A 30-50% storage capacity of the daily water production is usually sufficient. Hence, a clear water reservoir of about 50 m^3 volume should meet the requirements of phases 1 and 2 of our design example.

Piped Distribution Scheme

Public standposts are generally used in rural areas of piped water supplies. A standpost tap might serve about 150 persons. 2 taps are generally installed at each standpost. Hence, a total of 11 public standposts are required to supply the 3300 people of phase 1 of our design example. A proper drainage of the wastewater at the standposts is essential to keep the area clean around the water points.

Semi-piped Scheme

A semi-piped scheme can be operated without external energy input in pumped water supply systems. The treated water of a semi-piped scheme flows by gravity to a number of cisterns located between treatment plant and village. The cisterns act as small reservoirs to balance treatment plant production with daily water demand fluctuations. Hence, the construction of a separate clear water tank can be omitted. Each cistern is equipped with 2 handpumps. According to practical experience, each handpump supplies about 250 people.

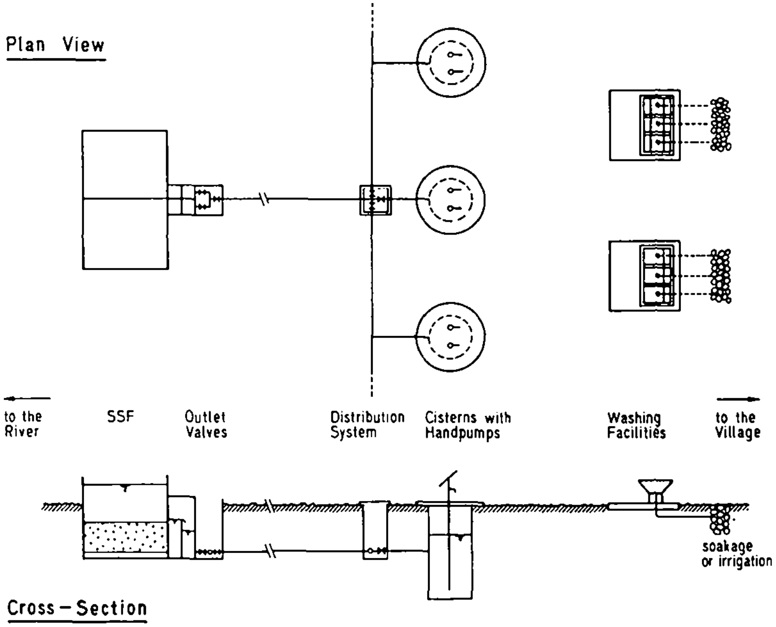


Fig. 33 Concept of a Semi-piped Distribution System

For our design example, 7 cisterns are required for the 3300 people. With a total required storage volume of 50 m^3, each cistern will need a 7 m^3 storage capacity. Several washing places with proper drainage structures should complement this semi-piped system, because part of the pumped water will be used for washing activities performed next to the cisterns. A possible lay-out of such a semi-piped system is illustrated in Fig. 33.

The presented design example is summarized in the design form of Table 6. This form is also attached to the manual as Appendix 6. An additional nomogramm for individual use is enclosed on page 90.

Table 6 Design Form for Design Example

DESIGN FORM

Name of water supply: Design Example
District/Region:
Designed by: M. Wegelin
Date: January 1986

1. Water Source

	dry season	rainy season	Dimensions
discharge	50	1000	l/s
turbidity	30 - 50	300 - 500	TU
filtrability	100 - 150	20 - 50	ml/3 Min
susp. solids conc.	20 - 50	200 - 500	mg/l
organics (~~KMnO4~~*, COD*)	4 - 6	2 - 4	mg/l
bact. test (E.coli*, ~~Fecal-Strept*~~)	500 - 10'000		/100 ml

2. Alternative Source

available yes*/~~no~~* name: ....
better quality ~~yes~~*/no* type of source: groundwater ......
constr. costs higher*/smaller*
remarks. . brackish water; 800 mg Cl/l ....

3. Water Supply System

(gravity scheme)*/pumped scheme: mechanical pump*
(handpump)*

4. Daily Operation Hours

for raw water pumping station .....8... hrs/day

for treatment plant	continuous	intermittent (....hrs/d)	declining rate (....hrs/d)
sedimentation tank	(☒)	☐	☐
HRF	☒	☐	☐
SSF	☒	☐	☐

5. Water Demand

	present	future phase 1	future phase 2	Dimensions
population	2'200	3'300	....	people
daily per capita demand	15	30	....	l/c·d
daily demand by population	....	100	100	m^3/d
additional demand for increased	....	....	....	m^3/d
pop., standard, . (specify)	....	....	50	m^3/d
total daily demand	33	100	150	m^3/d

6. Raw Water Supply

		phase 1	phase 2	Dimensions
gravity supply → go to 7.1				-
required pump capacity		3.5	5.2	l/s
number of pumps		2	3	-
volume of raw water tank → go to 7.2		100	100	m^3/d

7. Treatment

	design value	phase 1	phase 2	Dimensions
7.1 Sedimentation Tank				
surface load	(0.5)			m/h
required surface area		(10.4)	(10.4)	m^2
detention time	(2.5)			hrs
required volume		(16)	(16)	m^3
number of units		(1)	(1)	-
dimensions of 1 unit				
length	(8.0)			m
width	(1.5)			m
depth	(1.5)			m
7.2 HRF				
filtration rate	0.75			m/h
required filter area		5.6	8.4	m^2
number of units		2	3	-
dimensions of 1 unit				
width	2.4			m
depth	1.2			m
length				
gravel size .... mm	....			m
15 mm	4			m
10 mm	2			m
5 mm	1			m
7.3 SSF				
filtration rate	0.1			m/h
required filter area		42	62.5	m^2
number of units		2	3	-
dimensions of 1 unit				
length	4.6			
width	4.6			

8. Distribution

	design value	phase 1	phase 2	Dimensions
8.1 Piped water supply				
reservoir volume		50	50	m^3
number of units		1	1	-
8.2 Semi-piped water supply				
people per handpump	(250)			people
required number of handpumps		(14)	....	-
volume of 1 cistern	(7)			-
number of cisterns		(7)	....	m^3

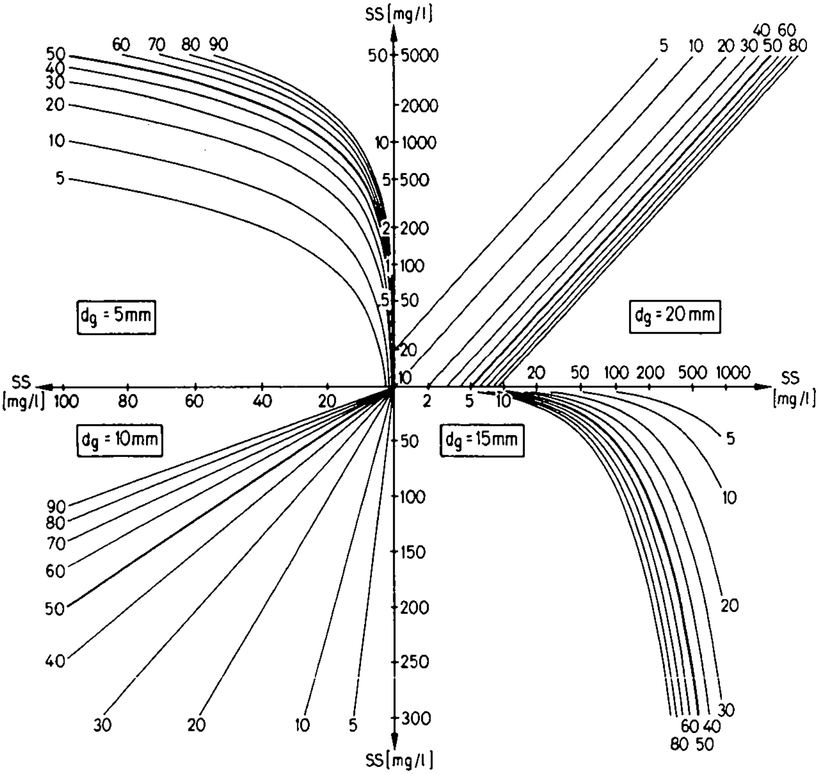
9. Hydraulic Profile

10. Situation

*delete where not convenient

remark: expressions in () as alternative option in design example

Nomogramm for HRF design



are you convinced of HRF ?

8. CONCLUSIONS AND FINAL REMARKS

If you have reached this part of the manual, you are either an experienced reader who first consults the executive summary and conclusions of a publication, or a person with a real interest in the HRF technology. After having given enough evidence in favour of HRF, this manual will conclude with some strong formulations on water supplies in developing countries and will point out some weak aspects concerning HRF.

1. *No water will reach people by just reading publications.* Hence, this manual presents a technology to be applied in the field. It is not just meant for mental pleasure nor to be piling in a bookshelf. The reader is therefore kindly requested to *take action* in his field of activity by promoting and implementing appropriate technologies.

2. Appropriate means adapted to the local situation. Therefore, *no technology is universally appropriate.* This also holds true for SSF. Its often failing practical operation in developing countries is mainly due to inappropriate raw water quality.

3. A rural cart will hardly be pulled by a racing car, but by a donkey, ox or horse. *Equal level of technology* is a critical factor for the viability of a system. For instance, insufficient flocculated and settled water will create operational problems for SSF. Raw water pretreated by riverbank infiltration, vertical prefilters or HRF will usually meet SSF requirements.

4. You would never wash yourself with champagne. *Real need and economic aspects* are decisive factors for the selection of a water supply system. HRF and SSF are a fascinating treatment combination since it represents a reliable, self-reliant and reproducible technology. However, the filters

require a considerable input of construction work. They should only be used if no other better water quality source is available and if water treatment is a necessity.

5. This manual is a technical document. Water supplies are like computers as both depend on *hardware and software*. The water supply users have to decide, contribute and operate the facilities. Sociocultural aspects must be integrated in a project. The degree of training, support and assistance to local caretakers greatly influences the lifetime of a water supply.

6. The presented *HRF technology is still being perfected.* HRF has been used in Europe for over 25 years but only for a few years in developing countries. Demonstration projects are under way to introduce this technology in Latin America, Africa and Asia. More practical experience is being gathered on the economic lay-out, hydraulic cleaning, use of local construction techniques and alternative filter material. Therefore, *the present HRF manual is a draft* to assist you in the design, construction and operation of HRF.

7. IRCWD in Duebendorf/Switzerland monitors the HRF demonstration project. The practical experience gained on HRF from different developing countries constitutes *an information pool available at IRCWD*. The Centre in Switzerland can give you technical assistance on HRF and might possibly help you secure some financial support from the Swiss Development Cooperation for the construction of your HRF.

8. Information exchange should be reciprocal. *Your feedback is essential*. IRCWD therefore hopes to receive your views on the present manual and especially your experience with HRF, possibly in combination with SSF.

Provision of save water is a challenge. IRCWD wishes you every success in your efforts to achieve this goal.

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Abbreviations

HRF	Horizontal-flow Roughing Filtration (Filter)
SSF	Slow Sand Filtration (Filter)
NTU	Nephelomatric Turbidity Unit

AIT	Asian Institute of Technology
CEPIS	Centro Panamericano de Ingenieria Sanitaria y Ciencas del Ambiente
DANIDA	Danish International Development Agency
EAWAG	Swiss Federal Institute for Water Resources and Water Pollution Control
ETH	Swiss Federal Institutes of Technology
IRC	International Reference Centre for Community Water Supply and Sanitation
IRCWD	International Reference Centre for Waste Disposal
NORAD	Norwegian Agency for International Development
SATA	Swiss Association for Technical Assistance
SDC	Swiss Development Cooperation
SKAT	Swiss Centre for Appropriate Technology

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Appendix 1:

Nomogram for HRF Design

1. Introduction

Tables 2 and 4 in part B of the manual give general guidelines for HRF design. Filtration rate and filter length are given for a certain range. The designer, however, might be interested in more detailed design information. For instance, he might want to know the effect on the HRF effluent quality if he doubles the length of the first gravel fraction. Therefore, an additional design tool will be presented in form of an "E-value" approach.

2. Theoretical Background

"E-value" stands for Efficiency value and describes the performance of the filter with respect to suspended solids removal. On the basis of the established filter theory, the filter efficiency can be expressed by the filter coefficient λ [/cm] and use of Iwasaki's equation:

$$\frac{dC}{dx} = - \lambda \cdot C$$

With C as solids concentration and x as filter depth. The filter coefficient λ is a function of the flow pattern, the filter medium and the physical properties of the water and suspended particles.

$$\lambda = f(v_F, d_g, p_g, d_p, \rho_p, \nu_w)$$

While the volume of retained solids increases with progressive filtration time, the filter porosity decreases. The degree of filter clogging can be expressed by the filter load σ [g/l], which is the mass of deposited material per unit of filter bed volume. The filter load varies with position x in the filter as well as with filtration time t. The filter coefficient λ is therefore also a function of:

$$\lambda = f(x, \sigma)$$

The correlation between the filter coefficient λ and the different parameters mentioned has been investigated in laboratory tests with the help of a kaolin suspension. More detailed results are presented in (7).

λ will assume a constant value with a constant particle size d_p and density ρ_p of the suspended solids, as well as with an uniform filter load σ over a considered filter length l_f.

These assumptions very much simplify the real filter conditions but enable to integrate Iwasaki's equation as follows:

$$C_{out} = C_{in} \cdot e^{-\lambda \cdot l_f}$$

3. Specific Conditions

The filter performance can herewith be determined for specific but simplified filter conditions. For this purpose, the filter efficiency which is defined as:

$$E = \frac{C_{out}}{C_{in}} = e^{-\lambda \cdot l_f}$$

has been calculated for the following conditions:

suspension	kaolin diluted in groundwater as per laboratory tests (7).
particle size	$d_p = 2\ \mu m$
filter load	$\sigma = 20$ g/l
filtration rate	$v_F = 0.5, 0.75, 1.0, 1.5, 2.0$ m/h
filter grain size	$d_g = 5, 10, 15, 20$ mm
initial porosity	$p_0 = 35\%$

The E-value for these specific conditions is presented in Table 7 for different filtration rates v_F, filter lengths l_f and grain sizes d_g. Hence, the suspended solids concentration in the effluent of a filter layer can easily be determined by:

$$C_{out} = C_{in} \cdot E$$

4. Numerical Solution

The effluent quality of different sequential filter layers can be calculated as follows:

$$C_{out1} = C_{in} \cdot E_1$$

$$C_{out2} = C_{in1} \cdot E_2 = C_{out1} \cdot E_2 = C_{in} \cdot E_1 \cdot E_2$$

$$C_{out3} = C_{in2} \cdot E_3 = C_{out2} \cdot E_3 = C_{in} \cdot E_1 \cdot E_2 \cdot E_3$$

$C_{out} = C_{in} \cdot E_1 \cdot E_2 \cdot E_3 \cdot E_4$ for a 4 gravel HRF

5. Graphical Solution

A nomogram has been developed to estimate graphically the suspended solids concentration in the filter effluent. The particular shape of this nomogram emerged from the following considerations:

- since the peak value for suspended solids concentrations is usually unknown, it will have to be estimated. This holds true especially for concentrations above 300 mg/l. On the other hand, high concentrations also result in high reduction rates. Therefore, a log-scale has been applied in the graph for concentrations above 300 mg/l.

- data might be available for moderate suspended solids concentrations ranging from 50 to 300 mg/l. A normal scale graph has therefore been chosen for this range.

- low concentrations must be achieved by the effluent of a HRF. Therefore, a log-scale illustration for concentrations between 0.1 and 50 mg/l has been used to increase the sensitivity in this part of the graph.

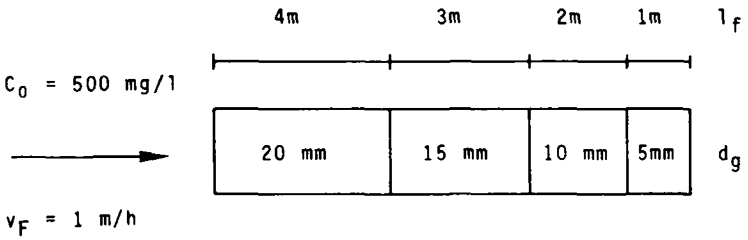
The E-values for specific design assumptions are given in Table 7. This enables to subsequently locate and connect the points with each other in the nomogram.

6. Design Example

The following example is used to demonstrate the application of the E-value concept.

max. suspended solids concentration in the presettled raw water	500 mg/l

1st assumption for HRF lay-out



The respective E-values from Table 7 amount to:

37.2 for the 20 mm gravel 37.4 for the 15 mm gravel
38.1 for the 10 mm gravel 39.9 for the 5 mm gravel

The HRF effluent quality can therefore be calculated as follows:

$C_e = 500 \cdot .372 \cdot .374 \cdot .381 \cdot .399 = 9.6$ mg/l

This value does not comply with the standard required by SSF. By reducing the filtration rate to 0.75 m/h, the HRF's efficiency will be increased. The new E-values from Table 7 amount to:

23.5 for the 20 mm gravel 24.3 for the 15 mm gravel
25.7 for the 10 mm gravel 28.3 for the 5 mm gravel

and the respective suspended solids concentration in the HRF effluent is calculated as follows:

$C_e = 500 \cdot .235 \cdot .243 \cdot .257 \cdot .283 = 2.1$ mg/l

Hence, a HRF with this lay-out and operating at a filtration rate of 0.75 m/h seems to be appropriate in reducing the suspended solids concentration to a value permitting a sound SSF application. The design example is also presented as graphical solution on page I/8.

Table 7 E-values for HRF

$$E = \frac{C_e}{C_o} = e^{-\lambda \cdot l_f} \quad [\%]$$

Gravel Size	Filtration Rate	Filter length l_f [m]				
d_g	υ_F [m/h]	1	2	3	4	5
5 mm	0.5	15.2	2.3	0.4	0.1	0.0
	0.75	28.3	8.0	2.3	0.6	0.2
	1	39.9	15.9	6.4	2.5	1.0
	1.5	59.0	34.8	20.5	12.1	7.2
	2	74.7	55.7	41.6	31.1	23.2
10 mm	0.5	35.6	12.7	4.5	1.6	0.6
	0.75	50.7	25.7	13.0	6.7	3.3
	1	61.7	38.1	23.5	14.5	9.0
	1.5	77.7	60.3	46.9	36.4	28.3
	2	89.5	80.2	71.8	64.3	57.6
15 mm	0.5	48.4	23.5	11.4	5.5	2.7
	0.75	62.4	39.0	24.3	15.2	9.5
	1	72.1	51.9	37.4	27.0	19.4
	1.5	85.4	72.9	62.2	53.1	45.3
	2	95.0	90.2	85.6	81.3	77.2
20 mm	0.5	56.9	32.4	18.4	10.5	6.0
	0.75	69.6	48.5	33.7	23.5	16.4
	1	78.1	61.0	47.6	37.2	29.0
	1.5	89.5	80.1	71.7	64.2	57.5
	2	97.7	95.4	93.2	91.0	88.9

7. Critical Review

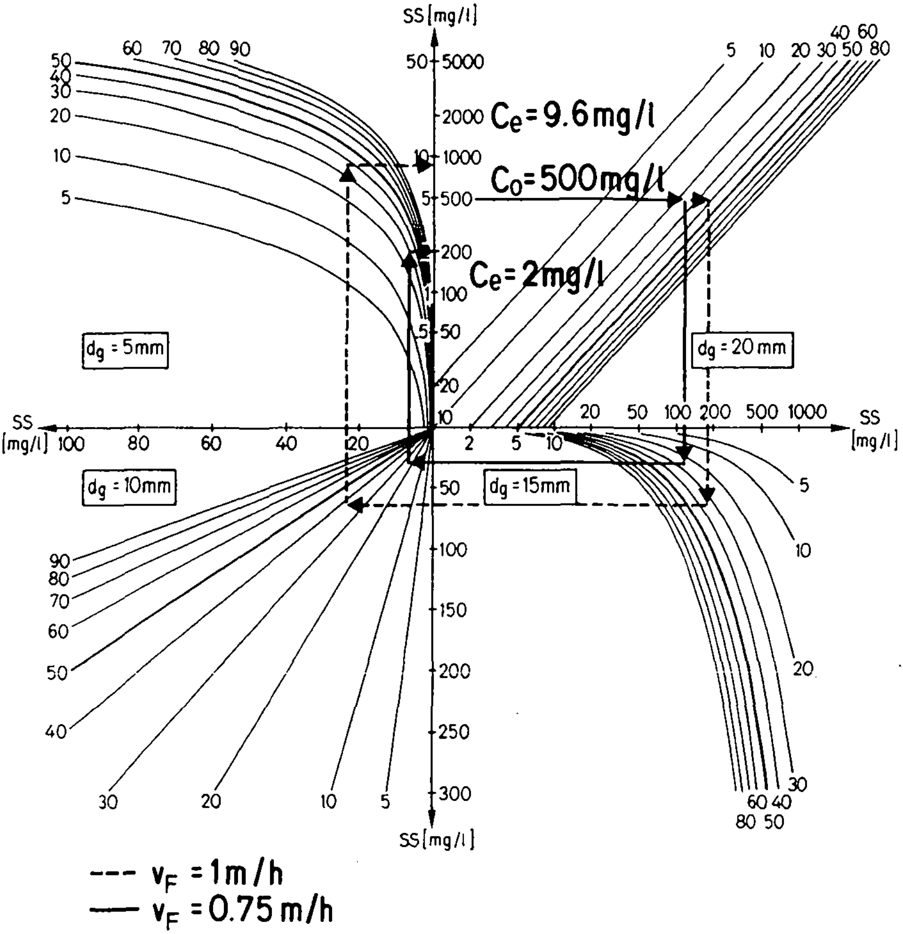
It should be remarked that the presented "E-value" was introduced as Efficiency value. However, the same "E" may also stand for Estimation. The real conditions in a filter are greatly simplified and the suspended solids in a natural river need not coincide with the investigated kaolin suspension. Hence, since the presented concept is rather a refinement of the general design guidelines (see also pages 17 and 40) it will not provide exact values.

More specifically, the results obtained for the first filter fraction tend to be conservative. A natural suspension does not have a uniform solid size of 2 µm as assumed in our calculation, but might vary between 20 and less than 1 µm in a presettled water. Hence, the first filter section will remove the coarsest solids and a small fraction of the finer material. The separated mass from such a natural suspension might therefore be greater than that of a uniform suspension.

The conditions might be totally different for the finest gravel fractions. Since all coarse solids have been removed, the remaining mean particle size will be smaller than 2 µm. As a consequence, the calculated removal rates might be too optimistic for this filter section.

However, the estimated overall removal rate for the entire filter will probably be of the same magnitude as that observed in reality. Therefore, the presented "E-value" concept can well be applied as a preliminary step in the HRF design. More detailed information can be obtained with the HRF computer programme (see also page 18), in which the particle size distribution of a natural suspension is adopted and a dynamic model applied to consider filter load increase with finite filter elements.

Graphical Solution of Design Example
(discussed on pages I/4 and I/5)



Appendix 2:

Simple Methods for Water Quality Analysis

1. Introduction

The following difficulties often hinder implementation of a water quality monitoring programme:

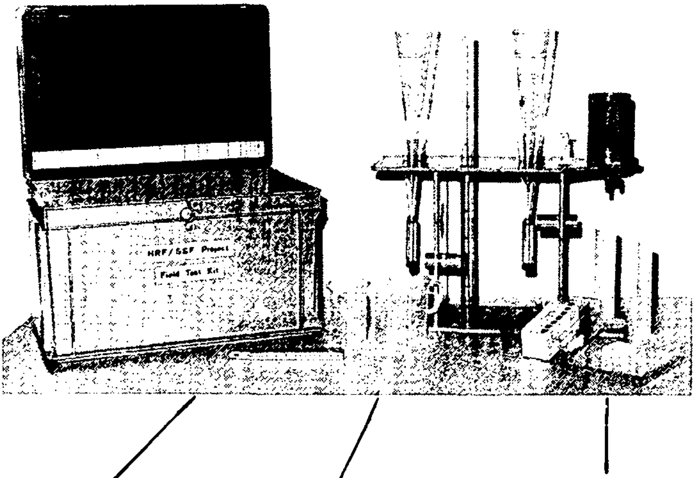
- availability of only a few water quality laboratories in the country and possible transport and communication difficulties between the laboratory and the field,
- analysis of water samples only possible in the laboratory for lack of appropriate field test equipment. Delay and mishandling of the samples might lead to errors,
- unavailability of basic infrastructure (e.g. power supply) and qualified personnel at the treatment plant.

As a consequence, water quality monitoring on a regular basis is frequently neglected. Water treatment processes, however, have to be controlled since neglection of water quality monitoring is usually combined with desinterest in the treatment as a whole.

In order to overcome the mentioned difficulties, some simple, sturdy field test methods have been developed to monitor the efficiency of HRF. Turbidity and the suspended solids concentration are the main parameters which determine HRF performance. In addition, the volume of settleable matter might be of interest if no pretreatment system (e.g. sedimentation tank, raw water reservoir) is available prior to HRF. Finally, the suspension stability has an influence on the settling characteristics of the suspended matter.

Simple methods and sturdy equipment are now available for the determination of the different parameters. IRCWD has developed a field test kit, as shown in Fig. 35, containing all the necessary equipment for turbidity, filtrability and settleable solids determination. Neither chemicals nor energy is necessary to carry out the tests. Only filter paper necessary for the filtrability test will have to be supplied from outside.

Fig. 35 Field Test Kit
(developed by IRCWD)



adapted Imhoff cones (settleable solids)

test tube (turbidity)

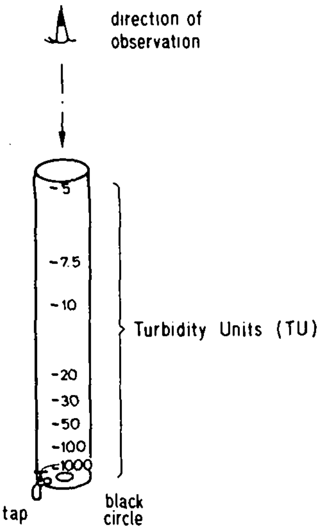
filtrability apparatus (suspended solids conc.)

2. Turbidity

Turbidity is measured by a test tube that has been developed by DelAgua and which is included in a field test kit for bacteriological (faecal coliforms) and physical/chemical analysis (pH, conductivity, chlorine). More information on this field test kit can be obtained from DelAgua, P.O.Box 92, Guildford GU2 5TQ, England.

Test Procedure for Turbidity Analysis:

- assemble the two turbidity tubes by placing the lower in the stand and by inserting the upper in the lower tube through the hole of the stand
- check the valve for closed position
- slowly pour the water to be analysed in the test tube avoiding splashing and the formation of bubbles. Fill the tube up to mark 5
- observe the test tube from a vertical position and open the valve



Turbidity Test Tube

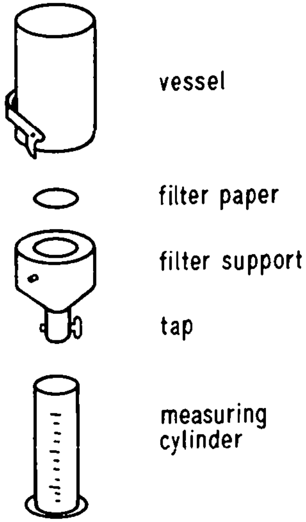
- close the valve as soon as you can see the black circle at the bottom of the test tube
- record the water level and enter the result in the record sheet
- remove all water from the test tube and clean it

3. Filtrability

The suspended solids concentration analysis which requires very accurate equipment is replaced by the filtrability test. The test will produce relative values sufficient to monitor the efficiency of HRF in solid matter removal.

Test Procedure for Filtrability Analysis:

- remove the vessel from the filter support by lifting the clamp
- place the filter support on the stand
- close the tap (horizontal position)
- fill the filter support with water
- place a filter paper No. 595 (Schleicher and Schüll) on the filter support and press it slightly to the grit to avoid air pockets below the filter paper
- place the funnel on the support and fix it with the clamp
- place a measuring cylinder under the filtrability apparatus



Filtrability Test Installation

- pour 500 ml of the water to be tested in the funnel

- open the tap (vertical position), turn the sand clock and record the filtered water volume in ml after 3 min. (after 1, 2 and 3 min. if watch is available)

- remove the filter paper and place a new paper according to the described procedure

- analyse a second water sample in the same way

- enter the results in the record sheet if they are of the same order of magnitude (deviation ± 20%), otherwise repeat the test for a third time

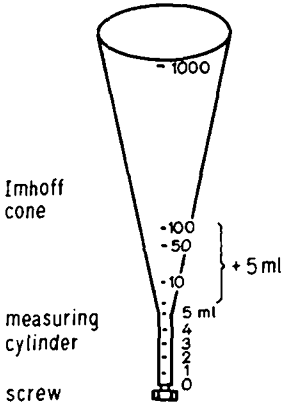
- remove all water from the filtrability apparatus and clean it

4. Settleable Solids

An adapted Imhoff cone, commonly utilized for the analysis of wastewater containing large volumes of settleable solids, is used here to measure also small quantities of settleable matter. With this test, filter porosity reduction due to solids accumulation in the filter can be determined by calculation.

Test Procedure for the Determination of Settleable Solids:

- check the tightness of the screw
- place the Imhoff cone on the stand
- pour 1 liter of water to be analysed in the Imhoff cone
- record the volume of settled material after 15 min, 30 min, 1, 2, 4, 8 and 24 hours and enter the results in the record sheet
- empty the water from the test tube by removing the screw and clean the Imhoff cone
- tighten the screw



Settleable Solids Test Cone

5. Suspension Stability

The stability of a suspension and the settling properties of the suspended matter can be determined by a sedimentation test. The record of turbidity decrease versus time is the simplest monitoring procedure for such a test. The water sample must be kept undisturbed during the test period. Therefore, small water volumes are extracted carefully and the turbidity measured in a common turbidity meter. The equipment for this test is not included in IRCWD's field test kit. However, a simpler procedure for the suspension stability test is being developed. The respective equipment will be included in the field test kit once its suitability has been established.

Test Procedure for Suspension Stability Analysis:

- pour 1 liter of the water to be tested in a beaker or an Imhoff cone
- carefully extract by a pipette and without creating turbulence about 25 ml of water approx. 2 cm below the water surface
- pour the 25 ml sample in the test glass of the turbidity meter and measure the turbidity
- take records after:

  0, 15, 20, 60, 90, 120 min.
  4, 8, 24, 32, 50 hrs.

Appendix 3:

Simple Methods for Discharge Measurements

1. Introduction

Discharge measurements are necessary to control the flow through the treatment plant. The total flow has to be distributed evenly to the different filter units running in parallel. Unequal flow distribution will usually reduce the overall performance of the filters. Flow adjustments are required to cope with the weekly and seasonal demand fluctuations. Furthermore, flow adjustments are also necessary before and after cleaning and maintenance work.

Fixed installations or mobile equipment are used for discharge measurements. Since flow control plays an important part in treatment plant operation, the use of fixed installations is recommended.

2. Fixed Installations

Flow meters are relatively sophisticated and mechanically sensitive. Especially solid matter (sand, silt), carried by the water, can easily damage the device. It is therefore strongly recommended not to use such equipment in water treatment plants. Flow measurements at the outlet of a clear water tank might be the exception.

V-notch weirs are simple, strong and cheap installations, and therefore most suitable for flow control in water treatment plants. Weirs can be made from wooden boards or preferably steel plates. The weir's discharge is measured by recording the water height above the deepest point of the weir's crest.

A gauging rod, fixed at a distance of minimum 30 cm from the inlet weir, will ease measurements. Compared to a 90° angle weir, V-notch weirs with a 60° angle will increase the accuracy of the readings. Slot-shaped holes in the weir's plate and in the gauging rod enable easy and accurate adjustment of the horizontal position. Fig. 36 gives more details on the possible dimensions of a weir's plate. The relationship between water height and weir's discharge is listed in Table 8 and graphed in Fig. 37.

Table 8 Discharge over a 60° V-notch weir

Height of water h_w (cm) above weir crest		flow rate	
	l/s	l/Min	m3/h
1	0.01	0.6	0.036
2	0.05	3.0	0.180
3	0.13	7.8	0.470
4	0.27	16	0.970
5	0.46	28	1.7
6	0.73	44	2.6
7	1.08	65	3.9
8	1.50	90	5.4
9	2.02	121	7.3
10	2.63	158	9.5

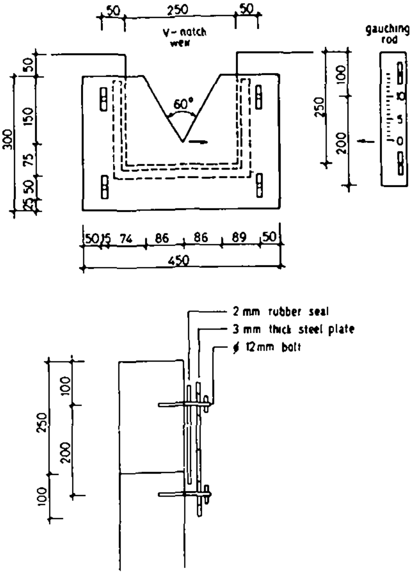


Fig. 36 Details of a 60° V-notch weir

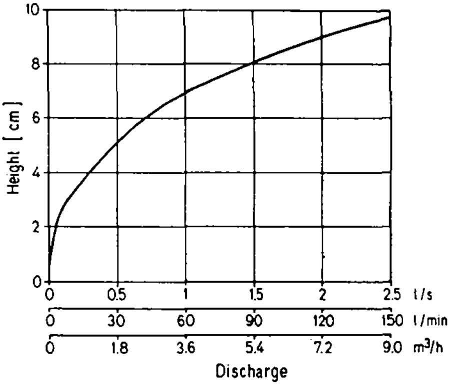
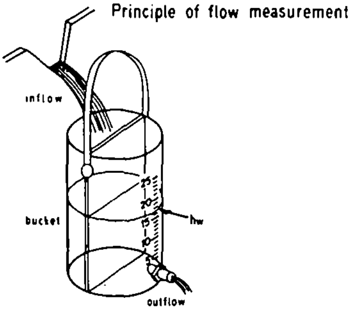


Fig. 37 Calibration Curve

3. Mobile Devices

Auxiliary equipment is required for the calibration of measuring weirs or for direct flow control if V-notch weirs are not provided. The simplest method to measure water flow is to record the filling time of a determined bucket volume. With this method, however, a watch is necessary but might not always be readily available. Furthermore, this procedure is inaccurate for high flow rates as the filling time becomes very short and easy handling is hampered by the weight of the filled bucket.

Therefore, IRCWD has developed a more suitable flow control device which is illustrated in Fig. 38. The overfalling water flows into a bucket whose lower end is equipped with a calibrated nipple through which the water is discharged. An equilibrium between in and outflow will soon be established. The water height from the centre of the nipple is recorded and the discharge read from the graph presented in Fig. 39. This method does not require a watch nor special material. A commonly used bucket or a small drum can be used as vessel. The nipple is assembled with standard pipe fittings and does not require great accuracy with respect to its length as shown by the graph. A separation wall with an opening of approx. 2 cm above the vessel's bottom creates a turbulence-free water level in the effluent's compartment. Finally, the distance from the centre of the nipple is marked on a half cm scale in the inner wall of the bucket. Flow rates between 6 and 30 l/min can be measured accurately with this simple device equipped with a 1/2" nipple. Larger nipple sizes can be used for higher flow rates and to reduce the water level difference required by the measurement. The presented device can easily be handled by a caretaker and should therefore be available at every treatment plant.



Principle of flow measurement

Section of the bucket

Section of the nipple

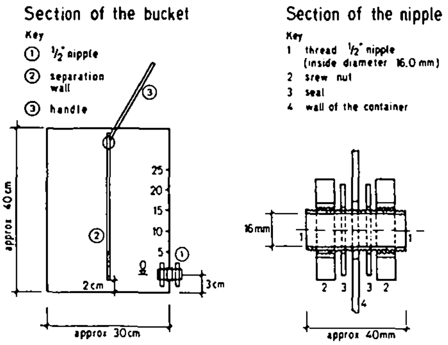


Fig. 38 Simple Flow Control Device

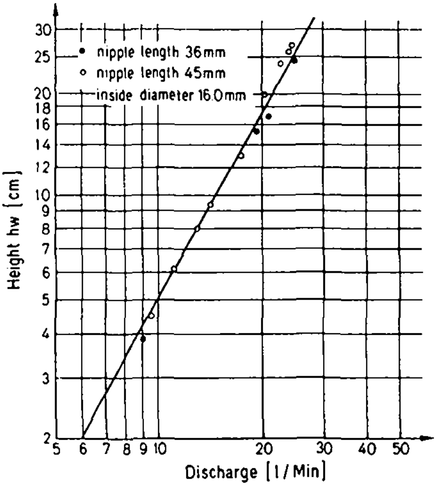


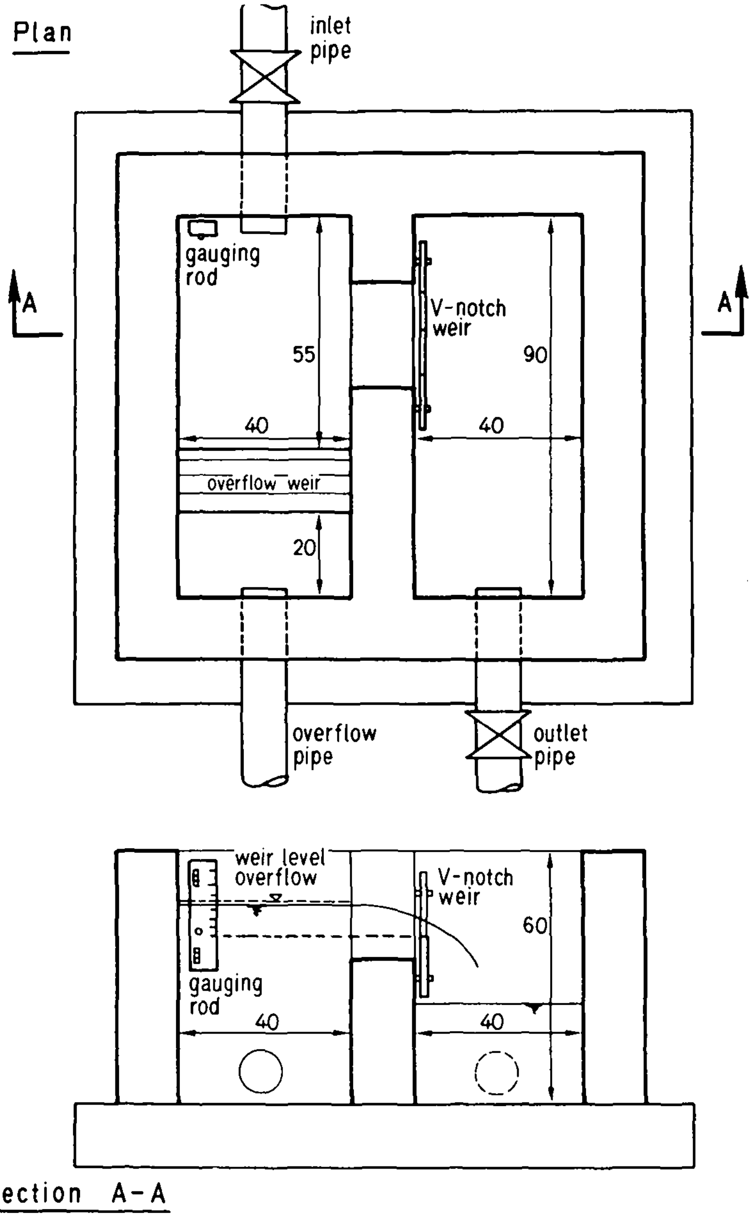
Fig. 39 Calibration Curve for $^1/_2$" nipple

4. Flow Control and Distributor Box

V-notch weirs are usually installed in special structures used for flow distribution and possibly also for maximum flow limitation. An example of such a structure is illustrated in Fig. 40. This illustration shows a flow control box used in the raw water supply line and placed in front of the treatment plant. The flow which runs through the outlet pipe to the treatment plant is measured by the V-notch weir and gauging rod. A rectangular overflow weir in the inlet chamber limits the maximum flow through the treatment plant. The surplus water is discharged through the overflow pipe.

The controlled total flow through the treatment plant must be evenly distributed to the parallel running treatment units. This is achieved by a distributor box equipped with several V-notch weirs. Since such a box concentrates the flow control in one installation, it simplifies the hydraulic lay-out of a treatment plant. In such a set up, the inlet weirs of the HRFs can for instance be omitted as illustrated in Fig. 32 and Appendix 4.

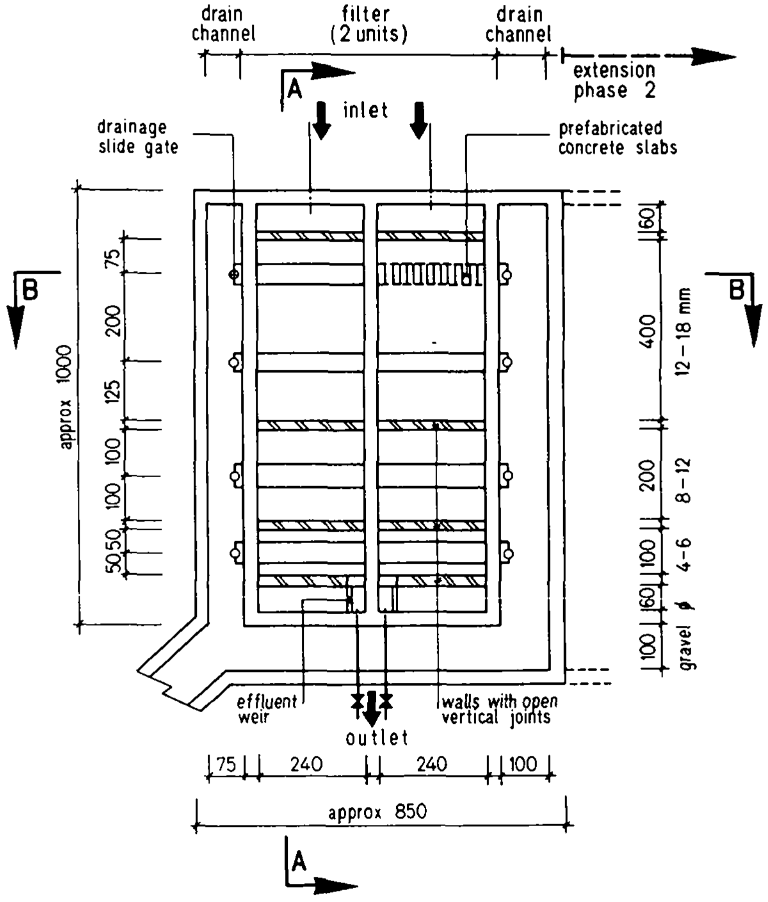
Fig. 40 Details of a Flow Control Box



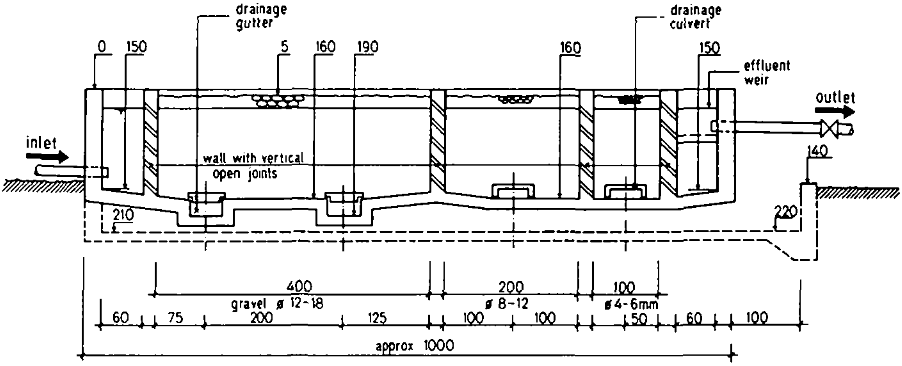
Appendix 4:

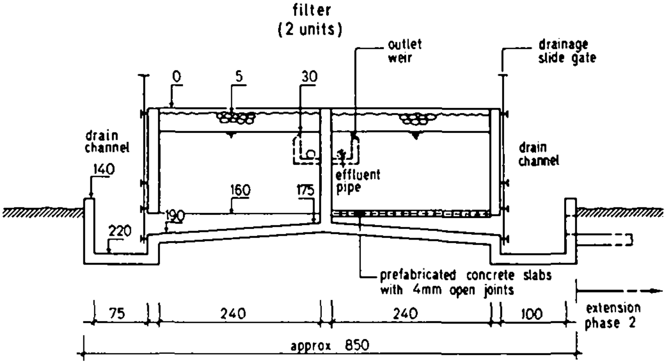
Construction Details of a HRF

Plan



Section A—A





Section B—B

Appendix 5:

Salient data and features of a SSF

(for more detailed information see Ref. [1])

Design criteria

filtration velocity	v_f	0.1 m/h (0.1 - 0.2 m/h)
area per filter bed	A	10 - 100 m^2
number of filter beds		minimum of 2
height of supernatant water	h_w	1 m (1 - 1.5 m)
depth of filter bed	h_f	1 m (1 - 1.4 m)
depth of underdrains system and filter support	h_s	0.4 m (0.3 - 0.5 m)
specification of filter sand		
effective size	$d_{10\%}$	$= d_{eff} =$ 0.15-0.35 mm
uniformity coefficient	UC	= 2 - 5
specifications of filter support size/depth		15 - 25 mm / 15 cm 4 - 6 mm / 10 cm 1 -1.5 mm / 10 cm

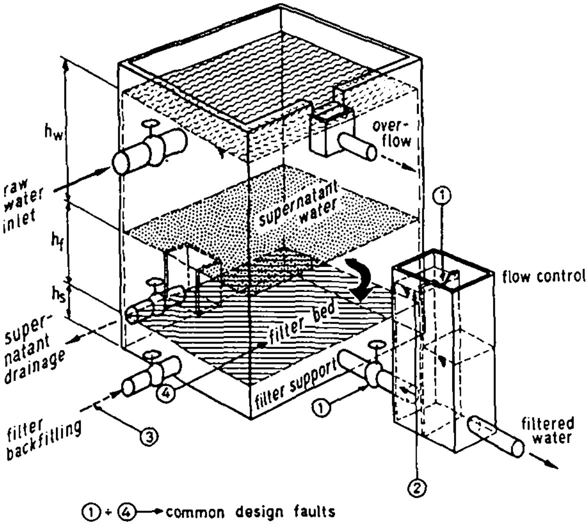


Fig. 41 Main Features of a SSF and Common Design Faults

Common design faults and their consequences (see also Fig. 41)

1. Inappropriate or missing flow rate control installations → filter often overloaded or operated at frequent flow rate changes.

2. Water pressure in effluent line lower than the top level of the sand bed → generation of negative pressure (vacuum) in the sand bed resulting in air release and additional filter resistance.

3. Missing installations for watering the sand bed from bottom to top → air binding in the sand bed resulting in a initially high filter resistance.

4. Inappropriate sand size and depth of filter bed → poor effluent quality (coarse sand, small depth) or short filter runs requiring frequent cleaning (sand too fine).

Common operational problems

1. Turbidity and suspended solids concentration in the raw water too high for SSF application. Turbidity should preferably be less than 10 turbidity units and the suspended solids concentration lower than 2 - 5 mg/l to achieve reasonable filter operation.

2. Missing auxiliary equipment such as tools and sand washing installations. Failing to clean and replace the sand will lead to exhaustion of the sand bed.

3. Untrained caretakers who do not understand the SSF process are generally not motivated to operate the treatment plant properly.

Appendix 6:

Design Form

DESIGN FORM

Name of water supply:
District/Region:

Designed by:
Date:

1. Water Source	dry	rainy	Dimensions
	season		
discharge			l/s
turbidity			TU
filtrability			ml/3 Min
susp. solids conc.			mg/l
organics ($KMnO_4$*, COD*)			mg/l
bact. test (E.coli*, fecal Strept.*)			/100 ml

2. Alternative Source

available yes*/no* name: . . . .

better quality yes*/no* type of source: . . . .

constr. costs higher*/smaller*

remarks. . . . .

3. Water Supply System

gravity scheme*/pumped scheme: mechanical pump*
handpump*

4. Daily Operation Hours

for raw water pumping station . . . . hrs/day

for treatment plant	continuous	intermittent (....hrs/d)*	declining rate (....hrs/d)
sedimentation tank	☐	☐	☐
HRF	☐	☐	☐
SSF	☐	☐	☐

9. Hydraulic Profile

10. Situation

5. Water Demand		future		Dimensions
	present	phase 1	phase 2	
population	....	....	....	people
daily per capita demand	....	....	....	l/c d
daily demand by population	....	....	....	m^3/d
additional demand for	....	....	....	m^3/d
. . . . (specify)	....	....	....	m^3/d
total daily demand	....	....	....	m^3/d

6. Raw Water Supply				
gravity supply → go to 7.1				
required pump capacity		....	....	l/s
number of pumps		....	....	-
volume of raw water tank → go to 7.2		....	....	m^3/d

7. Treatment	design value			
7.1 Sedimentation Tank				
surface load	....			m/h
required surface area		....	....	m^2
detention time	....			hrs
required volume		....	....	m^3
number of units		....	....	-
dimensions of 1 unit				
length	....			m
width	....			m
depth	....			m
7.2 HRF				
filtration rate	....			m/h
required filter area		....	....	m^2
number of units		....	....	-
dimensions of 1 unit				
width	....			m
depth	....			m
length				
gravel size .... mm	....			m
.... mm	....			m
.... mm	....			m
.... mm	....			m
7.3 SSF				
filtration rate	....			m/h
required filter area		....	....	m^2
number of units		....	....	-
dimensions of 1 unit				
length	....			
width	....			

8. Distribution				
8.1 Piped water supply				
reservoir volume		....	....	m^3
number of units		....	....	-
8.2 Semi-piped water supply				
people per handpump	....			people
required number of handpumps		....	....	-
volume of 1 cistern	....			-
number of cisterns		....	....	m^3

---

* delete where not convenient

Appendix 7:

Outline for Caretaker Training

1. Introduction

Proper caretaker training in the operation and maintenance of water supply installations is, in many cases, often seriously neglected. Incorrect use, damage and finally abandonment of the installations are generally the consequences of such a neglection. However, a sound and economic operation of a water supply system requires, among other prerequisites, well-trained and skilled manpower. Comprehensive training of local staff is therefore essential.

Transfer of knowledge is the main goal of a training programme, but motivation and guidance of the caretakers are other important components of such a programme and should therefore not be limited to a short-term course.

Caretakers are preferably trained in their local language by supervisors attached to the operation and maintenance section of the responsible institution. These supervisors will also visit the water supply schemes on a regular basis, check their proper operation, support the local staff in their activities and maintain an exchange of information between field and office.

A training programme is briefly outlined below. The topics of the programme cover the treatment part only. More comprehensive training guidelines for the operation and maintenance of rural water supply schemes have been published by IRC (12).

2. Schedule

An ideal training programme might be divided into 3 parts. Timing, aim, location and duration of the 3 parts are summarized in Table 9.

3. Outline of the Syllabus

The topics to be covered by the different parts of the training programme are suggested hereafter. The list might be incomplete and possibly needs to be adapted to local conditions.

Part 1:
- visit of an existing treatment plant comprising HRF and SSF
- explanation of the treatment process and operation of the plant
- discussion of the water quality problems faced by new schemes
- assessment of the interest in water treatment of future users

Part 2:
- the main objectives of water treatment
- the main features and processes of HRF and SSF
- the filter operation, especially
    - discharge measurements and adjustments
    - determination of the filter resistance
    - procedure for filter (re)start and cleaning
    - hydraulic and manual filter cleaning
    - gravel and sand cleaning
    - water sampling
- the carrying out of simple water quality tests (turbidity, filtrability, settleable solids)
- the monitoring of the treatment plant (logbook keeping)
- the maintenance work
- the annual working plan

Part 3:
- refreshment and consolidation of the basic training course (Part 2)
- on-site training in operation and maintenance of the plant
- review and discussion of experienced operational problems
- inspection of the installation and organisation of major maintenance work
- review of the logbook and the monitoring results

Table 9 Training Programme

Part	Timing	Aim	Location/Duration
1	pre-project phase or before/during construction of new treatment plant	presentation of treatment process to future users and motivation	existing HRF and SSF plant - 1 day
2	during or at the end of the construction phase	basic training of future caretakers in the operation and maintenance of HRF and SSF	existing or new HRF and SSF plant - 3-5 days
3	during the operational phase	supervision, guidance, support of the operation and maintenance of HRF and SSF (information exchange)	on the site - by regular field visit

Appendix 8:

HRF and SSF Monitoring Programme

1. Aim and Procedure

The aim of a monitoring programme is:

- to assess the treatment plant performance
- to establish guidelines for the operation of the treatment plant
- to improve treatment plant operation and efficiency

The caretaker carries out the field test and monitors, by logbook keeping, the operation and performance of the treatment plant. The supervisor attached to the operation and maintenance section of the responsible institution supervises by means of regular visits the monitoring programme of the caretaker, takes water samples to be analysed in the laboratory and summarizes the monitoring results in annual reports.

2. Field Records

The monitoring programme has to cover the quantitative and the qualitative aspects. Discharge measurements characterize the operational conditions of the treatment plant and provide the quantitative information. Water quality tests allow the qualitative assessment of the treatment process. Treatment plant operation requires flow control and adjustments on a daily basis. The water quality tests should also be carried out regularly, i.e. at weekly intervals. The equipment necessary for the discharge measurements and for the water quality tests must therefore be permanently available at every treatment plant.

A proposal for a field monitoring programme is summarized in Table 10.

3. Bacteriological and Chemical Water Analyses

Bacteriological and chemical water analyses require more costly equipment which can generally not be allocated to every treatment plant. The tests should also be performed by professional staff. It is therefore recommended for the supervisor to perform such tests either at the site, with field test equipment brought from the laboratory, or to take samples which will be analysed in the laboratory. Field testing excludes the risk of delay and mishandling of the water samples, and should therefore be taken into consideration provided the equipment is properly maintained and checked prior to each field visit.

A proposal for a bacteriological and chemical monitoring programme is summarized in Table 11.

4. Field Visits

The supervisor will conduct personally the on-site training of the caretaker, and will therefore also be present during the initial start of the treatment plant operation. Later, he will assist the caretaker in his daily activities and supervise the operation, maintenance and monitoring of the plant. The frequency of his visits depends, among other criteria, on the ability of the caretaker to operate his water supply system. Initially, however, the field visits will be carried out weekly, then monthly and subsequently every 2-3 months.

Such a post-project assistance is essential to ensure proper use of the installations, to identify possible problems at an early stage and to compile the practical experience gained for future projects.

5. Evaluation

The results of the monitoring programme are compiled in annual reports by the supervisors. These reports include the data sheet of the field records and possible analyses carried out in the laboratory. They also contain a short description of the operational experience (plant performance, encountered practical problems, exceptional events) and the planned activities (operational modifications of the plant, major maintenance work etc.).

Table 10 Field Monitoring Programme

parameter	record	frequency
flow rate	HRF + SSF	every 2 days
filter resistance	HRF	1 x / week
filter resistance	SSF	every 2 days
turbidity filtrability	of raw water and HRF + SSF effluents (at high turbidity, filtrate of each HRF gravel pack)	2 x / week (daily at periods of high turbidity)
settleable solids	raw water	1 x / week

Table 11 Bacteriological and Chemical Monitoring Programme

analysis	sample	frequency
E. coli or total coliforms or Fec. Strept.	raw water and HRF+SSF effluent	monthly for the first half year, later occasionally
pH conductivity total hardness alkalinity Ca^{2+} Mg^{2+} susp. solids conc.	raw water	every 2 months

Appendix 9:

Examples of HRF Application

In order to illustrate HRF application, 3 design examples are presented hereafter. A new water treatment plant comprising 2 HRF and 2 SSF units was set up in Kasote, Tanzania. The water treatment plant in Cocharcas, Peru, has been rehabilitated by the installation of 2 HRFs placed in front of 2 existing SSF units. The last design example presents an HRF application at the refugee camp FAU 5 in the Sudan. With respect to HRF application, IRCWD acted as technical advisor in the 3 projects. The salient figures of the HRFs installed at the 3 sites are presented in Table 12.

1. Kasote/Tanzania

Kasote which is located near Tanganyika Lake covers the water demand of its present 3000 inhabitants by drawing water from the river Kapondwe. A small weir feeding an open and 850 m long canal has been installed at the river. The water of this canal drives 2 hydraulic rams which pump the water to the storage tank located 70 m higher. This 90 m^3 volume reservoir feeds the distribution system consisting of a 3350 m PVC and PEH pipeline network and 14 double-tap public standposts. The construction of the water supply scheme was carried out with village participation between 1982-84.

Since the river water is bacteriologically polluted and of high turbidity, with peaks of approx. 200 NTU during the rainy season, the village decided to install a treatment plant which was completed in November 1985. It comprises 2 HRF and 2 SSF units located in front of the existing storage tank. A sedimentation tank was omitted as the coarse solids are retained by the open canal feeding the hydraulic rams.

Table 12 HRF Design Examples

name/country of the schemes		Kasote, Tanzania	Cocharcas, Peru	FAU 5, Sudan
design capacity	(m^3/d)	196	103	240
present population		3000	650	20000*
raw water source		river	irrigation canal	irrigation canal
max. turbidity	(NTU)	200	500	2000
HRF:				
- number of units		2	2	4
- filtration rate	(m/h)	1	0.6	0.75
- filter length	(m)			
• coarse gravel		6	3	4
• medium gravel		4	2	4
• fine gravel		2	1	2
- filter width	(m)	3.7	3.6	2.0
- water depth	(m)	1.1	1.0	1.2
construction period		May '84 - Nov.'85	Dec.'85 - April'86	Aug.'85 - Sept'85
specific construction costs of the HRF	($\$/m^3/d$)	130	41	130

*) planned number of refugees

The design figures of the HRF are summarized in Table 12. The foundation and the slab of the filters are composed of reinforced concrete and the HRF walls of reinforced concrete blocks. Drainage pipes (Ø 50 mm and perforated with slots) have been provided in order to allow hydraulic cleaning of the HRFs. 3 drainage pipes are installed in the first filter compartment, 2 in the second and 1 in the last filter section.

The SSFs are of circular shape (Ø 5.1 m) with walls consist of reinforced concrete blocks. The height of both the sand bed and the supernatant water are approx. 1 m. The 2 SSFs are operated at a constant filtration rate of 0.2 m/h.

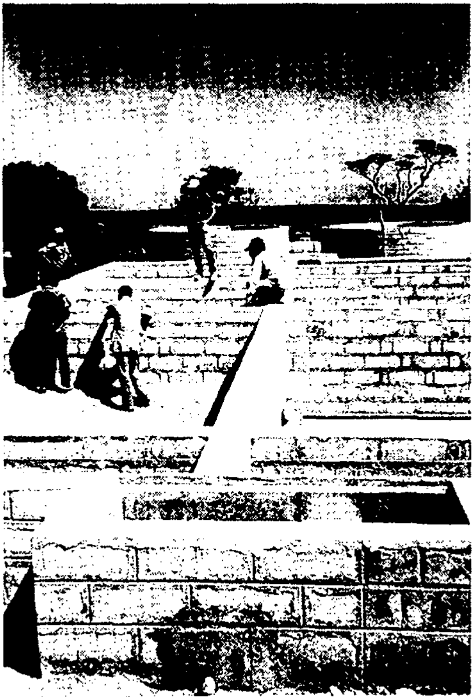


Fig. 42 HRF under construction at Kasote, Tanzania

Operation of the treatment plant started in January 1986. The first practical experience is promising. The filter resistance of the SSF was recorded at 60 cm after a filter running period of more than 4 months, which also included the rainy period between February and April. None of the filters had to be cleaned after this specific running period. In terms of bacteriological water quality improvement, the raw water faecal strept. level of 300/100 ml was reduced to 200/100 ml by the HRF, and to less than 2/100 ml by the SSF (counts during the dry season with a raw water turbidity of 5.5 NTU).

The water treatment plant has been constructed under the supervision of the Regional Water Engineer's office in Sumbawanga and with NORAD's support. Fig. 42 shows the construction stage of the HRF.

Cocharcas/Peru

Cocharcas is located in the Mantaro River Valley, Department of Junin in the high Peruvian sierra. The village counts at present approx. 650 inhabitants. The existing water supply scheme, which was constructed with community participation in 1977-78, comprises an intake located on a small irrigation canal, a sedimentation tank, two SSFs, a reservoir and distribution system with single-tap household connections.

The irrigation canal which draws its water from a river located 4-5 km upstream from the intake, is heavily exposed to human and animal contamination. Turbidity increases up to 500 NTU during the rainy season which lasts from November to March. This high turbidity together with a faulty design, insufficient construction experience, inadequate operation and maintenance gave rise to an unstable and irregular operation sequence and constituted a constant threat to the health of the community.

The most important component in the rehabilitation of the water supply scheme was the construction of 2 HRFs. Furthermore, the intake was repaired and equipped with adequate flow control devices. New sand beds and underdrainage systems as well as adequate overflow and cleaning facilities were installed in the SSF units. The salient figures of the HRF lay-out are also summarized in Table 12, whereas Fig. 43 shows the HRF construction and Fig. 44 contains more structural details on the HRFs.

The water supply scheme was rehabilitated between December 1985 and April 1986 with extensive community participation and with the assistance of DelAgua/ODA/CARE and direct involvement of the Rural Sanitation Division of the Ministry of Health (DISAR) in Huancayo.

Fig. 43 HRF under construction at Cocharcas, Peru
(picture by DelAgua)

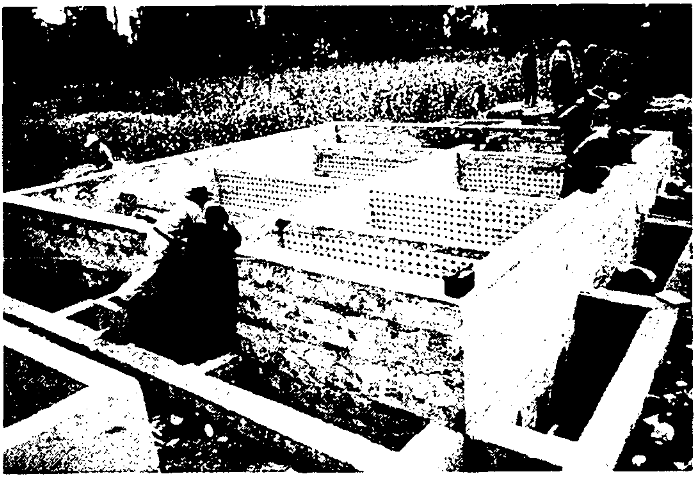
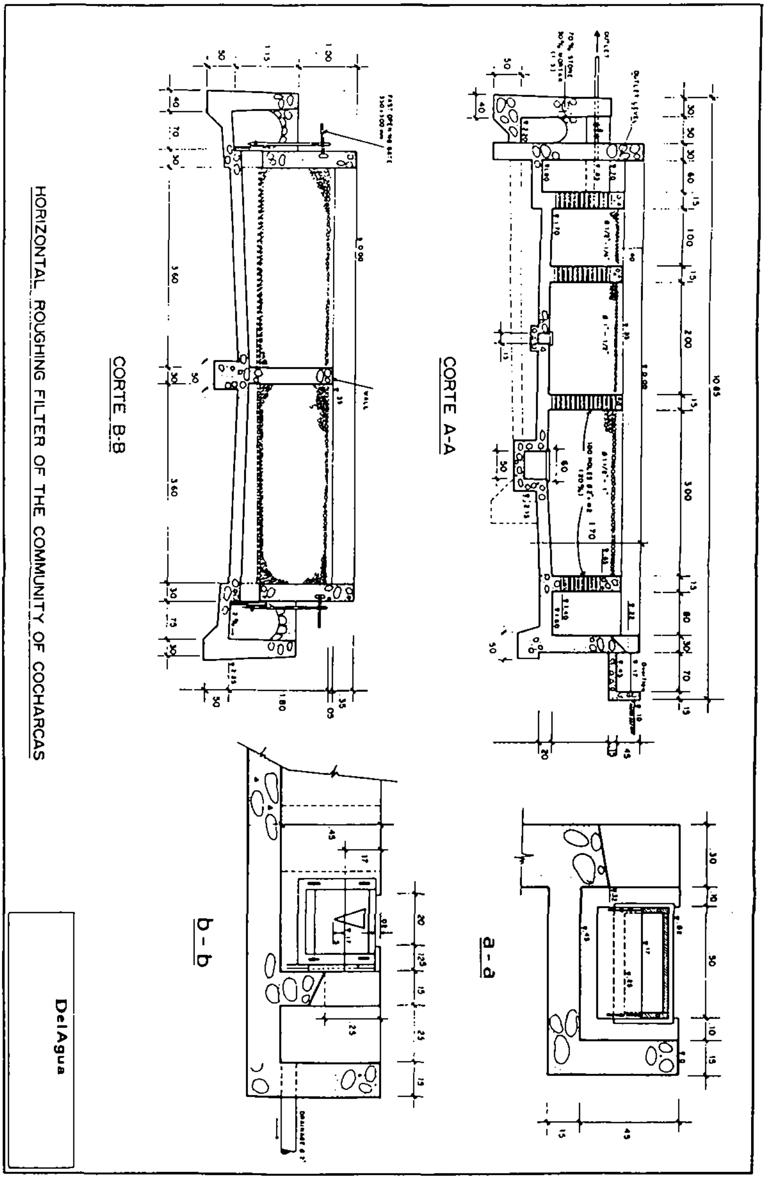


Fig. 44 Lay-out of the HRF at Cocharcas, Peru



3. FAU 5 / Sudan

The Swiss Disaster Relief Unit set up the infrastructure for a 20000 people refugee camp near Wad Medani in the Sudan in August/September 1985. A water supply system, permanent buildings required for a hospital, feeding centres and an administrative edifice had to be constructed. Great emphasis was placed on light-weight construction material, short construction time and simple installation. Furthermore, the installations had to be sturdy and easy to operate and maintain.

The raw water which is drawn from an irrigation canal situated nearby is supplied by the river Blue Nile and undergoes minimum treatment, i.e. turbidity reduction before disinfection. This is why the water treatment plant comprises 2 sedimentation tanks and 4 HRFs. The filtered water is thereafter disinfected before it is stored in a clear water reservoir and distributed to the camp by a number of public standpost. Disinfection is used instead of SSF since no sand is available at the site and because the medical personnel at the camp will be able to run the disinfection plant.

The sedimentation tanks and HRFs are designed as earth basins with inclined walls and earth dams consisting of bags filled with the excavated soil. The basins were then coated with a prefabricated plastic lining. Before the HRFs were filled with gravel, perforated pipes were installed to enable hydraulic filter cleaning which is carried out by means of a high discharge pump.

The HRF design values are presented in Table 12. Figs. 45, 46 and 47 illustrate the construction procedure of these HRFs. The appropriate and sound design of the treatment work made it possible to construct the plant with simple tools, minimum external material requirements and time. The treatment plant was completed in 6 weeks time by approx. 100 casual labourers under the supervision of a foreign overseer.

The raw water from the irrigation canal is heavily contaminated as several other refugee camps are located upstream from the intake. In addition, it exhibits high turbidity in the range of 1000 to 2000 NTU, and the chlorine demand amounts to 20 - 40 mg/l. The first practical experience with the treatment plant revealed that the raw water turbidity could be reduced by the sedimentation tanks to roughly half of its initial value. The HRF effluent turbidity was recorded at 5-20 NTU and the chlorine demand was reduced to 2 - 3 mg/l.

This last example illustrates an unconventional construction technique. The use of simple tools, proper guidance, minimal material requirements and time were the main characteristics for the installation of this self-reliant and efficient treatment plant.

Fig. 45 Excavation of the HRF earth basin
(picture by Swiss Disaster Relief Unit)

Fig. 46 Installation of the drainage pipes

Fig. 47 Filling the HRF with filter material (pictures by the Swiss Disaster Relief Unit)