CSIR

DIVISION OF WATER, ENVIRONMENT AND FORESTRY TECNOLOGY

WATER SUPPLY AND SANITATION PROGRAMME

Report to the

WATER RESEARCH COMMISSION

PART 1 on

A DYNAMIC CROSS-FLOW SAND FILTER FOR RURAL WATER TREATMENT

by

A W Kariuki

and

PART 2 on

A TECNICAL GUIDE FOR A DYNAMIC CROSS-FLOW SAND FILTER

by

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EXECUTIVE SUMMARY

1 INTRODUCTION

The dynamic filtration was initially developed by Russian sanitary engineers in the late nineteen fifties. However, it was in Argentina where the technology was first practically applied for water treatment. About fifty filters were built in the seventies most of which continue to supply water to rural communities. It is believed that they have continued to operate successfully because the filters are simple to operate and maintain and they are reliable. There is a paucity of documented data collected on monitoring carried out on these filters and therefore there is limited documented information on the performance of these filters. The diffusion of the technology has been limited to Latin America and it has not spread to other developing countries despite the technology being even simpler than, although it is a modification of, the conventional slow sand filter. In addition, there is no technical guideline available to assist in the design and operation and maintenance of dynamic filters. These reasons led to the formulation of a proposal to the Water Research Commission to develop a technical guide on dynamic filtration.

2 AIMS OF THE PROJECT

The main objective of the project was to produce a technical guide for the design, operation and maintenance of the dynamic filter .

The specific aims were:

- to gather information on the dynamic filter particularly from Argentina
- to construct, monitor and compare a pilot dynamic filter plant with a slow sand filter as a control
- to construct a dynamic filter for water treatment in a rural community and asses its performance

3 SUMMARY

The project was executed in the following phases:

- Information gathering and a production of a draft technical guide
- Construction and monitoring of a pilot dynamic filter plant
- Construction and monitoring of a plant in a rural community

A trip was undertaken to Argentina to obtain first hand, information on dynamic filters. Information was obtained by discussing the design, operation and maintenance and performance of the filters with engineers and plant operators. A vast amount of important information from the Argentinean experience was collected that would not have been otherwise obtained from literature of which, there is very little available. In addition, dynamic filters in operation were visited and observed first hand. Technical information was obtained on the sizes of the units and wherever possible the original designs.

Information and literature gathered led to the writing of a draft technical guide which was used as the basis for the design of the pilot dynamic filter plant.

A pilot dynamic filter plant was designed and constructed at the Daspoort Sewerage Plant premises in Pretoria. A slow sand filter was also set up as a control. Both plants were monitored and tests carried out on raw water and plant effluents indicated that the dynamic filter gave comparable results to and sometimes better results than the slow sand filter. In addition, the dynamic filter was tested using blastrite, a by-product from the mining industry, as a substitute for sand as the filter medium. It was found to give similar plant effluent quality as sand. On the basis of the experience of the pilot dynamic filter plant the technical guide was revised.

The community of Emmaus in KwaZulu Natal was identified as having a suitable site for the construction of a dynamic filter for water treatment. The guidelines in the revised technical guide were used in the design of the Emmaus dynamic filter. This phase of the project faced a number of challenges including mobilising the community, raising of funds for the infrastructure and floods during the construction period in 1996.

River sand purchased locally was successfully used as the filter media. However, before it was selected it was tested and met the prescribed specifications for dynamic and slow sand filter sand. The use of locally available sand was advantageous in that it was cheaper than graded sand and it makes it easier for the community to replace it once new sand is required. This is important for the sustainablility of the project.

The dynamic filter was able to significantly remove high levels of turbidity in the raw water and it was able to tolerate high levels of turbidity without much loss of filter capacity due to the daily cleaning process. Pretreatment may be necessary in order to meet the minimum drinking water standards level.

For the dynamic filter, the daily cleaning process of raking the filter bed surface affected the removal of turbidity and colour. In matured bed conditions, the fluctuations of levels of these parameters in the effluent are less in slow sand filters. This suggests that the biofilm or *"schmutzdecke"* plays a major role in the removal of these two parameters.

The enhancement of the pH and increase of conductivity in effluent from the dynamic filter was similar to that observed in slow sand filters indicating that, similar reactions occur within the filter bed.

The dynamic filter was able to significantly reduce faecal coliform densities at rates similar to slow sand filters. This was despite the frequent disturbance of the sand bed during the raking operation. This was in conformity with observations of similar filters in Argentina.

The operation and maintenance procedures of the dynamic filter were simple and straightforward and were understood and carried out by the plant operator who had limited formal education and skills.

The major advantages of the dynamic filter over the slow sand filter are its ability to tolerate high turbidity peaks, long filter runs and much simpler operation and maintenance requirements. Thus, the dynamic filter is an alternative to the slow sand filter in those situations where there is adequate water for crossflow and the topography is suitable to divert water by gravity to a filter near by.

4 CONTRACT OBJECTIVES AND PROJECT CONTRIBUTION

The Dynamic Filtration Technical Guide presents the state of the art and basic design parameters for the dynamic filtration. It is believed that it will assist planners and engineers to design, build, operate and maintain dynamic filters.

This report presents data obtained from monitoring a dynamic filter in a rural community that is operated by a plant operator from within the community. It presents conclusive evidence of the applicability of, and demonstrates, the efficacy of dynamic filtration. It is hoped this will convince planners, implementors of rural water supply projects as well as communities to consider dynamic filtration as an option for water treatment where the conditions are suitable for its use.

The contract objectives have been achieved with the production of the technical guide as well as this report.

5 RECOMMENDATIONS

A long term monitoring programme on dynamic filters is recommended to gather more information on design, operation and maintenance requirements in order and to update and refine the Dynamic Filtration Technical Guide. For the information to be relevant and useful, more dynamic filters need to be constructed and monitored.

It is recommended that the technology be promoted through the dissemination of the technical guide and this report to top decision makers, implementors and possible end users to create an awareness of the technology. In particular it should be targeted at those involved in rural water supply in the Reconstruction and Development Programme that is the responsibility of the Department of Water Affairs and Forestry on behalf of the government.

ACKNOWLEDGEMENTS

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The Water Supply and Sanitation Programme of the Division of Water, Environment and Forestry Technology, CSIR wishes to thank the following people for their contribution, assistance and or co-operation:

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The following organisations provided the funds for the construction of the plant without which the project could not have proceeded and their contribution is highly appreciated.

The Mvula Trust	for providing the bulk of the funds for training and the construction of the water plant
The Thukela Joint Services Board	for providing funds for training and for supervision in the construction of the project in the initial stages
The Emmaus Community	for community contribution

Lastly, to all who assisted in one way or another their contributions are acknowledged.

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1 INTRODUCTION

Field testing of a Dynamic Cross-Flow Sand Filter (DF) was carried out at a filter located at 28°51' 33" S and 29°22' 38" E (Map sheet: 2829CD ZUNKELS; appendix A1) in KwaZulu Natal. This belongs to the Emmaus Vulindelela Water Project which is managed by the Emmaus Vulindelela Water Committee.

The water project was jointly funded by the Mvula Trust who contributed the bulk of the funds and the Thukela Joint Services Board (JSB). The project was constructed by the community with the water committee managing the project under the supervision of the CSIR.

1.1 DYNAMIC FILTRATION

The filtration process in dynamic filtration (DF) is very similar to that of slow sand filtration (SSF). The purification processes that take place as water percolates slowly down a DF or SSF mimic the natural purification processes that occur in an aquifer. This results in considerable improvement of the physical, chemical and biological quality of the water.

The major difference between DF and SSF is in the physical layout of the filters (see diagrams in appendix A 2). Both have:

i. a bed of sand
ii. a system of under drains
iii. an inlet and outlet structure
iv. a set of filter regulation devices

The major difference is the chamber containing the sand bed and the water layer above the sand bed. In the SSF, this water layer is known as the supernatant water layer and is maintained at one metre above the sand bed and all the water is filtered eventually. In the DF a small water layer of 10 to 30 mm is maintained by water flowing over the sand bed. Only a fraction of this water is filtered (10-20%) and the rest of the cross flow flows over the filter bed and out of the filter to waste.

In both the DF and SSF the inlet structures allow water to flow into the filter. The main objective in both cases is to dissipate the energy of the incoming water so that the sand bed is not eroded.

Sand is most commonly used as filter bed material because it is cheap, inert, durable and widely available. It is described in terms of its effective size, (d_{10}) which is the sieve size opening allowing passage of 10% of a sample of sand by weight and the coefficient of uniformity (UC). The UC is the ratio of d_{60} to d_{10} where, d_{60} is defined similarly to d_{10} but for 60% passage. The sand used should have a d_{10} range of 0.15 to 0.35 mm, (Visscher JT et al 1988, Ellis KV 1985, van Dijk et al 1978, Huisman L et al 1974, Twort AC et al 1974). The UC is recommended to be less than 3.0 and preferably less than 2.0, (Visscher JT al 1988, Ellis KV 1987, Huisman L et al 1974, Twort AC et al 1974).

The minimum sand depths suggested for effective filtration for SSF are 0.5 to 0.6 m (Visscher JT et al 1988), 0.65 m (Ellis KV 1987) and 0.4 m (Muhammad et al 1995). In the DF the sand is not scraped and the sand depth recommended is 0.5 m (Solsona 1995).

The underdrain system provides an unobstructed passage way for treated water and supports the filter bed. It may consist of either a pipe network of perforated or corrugated pipes or a false bottom constructed of concrete blocks or bricks covered with layers, (usually three) of graded gravel.

The outlet chamber is a box that may contain a constant flow device (CFD), or a weir. Its main function is to remove the effluent or filtrate but it may also be used to regulate flow particularly in a SSF.

The filtered water purification process is a combination of physical, chemical and biological processes occurring on and in the sand bed the details of which are available in literature (Greaves GF et al 1988, Vochten P et al 1988, Visscher JT al 1988, Huisman L et al 1974). Biological activity is mainly responsible for the purification of the water as it percolates through the sand. The biological community is distinguished by two layers (Duncan A 1988) which are:

- the community on the bed surface referred to as *"schmutzdecke"* or filter skin
- the interstitial autotrophic and heterotrophic zones of sand flora and fauna which may extend to depths of over 400 mm in the sand.

As the biological community develops, particularly the filter skin, and as sediment is accumulated on the sand bed surface, filter resistance to water flow through the bed increases, necessitating filter cleaning for restoration of filter capacity. For the SSF capacity restoration is carried out by draining the supernatant water and scraping the top 20 to 30 mm of sand. In the dynamic filter the deposition process is slowed down by the cross flow and constant raking of the sand surface. Due to the crossflow, fewer sediments are deposited on the sand surface as they are carried over the sand surface. The constant raking of the top layer disturbs the filter skin development and debris trapped is carried out by the crossflow. This results in longer filter runs and less maintenance of the filter. Eventually in both types of filters, resistance as a result of particulate matter settling in the lower levels of the sand bed will result in inadequate filtered water production and the filter run will come to an end. Seasonal cleaning of the filter medium (sand) is then necessary.

Filtration rate for SSF is recommended at 0.1 to 0.2 $m^3/m^2/h$ (0.1 to 0.2 m/h) (Visscher JT al 1988, van Dijk et al 1978) where filters are the main treatment process although Huisman and Wood (1974) reported the use of higher rates of 0.25 to 0.45 resulted in no marked difference in effluent quality. Use of high filtration rates result in shorter filter runs while low rates require a bigger filter area.

1.2 DESIGN OF THE FILTER

The design of the filter was carried out using the guidelines compiled by Solsona (1993).

The key design parameters are summarised in table 1.1 below.

Table 1.1 Summary of the Emmaus Vulindelela Dynamic Filter Design Parameters

Demand (Ultimate 10 year)	55 m^3/d
Filtration Rate	0.1 $m^3/m^2/h$
Total Filter Area	12 m^2
No Filter Units	2
Area Per Unit	6 m^2 (L=6 m W= 1 m)
Gravel 13 mm	Depth 300 mm
Sand	Effective size d_{10}= 0.15 - 0.35 Uniformity Coefficient $d_{10}/d_{60} < 3.0$ Depth 800 mm
Cross Flow: Filter Flow Ratio	5:1

The filter was constructed of reinforced concrete which was preferred to blocks because of better strength and waterproof characteristics. Photographs and drawings of the filter are contained in appendix A 3. A detailed description of the filter is given in section 1.3.2 together with the operation and maintenance requirements of the filter.

1.3 DESCRIPTION OF THE WATER PROJECT

A brief description of the Emmaus Vulindelela Water Project is given is this section. A map of the area of the project and the scheme reticulation is provided in appendix A 1.

1.3.1 Inlet Weir

A weir was constructed to allow diversion of water from the Situnzini stream to the filter. The weir is a concave mass concrete structure 1.5 m high, 2.0 m wide and 3.5 m long. It was constructed on a natural rock ledge of what was a 1 m waterfall and the wings were embedded in rock on the river bank. The weir was designed to withstand a 50 year flood of 2.3 m above the top of the wall and it successfully withstood 2.5 m flood in 1995. Water is conveyed from the weir to the filter via a 90 mm high density polyethylene pipe (HDPE).

1.3.2 Dynamic Filter

The dynamic filter (DF) was constructed using reinforced concrete and consists of two parallel units. The units have three consecutive chambers and two side chambers which are the outlet chambers. The dissipation chamber or baffle box is the first chamber whose primary function is to render the flow into the next chamber as smooth as possible. The second chamber is the filter box which contains the filter medium (sand) whose level is the same as the partitioning wall between the dissipation chamber and the sand chamber. The sand is supported by a gravel layer which contains drain pipes to collect the filtered water and transport it to the outlet chamber. The third chamber is a sand trap for collecting sand carried by the cross flow. A channel was constructed after the sand trap to divert the crossflow back to the river. The outlet chambers are located on the sides of the sand traps and house the constant flow devices. A cement block box (not shown in the drawings) was constructed just upstream of the filter to house the V- notch weirs for each filter unit. Note that valves A are actually the inlet valves to the V-notch weir box which is connected to the two filter units via two separate pipes.

1.3.3 Clear Water Reservoir

A 50 m^3 ferrocement reservoir was constructed downstream of the filter to store filtered water.

1.3.4 Pump House

An 8 m^2 pump house was constructed of cement blocks to house the pumping equipment. The pump set consists of an 8 kW motor and a mono axial flow pump. Pumping to reservoir B is automatically controlled by a timer subject to water level in reservoir B.

1.3.5 Water Storage and Reticulation

The scheme layout is given in appendix A2. The storage consists of two 15 000 m^3 reservoirs. Reservoir C also acts as a break pressure tank. HDPE piping of various classes and sizes was used.

Fifteen public standpipes were installed from which the community draws water.

1.4 OPERATION AND MAINTENANCE OF THE DYNAMIC FILTER

1.4.1 Operation

Raw water is diverted from the inlet weir to the box containing the V-notch weirs for each of the filter units. The valve A1 just before each of the V-notch weirs is used to regulate flow. The water then enters the dissipation chamber or baffle box whose main purpose is to provide an energy dissipation zone so that water entering the filter box has smooth flow and turbulence is minimised. Most of the water (80-90%) is cross flow, which flows over the sand bed into the next chamber. As the water flows over the sand, some water (10-20%) flows downwards through the sand and is filtered and collected by a system of perforated pipes and delivered into an outlet chamber containing a floating constant flow device (CFD). Water flows into the CFD through orifices near the top into the outlet pipe and to the clear water reservoir. The last chamber is a sand trap for collecting sand carried by the cross flow. The water then flows into a drain that returns it to the river.

<u>Commissioning the Filter Procedure</u>

Commissioning of the filter is carried out whenever part or all of the sand has not been submerged in water. The objective is to slowly backfill the filter with water to ensure there is no air trapped in the filter medium. Air pockets trapped in the sand reduce the filter capacity. For the constructed filter, this was done by opening valves A1, B2 and C3 and closing valves D4 and E5 and allowing the water level to rise above the sand level. Once the sand was submerged valve B2 was closed and valve D4 opened to allow the filtrate to flow into the outlet chamber.

<u>Normal Operating Procedures of the Filter</u>

The inlet valves A1 are used to regulate the flow into the filter units so that adequate filtered water is produced. This is regulated so as to ensure that flow is as smooth as possible and that it is adequate to ensure that the CFD is above the minimum level or there is no overflow at the outlet. A V-notch weir is provided for measuring water flow to each of the filter units. The valves C3 and D4 remain open and the backfilling valve B2 and drain valve E5 are closed during normal operation and effluent valve C3 is fully open.

1.4.2 Maintenance

There are two cleaning operations which are:

- Daily cleaning
- Seasonal cleaning (end of filter run)

<u>Daily Cleaning</u>

The daily cleaning operation is carried out to restore the filter capacity by having the top 20 to 30 mm of sand disturbed so that the cross flow carries any debris and sediment out of the filter.

The effluent valve C3 is closed and the inlet valve A1 is left open so that the all the raw water entering the filter flows over the bed surface but none is filtered. The plant operator then uses a wooden rake to rake the top 20 to 30 mm of sand loosening sediment and debris deposited on the sand bed. The raking is carried out from side to side, that is from the side wall to the middle wall and vice versa starting from the dissipation chamber and progressively raking towards the sand trap. The raking operation should not stir the sand too much and the aim is to loosen the dirt accumulated on the sand so that it is carried by the cross flow out of the filter. Care should be taken not to lose too much sand. Sand trapped in the sand trap should be thoroughly cleaned and used to top up the filter. Once the raking operation is completed the effluent valve C3 is opened to restart the filter operation.

Daily filter cleaning is necessary if the water is highly turbid (dirty) especially during the rainy season. When the water is less turbid, the operation can be carried out once every two days.

Seasonal Cleaning (end of filter run)

This is necessary at the end of the filter run when the filter unit no longer provides adequate water even after the daily cleaning operation has been performed. Since sediment and biological matter will have settled in the lower sand layers causing filter resistance to increase, the sand has to be removed and thoroughly cleaned. The inlet valve A1 to the filter unit is closed and all the other valves are left open to drain the filter bed. The sand is then removed from the filter bed and cleaned manually by stirring it in wheel barrows or in a sand cleaning platform or chamber where provided.It is necessary to add new sand due to loss of sand during the cleaning process. The new sand may also have to be cleaned depending on source. The cleaning operation can be carried out preferably with the raw water when turbidity levels are low. The filter is then filled up with the clean sand and re-commissioned as described in 1.4.1.

2 THE FIELD TESTS

Tests on water samples from the Emmaus Vulindelela Water Filter were conducted between 23rd August and 30th November 1996 over a one hundred day period. The tests were carried out by the CSIR, Cathedral Peak, Forestek Laboratories. Only one unit of the filter was monitored.

2.1 SAMPLING

Grab sampling was done at the two sampling points chosen. Two samples at each point were taken using a sterilised 250 ml glass bottle that always preceded a 250 ml plastic bottle. The former was for bacteriological tests and the later for other tests.

The actual sampling points were:-

- at the inlet of the filter at the V-notch for raw water
- at the outlet of the filter at outlet chamber for the plant filtrate/effluent/filtered water

2.2 PARAMETERS INVESTIGATED

2.2.1 Water Quality Parameters

The parameters investigated are summarised in Table 2.1

Table 2.1 Water Quality Parameters Investigated

Water Quality	Parameter	Sampling Point	Frequency
Physical	Turbidity	Inlet - I & Outlet - O	Twice per week
	Colour	Inlet - I & Outlet - O	Twice per week
Chemical	Conductivity	Inlet - I & Outlet - O	Twice per week
	pH	Inlet - I & Outlet - O	Twice per week
Bacteriological	E- Coli	Inlet - I & Outlet - O	Twice per week except between days 46 and 67

2.2.2 Sieve Analysis

Sieve analysis of a sample of the filter medium was carried out by the Division of Building Technology, CSIR Pretoria.

2.3 METHODOLOGY

2.3.1 Turbidity

A Hach 2100N digital turbidimeter was used to measure the turbidity of the water samples in NTU in accordance with standard procedures, (APHA, AWWA & WPCF 1985). The instrument was pre-calibrated and does not require re-calibration before testing the samples. Each sample was shaken, poured into a clean cuvette to the required level which was then thoroughly dried with tissue and placed in position in the turbidimeter. The turbidity reading was then recorded.

2.3.2 True Colour

The samples were filtered using whatman no. 1 paper and measurement of true colour in Hazen Units was done using a Merck SQ18 spectrophotometer in accordance with standard procedures, (APHA, AWWA & WPCF 1985). Distilled water was poured to the required level in a cell which was dried and inserted into the instrument to calibrate the instrument before readings for the samples were taken. The readings for the samples were then taken using similar cells that were cleaned and dried.

2.3.3 pH

pH measurements were conducted using a Zeiss pH Meter 300 digital which had a glass electrode, a reference electrode and automatic temperature compensation in accordance with standard specifications, (APHA, AWWA & WPCF 1985). Before testing the samples contained in beakers, the instrument was calibrated using a pH 7 buffer solution. Before each measurement of the buffer solution or the samples, the probes were thoroughly rinsed with distilled water.

2.3.4 Conductivity

A Digital Microprocessor Conductivity Meter LF537 was used to measure conductivity of the water samples. The probe was always thoroughly rinsed with distilled water before inserting it into the sample which was contained in a beaker.

2.3.5 Faecal Coliform

Faecal coliform enumeration was carried out using Coli-Count Sampler, coliform blue from Millipore. This is a non standard technique chosen for its simplicity and also due to the fact that it was not possible to use a standard technique due to lack of adequate facilities at the CSIR, Forestek Laboratories, Cathedral Peak.

The sampler used for each sample consisted of a paddle inserted in a case sealed in a plastic bag. One side of the paddle had a gridded filter membrane. The procedure used is as follows:

- The casing was marked as either raw water or effluent depending on the sample being tested
- The paddle was removed carefully from the casing and the sample was filled to the upper graduation mark (18 ml). The paddle was held when filling the casing and care was taken not to touch the filter membrane.
- The paddle was then inserted firmly into the case and the unit was carefully laid down horizontally. It was left in this position for thirty seconds without any agitation to allow the membrane to absorb 1 ml of the sample.
- After thirty seconds the paddle was removed from the case and excess liquid shaken off with a firm snap of the wrist. The case was emptied of the sample and the paddle reinserted firmly to form an airtight seal with the case.
- The sampler with the gridded side facing down was incubated at 44 ^{0}C for 24 hours.
- After incubation the blue colonies of faecal coliforms were counted and the result recorded. The count per 100 ml was obtained by multiplying the results by 100.

2.3.6 Sieve Analysis

Sieve analysis was carried out according to the South African Bureau of Standards (SABS) Test Method 829:1994.

2.3.7 Flow Measurement

The flow measurements at the inlet were carried out by reading the height of water flowing over the 22.5° triangular weir (V-notch) on the inlet side.

3 RESULTS AND DISCUSSION OF THE FIELD TESTS

The prime use of the water from the filter was for human consumption. Therefore, the parameters measured have been compared to the South African Water Quality Guidelines Volume 1: Domestic Use (DWAF 1996), the South African Water Quality Criteria (Aucamp PJ et al 1990) and the South African Standard Specification for Water for Domestic Supplies (SABS 241-1984).

3.1 SIEVE ANALYSIS

The results of the sieve analysis of the sand used as the filter medium are given in appendix B 1. Figure 3.1 shows the sieve analysis plot for the filter sand.

From the plot the effective size of the sand d_{10} was found to be 0.19 mm. The sand was well within the recommended range of d_{10} which is 0.15 to 0.35 mm (Barrett JM et al 1991, Visscher JT al 1988, Van Dijk JK et al 1978, Huisman L et al 1974). The uniformity coefficient which is the ratio d_{10} to d_{60} was found to be 2.95 which was just below the upper limit of the recommended range of 1.5 to < 3 (Barrett JM et al 1991, Visscher JT al 1988, Van Dijk JK et al 1978, Huisman L et al 1974). Thus, the sand used in the filter was suitable for slow sand filter application.

3.2 TURBIDITY

The tabulated results of turbidity measurements are given in appendix B 2. These results are graphically illustrated in Figures 3.2 and 3.3.

The mean turbidity values at the inlet for the raw water and the outlet for the effluent were 198.4 and 46.1 NTU, respectively. The mean removal efficiency for turbidity by the filter was 46%. From Figures 3.2 and 3.3 it is observed that the removal of turbidity gradually improved with filter run although it appears there was a lagging influence by the high turbidity peaks of the raw water on the filtrate. The filter was able to tolerate high levels of turbidity particularly from the 7th of October to the 4th of November when the mean raw water turbidity of 358 NTU was reduced by 76% to a mean effluent turbidity of 85 NTU.

In a well operated SSF, the turbidity removal tends to improve with filter run and effluent turbidity fluctuates less as the *"schmutzdecke"* develops. With the dynamic filter, the constant raking of the top layer disturbs the development of the *"schmutzdecke"* and this would have an effect on turbidity removal. However, a slow sand filter operating under similar conditions without pre-treatment would have most probably clogged up more than once resulting in short filter runs necessitating frequent cleaning.

The target water quality range is 0-1 NTU (DWAF 1996). The maximum limit of the no risk range is 1 NTU while the maximum limit for low risk recommended is 10 NTU (Aucamp PJ et al 1990). The filter effluent was not able to meet the target water quality range in any of the samples but was able to meet the maximum limit for low risk range in

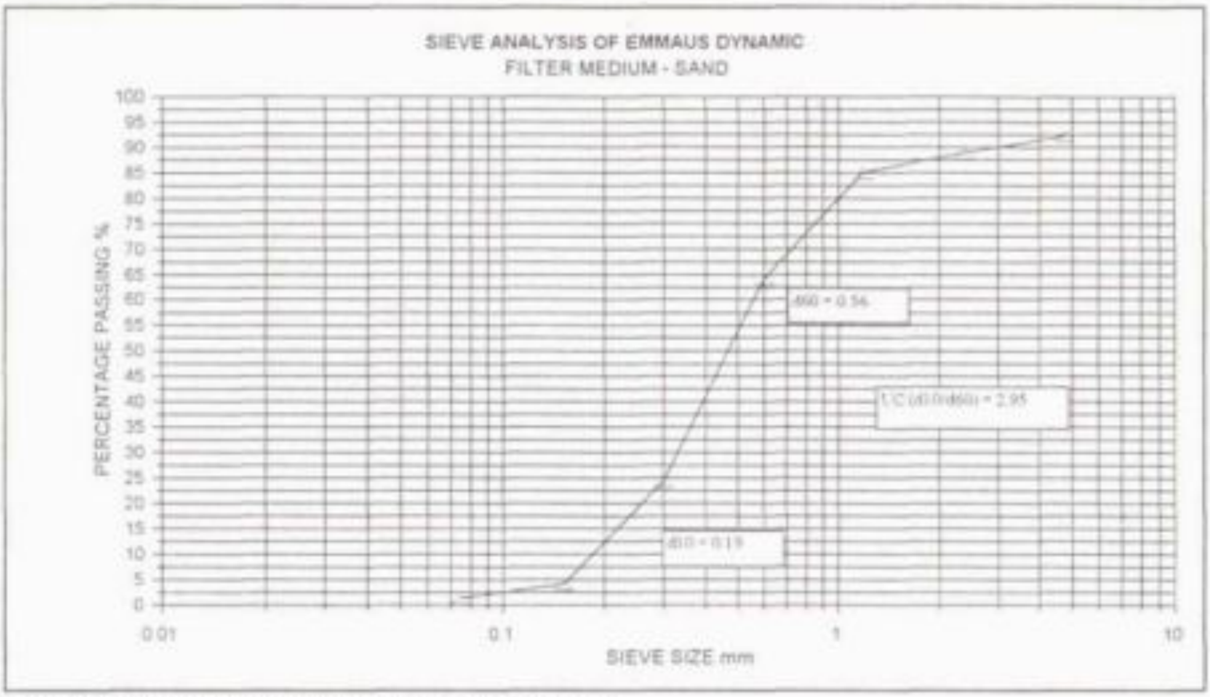

Figure 3.1 Sieve Analysis Curve for Filter Sand

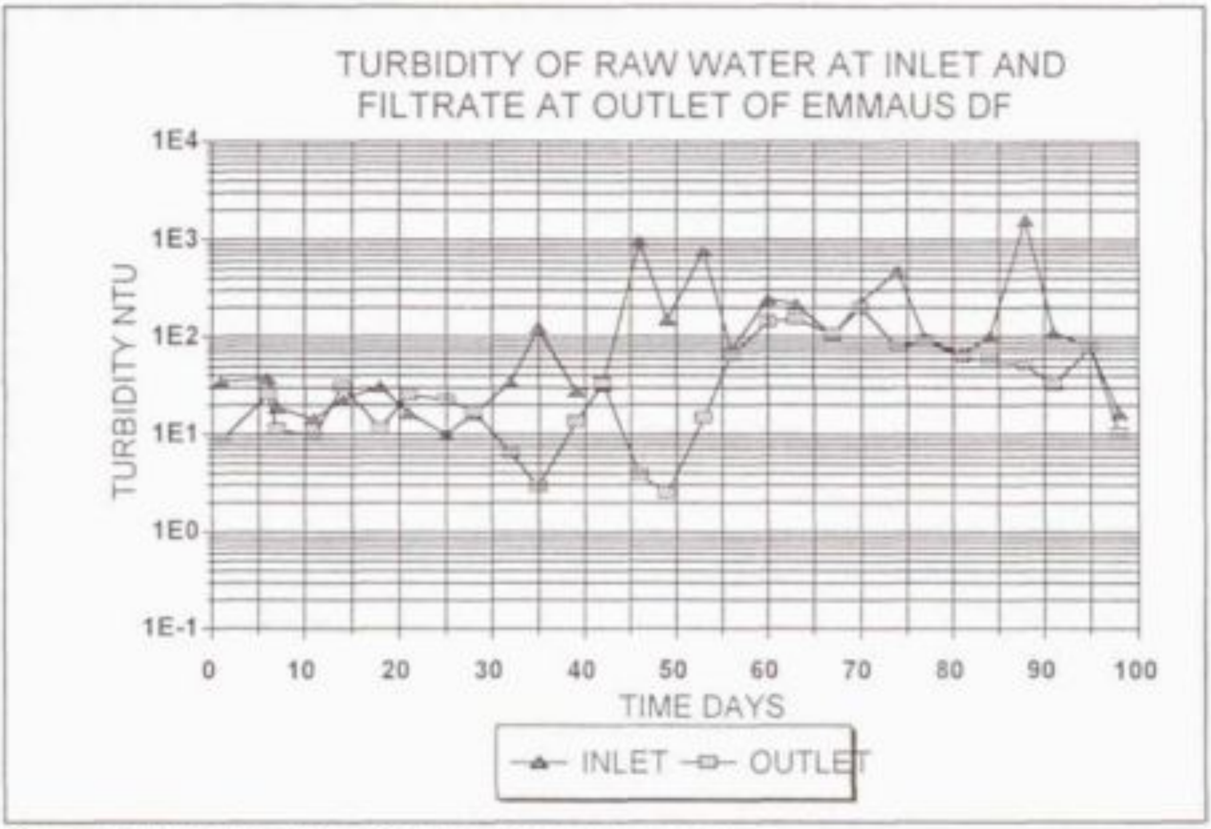

Figure 3.2 Turbidity of Raw & Filtrate Water (log scale)

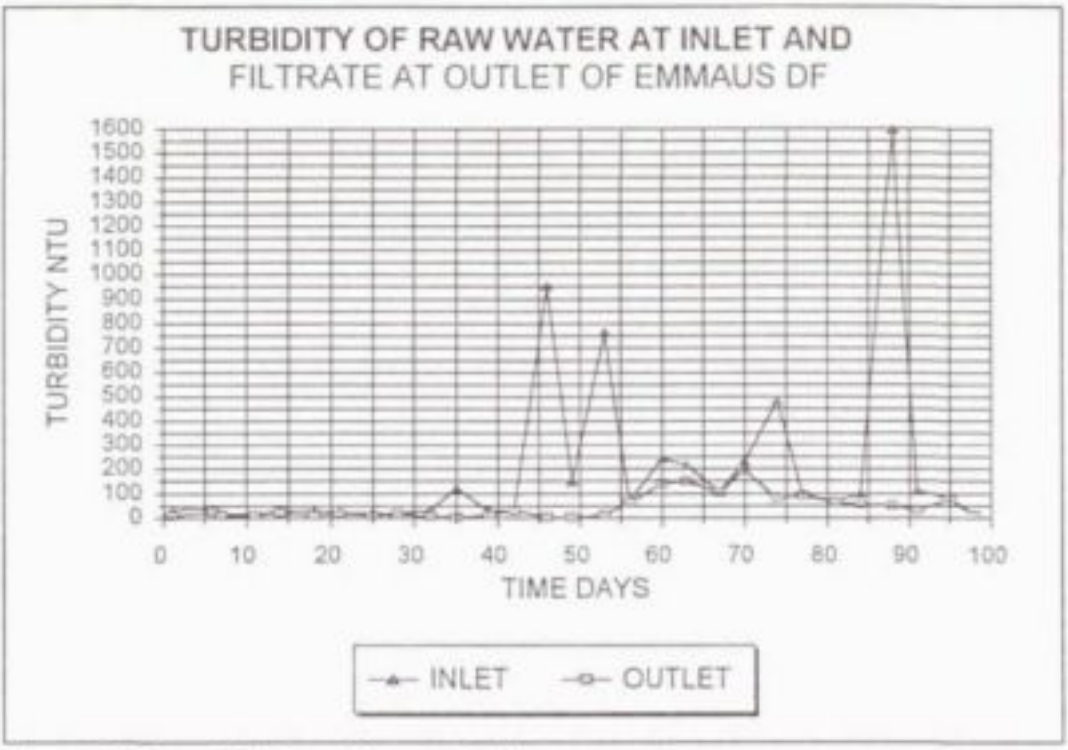

Figure 3.3 Raw & Filtrate Water Turbidity

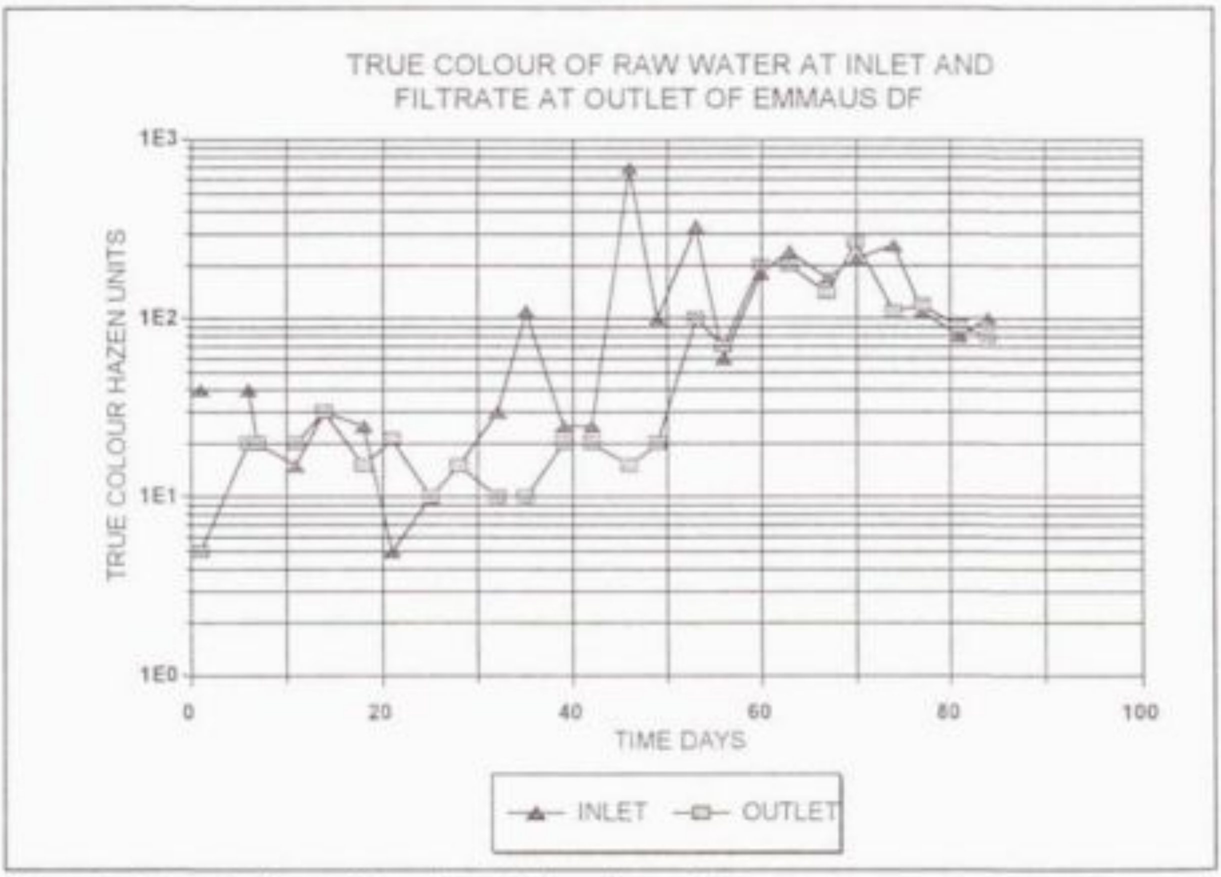

Figure 3.4 Raw & Filtrate Water True Colour (log scale)

six samples (21%) out of the twenty nine samples collected. Slow sand filters should be able to reduce turbidity to < 5 NTU generally (Visscher et al 1988). The raw water turbidity should preferably be less than 10 NTU and should exceed 50 NTU for only a few weeks and turbidities of 100-200 NTU can only be tolerated for a few days (van Dijk JK et al 1978). The same criteria would apply to dynamic filters and this suggests for this particular stream some form of pre-treatment is required in order to at least meet the recommended maximum allowable limit of turbidity although the target water quality range would be preferable. The DF however, demonstrated that it was able to cope well with the high turbidity peaks without loss of filter capacity as shown by the filtration rates (see fig 3.12). This was principally due to the daily cleaning operation carried out.

3.3 TRUE COLOUR

Appendix B 3 contains the tabulated results of true colour measurements obtained. Figures 3.4 and 3.5 graphically show these results. Appendix A3 contains a photograph that visually shows colour removal on day 88 (18^{th}-11-96).

The mean true colour values at the inlet for the raw water and the outlet for the effluent were 185.6 and 59.7 Hazen units (mg/ℓ Pt), respectively. The mean removal efficiency for true colour by the filter was 38%. This is at the lower end of the range for slow sand filters which is generally between 30 and 100% (Visscher et al 1988). From Figures 3.4 and 3.5 it is observed that the effluent colour curve tends to lag the raw water colour curve. The trend was similar to that of the turbidity curves indicating some relation between the two parameters.

The target water quality range is 15 mg/ℓ (DWAF 1996) and this limit was not exceeded in seven (24%) of the twenty nine effluent samples . The maximum limit for no risk is 20 mg/ℓ Pt (Aucamp PJ et al 1990, SABS 241-1984) and this limit was not exceeded in fifteen (52%) of the twenty nine effluent samples.

3.4 CORRELATION BETWEEN TRUE COLOUR AND TURBIDITY

The ordinary least squares method was used to find the correlation between true colour and turbidity for both the inlet and outlet samples. Colour was used as the independent variable. The tabulated results are in appendices B 4 and B 5 and these are graphically depicted in Figures 3.6 and 3.7.

The degree of correlation between colour and turbidity was high as expressed by correlation coefficients of 0.873 and 0.911 for both the raw water and filtrate, respectively. This suggests there is a relationship between the turbidity and true colour for this stream and explains the very similar trends of the turbidity and colour curves for the raw water and filter effluent. The removal of these two parameters in the raw water by the DF is affected by the frequent disturbance of the filter bed surface which checks the development of the *"schmutzdecke"*.

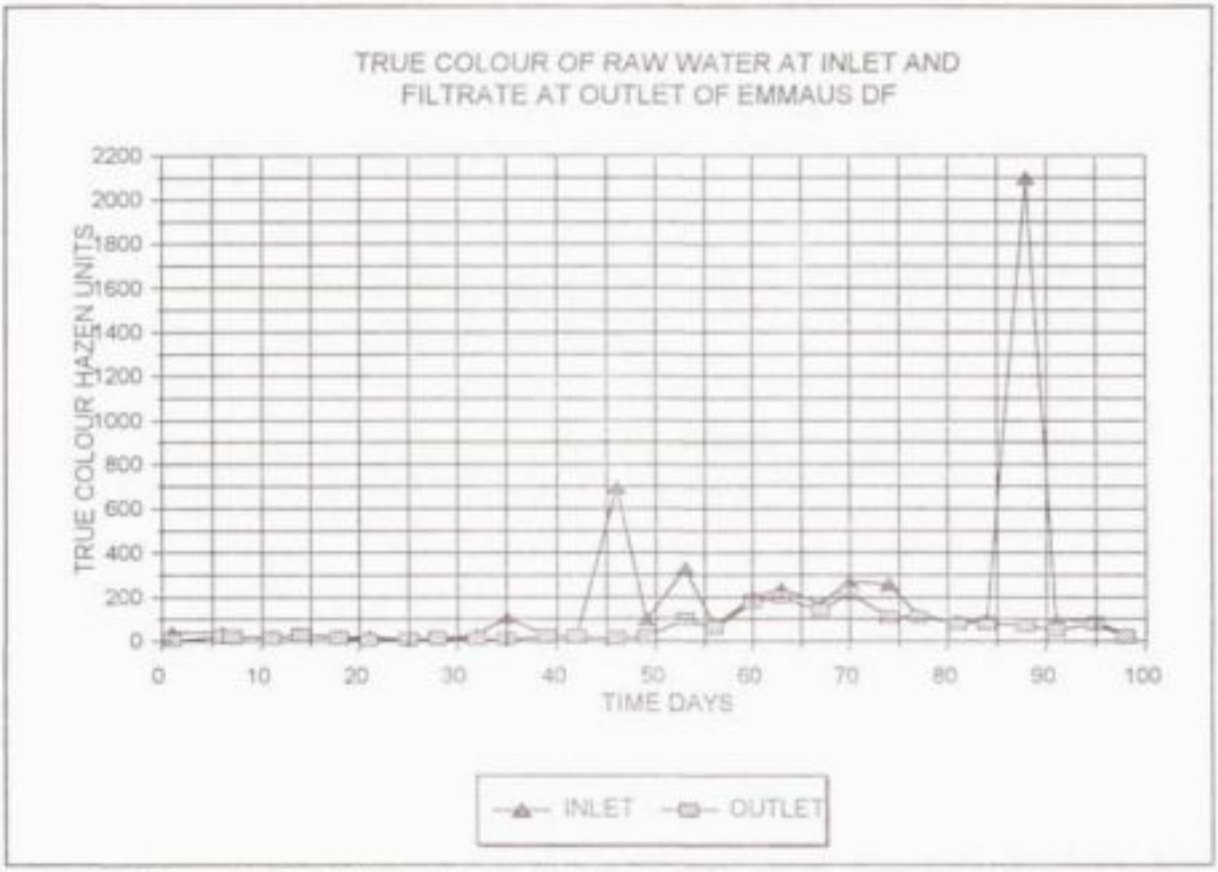

Figure 3.5 Raw & Filtered Water True Colour

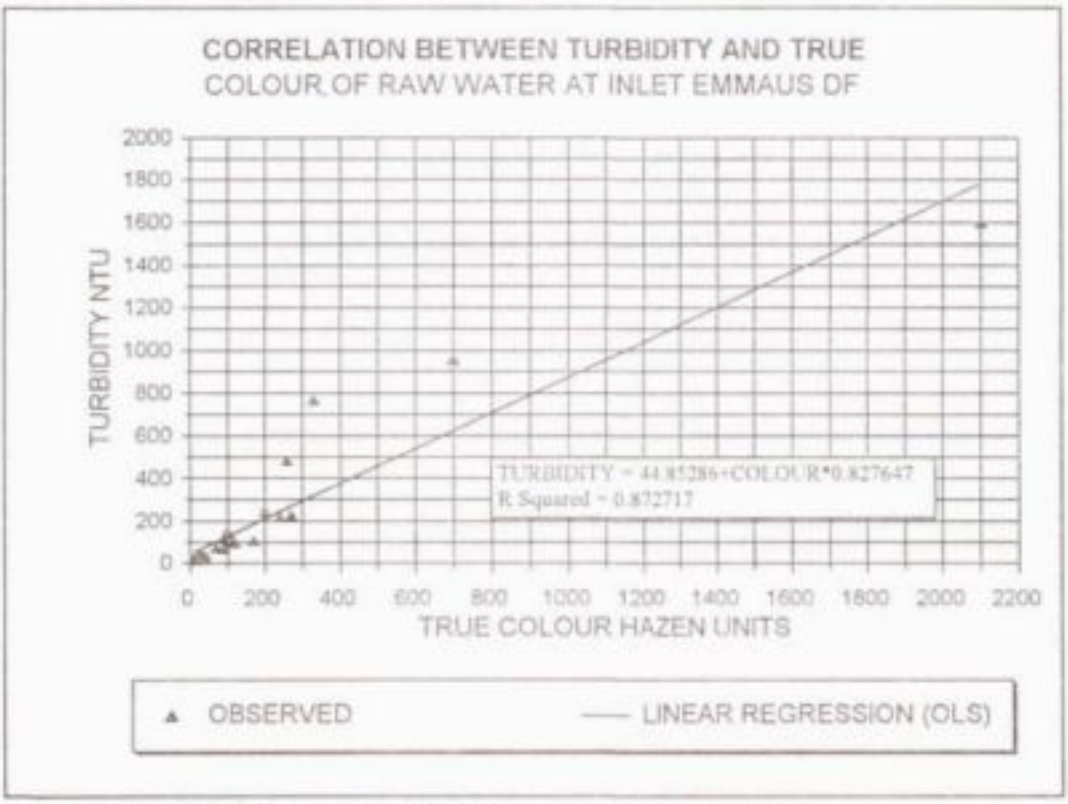

Figure 3.6 Correlation Turbidity & True Colour for Raw Water

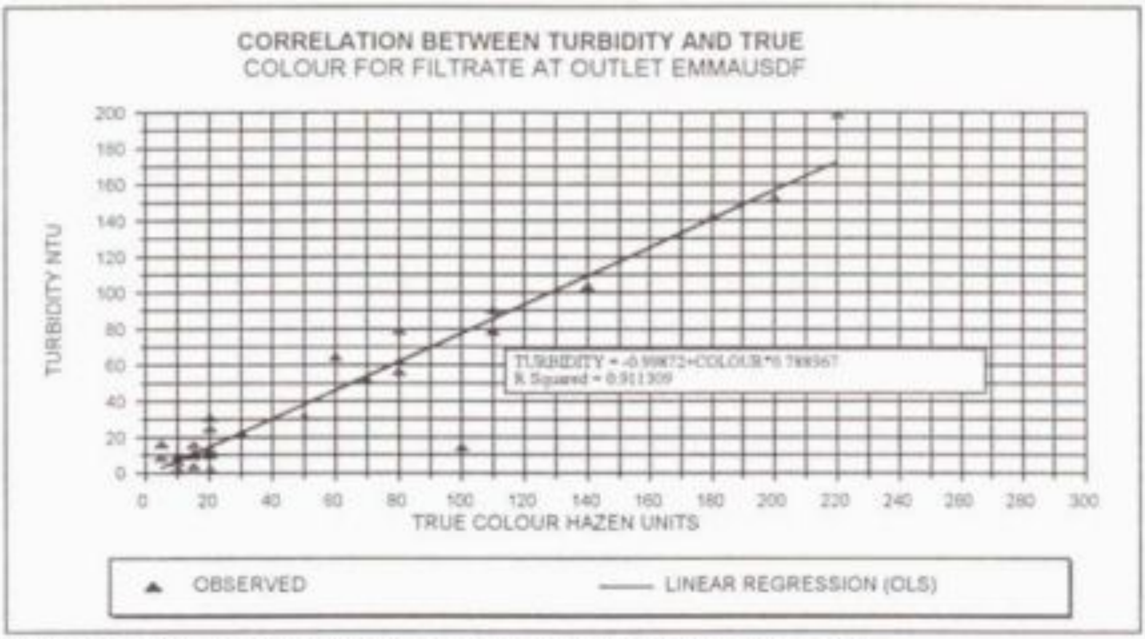

Figure 3.7 Correlation Between True Colour & Turbidity for Filtrate

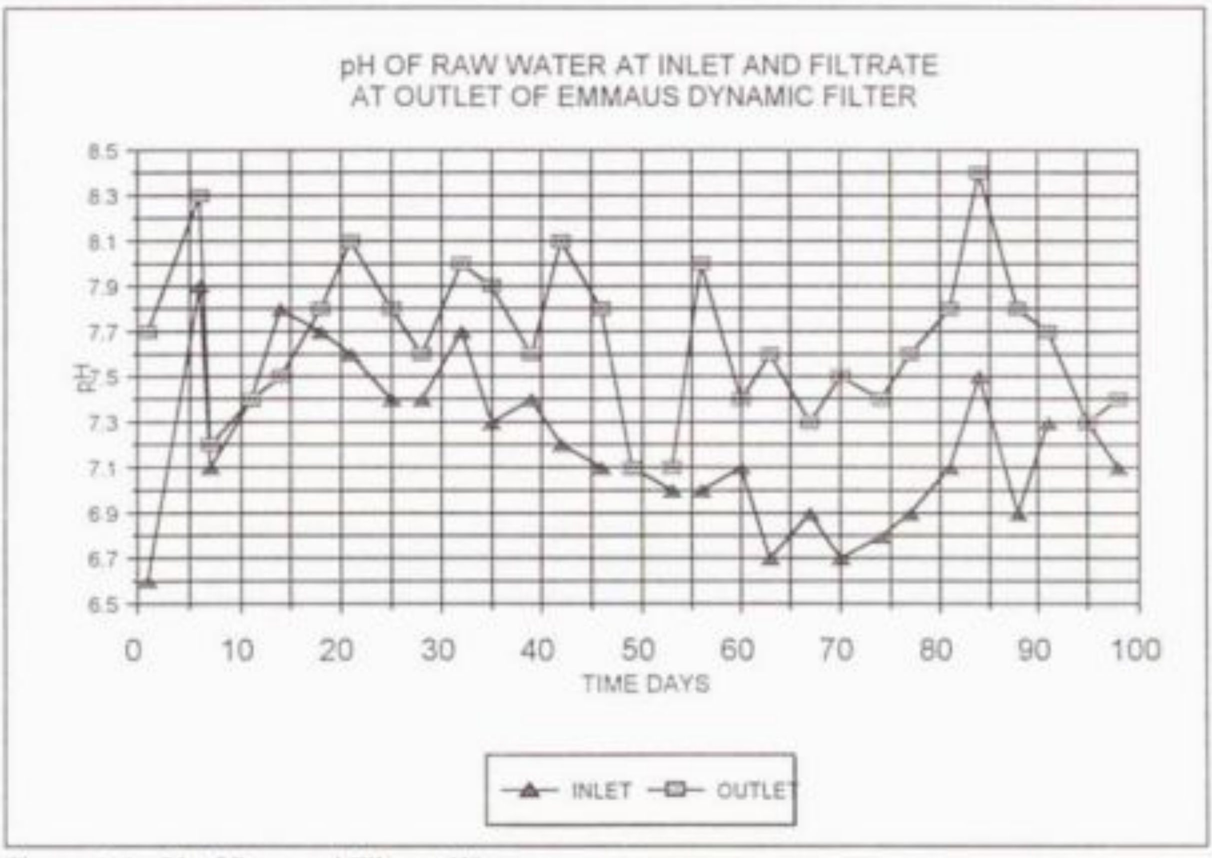

Figure 3.8 pH of Raw and Filtrate Water

3.5 pH

The pH measurements recorded are contained in appendix B 6 and Figure 3.8 shows these results graphically.

The mean and range of pH of the raw water was 7.2 and 6.6-7.9, respectively while for the effluent these values were 7.7 and 7.1-8.4. The filter generally enhanced the pH of the raw water as observed from Figure 3.9. This is in conformity with observations on slow sand filters and is as a result of the physico-chemical reactions occurring in the filter bed (Greaves GF et al 1988, Vochten P et al 1988).

The pH range of the filtered water was well within the target water quality range (DWAF 1996) which is also the maximum limit for no risk range of 6.0-9.0 (Aucamp PJ et al 1990, SABS 241-1984).

3.6 CONDUCTIVITY

Appendix B 7 contains the conductivity measurements which are graphically illustrated in Figure 3.9.

The mean and range of conductivity of the raw water was 7.9 and 5.0-14.0, respectively while for the effluent these values were 11.6 and 7.0-22.0. The filter generally enhanced the conductivity of the raw water as observed from Figure 3.9. This is in conformity with observations on slow sand filters and is as a result of the physico-chemical reactions occurring in the filter bed which result in an increase of the total dissolved solids (Greaves GF et al 1988, Vochten P et al 1988).

The conductivity range of the filtered water was within the target water quality range of 0-70 mS/m (DWAF 1996) and well below the maximum limit for no risk of 70 μS/m (Aucamp PJ et al 1990, SABS 241-1984).

3.7 FAECAL COLIFORM

The results of faecal coliform counts are tabulated in appendix B 8. These are graphically presented in Figures 3.10 and 3.11. No sampling was carried out between days 46 and 67 due to incubator problems and sampler kits. For six of the samples of raw water it was not possible to count the colonies because they were too numerous to count (TNTC) and therefore they are not recorded on the graphs. The laboratory facilities did not allow for aseptic dilution of the samples in order to get a count for such samples.

There was an increased attenuation of the faecal coliform density with filter run as observed from Figures 3.10 and 3.11. In particular, after day 28 the removal efficiencies improved to over 70%. Zero coliform counts were recorded for the effluent on four occasions over the 100 day sampling period. This indicated that development of the biological community particularly in the interstitial layer was progressively able to enhance the removal of faecal coliform. The filter appears to have matured within the period of

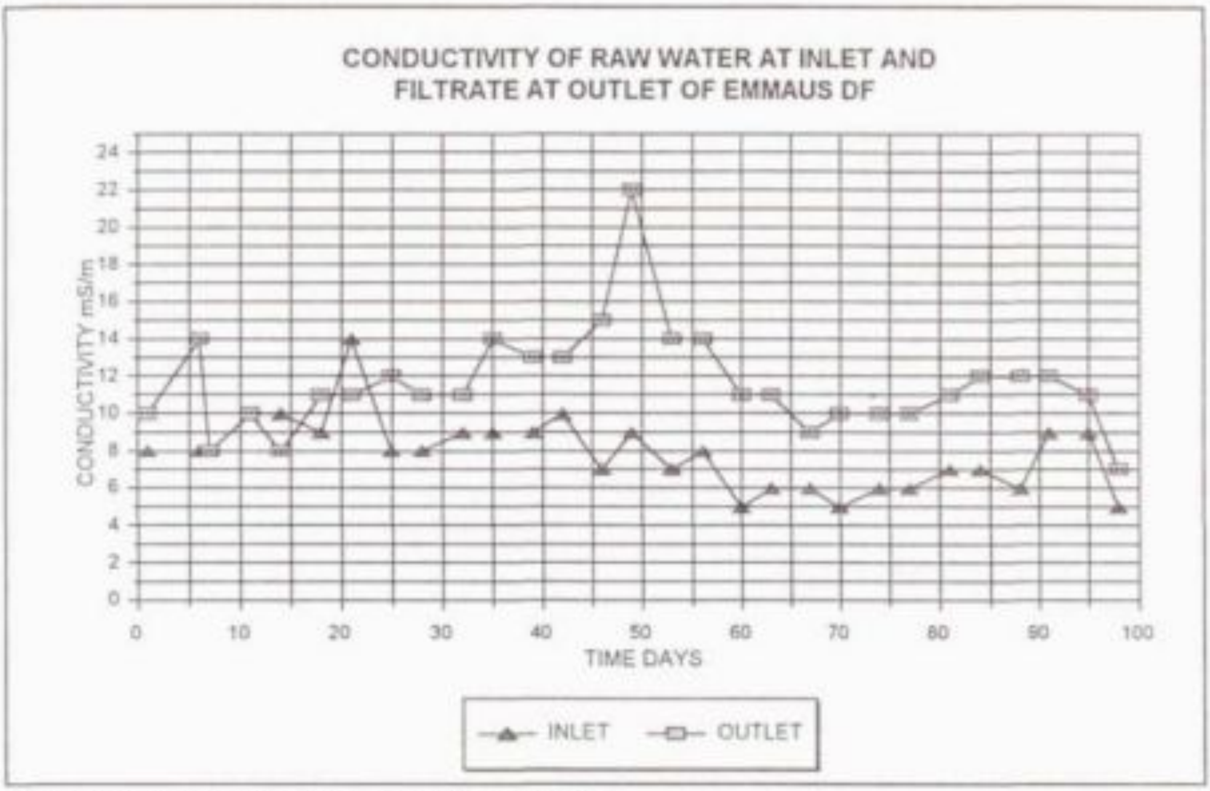

Figure 3.9 Raw & Filtered Water Conductivity

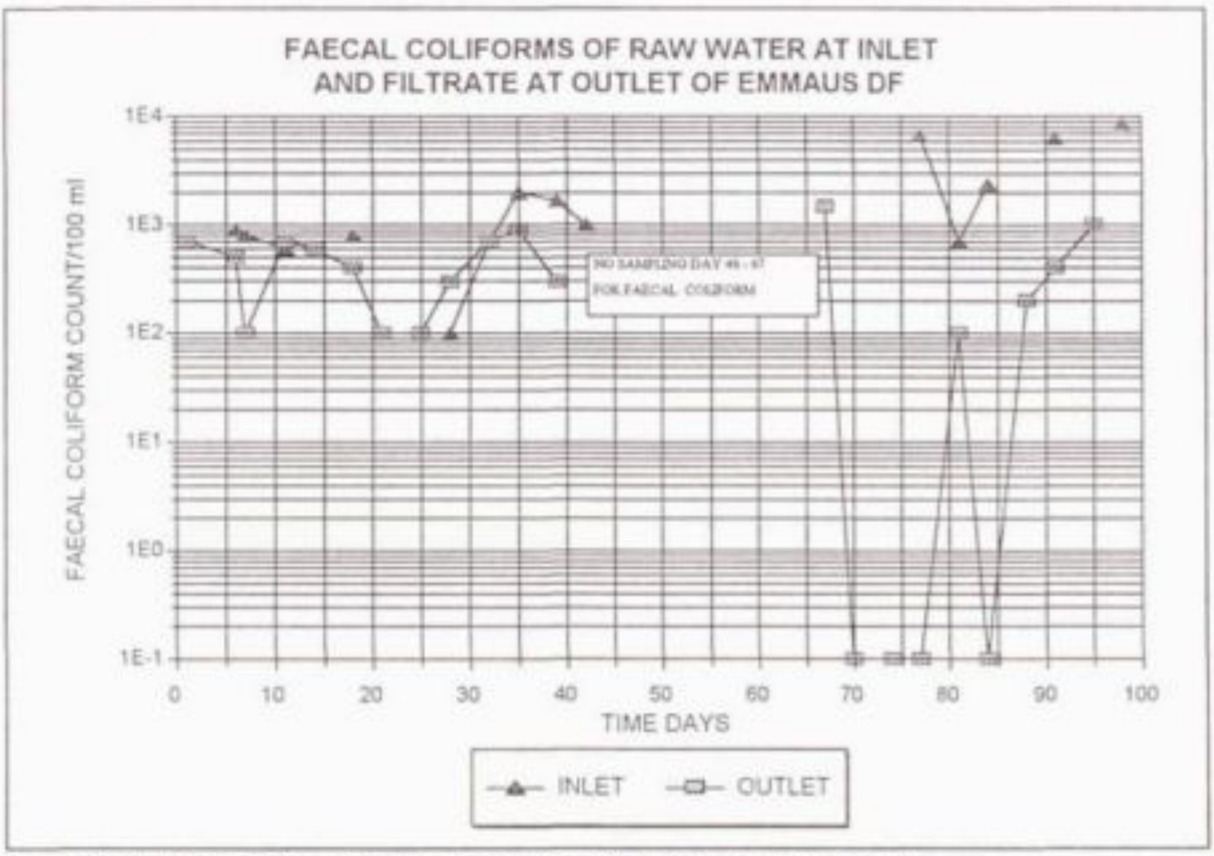

Figure 3.10 Raw & Filtered Water Faecal Coliform Densities (log scale)

the first four weeks although unfortunately, monitoring of faecal coliform was not possible between day 42 and 67. The initial ripening period has been generally recorded as three weeks and above depending on factors such as water quality, temperature, oxygen content and pH (Visscher et al 1988) for slow sand filters. However, the maturing of dynamic filters has been observed to be much faster by Solsona (1993).

SSF reduction of faecal coliform has been given as 95-100% (Visscher et al 1988, Ellis KV 1987, Huisman L et al 1974). Thus, the dynamic filter compares favourably with slow sand filters despite the regular raking of the top 20-30 mm of sand which disrupts the "*schmutzdecke*". Observations by Solsona (1993) in pilot plant studies, showed that the dynamic filter removal rates for faecal coloiform were comparable to a control slow sand filter.

The target water quality range (DWAF 1996) which is also the maximum limit for no risk is 0 counts /100 ml (Aucamp PJ et al 1990, SABS 241-1984) while the maximum limit for the low risk range recommended is 10 counts /100 ml (Aucamp PJ et al 1990). The filter effluent was able to meet both the former and latter limits in four samples (19%) of the twenty one samples collected. These results suggest that terminal disinfection is necessary to meet drinking water standards.

3.8 FLOW RATES AND FILTRATION RATES

The raw water, effluent and cross flow of raw water over the filter sand and the filtration rates through the sand are tabulated in appendix B 9. These are graphically shown in Figures 3.13 and 3.14.

The ratio of the cross flow to filtered water was 5:1 which is at the lower end of the suggested range of 5:1 to 15:1 (Solsona 1993) due to the low flow available from the stream. The mean filtration rate of the filtered water was 0.06 $m^3/m^2/h$ which was below the suggested range of 0.1 to 0.2 $m^3/m^2/h$ (Solsona 1993). However, this is adequate for the present demand and both units will have a filtration rate of 0.19 $m^3/m^2/h$ when the ultimate demand is reached.

The generally high turbidity peaks of the raw water during the monitoring period did not affect the filtration rates and hence the filter capacity.

3.9 OPERATION AND MAINTENANCE

3.9.1 Operation

The simple layout of the plant made it easy for the operator to understand the procedures for commissioning the filter and the normal operation. No problems were encountered and flow regulation was done at valves A.

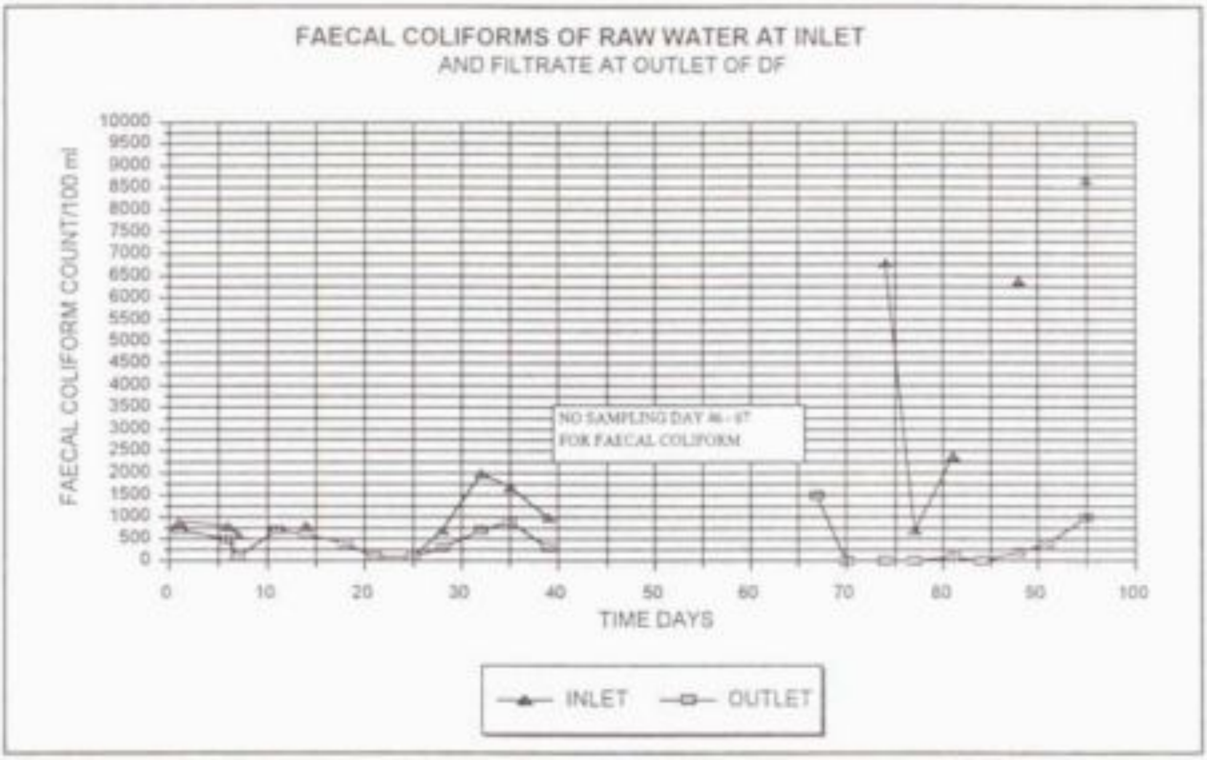

Figure 3.11 Raw & Filtered Water Faecal Coliform Densities

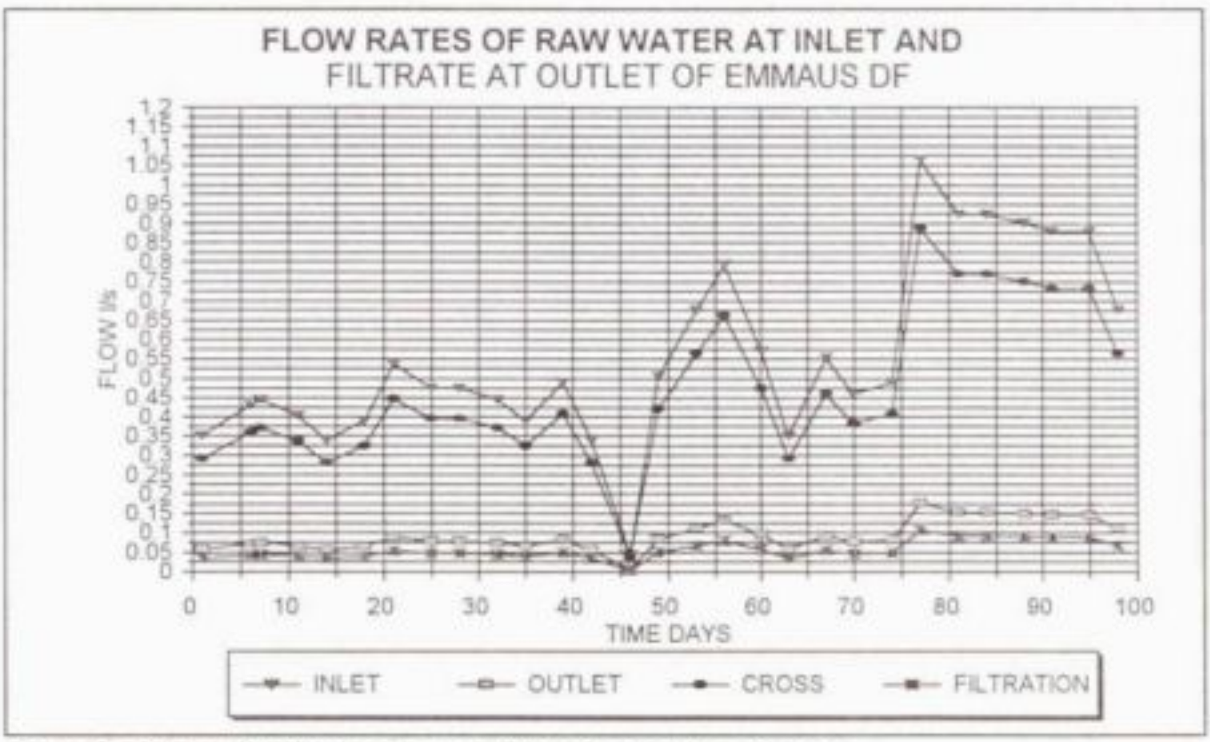

Figure 3.12 Flow & Filtration Rates of Water in the Dynamic Filter

3.9.2 Maintenance

Daily Cleaning of the Filters
This was an easy and straight forward raking operation for the plant operator that took about twenty minutes a day to complete.

Seasonal Cleaning of the Filters
This operation was not carried out because it was not necessary. This is a major cleaning operation which would require extra labour. This operation can be simplified by replacing all the sand with new sand. However, the dynamic filter does have the advantage in that this operation is requiresd less frequently compared to a slow sand filter.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

4.1.1 The river sand purchased locally was suitable for use as filtration medium in the dynamic filter as observed from the parameters obtained from sieve analysis. This was an advantage because it is cheaper than graded sand.

4.1.2 The dynamic filter was able to significantly remove high levels of turbidity in the raw water. It tolerated high levels of turbidity well, without much loss of filter capacity due to the daily cleaning process. However, the high turbidity values obtained during the summer rains suggest that pre-treatment is necessary in order for the filter to produce effluent that consistently meets the maximum limit for the low risk value of 10 NTU.

4.1.3 Although the filter was able to remove the true colour in 52% of the samples to below the low risk value, the removal rate was on the lower end of the range for slow sand filters. The high degree of correlation between turbidity and true colour and the similar trends of their levels in the raw and filtered water suggests a relationship between turbidity and colour.

4.1.4 For the dynamic filter, the daily cleaning process of raking the filter bed surface affects the removal of turbidity and colour as evidenced by the fluctuating levels of these parameters in the effluent. In matured bed conditions, the fluctuations of levels of these parameters in the effluent are much less in slow sand filters. This suggests that the *"schmutzdecke"* plays a major role in the removal of these two parameters.

4.1.5 The enhancement of the pH and increase of conductivity in effluent from the dynamic filter is similar to what has been observed in slow sand filters indicating the similar reactions which occur within the filter bed.

4.1.6 From the faecal coliform colony counts of raw water from Situnzini stream, the river is highly bacteriologically contaminated and unsuitable for drinking water. The dynamic filter was able to significantly reduce these at rates similar to slow sand filters. Despite the frequent disturbance of the sand bed during the raking operation, the dynamic filter was able to reach maturation in a comparable period to slow sand filters.

4.1.7 The operation and maintenance procedures of the filter are simple and straightforward and the operator understood and followed them.

4.1.8 The major advantages of the dynamic filter are long filter runs, its ability to tolerate high turbidity peaks and ease of operation and maintenance. Thus, the dynamic filter is an alternative to the slow sand filter in those situations where there is adequate water for crossflow and the topography is suitable to divert water by gravity to a filter near by.

4.2 RECOMMENDATIONS

4.2.1 A long term monitoring programme to obtain more data is recommended in order to obtain more information on operation and maintenance requirements and to refine the design guidelines. For the information to be relevant and useful, more dynamic filters need to be constructed, monitored and the data analysed.

4.2.2 Terminal disinfection is always recommended in order to ensure safe drinking water and to maintain a residual disinfection capacity in the water in the distribution system.

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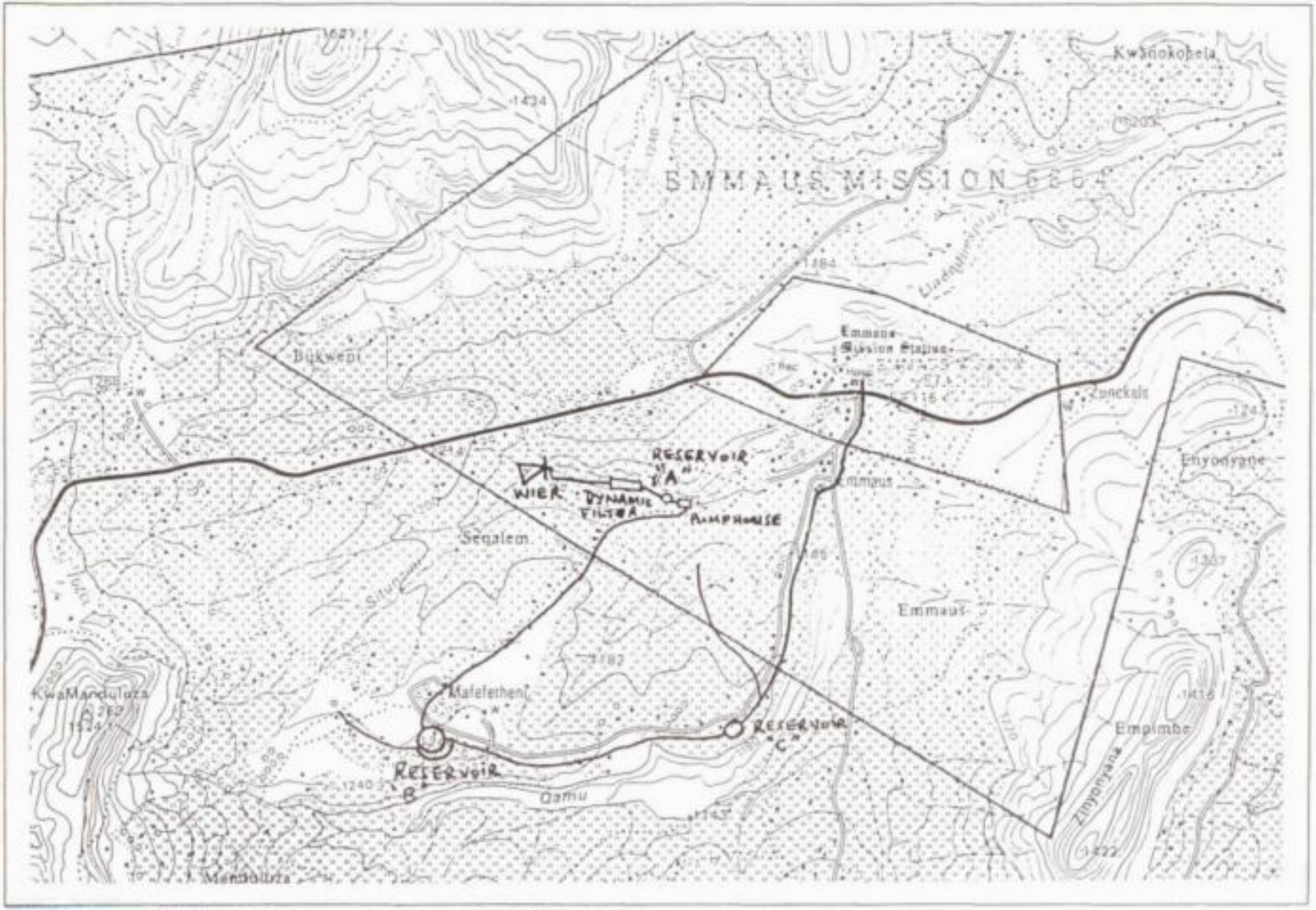
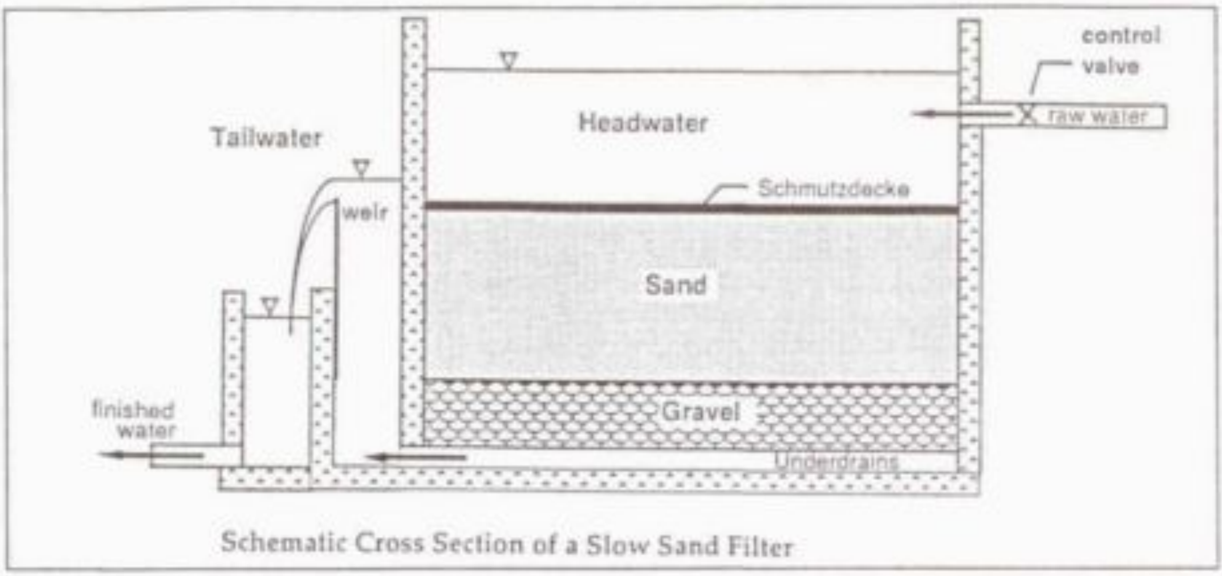
APPENDICES

APPENDIX A1
LOCATION & LAYOUT OF THE PROJECT

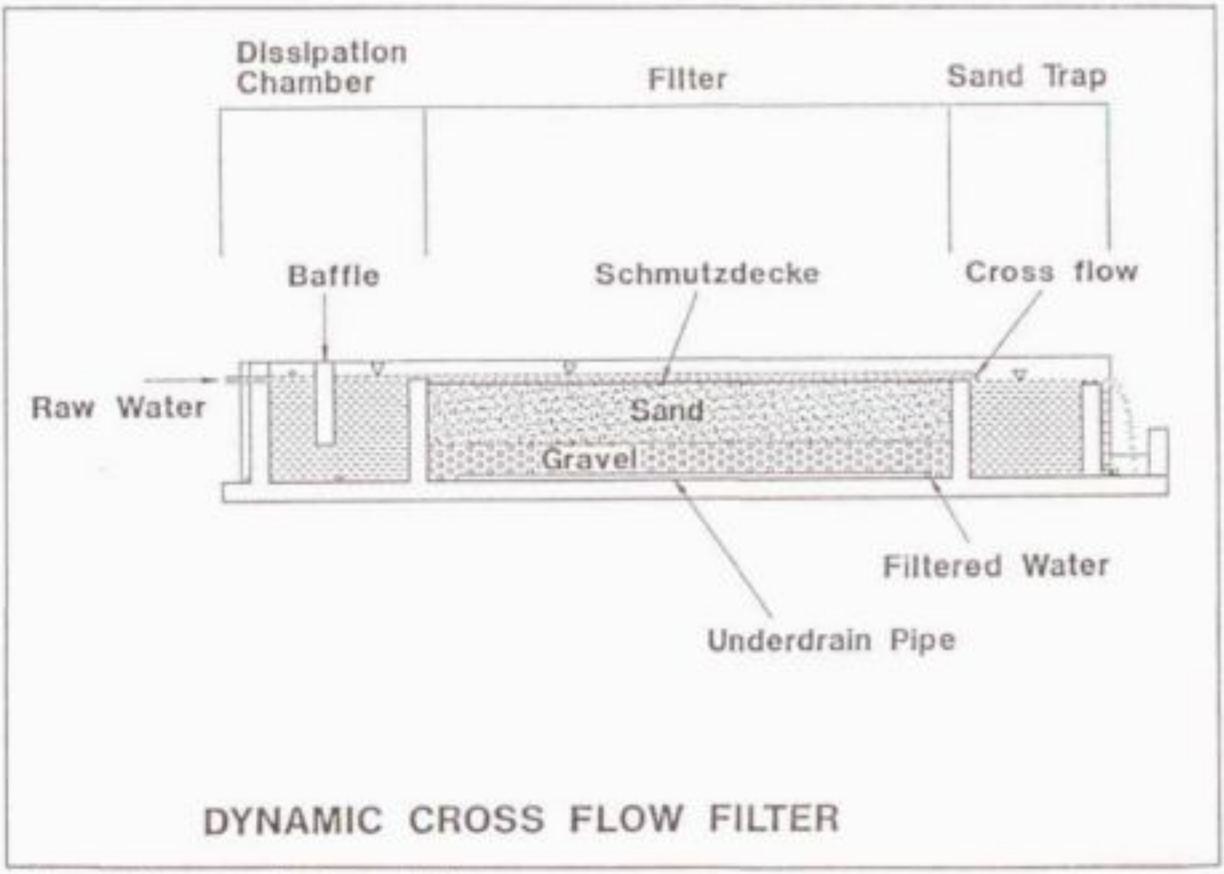


The Emmaus Vulindelela Water Project Layout (2829CD ZUNKELS)

APPENDIX A2
SCHEMATIC DRAWINGS OF A SLOW SAND FILTER AND A DYNAMIC FILTER



Schematic Section of a Slow Sand Filter

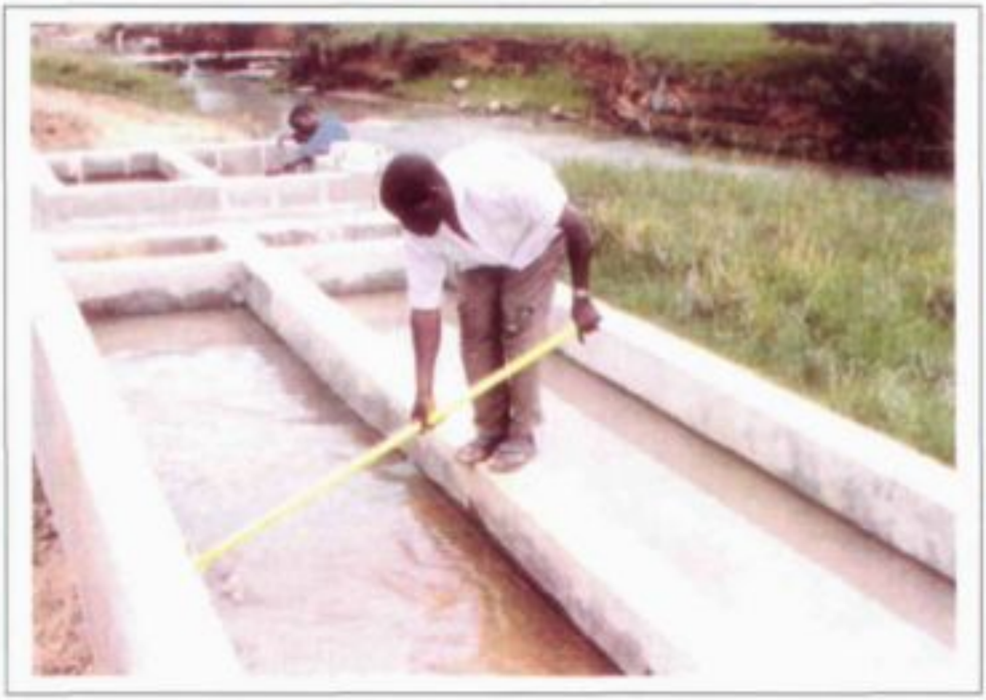


Schematic Section of a Dynamic Filter

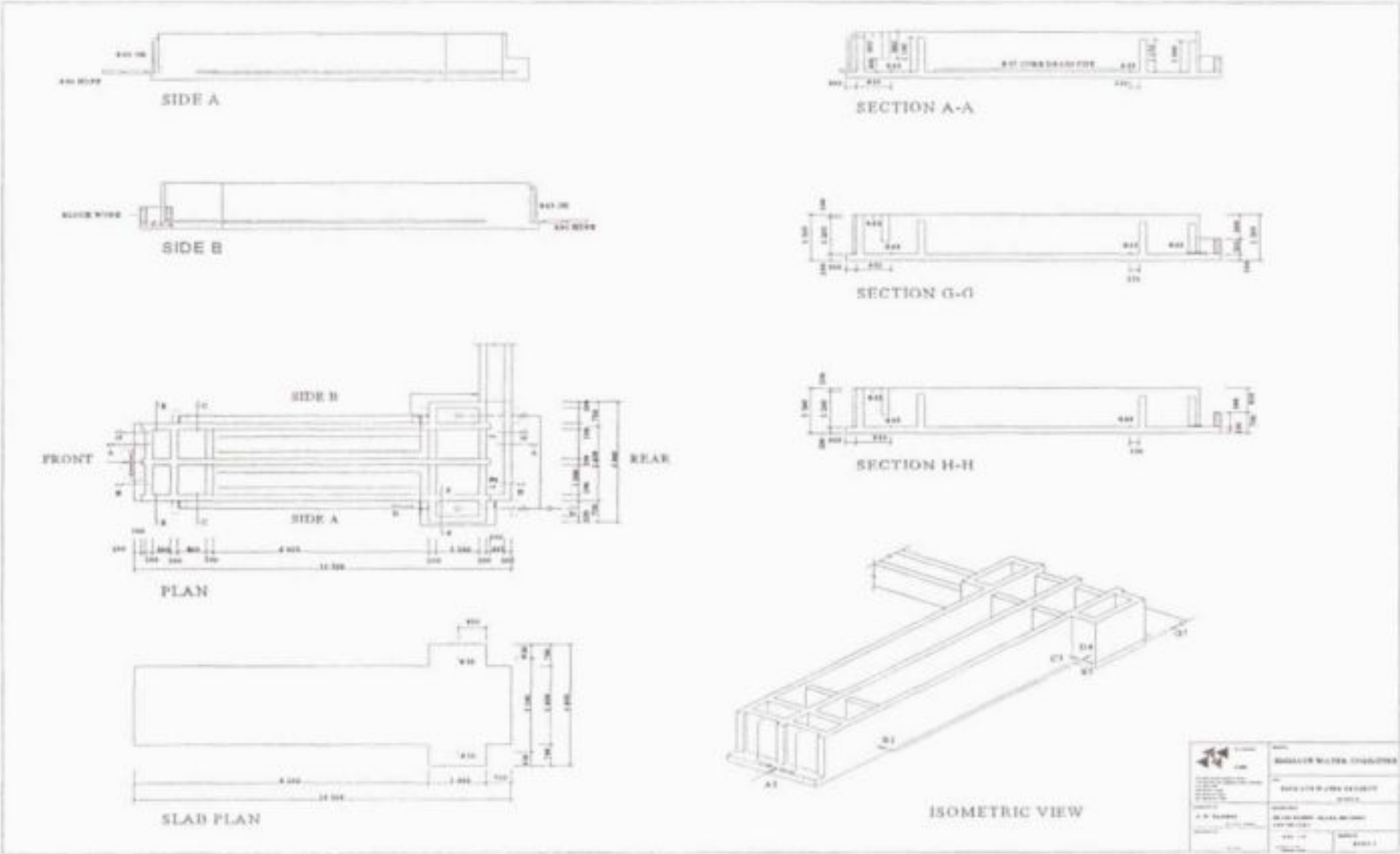
APPENDIX A3
PHOTOGRAPHS & DRAWINGS OF THE EMMAUS DYNAMIC FILTER

Emmaus Dynamic Filter

Colour removal by the Dynamic Filter on 18/11/96-r - filtrate, raw water



Sampling at Inlet and Daily Cleaning of the Dynamic Filter



Plan, Side and Section Elevations of the Emmaus Dynamic Filter

APPENDIX B1

SIEVE ANALYSIS OF EMMAUS DYNAMIC FILTER MEDIUM - RIVER SAND

SABS TEST METHOD 829:1994

Total mass of sand: 597 grams

Fineness modulus of sand: 2.40

Comments on sizes	Sieve Size (micron)	Individual mass retained (g)	Individual percentage retained (%)	Cumulative percentage retained (4750 to 150 (micron sieves)	Percentage material that passed (%)
Bigger than 4.75 mm	4.75	46.1	7.7	7.7	92.3
Bigger than 2.36 smaller than 4.75 mm	2.36	20	3.4	11.1	88.9
Bigger than 1.18 smaller than 2.36 mm	1.18	23	3.9	14.9	85.1
Bigger than 0.6 smaller than 1.18 mm	0.6	124.4	20.8	35.8	64.2
Bigger than 0.3 smaller than 0.6 mm	0.3	237.4	39.8	75.5	24.5
Bigger than 0.15 smaller than 0.3 mm	0.15	121.4	20.3	95.9	4.1
Bigger than 0.075 smaller than 0.15 mm	0.075	16.2	2.7	98.6	1.4
Smaller than 0.075 mm (dust in pan)	<0.075	7.4	1.2	99.8	0.2
	Checks:	595.9	99.8		

PARAMETER	SAMPLE VALUE		RECOMMENDED VALUE
d10	0.19		0.15 - 0.35
d60	0.56		
UC = d60/d10 (Uniformity Coefficient)	2.95		< 3

APPENDIX B2
TURBIDITY MEASUREMENTS OF RAW WATER AT INLET AND FILTRATE AT OUTLET OF THE EMMAUS DYNAMIC FILTER

DATE	DAY	TIME	INLET TURBIDITY NTU	OUTLET TURBIDITY NTU	% REMOVAL	COMMENTS
23-08-96	1	11:50	34.1	8.9	74.0	
28-08-96	6	12:00	37.7	25.7	31.8	
29-08-96	7	13:13	18.9	11.3	40.2	
02-09-96	11	13:15	14.4	9.9	31.3	
05-09-96	14	13:33	22.7	30.6	(34.8)	
09-09-96	18	11:34	31.1	11.5	63.0	
12-09-96	21	11:50	16.6	25.5	(53.6)	
16-09-96	25	14:40	10.1	22.4	(121.8)	
19-09-96	28	14:50	16.3	17.4	(6.7)	
23-09-96	32	14:47	34.0	6.5	81.0	
26-09-96	35	14:02	123.0	2.9	97.6	
30-09-96	39	10:05	28.3	13.6	51.9	
03-10-96	42	10:05	31.5	33.1	(5.1)	
07-10-96	46	16:22	958.0	3.9	99.6	Rain storm
10-10-96	49	13:38	150.0	2.5	98.4	
14-10-96	53	11:40	767.0	14.8	98.1	
17-10-96	56	15:40	72.7	65.1	10.5	
21-10-96	60	11:20	245.0	143.0	41.6	
24-10-96	63	11:20	217.0	153.0	29.5	
28-10-96	67	15:00	104.0	106.0	(1.9)	
31-10-96	70	15:30	230.0	199.0	13.5	
04-11-96	74	14:30	484.0	79.2	83.6	
07-11-96	77	09:20	96.6	90.8	6.0	
11-11-96	81	16:00	68.1	62.4	8.4	
14-11-96	84	13:05	101.0	57.0	43.6	
18-11-96	88	11:27	1,600.0	52.1	96.7	Rain storm
21-11-96	91	14:15	112.0	32.0	71.4	
25-11-96	95	09:30	80.0	79.4	0.8	
28-11-96	98	10:00	16.4	10.4	36.6	
TOTAL			5,720.5	1,369.8	985.2	
MIN			10.1	2.5	(121.8)	
MAX			1,600.0	199.0	99.6	
MEAN			197.3	47.2	34.0	
STDS			350.4	50.4	51.5	
N			29.0	29.0	29.0	

APPENDIX B3
TRUE COLOUR MEASUREMENTS OF RAW WATER AT INLET AND FILTRATE AT OUTLET OF THE EMMAUS DYNAMIC FILTER

DATE	DAY	TIME	INLET TRUE COLOUR HAZEN UNITS	OUTLET TRUE COLOUR HAZEN UNITS	% REMOVAL	COMMENTS
23-08-96	1	11:50	40	5	87.5	
28-08-96	6	12:00	40	20	50.0	
29-08-96	7	13:13	20	20	0.0	
02-09-96	11	13:15	15	20	(33.3)	
05-09-96	14	13:33	30	30	0.0	
09-09-96	18	11:34	25	15	40.0	
12-09-96	21	11:50	5	21	(320.0)	
16-09-96	25	14:40	10	10	0.0	
19-09-96	28	14:50	15	15	0.0	
23-09-96	32	14:47	30	10	66.7	
26-09-96	35	14:02	110	10	90.9	
30-09-96	39	10:05	25	20	20.0	
03-10-96	42	10:05	25	20	20.0	
07-10-96	46	16:22	700	15	97.9	
10-10-96	49	13:38	100	20	80.0	
14-10-96	53	11:40	330	100	69.7	
17-10-96	56	15:40	60	70	(16.7)	
21-10-96	60	11:20	180	200	(11.1)	
24-10-96	63	11:20	240	200	16.7	
28-10-96	67	15:00	170	140	17.6	
31-10-96	70	15:30	220	270	(22.7)	
04-11-96	74	14:30	260	110	57.7	
07-11-96	77	09:20	110	120	(9.1)	
11-11-96	81	16:00	80	90	(12.5)	
14-11-96	84	13:05	100	80	20.0	
18-11-96	88	11:27	2,100	70	96.7	
21-11-96	91	14:15	100	50	50.0	
25-11-96	95	09:30	80	90	(12.5)	
28-11-96	98	10:00	30	20	33.3	
TOTAL			5,250.0	1,861.0	476.7	
MIN			5.0	5.0	(320.0)	
MAX			2,100.0	270.0	97.9	
MEAN			181.0	64.2	16.4	
STDS			395.2	68.0	75.7	
N			29.0	29.0	29.0	

APPENDIX B4
CORRELATION BETWEEN TRUE COLOUR AND TURBIDITY OF RAW WATER AT INLET OF EMMAUS DYNAMIC FILTER

DATE	DAY	TIME	INLET TRUE COLOUR HAZEN UNITS	INLET TURBIDITY NTU	CALCULATED TURBIDITY NTU
23-08-96	1	11:50	40.0	34.1	80.4
28-08-96	6	12:00	40.0	37.7	80.4
29-08-96	7	13:13	20.0	18.9	63.8
02-09-96	11	13:15	15.0	14.4	59.7
05-09-96	14	13:33	30.0	22.7	72.1
09-09-96	18	11:34	25.0	31.1	68.0
12-09-96	21	11:50	5.0	16.6	51.4
16-09-96	25	14:40	10.0	10.1	55.5
19-09-96	28	14:50	15.0	16.3	59.7
23-09-96	32	14:47	30.0	34.0	72.1
26-09-96	35	14:02	110.0	123.0	138.4
30-09-96	39	10:05	25.0	28.3	68.0
03-10-96	42	10:05	25.0	31.5	68.0
07-10-96	46	16:22	700.0	958.0	627.3
10-10-96	49	13:38	100.0	150.0	130.1
14-10-96	53	11:40	330.0	767.0	320.7
17-10-96	56	15:40	60.0	72.7	97.0
21-10-96	60	11:20	180.0	245.0	196.4
24-10-96	63	11:20	240.0	217.0	246.1
28-10-96	67	15:00	170.0	104.0	188.1
31-10-96	70	15:30	220.0	230.0	229.5
04-11-96	74	14:30	260.0	484.0	262.7
07-11-96	77	09:20	110.0	96.6	138.4
11-11-96	81	16:00	80.0	68.1	113.5
14-11-96	84	13:05	100.0	101.0	130.1
18-11-96	88	11:27	2,100.0	1,600.0	1,787.4
21-11-96	91	14:15	100.0	112.0	130.1
25-11-96	95	09:30	80.0	80.0	113.5
28-11-96	98	10:00	30.0	16.3	72.1

Regression Output:		
Constant		47.241372
Std Err of Y Est		126.88875
R Squared		0.8735277
No. of Observations		29
Degrees of Freedom		27
X Coefficient(s)	0.8286477	
Std Err of Coef.	0.0606802	

APPENDIX B5
CORRELATION BETWEEN TRUE COLOUR AND TURBIDITY OF FILTRATE AT OUTLET OF EMMAUS DYNAMIC FILTER

DATE	DAY	TIME	OUTLET TRUE COLOUR HAZEN UNITS	OUTLET TURBIDITY NTU	CALCULATED TURBIDITY NTU
23-08-96	1	11:50	5	8.9	5.0
28-08-96	6	12:00	20	25.7	15.7
29-08-96	7	13:13	20	11.3	15.7
02-09-96	11	13:15	20	9.9	15.7
05-09-96	14	13:33	30	30.6	22.8
09-09-96	18	11:34	15	11.5	12.1
12-09-96	21	11:50	21	25.5	16.4
16-09-96	25	14:40	10	22.4	8.6
19-09-96	28	14:50	15	17.4	12.1
23-09-96	32	14:47	10	6.5	8.6
26-09-96	35	14:02	10	2.9	8.6
30-09-96	39	10:05	20	13.6	15.7
03-10-96	42	10:05	20	33.1	15.7
07-10-96	46	16:22	15	3.9	12.1
10-10-96	49	13:38	20	2.5	15.7
14-10-96	53	11:40	100	14.8	72.8
17-10-96	56	15:40	70	65.1	51.4
21-10-96	60	11:20	200	143.0	144.2
24-10-96	63	11:20	200	153.0	144.2
28-10-96	67	15:00	140	106.0	101.4
31-10-96	70	15:30	270	199.0	194.2
04-11-96	74	14:30	110	79.2	79.9
07-11-96	77	09:20	120	90.8	87.1
11-11-96	81	16:00	90	62.4	65.7
14-11-96	84	13:05	80	57.0	58.5
18-11-96	88	11:27	70	52.1	51.4
21-11-96	91	14:15	50	32.0	37.1
25-11-96	95	09:30	90	79.4	65.7
28-11-96	98	10:00	20	10.4	15.7

Regression Output:		
Constant		1.4266199
Std Err of Y Est		13.696818
R Squared		0.9287641
No. of Observations		29
Degrees of Freedom		27
X Coefficient(s)	0.713798	
Std Err of Coef.	0.0380443	

APPENDIX B6

pH MEASUREMENTS OF RAW WATER AT INLET AND FILTRATE AT OUTLET OF THE EMMAUS DYNAMIC FILTER

DATE	DAY	TIME	INLET pH	OUTLET pH	% INCREASE pH	COMMENTS
23-08-96	1	11:50	6.6	7.7	16.7	
28-08-96	6	12:00	7.9	8.3	5.1	
29-08-96	7	13:13	7.1	7.2	1.4	
02-09-96	11	13:15	7.4	7.4	0.0	
05-09-96	14	13:33	7.8	7.5	(3.8)	
09-09-96	18	11:34	7.7	7.8	1.3	
12-09-96	21	11:50	7.6	8.1	6.6	
16-09-96	25	14:40	7.4	7.8	5.4	
19-09-96	28	14:50	7.4	7.6	2.7	
23-09-96	32	14:47	7.7	8.0	3.9	
26-09-96	35	14:02	7.3	7.9	8.2	
30-09-96	39	10:05	7.4	7.6	2.7	
03-10-96	42	10:05	7.2	8.1	12.5	
07-10-96	46	16:22	7.1	7.8	9.9	
10-10-96	49	13:38	7.1	7.1	0.0	
14-10-96	53	11:40	7.0	7.1	1.4	
17-10-96	56	15:40	7.0	8.0	14.3	
21-10-96	60	11:20	7.1	7.4	4.2	
24-10-96	63	11:20	6.7	7.6	13.4	
28-10-96	67	15:00	6.9	7.3	5.8	
31-10-96	70	15:30	6.7	7.5	11.9	
04-11-96	74	14:30	6.8	7.4	8.8	
07-11-96	77	09:20	6.9	7.6	10.1	
11-11-96	81	16:00	7.1	7.8	9.9	
14-11-96	84	13:05	7.5	8.4	12.0	
18-11-96	88	11:27	6.9	7.8	13.0	
21-11-96	91	14:15	7.3	7.7	5.5	
25-11-96	95	09:30	7.3	7.3	0.0	
28-11-96	98	10:00	7.1	7.4	4.2	
TOTAL			209.0	222.2	187.1	
MIN			6.6	7.1	(3.8)	
MAX			7.9	8.4	16.7	
MEAN			7.2	7.7	6.5	
STDS			0.3	0.3	5.2	
N			29.0	29.0	29.0	

APPENDIX B7
CONDUCTIVITY MEASUREMENTS OF RAW WATER AT INLET AND FILTRATE AT OUTLET OF THE EMMAUS DYNAMIC FILTER

DATE	DAY	TIME	INLET CONDUCTIVITY mS/m	TEMPERATURE CELSIUS	OUTLET CONDUCTIVITY mS/m	TEMPERATURE CELSIUS	% INCREASE CONDUCTIVITY	COMMENTS
23-08-96	1	11:50	8	22.8	10	22.8	25.0	
28-08-96	6	12:00	8	22.9	14	22.9	75.0	
29-08-96	7	13:13	8	22.9	8	22.9	0.0	
02-09-96	11	13:15	10	22.9	10	23.1	0.0	
05-09-96	14	13:33	10	23.2	8	23.3	(20.0)	
09-09-96	18	11:34	9	23.3	11	23.2	22.2	
12-09-96	21	11:50	14	23.0	11	23.0	(21.4)	
16-09-96	25	14:40	8	23.0	12	23.0	50.0	
19-09-96	28	14:50	8	23.0	11	23.0	37.5	
23-09-96	32	14:47	9	23.1	11	22.9	22.2	
26-09-96	35	14:02	9	23.2	14	22.9	55.6	
30-09-96	39	10:05	9	23.1	13	22.9	44.4	
03-10-96	42	10:05	10	23.1	13	22.8	30.0	
07-10-96	46	16:22	7	23.0	15	23.0	114.3	
10-10-96	49	13:38	9	23.2	22	23.0	144.4	
14-10-96	53	11:40	7	23.1	14	23.1	100.0	
17-10-96	56	15:40	8	23.3	14	23.4	75.0	
21-10-96	60	11:20	5	23.6	11	23.5	120.0	
24-10-96	63	11:20	6	23.6	11	23.6	83.3	
28-10-96	67	15:00	6	23.6	9	23.6	50.0	
31-10-96	70	15:30	5	23.6	10	23.7	100.0	
04-11-96	74	14:30	6	23.8	10	23.7	66.7	
07-11-96	77	09:20	6	23.7	10	23.7	66.7	
11-11-96	81	16:00	7	23.7	11	23.8	57.1	
14-11-96	84	13:05	7	23.6	12	23.8	71.4	
18-11-96	88	11:27	6	26.5	12	26.5	100.0	
21-11-96	91	14:15	9	26.5	12	26.5	33.3	
25-11-96	95	09:30	9	26.5	11	26.6	22.2	
28-11-96	98	10:00	5	26.8	7	26.7	40.0	

APPENDIX B8

FAECAL COLIFORM DENSITIES OF RAW WATER AT INLET AND FILTRATE AT OUTLET OF THE EMMAUS DYNAMIC FILTER

DATE	DAY	TIME	INLET COUNT / 1 ml	INLET COUNT / 100 ml	OUTLET COUNT / 1ml	OUTLET COUNT / 100 ml	% REMOVAL	COMMENTS
23-08-96	1	11:50						
28-08-96	6	12:00	9.0	900.0	7	700	22.2	
29-08-96	7	13:13	8.0	800.0	5	500	37.5	
02-09-96	11	13:15	6.0	600.0	1	100	83.3	
05-09-96	14	13:33	TNTC		7	700		TNTC = TOO NUMEROUS TO COUNT
09-09-96	18	11:34	8	800.0	6	600	25.0	
12-09-96	21	11:50	TNTC		4	400		
16-09-96	25	14:40	1.0	100.0	1	100	0.0	
19-09-96	28	14:50	1.0	100.0	1	100	0.0	
23-09-96	32	14:47	7.0	700.0	3	300	57.1	
26-09-96	35	14:02	20.0	2,000.0	7	700	65.0	
30-09-96	39	10:05	17.0	1,700.0	9	900	47.1	
03-10-96	42	10:05	10.0	1,000.0	3	300	70.0	
07-10-96	46	16:22						NO SAMPLING DONE FROM DAY 46
10-10-96	49	13:38						TO 67
14-10-96	53	11:40						
17-10-96	56	15:40						
21-10-96	60	11:20						
24-10-96	63	11:20						
28-10-96	67	15:00						
31-10-96	70	15:30	TNTC		15	1500		
04-11-96	74	14:30	TNTC		0	0	100.0	
07-11-96	77	09:20	68.0	6,800.0	0	0	100.0	
11-11-96	81	16:00	7.0	700.0	0	0	100.0	
14-11-96	84	13:05	24.0	2,400.0	1	100	95.8	
18-11-96	88	11:27	TNTC		0	0	100.0	
21-11-96	91	14:15	64	6,400.0	2	200	96.9	
25-11-96	95	09:30	TNTC		4	400		
28-11-96	98	10:00	87	8,700.0	10	1000	88.5	
TOTAL				33,700.0		8,600.0	988.5	
MIN			0.0	100.0		0.0	0.0	
MAX			TNTC	8,700.0		1,500.0	100.0	
MEAN				2,246.7		409.5	61.8	
STDS				2,729.2		399.9	36.0	
N			21.0	15.0		21.0	16.0	

APPENDIX B9
FLOW RATES OF RAW WATER INTO, FILTRATE OUT OF, CROSS FLOW OVER AND FILTRATION RATE OF THE EMMAUS DYNAMIC FILTER

DATE	DAY	TIME	HEIGHT OF WATER WEIR mm	INLET FLOW l/s	OUTLET FLOW l/s	CROSS FLOW l/s	FILTRATION RATE m^3/m^2/h	COMMENTS
23-08-96	1	11:50	69	0.35	0.06	0.29	0.04	
28-08-96	6	12:00	75	0.43	0.07	0.36	0.04	
29-08-96	7	13:13	76	0.45	0.07	0.37	0.04	
02-09-96	11	13:15	73	0.40	0.07	0.34	0.04	
05-09-96	14	13:33	68	0.34	0.06	0.28	0.03	
09-09-96	18	11:34	72	0.39	0.07	0.33	0.04	
12-09-96	21	11:50	82	0.54	0.09	0.45	0.05	
16-09-96	25	14:40	78	0.48	0.08	0.40	0.05	
19-09-96	28	14:50	78	0.48	0.08	0.40	0.05	
23-09-96	32	14:47	76	0.45	0.07	0.37	0.04	
26-09-96	35	14:02	72	0.39	0.07	0.33	0.04	
30-09-96	39	10:05	79	0.49	0.08	0.41	0.05	
03-10-96	42	10:05	68	0.34	0.06	0.28	0.03	
07-10-96	46	16:22	30	0.05	0.01	0.04	0.00	INLET PIPE BLOCKED
10-10-96	49	13:38	80	0.51	0.08	0.42	0.05	
14-10-96	53	11:40	90	0.68	0.11	0.57	0.07	
17-10-96	56	15:40	96	0.80	0.13	0.66	0.08	
21-10-96	60	11:20	84	0.57	0.10	0.48	0.06	
24-10-96	63	11:20	69	0.35	0.06	0.29	0.04	
28-10-96	67	15:00	83	0.55	0.09	0.46	0.06	
31-10-96	70	15:30	77	0.46	0.08	0.38	0.05	
04-11-96	74	14:30	79	0.49	0.08	0.41	0.05	
07-11-96	77	09:20	108	1.07	0.18	0.89	0.11	
11-11-96	81	16:00	102	0.92	0.15	0.77	0.09	
14-11-96	84	13:05	102	0.92	0.15	0.77	0.09	
18-11-96	88	11:27	101	0.90	0.15	0.75	0.09	
21-11-96	91	14:15	100	0.88	0.15	0.73	0.09	
25-11-96	95	09:30	100	0.88	0.15	0.73	0.09	
28-11-96	98	10:00	90	0.68	0.11	0.57	0.07	
TOTAL				16.23	2.71	13.53	1.62	
MIN				0.05	0.01	0.04	0.00	
MAX				1.07	0.18	0.89	0.11	
MEAN				0.56	0.09	0.47	0.06	
STDS				0.23	0.04	0.20	0.02	
N				29	29	29	29	

PART 2

TECHNICAL GUIDE

for

DYNAMIC FILTRATION

ABSTRACT

Dynamic filtration is a special type of slow sand filtration. Although originally the concept was developed in Russia, Argentine engineers further developed and applied the technology for water treatment. No less than fifty filters had been built and commissioned by the late seventies. Most of these are still in operation, providing water of excellent quality.

The author compiled the information in this guide after a tour through several Argentine provinces, monitoring of an experimental unit installed at the Daspoort Sewerage Plant in Pretoria and a dynamic filtration plant constructed to supply water to the rural community of Emmaus in KwaZulu Natal.

This document is intended for engineers and presents the state of the art and basic design parameters. The document will allow them to design, build and operate dynamic filters which have proved to be reliable, economical and simple, while providing drinking water of good quality to rural communities.

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1. THE REASON FOR THIS TECHNICAL GUIDE

From 1975 until 1986 the author of this guide worked as the Director of an environmental protection service in the Argentine province of Chubut. One of his tasks was to monitor the quality of the water produced and distributed by the rural drinking water treatment plants in his area. Among several systems in operation, there were a few dynamic filters. Their performance, over more than a decade, showed that this was a very simple technology, highly reliable and very appropriate for rural areas of third world countries.

Contact with the Argentine water authorities that had to do with the initial development of this technology, as well as contact with other engineers working on, or controlling, dynamic filters in neighbouring provinces, convinced him that this was an important technology that deserved more understanding, study and promotion.

During that decade, the few tests conducted by individuals were not enough to acquire extensive knowledge of its characteristics and possibilities. The only sure thing was that the filters would always operate in a reliable way. As for any other research, very little had been done.

Year after year the filters built in Argentina continued to work, producing megalitres of good drinking water. The International Reference Centre (IRC), the World Health Organization (WHO) collaborating centre based in The Hague, highlighted this technology in one of its annual reports.

Nevertheless, there were no clear records of any recent follow-up or research done in order to:

a. gather the information available in Argentina after more than twenty years of operation;
b. try to understand the technology;
c. find new ways of improving it; and
d. produce a document that would at least present the basic design criteria to assist engineers in the design and construction of this type of unit, which is suitable for mountainous rural areas.

It is somewhat ironic that the author found support to undertake the above research in another continent and in a country where mountains do not abound.

2. INTRODUCTION

Although the relationships between the different physical parameters, the hydraulics that govern the whole process and the biological mechanism that takes place in it are complex, slow sand filtration is one of the simplest technologies. Most probably it is one of the most noble and reliable technologies as well.

A slow sand filter is very simple. The filter is just a bed of sand supported by another bed of gravel, all contained in a box, with an inlet for raw (untreated) water and an outlet for treated water. Slow sand filtration is an option that is being used more and more in rural areas of developing countries. This technology is not new as the first sand filter for town water supply was built in 1829, in London by the Chelsea Water Company.

There are several advantages to slow sand filters and they remove organic matter and pathogenic organisms most efficiently from raw water of relatively low turbidity. Nevertheless, efficiencies as high as 75 % can be expected from the use of such elements in turbidity reduction.

Some important advantages, when installed in rural areas of developing communities, are the following:

- low construction cost
- simple design and easy construction
- little special pipe work, ancillary equipment or instruments are needed for installation
- very simple operation and maintenance (O&M)
- little time needed to perform such operations
- no special equipment required for operation and maintenance
- there are no moving parts in the system
- no chemicals needed
- can cope with changes in water quality (up to a certain extent)
- do not need clean water for backwash
- no power requirements

This document refers to **DYNAMIC FILTRATION** and **DYNAMIC FILTERS**, a **dynamic filter (df)** being a different type of **slow sand filter (ssf).**

Just as the depth of filtering media and the beds' general characteristics are the same, the drain systems and tail water (filtered water) controllers, and most of the operational parameters like filtration rate and the biofilm principle are similar. The major difference between these types of filters is the way in which the raw water is fed into the unit.

Instead of the standard one metre static head of supernatant water on top of the upper layer of sand in the typical ssf, the df has a running flow with a head of a few millimetres.

The effect of this cross flow is to push the heavier suspended particles over a weir at the end of the filter which then drains back into the river. Part of the flow percolates through the sand bed into the underdrain system, and is conveyed to a clear water well or reservoir. The latter action, that is filtration, is similar to that of the ssf.

If one of the disadvantages of the df is the fact that it requires a great deal of feed water, the greatest benefit is its cleaning simplicity. The disadvantage of high volumes of water required reduces the applicability of these filters to mountainous or hilly areas where rivers have positive gradients and there is no need for pumping. The excess water overflows back to the river from where it was diverted.

In the case of a ssf, the cleaning procedure is related to the amount of turbidity with which the filter can cope. Although a typical ssf can be used with water with up to 30 - 40 Nephelometric Turbidity Units (NTU), it operates better with turbidity under 10 NTU. If the turbidity is high, the run (period between cleaning) is very short. To clean a ssf requires that operation is stopped and the supernatant water is drained. A few centimetres of the upper layer of sand are then removed by scraping. The unit has then to be slowly backfilled with water and set into operation again. Time is needed to perform the whole process and for the biofilm to develop in the new upper layers of sand.

Dynamic filters, on the other hand, are relatively easy to operate, as normal cleaning is done by raking the sand surface in an operation that takes only a few minutes and is performed on a recommended daily basis.

Raw water with a turbidity of over 50 NTU can be filtered by a df. Advantages, disadvantages and cleaning procedures are discussed in more detail further on. Nevertheless, and just to close this brief initial introduction on the general description of a df, it can be said that if the operation and maintenance of a ssf are simple and appropriate for rural populations of third world countries, the operation and maintenance of a df are far less complicated and demand less time.

In this lies the secret and the great value of this technology!

3. HISTORY

In the late fifties and early sixties the Russian sanitary engineers achieved a number of successes through applied research in the field of drinking water treatment. Among the various lines of development, the filtration technologies constituted an important part of their work. Careful manipulation of design parameters in slow sand filtration, the upflow filter design, and work on mixed beds and upflow downflow filters (superfiltration) were typical practical developments in those days that found rapid acceptance around the world.

There is, however, not much evidence that dynamic filtration was no more than a theoretical exercise or just a simple first stage of research which did not reach the necessary level of thorough understanding for it to be widely spread.

After a Russian paper was presented at a local seminar in Argentina, the theory became widely accepted throughout Latin America. Mr Y. Ayrapetov, a Russian engineer lecturing at a university in a Northern state of Argentina, translated that paper into Spanish. Engineers and authorities of the Servicio Nacional del Agua Potable (National Service of Potable Water) -SNAP-, the Argentine organisation dealing with the provision of water to rural communities of less than 2 000 people, became interested in the technology.

The concept of dynamic filtration caught on rapidly in an environment where sanitary engineering was in the lead and after a short period of theoretical discussions, the first dynamic filter was built and commissioned. This took place in Anillaco, La Rioja, during 1969.

After that filter others followed. Besides the province of La Rioja, other Argentine states like Catamarca, Chubut, Cordoba, Mendoza, San Juan and Tucuman built several units to serve rural villages and small towns. Although there are no certain figures, it is believed that throughout the country, around 50 filters were in full operation by the late seventies.

Besides these units built in Argentina and the initial experiments performed there, only Ecuador and Chile developed limited expertise in this technology.

As is typical of developing countries, the original idea caught on rapidly and many theoretical studies were pursued in order to provide design criteria. Complicated formulations and ideal considerations were developed and published as papers or reports: Perez Farras (1); Arboleda (2); Rodriguez (3); Aguilar and Fernandez (4).

Typical also of developing countries, few practical evaluations were undertaken in order to obtain the final and proper design criteria parameters.

The reason for this was the lack of sufficient support for these researchers. To understand a filtration technology there is, besides researchers, a need for adequate support through facilities and funds, which, in this case, were not freely or abundantly available.

The Pan American Health Organization/World Health Organization, charged Mr J. Perez, one of its engineers based in Lima, Peru, in the Centro Panamericano de Ingenieria Sanitaria y Ciencias del Ambiente -CEPIS- (Pan American Centre of Sanitary Engineering and Environmental Sciences), with the task of obtaining the state of the art of this technology. Perez produced a technical report dated 4-4-77 (5). Perez not only gathered the available information in that time but also proposed an evaluation programme be carried out in Argentina. Two years later, in 1979, a research programme was established between the SNAP, the La Rioja province representation of Water Works and the State University.

Filters with special features were constructed near the capital of the province of La Rioja and were set into operation. This did not however, have any success as a shortage of funds and human resources very soon brought the work to a standstill and the data collected were totally irrelevant.

The result of the whole Latin American experience, as described in this historical overview, is that very little was done in order to understand the operation of the dynamic filters and to produce a design criteria manual, which was the ultimate aim of those groups of highly skilled and interested engineers.

It is nonetheless intriguing to note that a technology that had had some exposure, (the Latin American sanitary engineers have good connections and excellent relationships with their peers in other regions of the country and the continent, Pan American Health Organisation (PAHO) gave widely publicised the achievements of the Argentineans) never aroused interest in other First World research centres to pursue further research on it.

Does this mean that the technology was not good or reliable enough? Is it possible that operational and/or maintenance problems had discouraged engineers to develop other filters? Is this technology inferior and more troublesome than the standard slow sand filtration? Are the construction and operation costs greater than those of the ssf?

The answer to all these questions is an unequivocal: NO!

There is a remarkable fact that supports this reply: the filters built in Argentina more than 20 years ago are still operating without problems, producing water of excellent quality without posing any particular problem.

It was in trying to re-discover the potential of this technology that the CSIR and the Water Research Commission supported a trip to Argentina, and thus the research that resulted in this technical guide.

In January 1993, a trip was taken to La Rioja and Catamarca (Argentine provinces). Fifteen communities using dynamic filtration were visited. Information was collected through discussions with authorities in the provinces and SNAP. Information on actual filter operation and maintenance was collected through discussions with operators on their experiences.

In 1992 a dynamic filter was constructed at the CSIR Division of Water Technology's facilities in Daspoort, Pretoria. Water was abstracted from the Apies river and numerous tests were carried out comparing the filter against a standard slow sand filter, that acted as a reference unit.

A unit was constructed in 1996 to serve the Emmaus community in KwaZulu Natal South Africa and a separate report on its performance is available.

4. AIM OF THIS TECHNICAL GUIDE

As was clearly explained in the previous section, there is no definite understanding of the dynamic filtration technology. The tests and experiments performed at Daspoort and Emmaus provided very good data, but this information and the Argentinean experience, are not enough to write the ultimate manual on design criteria for dynamic filtration. Too many parameters are involved in this technology and thus far more time would be needed to achieve complete understanding. The successful collation of such a document (manual) will demand far greater efforts in terms of manpower, time and funding than that obtained for the present research.

Nevertheless, it is important to note that, due to the tasks carried out, there is enough information available to provide the **basic design criteria** and facilitate a proper understanding of the basic parameters required for the design and construction of dynamic filters.

This technical guide will give sufficient information to the engineer for the design of a dynamic filter. Proper explanation of the most important parameters and the criteria for the chosen values and/or limits, plus the section on design and the exercise to plan for a specific filter based on real conditions, will give strong support to the engineer responsible for the design of one of these units.

Although this guide provides sufficient, as well as useful information, it will benefit from additional data that new developments, research and experiences with new filters may bring. This technical guide is intended to be continuously updated and enhanced with such new information.

5. GENERAL DESCRIPTION

The df system consists of an intake (normally a structure in a mountain river), a delivery conduct that delivers the water from the river to the filter location, pre-treatment (if necessary), flow controlling sluice gates and flow measuring weirs, a dissipation entrance by means of which the water will access the filter, the filter itself with a sand recovery chamber, a box for tail water control, and an overflow conduit that returns the unused water to the river.

Disinfection should be considered an important if not necessary addition in the treatment stream, as well as a reservoir for the distribution of water to the end users.

A typical layout can be seen in **Fig 1** (appendix A).

6. WATER SOURCE - THE RIVER

A df is a system that obtains its water from a mountain river or steam. Because of this, it is important to have as much information as possible about the source that will serve as the continuous feed for the unit.

Prior to the construction of a df, data should be gathered from direct determination, from the body that manages the river as a resource, from organizations working in the area, from local committees or from neighbours and villagers. The data should include: flows, flow variations during the year, records of maximum and minimum levels throughout different seasons and during different years. Also required is information such as the general water uses up and down stream, right of access to the river, whether others use the river, possibility of fencing the units, accessibility to the intake and possibility of vandals damaging the filters.

Floods constitute an important part of this investigation. Is it common for this river to flood? Are the floods predictable? Does it flood with violence? What are the maximum levels to which the water rises during these floods? What materials do the floods carry on their way down?

As for the water quality, it is necessary to know the maximum and minimum values for different parameters during different times of the year. Microbiological and biological data should be the most important parameters in this regard.

A thorough inspection to detect any other possible uses, either "natural" (like drinking water for cattle) or industrial (effluent receptor) should be considered. If industrial effluent is dumped into the river, it is of utmost importance to know the characteristics of such effluent and the parameters that may be harmful to human or animal health.

Permission to build the unit and to abstract water from the river should be obtained from the respective bodies. Several meetings should also be held with neighbours using water downstream (the use of water for drinking purposes may diminish the quantity of water that other users downstream may have).

Finally, gradients should be investigated in order to detect an appropriate difference in level from the sites of intake, filter location and unused water return.

7. WATER QUALITY LIMITS IN RAW WATER PRETREATMENT

Once the requisite information has been obtained, it is important to evaluate the impurity removal efficiencies of the filter and weigh them up against the problem of is removal of contamination from the raw water.

When considering a df as the treatment system to provide potable water to rural groups, it is expected that these communities/groups (such as a village, a school, a group of families) would be isolated and that it is improbable that there would be factories or industrial activity that would affect the water source. For this reason, the only real problems the raw water is expected to present are turbidity and/or organic contamination - either in the microbiological or biological form.

It is important then to have an idea of the limitations of a slow sand filter and as mentioned in the introduction, a slow sand filter will operate efficiently and "at ease" when turbidities are under 10 NTU. Should the turbidity be in the region of 30 - 40 NTU, a slow sand filter will operate efficiently for a very reduced period of time. But if the water is consistently turbid, then it is recommended that there should be pre-treatment when the values of the raw water are above the 25 NTU level.

As for a dynamic filter's tolerance to high turbidity, there is not much information available, except for that obtained through research by the CSIR. No upper limit has been suggested as the "maximum permissible", or the "maximum turbidity level the filter will operate at without stoppage". As the cleaning of a df is so simple, the turbidity limit should be determined in such a way that it would not stop the filtering operation before the time of routine cleaning, which is 24 hours.

In other words: the operator should clean the filter daily during "normal" operation periods. During the period of 24 hours the filtering rate may diminish due to the build up of the "cake" on the surface of the filter. If the lower flow rate is unacceptable to the consumption needs (or the production expected from that particular filter), then the turbidity that caused it, should be considered as above the operational limit.

Nevertheless, the research undertaken by the CSIR has shown it is possible to operate a df without problems and on a daily basis with raw water having a turbidity of over 50 NTU. It would, however, be sensible to install a pre-treatment system if the turbidity of the raw water is likely to be above 50 NTU for prolonged periods of time.

The typical pre-treatment should be either sedimentation basins, filtration through the river bed, or roughing filtration (filtration through coarser material usually crushed stone). Water analyses should provide information on basic parameters for the proper design of any of these units.

A comparison between the typical slow sand filters and the df with regard to the organic removal follows:

The presence of a bio-film, also called "schmutzdecke" (a German term for "dirty layer"), seems to be the main factor responsible for the removal of the organic live contamination present in the raw water. The schmutzdecke is a kind of biological film covering the grains of sand that occupy the upper layers (or the first few top centimetres) of sand. This biological film is formed by a multitude of organisms like plankton, protozoa, rotifers and bacteria. In this layer the biological activity is at its peak, as those organisms will trap and digest the organic matter contained in the water passing through. Inorganic salts are formed in the process and carbon compounds are broken down, while the nitrogen is oxidized to more stable forms.

Nevertheless, this bio-film is not instantly formed in a ssf, and some time is needed for what is called the "ripening" or "maturing" of the filter. How long this takes will depend on different factors such as the quality of the raw water, the rate of filtration, pH and temperature and it usually takes from several days to a few weeks. Until the schmutzdecke is built up, the bacterial removal usually remains low.

It has been noted that, in conjunction with the development of the schmutzdecke, the "maturation of the bed sand" also occurs, which in fact means the possible extension of the bio-film to deeper layers where other types of organisms predominate. Although the activity in deeper layers seems to be not as strong as that in the upper ones, it is evident that, after the removal of an upper portion of sand in the ssf (to clean the filter), it requires less time to start purifying the water than when the filter is initially set into operation. The biomass still existing in the deeper layers, helps to destroy the microorganisms in the percolating water and in the more rapid development of a new schmutzdecke in the new top layers.

It is of vital importance to understand this mechanism and how it works in a ssf and the difference between this process in a ssf and a df. It has been noted that the development of the schmutzdecke occurs more rapidly in the df than in the ssf. Tests carried out at the CSIR show that, to reduce the E. Coli content in both a df and a ssf containing sand with the same characteristics and being fed with the same water, does not take the same time.

To reduce the initial count of bacteria by a factor of 10^2, it took one day in a df and two days in a ssf. To reduce that initial count by a factor of 10^3, it took two days in the dynamic filter and three days in a slow sand filter.

It is clear that the reason for this is the quicker formation of, and a stronger schmutzdecke in the df. This has also been observed by Argentine engineers. They usually make mention of active biofilms that develop in as little as 24 hours.

In search of a reason for this faster development, it can be theorized that:

a. the very thin and active flow of water running over the surface of the df can possibly incorporate oxygen in a way that the static layer of supernatant water over the ssf surface cannot; and
b. the stronger solar action (caused by the very thin head water), might have a positive effect on the biofilm growth.

This explanation, and also the fact that the maturation of the bed seems to take place very quickly, ensures two important things for the df.

Firstly, that the filter will produce water free from most microorganisms shortly after its inception, and secondly, that the normal operation (the daily raking of the filter grains, with the hypothetical destruction of the schmutzdecke) does not in fact not take place in this way. Either the grains do not lose their bio-film membrane, even with a lot of agitation, or the maturation of the bed copes with the contamination while the schmutzdecke recovers and reimplants quickly on the grains of the upper layers of sand.

Tests done with ssf have shown that a reduction of E. Coli by factors of 100 to 1 000 can be expected. The tests at the CSIR indicated that the reduction factors for E. Coli for a df can even be as high as almost 10 000.

No experiments have been undertaken regarding the removal of other constituents by a df, but it is expected that they will be removed with at least the same efficiency as a ssf.

Table 1, extracted from the Manual of Design for Slow Sand Filtration (6), gives an idea of the removal possibilities of a df for some water quality parameters.

TABLE 1. WATER QUALITY GUIDELINES FOR SELECTION OF DF

Constituent	Removal experiences %	Guidelines (maximum levels)
Turbidity	75	<50 NTU >50 NTU with pre-treatment
Colour	25	5-10 Pt-Co
Total Organic Carbon	25	None
Coliform bacteria	99-99.99	None
Giardia cysts	99-99.99	10-50 cysts/m^3

8. INTAKE

The simplest form of intake is the installation of a pipe or a channel. Not too much information will be provided on this issue as the best structure will depend on the particular conditions of the river and on the specific point of abstraction. Nevertheless, it is very important that the importance, frequency and power of eventual floods are taken into account. The structure should be strong enough to cope with the worst flooding conditions.

Minimum levels should be very well defined for all seasons and all conditions, as water should always be available for the filter at the site of intake. Topography and altitude levels should be measured in order to assure the stipulated head, as calculated in the design of the delivery channel, that carries the water entering the filter. Protection against animals is another aspect to consider.

Finally, great care should be taken should the river carry litter. Grit chambers with bars should be installed in order to prevent clogging of the intake. In some areas this can be a real problem.

9. DELIVERY CONDUIT

It is recommended that a channel be built instead of piping as it is easier to inspect and to clean a channel. Problems can be detected easily the quality of the water can even be roughly determined without having to go to the river.

The installation of a pipeline is, on the other hand, simpler, less time consuming and probably cheaper.

The option chosen will depend on local conditions, manpower and funds, possible problems with vandalism (the channel is more vulnerable than a buried piping).

In the section on the design of a df, both types of intake systems are considered.

10. FLOW CONTROL AND FLOW MEASUREMENT

Two main types of flow should be controlled and measured. Firstly, the *total flow* (the flow that will be abstracted from the river), and secondly, the tail water or *filter flow* (the water that will be supplied to the community). Once the values for these flows have been determined, they should be managed, controlled and measured.

For the flow abstracted from the river, there are two possibilities in this regard:

If the design makes use of a channel as delivery conduit, the best way to regulate this flow is by means of a controlling sluice gate. A controlling sluice gate is a plate that can be raised or lowered in order to allow only the required amount of water to pass through.

There should be a gate at the beginning of the delivery channel. This will provide a rough regulation of the flow. The finer regulation is controlled by a second, similar sluice gate, placed near the filter entrance.

An overflow conduit (in the form of a pipe or a channel) is used to lead away any excess water. This should be linked to this gate in order to return the unused water to the river. See **Fig 2**.

If the design makes use of piping, the flow should be controlled by means of a valve placed in the main delivery conduit (rough control) and another one near to the filter (finer regulation).

The best and easiest way to measure the flow, if the delivery conduit is a channel or a pipe, is to use an independent measuring weir. If a pipe is used, it should open into a channel before the water enters into the filter. It is in that channel that the weir should be installed.

The best type of weir is the V-notch weir. This is a plate with a 60° V-notch, placed perpendicularly to the flow and downstream of the flow controlling gate. The flow is determined by using a ruler to measure the depth of water above the notch (measured in centimetres). **Fig. 3** illustrates the weir, and a calibration curve to obtain the flow. The flow can also be obtained by using the mathematical equation included in the same figure.

For the second flow (the filter flow), there should be both a volumetric and an instant flow meter. There are several types of these devices, any of which could be used.

11. DISSIPATION CHAMBER (DISSIPATION ENTRANCE)

Although a few filters were built in Argentina with a baffle box in front of the filter itself most of the units were based on the original design which allows the water to flow into the filter through different zones: the entrance channel, then a transition and finally an energy dissipation zone which reduces turbulence.

This typical layout can be seen in **Fig 4**. The idea is to reduce turbulence and allow a very even distribution of the water once it begins to flow over the sand surface.

The CSIR's research has established that this elaborate system is less efficient than the first described, i.e. the chamber with a baffle inside, called the baffle box or **dissipation chamber**. This can be seen in **Fig 5**.

This baffle box is simpler to design and build and research has proven its great value as an energy diffuser. Besides this, there is another important advantage when using this box. It acts as a sedimentation basin, helping to prevent clogging of the filter. (For this reason, provision should be made for the sediments to be flushed away by means of a bottom outlet controlled by a valve).

The depth and width of the chamber are the same as the depth and width of the filter.

The length should be 1/5 of the length of the filter and this box should have a vertical baffle perpendicular to the direction of flow.

The baffle should be placed at 2/5 of the total length of the box (measuring from the place where the water enters the unit).

The baffle should have an opening at the bottom for the water to pass under it. The free passage should be 1/3 of the water head.

Any material can be used for the baffle, for example a board or a corrugated asbestos plate. If built of bricks or concrete, however, it will most probably have a longer life and will require less protection.

12. THE FILTER

Different elements constitute the filter, and these will be treated separately. The elements are: the weirs, the sand recovery chamber, the filter box, the drain system, overflow water conduit and the tail water controlling system.

12.1. THE WEIRS

The weirs are very important for two reasons; first, the inlet weir will be responsible for the distribution of an even flow in the filter bed, and secondly, the difference in height between the weir at the entrance and the one at the end of the filter will determine the slope of the filter bed.

The sand should then be levelled to the height of these two weirs. The difference will on occasions be a few millimetres.

To prevent loss of sand, there is a chamber or box that intercepts all sand escaping from the filter. It is only after having passed through this chamber that the overflow water will finally leave the filter box.

Three weirs should then be placed; one at the very entrance, one at the end of the filter bed and between it and the sand recovery zone (level controlling weir), and finally, the third one where the water leaves the water box (outlet weir). See **Fig 6**.

The weirs are very easy to make, install and manipulate. Although there are a number of ways to do this, a very practical one is the following:

The inlet weir should be attached to the wall of the dissipation chamber. It should be placed at the wall shared by the dissipation chamber and the filter box, but on the side of the filter containing the sand. The wall should be 5 centimetres lower than the expected level of the sand bed. The weir should obviously run along the width of the filter.

The inlet weir should be embedded 25 centimetres into the sand. See **Fig 7**. This will allow the easy raising, lowering and levelling of it by just pulling or pushing it from the top. As the levelling of this weir is very important, its surface should be as straight and even as possible. The best material to achieve this is steel. Anti-oxidant, painted, mild steel, 3 - 7 mm thick, is recommended for all the weirs.

The second weir (the level controlling weir), together with the inlet weir, will control the slope of the filter bed, and it is placed just in front of the sand recovery zone.

This weir should be fixed on the filter's side and should have the same characteristics as the inlet weir.

For practical purposes the height of the wall between the dissipation chamber and the filter, and that of the wall between the last part of the filter box and the sand recovery box, can be the same. The slope of the filter, which is determined by the difference in height between the inlet and outlet weirs, can be manipulated by adjusting the heights of these weirs.

The sand recovery zone should be some kind of box, placed in the last portion of the filter. As in the case of the inlet weir, the top of this box's wall should be approximately

5 centimetres below the sand bed level.

The last weir (the outlet weir), should be made from the same material and have the same dimensions as the other two weirs. This weir, on the other hand, will not be embedded in the sand, but attached to the outlet wall of the filter by means of bolts and wing nuts. This weir should have two slots on each side in order to level it, this feature being the only difference between this weir and the other two. See **Fig 8**.

The height of the outlet weir should be approximately 10 cm lower than that of the controlling weir. This is important in case there is a need to agitate the water in order to get the sand out of the sand recovery chamber. The turbulence that can be initiated will then not disturb the filter sand.

12.2. SAND RECOVERY CHAMBER

As the sand is almost the same height as that of the weir, it is easy to lose some of the sand at the end of the filter surface, either from the flow of the water or when cleaning activities are performed.

To solve this problem, a **sand recovery zone** is introduced in the very last portion of the filter. The sand that crosses the level controlling weir and that would normally be lost, is gathered in this zone, and can be collected by means of a simple valve. This recovery zone is in fact a box with a length 1/5 of the filter's length and a depth of 0.5 m.

Provision should be made for a small catchment area (a kind of small basin) in the ground near the filter, at the outlet of this chamber drain. The sand can then be collected here while the water drains away.

12.3. THE FILTER BOX

The filter box contains the filtering media. Although this is the core of the system, it is the simplest element of them all.

The box should have room enough for the drain system, the filtering bed and the head of running water. The free board should be 0.2 m.

The method used to clean a df differs from that of a ssf. In a ssf the upper layers of sand are scraped and taken away, lowering the height of the bed. In the case of a df, the cleaning is done by means of raking the surface, and only minimal loss of sand should occur. If any sand is lost, it is checked by the sand recovery box. The sand is cleaned and then replaced on the filter bed. None the less, the variations of the sand levels in the df are very small. For practical purposes, the design height for the sand should be considered as always remaining constant. This is another advantage compared to ssf, as scraping of the dirty sand reduces the ssf's bed height. Such filters should then be at least 0.6 m higher than a normal df.

The first design parameter should be the ratio Length/Width. In the original literature a ratio of 5:1 was fixed.

The reason for this was that, if the filter had the configuration of a channel, a more even distribution of the water cross flow (this is obvious as the head is very small), and less short-circuiting, were to be expected. Another reason was that, with the ratio of 5:1, any filter would be narrow enough so that any part of its surface would be easy to reach from either side of the filter.

Practical experiments in Argentina have shown that filters with length/width ratios of even 3:1 can function properly. This, however, should be the limit, as a more square surface will inevitably lead to water short-circuiting.

Attempts have also been made to increase the ratio, even with up to 9:1. This is also not recommended as the debris and grit particles have then to be pushed along over a very long distance.

Where filters have been constructed in a very long channel with ratios above 6:1, it was observed that the first part of the filters were very dirty compared to the last part (in other words, dirt quickly accumulates on the surface of the filters at the beginning rather than at the end).

For these reasons the recommended ratio Length/Width should be

Ratio Length/Width for the filter	3:1 to 6:1

The selection should be so as to allow the rake to reach the centre of the filter from either side.

The material for this box should be stone or brick masonry, reinforced concrete, or painted mild steel for the smaller tanks.

12.4. THE DRAIN SYSTEM

The under-drain system has the purpose of supporting the filter bed without loss of the media. It should allow the passage of water with little head loss.

There are three different types of drains for these types of rural filters. The first system is one made with pipes, the second with bricks or blocks, and the third directly with crushed stone or gravel.

The three systems are described as follows:

Depending on the size of the filter, different arrays can be used with PVC or polyethylene piping. The simplest is a main collector or manifold running along the filter in the same direction as the cross flow, and having perforated or slotted laterals. **Fig 9** shows such an array. The laterals should be long enough so as to reach the side wall of the filter. The slots should cover half of the pipe. There are two possibilities of where the slots and the holes can be placed: either on top (facing up), or at the bottom (facing down). Experience has shown that any of these will be suitable and will function properly.

The practical suggestions for the design of these systems are the following:

The laterals should be evenly spaced over the length of the filter and they may have either holes or slots.

Distance between laterals	0.5 - 1.5 m
Diameter of holes	2 - 3 mm
Width of slots	1 mm
Velocity in the holes or slots	0.3 - 1 m/s

This last parameter refers to the velocity the water should have while passing through the **sum** of the holes or slot areas. The flow passing through them should be the value of the flow obtained from the maximum filtration rate (filtration rate as theoretically calculated or filtration rate with the filter clean - which are the same).

The number of laterals and their spacing, as well as the number of slots or holes, should be obtained by playing with these parameters (see exercise).

The pipe drain should be covered by gravel.

If using bricks or blocks the layout is very simple. The bottom can be made of stacked bricks, concrete slabs, blocks or porous concrete. The bricks or blocks should be placed in such a way that the clear spacing between adjacent bricks is not bigger than the size of the supporting media immediately above them. The supporting structure is a series of rows of the same material, in the case of bricks or blocks packed in order to obtain lateral drainage conduits leading into a central large collector. These rows should be spaced in such a way so as to support the bricks or blocks on top of them. The collector is usually connected to the tail water chamber through an orifice or pipe. As the area where the water should be flowing through is extensive enough, there is no need for any calculation.

For the third type of under-drain, in other words when using crushed stone or gravel, there is only a need to place a bed of the material as the bottom layer. The suggested maximum area is 25 m^2 if this type of underdrain system is to be used in a filter.

The characteristics of the media should be:

Diameter of gravel or stone	25 - 50 mm
Height of the gravel or stone bed	0.15 m

12.5. OVERFLOW

The unused cross flow water leaves the filter surface by flowing over the last weir and usually it is returned to the river from where it was obtained.

This overflow can be allowed to freely flow down the outlet wall of the filter. This would mean a drop of about 1 metre (the water head from the sand surface to the bottom of the filter). If there is enough gradient for the water to be easily returned to the river, this is the best and cheapest option.

If there is not enough gradient, then the overflow should be discharged into a channel, placed about 0.2 m below the level of the last weir. The channel, being at a higher level than the bottom of the filter, will mean a loss of head of about 0.2 - 0.3 m.

From this channel, the water is returned to the river. This channel is similar to the delivery channel.

This should be calculated in the same way as was done in the case of the delivery conduit.

12.6. TAIL WATER CONTROLLING SYSTEM

Two ways of controlling the tail water (that is the water leaving the filter through the drain system) are recommended.

The first is to directly connect the drain to a pipe that will conduct the effluent to a reservoir.

If there is no cleaning, the filter will clog up and the head loss will increase. The filter rate will diminish, and for this reason this type of array is called filtering at a decreasing rate of filtration. Some kind of flow meter should be placed in this conduit in order to monitor the diminishing rate of filtration. (A sampling tap or valve should also be installed in this conduit). The filtration rate should recuperate after each cleaning and variations in the filtration rate should be almost negligible if the filter is properly operated by cleaning it daily.

The second way is to build a small box and to attach it to the filter. This box will collect the water coming from the drain system after passing through a flow regulator.

The flow regulator will maintain the filtering rate by absorbing the head loss. In essence this regulator is a float with an orifice or inlet at a certain distance below the float. This inlet has a constant head which is the distance between the water surface in the box and the orifice. As the height of the water in the box slowly drops due to the clogging up of the filter resulting in head loss in the filter sand, the level of the float will fall. The distance between the water surface and the orifice will however always remain the same. Once the float reaches a predetermined level, its level will no longer fall and water passing through to the system will decrese as the water level above the orifice decreases.

Fig 10 shows a regulator of this type (also see the photo section)

13. FILTER BED

It is important to note that if the support and filtering layers are properly selected so that the quality of the filtered water will be good. This will also prevent certain matter like debris from penetrating to the support layers from which it cannot be easily removed during normal cleaning of the filter.

Several methods can be used to design the type of bed to be used. Among them, Hazen's, Bellamy's and Huisman-Wood's are the best known. Nevertheless, and for practical reasons, some approximations can be made in rural areas without losing too much precision in the final result. The approximation can be made mainly on the support layers.

13.1 SUPPORT BED

"Support" refers to the different materials that are placed under the real filtering element which is the finest media where debris will be retained and microorganisms destroyed.

For practical purposes, the support media can be made up of four layers of gravel and coarse sand with the characteristics shown in Table 2:

TABLE 2. CHARACTERISTICS OF SUPPORT BED

LAYER	TYPE	PARTICLE DIAMETER mm	LAYER THICKNESS mm
Top	Coarse sand	1 - 2	50
Second	Fine gravel	2 - 5	50
Third	Gravel	5 - 10	50
Bottom	Coarse gravel	10 - 25	150
TOTAL			300

13.2. SAND FILTER BED

The suggestion of this technical guide is that, when dealing with the filtering bed, the proper selection of the sand through a sieve analysis can be highly rewarding and should be done every time local conditions and costs allow it. (An alternative would be to adopt a loose approach and use the river sand locally available without carrying out sieve analysis - which has been done frequently.)

To explain the necessity of sieve analysis it is necessary to discuss Hazen's theory. In 1913 Hazen proposed a study of the characteristics of sand as a filtration media. There was a need to individualize and specify the parameters that were responsible for the proper functioning of the filter.

The first concept he dealt with was the *grain size distribution*.

In a sample of sand there are different sizes, and the analysis of the size distribution is done by passing the sample through a series of standard sieves. This will enable the researcher to draw up a curve with the distribution of the different diameters in the sample. The curve is plotted on log paper with the x-axis being the sieve size (grain diameter), and the y-axis the percentage (by weight) of grains passing through that specific sieve size.

The second concept is that of the *effective size* (d_{10}).

From the curve the size of the sieve opening (grain diameter) through which only 10% of the sand (by weight) will pass, is obtained.

The third concept is that of the *uniformity coefficient (UC)*.

This is the ratio of the size of grain that has 60 % of the sample finer than itself to the size that has 10 % finer than itself. This is to say the ratio $\mathbf{d_{60}/d_{10}}$.

An example of this can be seen in the graph in **Fig 11**.

Fig 12 presents a clean sieve analysis plotting form that can be used when determining the quality of the available sand.

As for the design of the df, the values recommended for both parameters are:

Effective size, d_{10}	0.15 - 0.45 mm
Uniformity coefficient	1.5 - 4.0

Finally, the last parameter needed for the design of the filter bed, is the depth.

Filter media depth	0.5 - 0.7 m

13.3. BLASTRITE

South Africa is a country with a great deal of mining activity. The processes and chemistry involved in mining sometimes lead to useful by products. A by-product of platinum mining is a product very similar to sand. It is commercially sold under the name of Blastrite.

Blastrite is a crystalline compound matching the structure of Magnesium Fayalite $(Fe,Mg)_2SiO_4$. It has the same qualities as silica sand (grain grading, acid and alkalinity resistance, non-toxicity). Furthermore, Blastrite has the advantage of being harder (by 1 point on the MOH scale) and heavier (about 20 % heavier) than sand (7).

This last point is very important as a filtering bed of Blastrite can be used with cross flows of higher values than those used for sand of the same graduation. The higher velocities will also help in cleaning the filter's surface more effectively.

As will be explained later, the maximum velocity of the cross flow for sand with the specified characteristics is 0.20 m/sec. In the case of Blastrite, the cross flow velocity can be allowed to go up to 0.28 m/sec.

Tests performed with this compound, which is not more expensive than graded sand, showed great potential for its use in dynamic filtration.

14. RESERVOIR

This technical guide deals with df. Water reservoirs or water tanks are considered only as ancillary systems. However, it is important to briefly mention the role of reservoirs.

There are many publications that explain how to build reservoirs.

Although the designed system might not make provision for a reservoir, it is in any case suggested that there should be a reservoir placed after the filter and before the distribution system.

The reservoir will act as a "lung", allowing the design of the filter with an average consumption value instead of a peak consumption value. Besides, if disinfection is carried out using a chlorine compound, the reservoir will provide the needed retention time.

There is a relatively simple method (mass flow curve) that is used to determine the volume the reservoir should have. This takes into consideration the consumption patterns, cumulative flow volumes and equalization storage. A far more practical and even less complicated approach used in many third world countries is the one proposed by the IRC's Technical Document N° 11 (8). The same approach is suggested here, and it is the following:

"The volume of the reservoir should be 50 % of the daily filtered water production".

15. DISINFECTION

If the dynamic filter is properly designed, built and operated, it is expected that the reduction of bacterial and viral content should be sufficient to provide a good margin of safety to the consumers. Thousands of ssfs operate in rural areas of developing countries without any further disinfection.

Nevertheless, it is of great importance to note that occasional heavy contamination, careless operation, and even post filter contamination, strongly support the need for disinfection, even if only carried out as a preventative procedure.

If the filter is presenting contamination problems due to improper operation and maintenance, it is unlikely that any disinfection practice would be carried out correctly. Nevertheless, this guide suggests that whenever possible, provision should be made for a good disinfection system.

There are a number of methods that can be used in rural areas either by using chlorine compounds, or even better, using other simpler alternatives.

On-site hypochlorite production, MOGGOD systems and UV radiation are considered today as very appropriate for the rural environment. They are simple, reliable, affordable, and do not require any chemicals.

For detailed systems and techniques for rural water disinfection it is recommended that the CSIR's technical guide on the subject (9), written by the author of this document be consulted.

16. ELEMENTS OF DESIGN

In this section some basic concepts will be described. Elementary hydraulic theory, which is necessary for the design of a df, will also be discussed.

This section complements the descriptions and explanations given in previous sections and gives theoretical, mathematical and engineering support for the design exercise.

This section will also augment the presentation of some design parameters that are still lacking. The full picture will only emerge in the design exercise section, which is a practical application through which the user of this guide will be given an example.

16.1. NUMBER OF PEOPLE TO BE SERVED

This section and the following one deal with the determination of the daily water demand for a community.

Calculations to determine the water demand of a village are based upon the future population. The lifespan of a community's water system should be 10 - 25 years. The choice of the system's lifespan will depend on the design criteria as to how the village will change in the future. For a remote area it is better to calculate for a 25 year lifespan. If imminent changes are expected, a shorter period should be used. The reason for this is the relative unpredictability of the population in the future.

The population forecast is the number of inhabitants that the community will have in the future, considering the growth factor of that particular area. The growth factor or average annual growth rate should be obtained from the local branch of the government's statistics department or other sources of demographic data.

Table 3 gives percentage increases in the population for different growth rates over periods ranging between 10 and 15 years.

TABLE 3. POPULATION INCREASE FORECAST

AVERAGE ANNUAL GROWTH RATE	PERCENTAGE INCREASE YEARS			
	10	15	20	25
1.0	11	17	23	30
1.3	13	20	28	36
1.6	18	27	38	48
2.0	22	35	49	58
3.0	34	56	81	99

The selection of the designer criteria leads to an estimate of the village population for the last year of the period selected as the probable lifespan of the water system. That number of inhabitants will be called the design population or the future population.

The **future population** is the actual population plus the percentage increase in the chosen period of years.

$$\text{Future population} = \text{Actual population} + \text{Growth} \quad (1)$$

16.2. WATER DEMANDS

It is difficult to be certain of the exact amount of water a particular village will use based on a **daily individual consumption**.

If the people have to fetch water from a nearby source like a stream located 50 m from the house, the daily individual consumption would most probably be 12 - 20 litres. Nevertheless, if there is a means by which access to the water can be facilitated, then the daily water consumption can be expected to increase.

According to the World Health Organization, if there is no specified figure for a particular area, the daily individual water consumption should be taken as 45 litres. The basic level of service stipulated by DWAF in the Water Supply and Sanitation Policy White Paper is 25 ℓ/person/ day.

The designer should keep in mind that local conditions, uses, expectations and other factors may lead to other figures for the daily consumption, and these should be taken into consideration.

Besides this, attention should also be given to **special needs** derived from special and additional village facilities such as schools and clinics. Table 4 gives typical figures for different uses in the rural environment.

TABLE 4. WATER REQUIREMENTS IN THE RURAL AREAS

FACILITY	TYPICAL WATER USE
School	10 - 30 l/pupil/day
School with boarding	40 - 80 l/pupil/day
Clinic (no beds)	2 500 l/day
Hospital	200 - 300 l/bed
Railway and bus station	15 - 20 l/user/day
Livestock Cattle Horse Pig Sheep	 25 - 35 l/head/day 20 - 25 l/head/day 10 - 20 l/head/day 10 - 25 l/head/day
Poultry Chicken	 15 - 25 l/100*day

16.3. VOLUME OF WATER TO BE FILTERED - THE DAILY FLOW

The filter should be able to produce the amount of water that is going to be needed at the end of the system's lifespan.

The village's total daily water requirements will then be the sum of the daily future population demand plus the special needs demand, as projected for the end of the design period.

The volume of water that the filter will have to produce per day is called the **daily flow**.

$$\text{Daily flow} = \text{Future population} \cdot \text{ind. daily consumption} + \text{special needs} \quad (2)$$

Daily flow	= m^3/day
Future population	= Number of persons
Individual daily consumption	= m^3/person/day
Special needs	= m^3/day

The daily flow divided by 24 hours is the **total filter flow**. The total filter flow is expressed in m^3/hour.

16.4. FILTRATION RATE

To determine the filter's surface area, it is necessary to decide upon the filtration rate first.

The **filtration rate** (or hydraulic loading rate) is the flow of water to be filtered by a unit of area. The values this parameter can adopt have been widely studied and they have been established. The filtration rate covers a narrow band. Slow sand filters can filter water with a rate ranging from 0.1 to 0.35 m^3/m^2/hour (or m/h).

This range of values results in good and reliable operation of the filter, which in turn means that the filter will destroy microorganisms and retain turbidity particles. Higher values may not result in acceptable filter effluent. Lower values are possible, but obviously they will not render any extra benefit and they would increase construction costs as the filters would be bigger.

The values stated in the above paragraph will also apply to a dynamic filter, although it is suggested that the upper limit (maximum) should be lowered to 0.3 m/h. This will ensure optimal performance and provide an extra margin of security as well.

Filtration rate = 0.1 - 0.3 m^3/m^2/hour

16.5. RATE: CROSS FLOW/FILTER FLOW

At this point one important parameter should be discussed. This is the ratio between the cross flow and the filter flow. The original Russian and Argentine works stipulated that this ratio should be 10:1.

The original idea was that the cross flow would be strong enough to carry the particles that cause turbidity to the overflow and return back to the stream. The concept here was that cleaning should be done when the head loss was maximum, possibly 0.4 - 0.6m, and it was thought that this would be reached after several weeks or months as in the case with the ssf.

Instead, practical experience showed that cleaning by raking the surface, which is a very simple operation that does not take long, re-establishes the initial head.

The statement "to wait until the maximum head loss was reached", had no meaning then, and in practice, with daily or every two days's raking, the initial head is re-established, and the filtering rate is regained on a daily or frequent basis.

This mode of the operation allows less strict ratios, as the surface will always be clean. Besides this, it has been noted that the velocity of the water is more important than this ratio, and it is possible to obtain the required velocity with even lower cross flows.

For design purposes, the lower limit for this ratio is placed at 5:1. If there is enough water, as is the case in many mountain rivers, and if there is also a steep enough gradient, then there is no reason for limiting the flow that can be used as cross flow. The decision as to where the limit should be imposed, ought to be based more on logistic questions (e.g.: the size of the delivery channel, the costs of bigger weirs and gates) than on any other specific parameter.

On the other hand, if there is a possibility of using bigger flows, then there is more room to play with other parameters like slope and velocity. Studies performed by the CSIR indicated that an upper limit of 15:1 (for the ratio cross flow/filter flow) could be allowed.

So: Ratio cross flow/filter flow = 5:1 to 15:1

16.6. NUMBER OF FILTERS

It is standard practice that a system with slow sand filtration should have at least two units in parallel. This will allow the continuity of the water provision even if there is a problem with one of the filters.

So: Minimum number of filters = 2 units

16.7. TOTAL FILTER AREA

The area of the filter may be obtained from the water flow (in m^3/h) and the filtration rate.

$$\text{Total Filter Area} = \frac{\text{Total Filter Flow}}{\text{Filtration rate}} \quad (3)$$

Total filter area = m^2
Flow = m^3/h
Filtration rate = $m^3/m^2/h$ or m/h

16.8. FILTER AREA OF EACH UNIT

It is important to individualize the **filter area of each unit (FA)** as these filters will be designed as unitary elements.

$$\text{Filter Area of Each Unit} = \frac{\text{Total filter area}}{\text{Number of filters}} \quad (4)$$

FA = m^2

16.9. FILTER FLOW

The **filter flow** is the flow that each filter will manage individually. Together with the filter area of each unit this is a useful tool because, although the filters will be exactly the same, they will be designed individually.

$$\text{Filter Flow} = \frac{\text{Total filter flow}}{\text{Number of filters}} \quad (5)$$

Filter flow = m^3/hour
Total filter flow = m^3/hour

16.10. TOTAL FLOW

Total flow is the total amount of water that will be abstracted from the river source.

By knowing the daily flow, having chosen the appropriate ratio cross flow/filter flow and having decided what number of filters the system would have (which normally is 2), the total flow can easily be obtained.

$$\text{Total flow} = \text{daily flow} + R \cdot \text{daily flow} \quad (6)$$

R = Ratio cross flow/filter flow (e.g.: if the ratio is 8:1 then R = 8)
Total flow = m^3/day
Daily flow = m^3/day

As defined, the total flow will be expressed in m^3/day, but when divided by 24, it will be expressed in m^3/hour.

16.11. DESIGN FLOW

The **design flow** is the flow value that will be used to make all the calculations for the design of each filter unit (individually).

$$Design\ Flow = \frac{Total\ flow}{Number\ of\ filters} \qquad (7)$$

The units of design flow will depend on the units used for the total flow. It will be expressed either in m^3/day or m^3/hour.

16.12. IMPORTANT HYDRAULIC RELATIONS

At this point a short discussion on basic hydraulics is necessary in order to define several parameters that will be useful when designing different elements of the system.

Velocity of the water, head of the water on the filter surface or on a channel and slope of the filter bed surface or of a channel floor, will be discussed in this section.

Several formulae describe the behaviour of water flow in a channel. The Manning's formula will be used here, as this is one of the most generally utilized.

This formula starts by defining the **velocity** of water in a channel, and can be used either in the design of the delivery channel or of the filter, as the sand surface and the filter's free board can be considered as a channel consisting of a rough floor and walls.

$$v = \frac{r^{2/3} * s^{1/2}}{n} \qquad (8)$$

v	= velocity of the water	= m/sec
n	= Coefficient	= 0.03 (for a channel with vertical walls and made from mortar. This value will also be used for the channel that forms the filter itself).
r	= hydraulic radius	= m
s	= slope	= a-dimensional

The **hydraulic radius** is the quotient between the cross sectional area through which the water flows and the contour of the channel that is in contact with the water (this is called the wetted perimeter).

$$r = \frac{A}{p} \tag{9}$$

A = m^2
p = m

The **wetted perimeter** in **Fig 13** is the segment *abef* or:

$$p = W + 2 \cdot h \tag{10}$$

W = m
h = m

Also from Fig. 13 the hydraulic radius is:

$$r = \frac{W \cdot h}{W + 2 \cdot h} \tag{11}$$

Making use of those definitions the velocity will be:

$$v = \frac{1}{n}\left(\frac{W \cdot h}{W + 2 \cdot h}\right)^{2/3} s^{1/2} \tag{12}$$

v = m/sec
n = 0.03
W = m
h = m
s = a-dimensional

Changing terms, the slope can be expressed as:

$$s = \frac{v^2 * n^2}{\left(\frac{W * h}{W + 2 * h}\right)^{4/3}} \tag{13}$$

The extreme values for the **velocity** (**v**), the **slope** (**s**) and the **water head** (**h**) on the filter surface that can be tolerated in the design of a df, are given next. These values are somehow different from the original ones, and are based on the experience gained by the CSIR during the research phase that led to the publication of this guide. Besides, the velocity values are estimated for sand of the specific characteristics recommended in this guide.

$$0.05 \text{ m/sec} < \mathbf{v} < 0.20 \text{ m/sec}$$

$$0.1\ \% < \mathbf{s} < 2.5\ \%$$

$$\mathbf{h} \geq 10 \text{ mm}$$

16.13. DELIVERY CHANNEL

As mentioned in section 9, the best way to divert water from the river is by means of a channel.

With the value of Total Flow (the maximum amount of water to be abstracted from the river) determined, the reasoning is as follows:

If:

$\mathbf{Q_a}$ = total flow m^3/h

Firstly, any value ($\mathbf{W_c}$) is chosen for the width of the channel.
So:

W_c = width of channel m

The water velocity in the channel should be:

$6.0 > \mathbf{v_c} > 0.5$ m/sec

Above 6 m/s some erosion can be expected in a concrete channel, Kennedy (10). Below 0.5 m/s, probable sedimentation may occur.

The water head (h_w) in the channel should be:

$$h_w = \frac{Q_a}{V_c * W_c} \qquad (14)$$

(Please take unit conversions into consideration!)

The free board of the channel should be about 40 % above the water head.

The total height of the channel wall (h_c) will be:

$$h_c = h_w + 0.4 * h_w = 1.4\ h_w \qquad (15)$$

To calculate the slope in the channel, equation (13) can be used.

It is possible to infer the length of the channel (L_c) from the location of both the intake and the filter (i.e.: the distance between these elements).

Once these locations have been established, the relative height of both should be measured and the vertical elevation or difference in levels determined thereafter.

The difference in level between these two points is **ΔZ**

$$\Delta Z = H_i - H_f \qquad (16)$$

ΔZ	= difference in level between intake and filter	= m
H_i	= Level position of intake	= m
H_f	= Level position of filter inlet	= m

If using the value of the slope then:

$$\Delta Z = s * L_c \qquad (17)$$

L_c = length of channel = m

16.14. DELIVERY PIPING

If a pipeline is preferred as delivery medium, the way to design the diameter of the piping is the following:

The velocity ($\mathbf{v}_p$) in a plastic pipe (e.g.: HDPE) should be:

$$3.0 > \mathbf{v}_p > 0.7 \quad \text{m/sec}$$

The calculation is very simple as it is supposed that the piping would be relatively short and the water will be discharged freely into the atmosphere. The flow that will be carried in the pipe is called the "natural flow" and is the maximum flow that can be moved by gravity. The natural flow can be controlled by selective pipe sizing.

The flow value will be the same as in the previous case: the total flow Q_a

The procedure is as follows: First determine the slope (s). The slope can be obtained from the vertical elevation between intake and filter (ΔZ) and the pipe length (L_p)

$$s = \frac{\Delta Z}{L_p} \qquad \textbf{(18)}$$

s = a-dimensional
ΔZ = m
L_p = m

The pipe will introduce a friction factor which in turn will produce a head loss, in this case called the **frictional head loss or** natural frictional factor (F_n)

F_n is defined as:

$$F_n = s \cdot 100 \qquad \textbf{(19)}$$

F_n = m/100 m of piping

With the nomograph presented in **Fig 14** (extracted from (11)) -- connecting the "Head loss" figure with the "Quantity of water" (which in fact is Q_a in litres/sec) -- the inner diameter of the pipe can be obtained (in mm) from the specific column.

The nomograph will also allow one to check the velocity of the water in the piping.

16.15. FILTER BOX CHARACTERISTICS

As previously said, each unit will be designed individually. The length (**L**) and the width (**W**) will be obtained in the following way:

Firstly, the designer will choose a relation L/W that will be called "N".
So:

$$\frac{L}{W} = N \quad \textbf{(20)}$$

L = m
W = m

The area of the filter is already known and it has been called the "filter area of each unit" (FA) (see eq 4)

The following can be used to obtain L and W:

$$FA = L \cdot W \qquad L = N \cdot W \qquad A = N \cdot W^2 \qquad W = \left(\frac{A}{N} \right)^{1/} \quad \textbf{(21)}$$

It is important to note here that the value of the sand recovery box (that should be 1/5 (20 %) of the length of the filter as explained in point 12.2) should be added to the value of L (obtained by the previous equation). The total filter box length will then be:

$$L_{box} = L \cdot 1.2 \quad \textbf{(22)}$$

L_{box} = total filter box length = m

The wall of the filter box will have the following height:

$$H_{boxw} = H_{sppt} + H_{sbed} + H_{free} \quad \textbf{(23)}$$

H_{boxw}	= Height box wall	= m
H_{sppt}	= Height support bed (includes the drain system)	= 0.3 m
H_{sbed}	= Height of sand bed	= m
H_{free}	= Height free board	= 0.2 m

These are the basic parameters for the design of the filter box.

Taking into consideration the maximum and minimum values that the sand bed may adopt (0.5 - 0.7 m), the total height of the box wall would be between 1.0 and 1.2 m; and the water head on the filter box between 0.8 and 1.0 m.

This box can be built at ground level or on a platform. Neither option will pose major structural problems, due to the limited height, which in turn will not cause undue pressure on the walls.

For this reason it can be constructed from brick or stone masonry. A simple, easy to build wall, called "gravity wall" is shown in **Fig 15**. This wall is horizontally enlarged at the bottom and the pressure exerted by the water against it is supported by the weight of the same wall.

Jordan (11) proposes a table (Table 5) for this type of wall considering the head of water in a tank.

TABLE 5. GRAVITY WALL DIMENSIONS

WATER HEAD H (cm)	STONE MASONRY (cm)			BRICK MASONRY (cm)		
	A	B	C	A	B	C
80	65	15	--	60	20	--
85	65	20	--	60	25	--
90	65	25	--	60	30	--
95	65	30	--	55	25	15
100	65	25	15	60	25	15

A simple slab, with or without reinforcement, can be used as the filter floor.

Concrete walls are a typical example of structures that will present less problems with time. Although they are more expensive and require more skilled manpower, they are the best option in terms of reliability.

For the design of a concrete filter there are several publications that may help in the structural analysis, the concrete mix to be used and of curing. (12), (13).

Ferrocement structures are also another possible alternative for use in the filter box. Appropriate bibliography on this issue is (14), (15).

Finally, mild steel boxes are suitable for small units. They may be more expensive, but if properly coated with anti-oxide paints they have the great advantage of being ready for use as soon as they leave the workshop. Channels, baffles, sockets, valves and weirs are easily worked on and easily coupled to the box. Maximum sizes would be limited by the transporting vehicle.

The filter box facility to drain or fill the filter should be placed at floor level. This should have a valve and could be used either for the filling of the filter (bottom-up) in order to displace the air trapped in the sand, or to help drain the filter.

16.16. DISSIPATION CHAMBER

The design of this chamber is very simple as it is linked to the dimensions of the filter itself. The width of this chamber is the same as that of the filter, and its length, as already mentioned, is 1/5 of the filter's length.

The only baffle should be placed at 2/5 of the chamber's length (from the water entrance) and the opening at the bottom should be 1/3 of the water head.

16.17. LENGTH OF THE STRUCTURE

The length of the dissipation chamber is not included in the design of the filter box, therefore it should be added to the total filter box length. This is important to keep in mind as the structure will be built as one unit, although the dissipation chamber is in actual fact a different element of the unit.

The **total length of the structure** would thus be the total filter box length plus the length corresponding to the dissipation chamber. As this length is the same as the sand recovery chamber (1/5 or 0.2), the total structure length will be:

$$L_{structure} = L \cdot 1.4 \qquad (24)$$

L	= length of filter	= m
$L_{structure}$	= total length of the structure	= m

16.18. TAIL WATER BOX CHARACTERISTICS

The filtered or tail water can be delivered directly from the filter (that is, from the outlet of the drain system - the manifold -) to the reservoir or the users. If cleaning is not properly done and performed on a daily basis, then the filtering rate may decrease because the cake keeps growing thicker and more compact. The head loss will increase and as a result the filtration rate will diminish.

To avoid this eventually becoming a problem and to cope with the real head loss that will occur in the long run (see the section on "operation and maintenance"), a tail water box with a flow controller should be built.

The box is just a simple container placed next to the filter, sharing one of the filter's walls.

Its height would be the same as the filter's height.

It should be square and each side should be approximately 0.80 - 1.0 m.

The material should be the same as that of the filter box.

The box should have two connections at the bottom. One will be connected to the manifold of the filter drain, and the other to the tail water controller (on the inside) and with the outlet of the system (on the outside). Refer again to **Fig 10**.

16.19. TAIL WATER CONTROLLER

To maintain a constant flow of filtered water a flow controller should be used. Several types of devices can be used for this purpose, but the one shown here has proved to be effective and is easy to make. Fig 10 depicts this device.

The controller is a float connected to a piece of PVC pipe. The floats shown in the drawing and in the photos are made of PVC fittings. Nevertheless, any other float can be used, as long as it does not rust easily.

The float is connected to the PVC pipe by any means. There should be a distance of 0.15 - 0.25 m between the float and the orifice(s). This distance will be the head the water will have on the pipe's above the orifice(s).

The pipe should slide loosely either inside or outside another similar pipe which should be slightly bigger or smaller. This second pipe is fixed to the floor and is connected to the outside. It is the outlet for the filtered water.

The filter rate will be controlled by the water head on the sliding pipe and by a valve in the outlet.

A second valve should be placed immediately after the regulation valve. This valve is a shut off valve used to isolate the filter from the rest of the downstream system.

16.20. VALVES

Several valves will be placed in different parts of the system. Besides the valves already described in this guide, other ones should be installed in order to operate the system. Extra valves should be included in order to isolate the filter from the whole system, to drain, and to sample.

Fig 16 shows the complete set of valves and indicates their function (regulation, shut-off or sampling).

17. DESIGN EXERCISE

In order to assist the designer in a real calculation, an example of a rural community having the following characteristics, is presented:

The actual population of the village is 500, with an average annual growth rate of 1.6. There is a school in the community where 200 pupils attend daily, and the village will be supplied with dynamic filters using water from a nearby river. Analyses conducted on such water has proved to be fairly acceptable for this purpose.

This is a very rural population where the traditional way of obtaining water (the housewife fetches one or two containers of water per day from the river) signifies a very low consumption per capita.

Due to this fact and to the lack of abundant resources it is estimated that the daily individual consumption will be 25 litres. This has been discussed with the community and its members have approved this figure. The community is also happy with a system lifespan of 20 years.

The calculation will begin with the actual and future population.

Actual population	500	people
Lifespan	20	years
Average annual growth rate	1.6	

From table 3:

Percentage population increase in 20 years	38%
Daily individual consumption	25 ℓ/p/day

With these initial figures, the calculation can commence.

Future population

(eq 1)	500 p * 1.38	=	690 people
Special needs: 1 school		=	200 pupils

Future school population (this is only an approximation as schools do not grow like populations - they do it more in stages). Nevertheless, to include some type of growth forecast it is better than no consideration at all).

	200 p * 1.38	=	276 pupils
Water consumption per pupil			20 ℓ/day
Future needs: 276 p * 20 ℓ/p/day		=	5.5 m^3/day

Daily flow (volume the system will produce/day)

(eq 2) 690 p * 0.025 $m^3/p/d$ + 5.5 m^3/d = 22.8 m^3/day

The daily flow to be adopted will be: 24 m^3/day

Total filter flow (volume the system will produce per hour)

Total filter flow	1 m^3/h
Filtration rate assumed	0.2 $m^3/m^2/h$
Ratio cross flow/filter flow adopted	10 : 1
Minimum number of filters	2

Total filter area (the system's filtering surface area)

(eq 3) 1 $m^3/h \div 0.1\ m^3/m^2/h$ = 10 m^2

Filter area of each unit (surface area of each filter)

(eq 4) 10 $m^2 \div 2$ = 5 m^2

Filter flow (the flow that each filter will process)

(eq 5) 1 $m^3/h \div 2$ filters = 0.5 m^3/h

Total flow (total amount of water to be obtained from the river)

(eq 6) 24 m^3/d + 10 * 24 m^3/d = 264 m^3/d
= 11 m^3/h
= 3 ℓ/s

Design flow (this is the flow figure used to make the calculations)

(eq 7) 264 $m^3/d \div 2$ = 132 m^3/d
= 5.5 m^3/h
= 1.5 ℓ/s

Filter box

It will be given a ratio L/W = 5

(eq 21) L/W = 5 W = $(5\ m^2/5)^{1/2}$ = 1 m

So:

	L	=	5 m
	W	=	1 m

The filter box and filter structure dimensions will be:

Sand recovery chamber

Length	5 m * 0.2	=	1 m
	L_{box} = 5 m * 1.2	=	6 m

Dissipation chamber

Length	5m * 0.2	=	1 m

The total structure's length (length including dissipation chamber and sand recovery chamber) can be obtained either by adding up the different elements' lengths

5 m + 1 m + 1 m	=	7 m

or with eq 24:

(eq 24)	$L_{structure}$ = 5 m * 1.4	=	7 m

The box height can be obtained:

Height support bed	0.3 m
Height sand bed (adopted)	0.6 m
Height free board	0.2 m
Height box wall	1.1 m

Hydraulic relationships

The value adopted for the water head on the filter surface will be:

Head on the filter surface 15 mm

Wetted perimeter

(eq 10)	p = 1 m + 2 * 0.015 m	=	1.03 m
Wetted area	W * h = 1 m * 0.015 m	=	0.015 m^2

Hydraulic radius

(eq 9) $r = 0.015\ m^2 \div 1.03\ m$ = 0.0146 m

A slope of 1 % is assumed throughout the filter surface

Slope of the filter surface 0.01

The velocity will be:

(eq 12) $v = (1/0.03) * 0.0146^{2/3} * 0.01^{1/2}$ = 0.2 m/s

Which falls within the allowed range of velocities.

The difference in height between the inlet weir and the level controlling weir will be:

(eq 17) $\Delta Z = 0.01 * 5\ m$ = 0.05 m

Related systems:

Delivery channel:

Total flow = Q_a = 11 m^3/h

It has a channel width of:

W_c = 0.1 m

and a velocity

v_c = 2 m/s

The water head in the channel will be

(eq 14) $h_w = 11\ m^3/h \div 2\ m/s * 0.1\ m$ = 0.015 m

(Remember to take the units' conversions into account!)

The free board should be 40 % higher than the water head in the channel, but as the value obtained for h_w is low (only 1.5 cm) a value of 0.15 m is adopted for the channel wall height. This is done for building convenience.

To calculate the slope in the channel eq 11 should be used first to get the hydraulic radius, followed by eq 13.

(eq 11) $r = (0.1 * 0.015) \div (0.1 + 2 * 0.015)$= 0.011 m

(eq 13) $s = (2^2 * 0.03^2) \div (0.011)^{4/3}$ = 1.45

If the slope exceeds the suggested limits, it is not acceptable.

A second attempt should be made by changing, for example, the velocity. The new assumed velocity will be a lower one:

	v_c	=	0.5 m/s
	W_c	=	0.1m
(eq 14)	$h_w = 11\ m^3/h \div (0.5\ m/s * 0.1\ m)$	=	0.06m
(eq 11)	$r = (0.1 * 0.06) \div (0.1 + 2 * 0.06)$	=	0.027m
(eq 13)	$s = 0.5^2 * 0.03^2 \div 0.027^{4/3}$	=	0.027
		=	2.7 %

Which is very reasonable.

Now let us assume that the distance between the intake and the filter is 30 m.

It is important to verify the difference between the intake and the filter location heights to see if the selected location is appropriate for the system.

From eq 17 the difference in levels between those two points can be obtained.

(eq 17) $\Delta Z = 0.027 * 30\ m$ = 0.81 m

The difference in level between the two points should thus be at least 81 cm.

If this difference was bigger, it would increase the slope, which is not problematic as the value obtained for that parameter (2.7%) is not excessive. The higher value for the slope would have in turn increased the velocity value. But this also does not pose a problem as the value selected for the velocity is in the lower range. In any case, the designer would have to "play" with the real values in order for all his parameters to fall between the suggested limits.

A similar reasoning should be followed for the channel that will convey the unused water back to the river.

Drain system:

The dimensions of the filter box have been established as:

L	5 m
W	1 m

The drain system will comprise of one manifold and laterals on each side. The laterals will have holes.

The laterals will be spaced 1 m apart. So there will be:

Number of laterals on each side	6
Total number of laterals	12

If each lateral has 10 holes of 2 mm diameter each, then:

Area of 1 hole		0.0000031	m^2
Area of 10 holes (1 lateral)		0.000031	m^2
Area of all holes (12 laterals)		0.00038	m^2
Filter flow = 0.5 m^3/h	=	0.000139	m^3/s

Velocity in the total hole area:

Filter flow ÷ total area = 0.000139 m^3/s ÷ 0.00038 m^2 = 0.37 m/s

which is within the suggested range.

18. OPERATION AND MAINTENANCE

The operation of the df is very simple. A couple of minutes per day will suffice to provide everything a df needs to operate and stay "healthy" (i.e. to provide clean and safe water at the expected production rate).

Two activities should be performed by the operator. The first is a sanitary inspection and the second is the cleaning operation.

18.1. INSPECTING THE SYSTEM

The operator should undertake a sanitary inspection of the surrounding area.

The concept of "sanitary inspection" was developed more than a decade ago and has since then been sustained by experts associated with the World Health Organization. It was found that sanitary inspections were an efficient, quick, simple and cheap way of preventing problems when dealing with drinking water quality control programmes. A good sanitary inspection can detect problems before they cause any harm to or deteriorate the final product: the drinking water.

For an inspection of this kind to be performed on a df, very little is needed. Any operator can, with minimal skills, do his "round" and find any potential or actual problem and provide the solution or see to it that it gets fixed as soon as possible.

During the inspection he should verify the state and condition of intake, channels, valves and the filter itself. Obstructions, damages, leaks and any other problem should be fixed immediately. If he can not do it himself, he must report the problem to his closest authority as soon as possible.

It is important that he read the meters and take note of the amount of water being produced and the amount already produced (volumetric reading).

If there is a possibility to analyze the water for turbidity and E-Coli bacteria, he should take the corresponding samples.

All these evaluations should be written down on the appropriate forms, which should be as simple as possible.

18.2 CLEANING THE FILTER

Two filter cleaning operations should be carried out and these are daily cleaning and seasonal cleaning.

By cleaning the filter on a daily basis the operator will be restoring the filtering capacity to the same level as that of the previous day. He will hardly notice any fall in the filtration rate.

Nevertheless, some debris and particulate matter will be deposited on the lower layers of the filter resulting in head loss. (This will depend on the raw water quality, and will happen even if the daily cleaning is done properly.)

If the filter has a tail water box, the head loss will result in a water level fall in this box and hence the level of the tail water controller. If there is no such device, then the operator will see that the filtering rate decreases with time, and to maintain the same tail water flow he would have to open the regulation valve more and more until it reaches a stage where no further opening will yield the original flow. This phenomenon (which could be called the "dynamic filter run") will take a long time to reach. At this stage cleaning is mandatory. This run will take far longer than the run of a conventional ssf. It will most probably be a seasonal phenomenon. The word "seasonal" is used because this problem will appear in the rainy season when the water is more turbid. Another reason for "season" is because this cleaning is expected to be required once a year.

The procedure **to clean the filter on a daily basis** is as follows:

The operator should close the tail water outlet valve (using the shut-off valve and not the regulation valve!). The *inlet flow should not be touched!* It is *important* to let the cross flow continue running in order to carry the debris particles. The only difference between this procedure and the normal operation is that the filter will not be filtering any water now.

Using a wooden rake (see photo), the operator will disturb the surface of the filter trying to scour the upper layers of sand (not deeper than 5 cm from the surface).

He should start at the end nearest to the dissipation chamber, and finish at the end nearest to the sand recovery chamber.

During this activity, the dirt of the cake will be moving from the entrance to the end of the filter, and most of it will pass over the sand recovery chamber. The operator should rake the last portion of the filter gently, because if he is not careful, too much sand might pass over the level controlling weir.

Although there is a sand recovery chamber to hold this escaping sand, it is better not to lose too much sand there, as this will have to be recovered and eventually washed and replaced on the filter's surface.

Once the filter is clean, the operator should open the tail water valve and re-start the filter operation.

It is suggested that the cleaning be done on a daily basis. It is however possible that the cleaning operation could be done every two, three or more days, depending on the characteristics of the water and how the filter operates. Nevertheless, the operator should initially be told to do this job every day, and later on, if the particular conditions of the filter behaviour allow it, only then should a more relaxed cleaning schedule be adopted.

When too much sand starts to gather in the sand recovery chamber (there is not a fixed amount for "too much"), this chamber should be drained and the sand collected. If it is clean, it should be immediately replaced. If it is too dirty, some means should be introduced in order to clean it by washing it with filtered water. This will depend upon local conditions, the filter behaviour and the engineer's design.

The **seasonal cleaning** is considerably more important and takes more time.

The filter is stopped, the inlet cross flow closed and the box drained. Using a shovel, approximately 20 cm of sand should be removed from the top layers, along the entire surface of the filter. The sand is replaced by new and clean sand or the dirty sand can be washed, and returned to the filter once clean. Although this operation is also very simple, it may demand one or two days to be completed and the filter re-started. This is the equivalent to the cleaning of a standard ssf, which in this case has to be performed far less frequently.

19. DESIGN PARAMETERS

It is important to have all the design parameters shown together on a separate table or section.

This constitutes a quick reference tool that helps the design engineer to obtain the information required without having to scan the whole document.

The following is the sum of all the parameters as recommended in the guide.

Maximum turbidity allowed in raw water — 50 NTU

Dissipation chamber:

depth and width	= the same as that of the filter
length	= 1/5 of the filter's length
baffle position	= 2/5 of box's length, measured from the entrance opening
the bottom of baffle	= 1/3 of water head

Weirs:

material	= anti-oxide painted mild steel, 3 - 7 mm thick
length	= the same as the filter width
width	= 0.25 m

Filter:

ratio Length/width for the filter	3:1 - 6:1
extra length for the sand recovery zone	1/5 Length of filter box
free board above water level	0.2 m

Sand recovery box:

length	= 1/5 of filter's length	
width	= filter's width depth	0.5m

Drain:

distance between laterals	0.5 - 1.5 m
diameter of holes	2 - 3 mm
width of slots	1 mm
velocity in the holes or slots	0.3 - 0.5 m/s
diameter of gravel or stone	25 - 50 mm
height of the gravel or stone bed	0.15 m

Support media bed:

LAYER	TYPE	PARTICLE DIAMETER mm	LAYER THICKNESS mm
Top	Coarse sand	1 - 2	50
Second	Fine gravel	2 - 5	50
Third	Gravel	5 - 10	50
Bottom	Coarse gravel	10 - 25	150

Filter media:

effective size, d_{10}	0.15 - 0.45 mm
uniformity coefficient	1.5 - 4.0
filter media depth	0.5 - 0.7 m
Reservoir volume	50 % of daily filtered water production

Design:

Lifespan of filter	10 - 25 years
Daily individual water consumption	45 litres/person/day
Filtration rate	0.1 - 0.3 $m^3/m^2/h$
Ratio cross flow/filter flow	5:1 - 15:1
Minimum number of filters	2
Water velocity in the df(if sand bed)	0.05 - 0.20 m/sec
Water velocity in the df (if blastrite)	0.05 - 0.28 m/sec
Water velocity in delivery channel	6.0 - 0.5 m/sec
Water velocity in delivery piping	3.0 - 0.7 m/sec
Slope in the df	0.1 - 2.5%
Slope in delivery channel	0.1 - 20%
Head of water in the df above the sand surface	$\geq$ 10 mm
Coefficient (Manning) for df	0.03

Tail water box:

Height	= filter's height (both sides equal)	0.80 - 1.00 m

20. GLOSSARY

Bed = a certain amount of gravel or sand placed in the filter box. The sand bed is responsible for the filtering action.

Blastrite = by-product of South African mining industry. Very similar to sand, but with better properties (harder, and heavier). Produced by Blastrite GA. PO Box 5515, Cape Town 8000, South Africa.

Cake = debris and dirt building up in the top layer of the filter and responsible for the head loss.

Cross flow = flow of raw water running across the filter's surface

Daily flow = volume of water that the filter should produce per day. It is expressed in m^3/day

Daily individual consumption = the amount of water a person will consume per day (all uses included)

Delivery conduit = channel or pipeline that brings the water from the river to the filter

Dissipation chamber = inlet chamber that distributes the water at the entrance of the filter, and most important, it dissipates the energy the water carries along the entrance channel

DF = Dynamic filter

Drain = system consisting of pipes, bricks or blocks or even stone and gravel that allows the collection of the filtered water and its conduction to the filter's outlet

E. Coli = indicator bacteria. Its presence suggests contamination by human or animal faeces

Effective size (d_{10}) = the size of the sieve opening through which only 10 %by weight) of the sand will pass.

Filter area of each unit = the surface area of each filter in the system

Filter box = the structure (in the shape of a box) that contains the support and filtering beds and the drain system

Filter flow = the flow that each filter unit will manage individually

Filter rate = flow of water to be filtered by unit of filter area

Flow regulator = device to maintain the constant flow of the tail water.

Future population = is the actual population plus the percentage increase in the chosen period of years considered as the lifespan of the system

Free board = the part of channel wall or filter wall that is above the maximum water level

Friction head loss = factor depending on the material a pipe has been made of. It gives an idea of the loss of head due to that material

Giardia = Giardia lamblia is a pathogenic protozoan that causes severe diarrhea

Gradient = the amount of slope between two points

Grain size distribution = analysis of a sand sample showing the different amounts (by weight) of certain particle diameters. It is plotted on semi-log paper

Gravity wall = a filter wall made of bricks or stones. It counteracts (neutralises) the pressure exerted by the water with its own weight

Growth factor = is the average annual population growth rate in a certain region

HDPE = High density polyethylene

Head = height of water above a certain surface

Head loss = difference in water height between two points belonging to different parts of an element or to different elements, caused by loss of media permeability and increased flow resistance

Hydraulic loading rate = the same as "filter rate"

Hydraulic radius = the quotient between cross sectional area through which the water flows and the perimeter of the channel that is in contact with the water (this is called the wetted perimeter)

Maturing = the biological process by which the sand bed develops the biofilm or schmutzdecke

MOGGOD = Mixed Oxidant Gases Generated On-site for Disinfection. A new technology that produces chlorine and ozone related compounds by electrolysis of table salt solution

Natural flow = the maximum flow that can be moved in a pipe by gravity

NTU = Nephelometric turbidity units

Raw water = the water obtained from the river without treatment

Ripening = see "maturing"

Rough filtration = filtration through several layers of coarse media (stone, gravel) to reduce raw water turbidity

Run = period of time between filter cleanings

Sand recovery chamber = a box inside the filter structure where sand will be collected for replacement in the filter

Schmutzdecke = biofilm that covers the sand grains and that is responsible for the elimination of the organic contamination in the raw water

Sieve = device consisting of a frame and a wire mesh used for sorting different sizes of sand particles

Slope = the difference in height between two points per unit of length

Sluice gate = plate in channel to control water flow

Special needs = amount of water consumed or used daily for other purposes than the direct individual house-related consumption (e.g.: schools, clinics, etc.)

SSF = Slow sand filter

Tail water = Filtered water

Tail water box = small box by the filter that receives the tail water. It houses the flow regulator

Tail water controller = see flow regulator

Total filter area = is the total surface area the filtering system should have

Total filter flow = is the filter flow expressed in m^3/hour

Total flow = the total amount of water that will be obtained from the river (in m^3/day or in m^3/h)

Total length of structure = the filter box length plus the length corresponding to the sand recovery chamber and the dissipation chamber

Uniformity coefficient (UC) = is the ratio d_{60}/d_{10} that is the ratio of the sieve size through which 60 % of the sand will pass to the size through which 10 % will pass

Velocity = the velocity the water has in a conduit (pipe, channel or filter surface)

V - Notch weir = weir with a 60° V-notch, used to measure the flow in a channel

Weir = plate in a channel or the filter to control flow and slopes

Wetted perimeter = the contour of the channel or pipe that is in contact with the water running inside that channel or pipe

Wooden rake = a simple tool made out of a piece of flat wood which is used to clean the filter.

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22. ACKNOWLEDGEMENTS

I wish to express my most sincere gratitude to the people who made the production of this technical guide possible. My idea was to produce a document that would be a useful tool for the spread of the dynamic filter technology. Nevertheless, without the open help of many people, that idea would have never been more than a good intention.

The helping hands of friends and colleagues from two continents, were the instruments that led to what I hope may be a new start, a re-birth of a worthy technology.

Special thanks are due to:

Dr T. C. Erasmus, Research Manager from the Water Research Commission (WRC) for his support and assistance.
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To the **CSIR** and **Water Research Commission**, the organizations that supported and funded the research performed in South Africa, my trip to Latin America and the production of this technical guide.

F. Solsona
Pretoria, South Africa
June 1993

APPENDICES

APPENDIX A
FIGURES

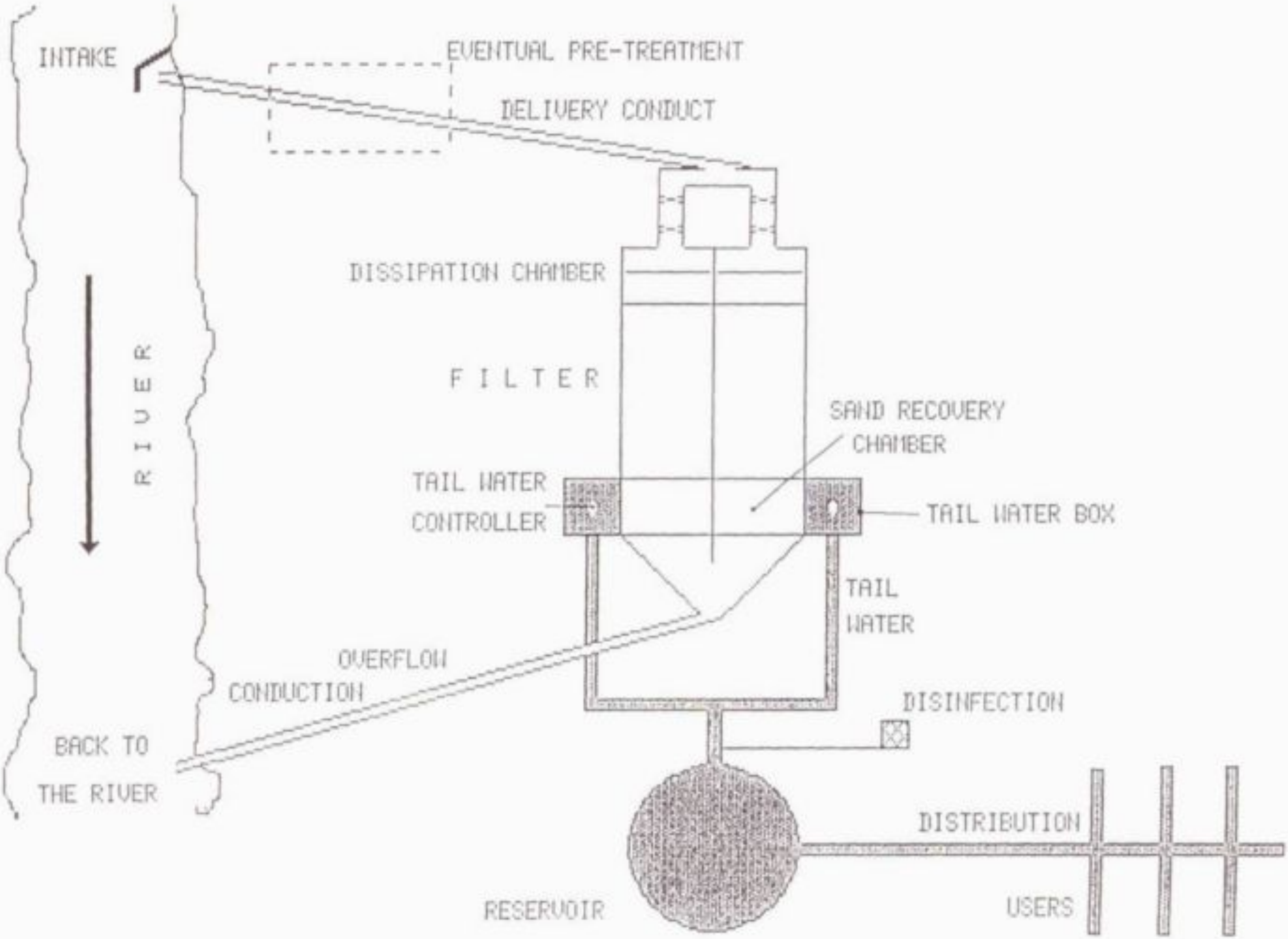
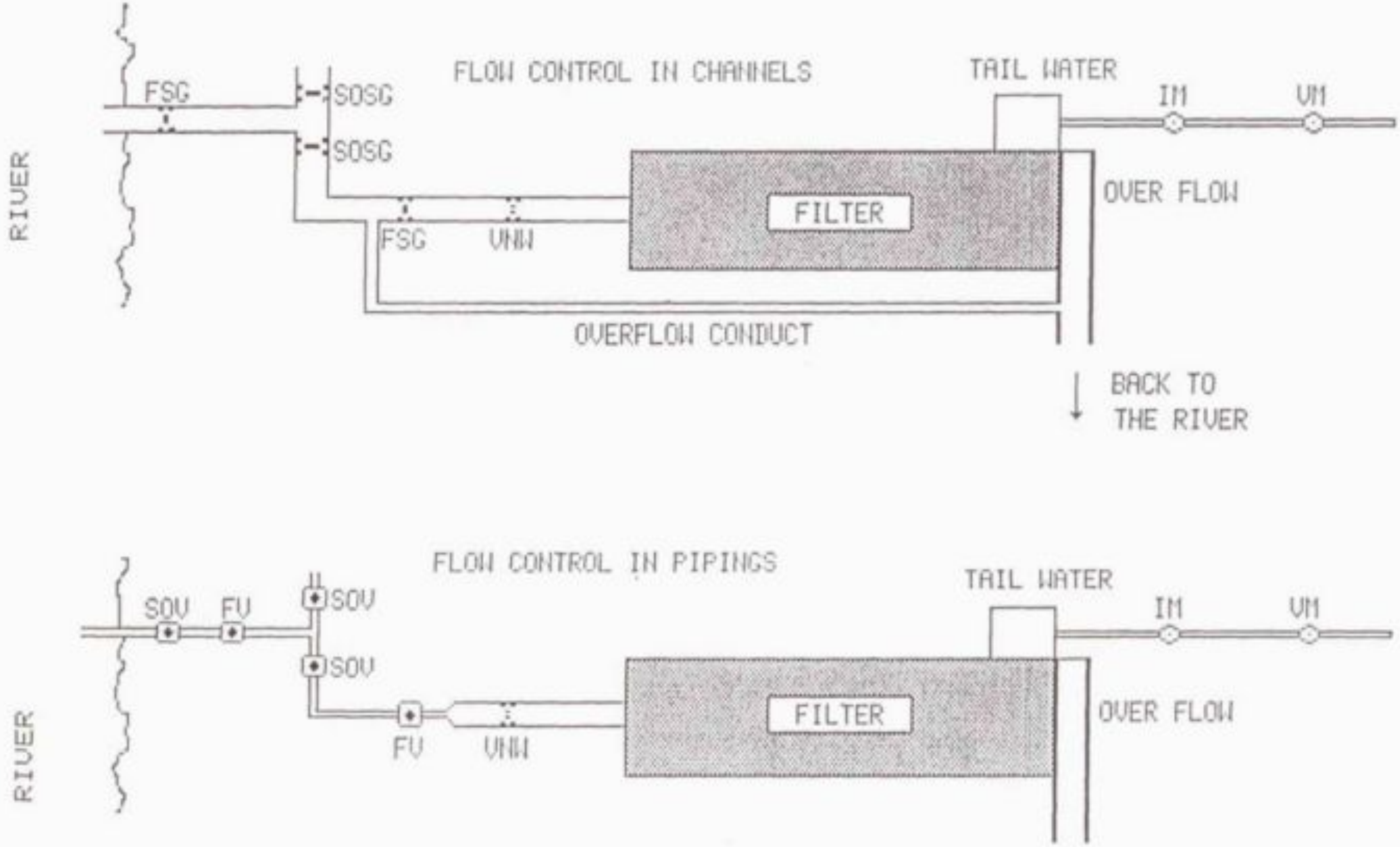


FIG. 1 - TYPICAL LAYOUT OF A DYNAMIC FILTER SYSTEM



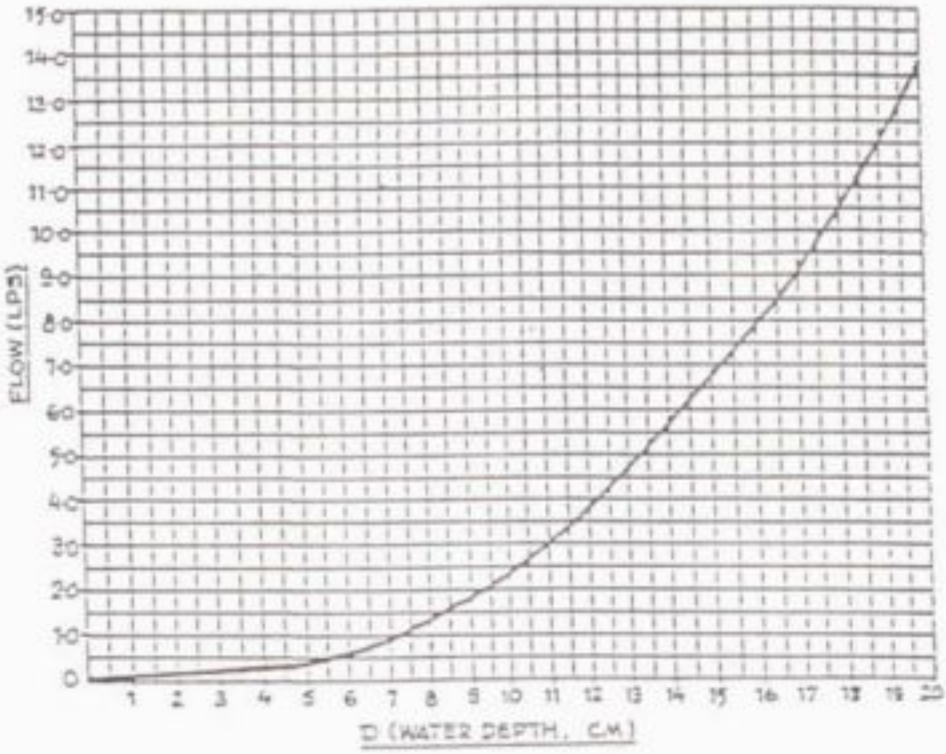
FSG = Flow controlling sluice gate
SOSG = Shut-off sluice gate
VNW = V-Notch weir

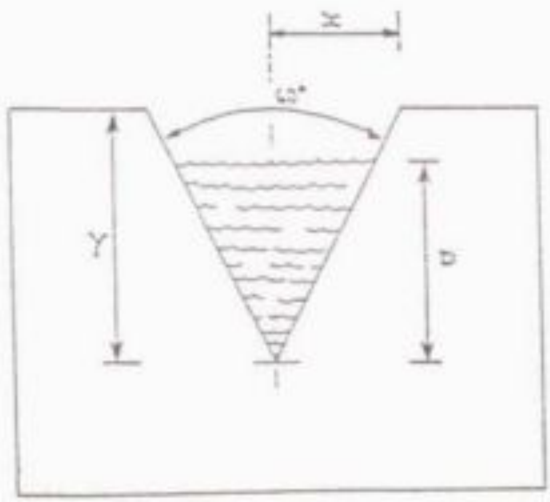
FV = Flow controlling valve
SOV = Shut-off valve
IM = Instant flow meter
VM = Volumetric meter

FIG. 2 - FLOW CONTROL - IN CHANNEL AND IN PIPE SYSTEMS

$$Q = 775 \cdot h^{2.47}$$

$$[Q] = l/sec$$
$$[h] = m$$





$$\frac{X}{Y} = \frac{1}{1 \cdot 73}$$

FIG. 3 - 60° V-NOTCH WEIR - FLOW GRAPH AND FORMULA

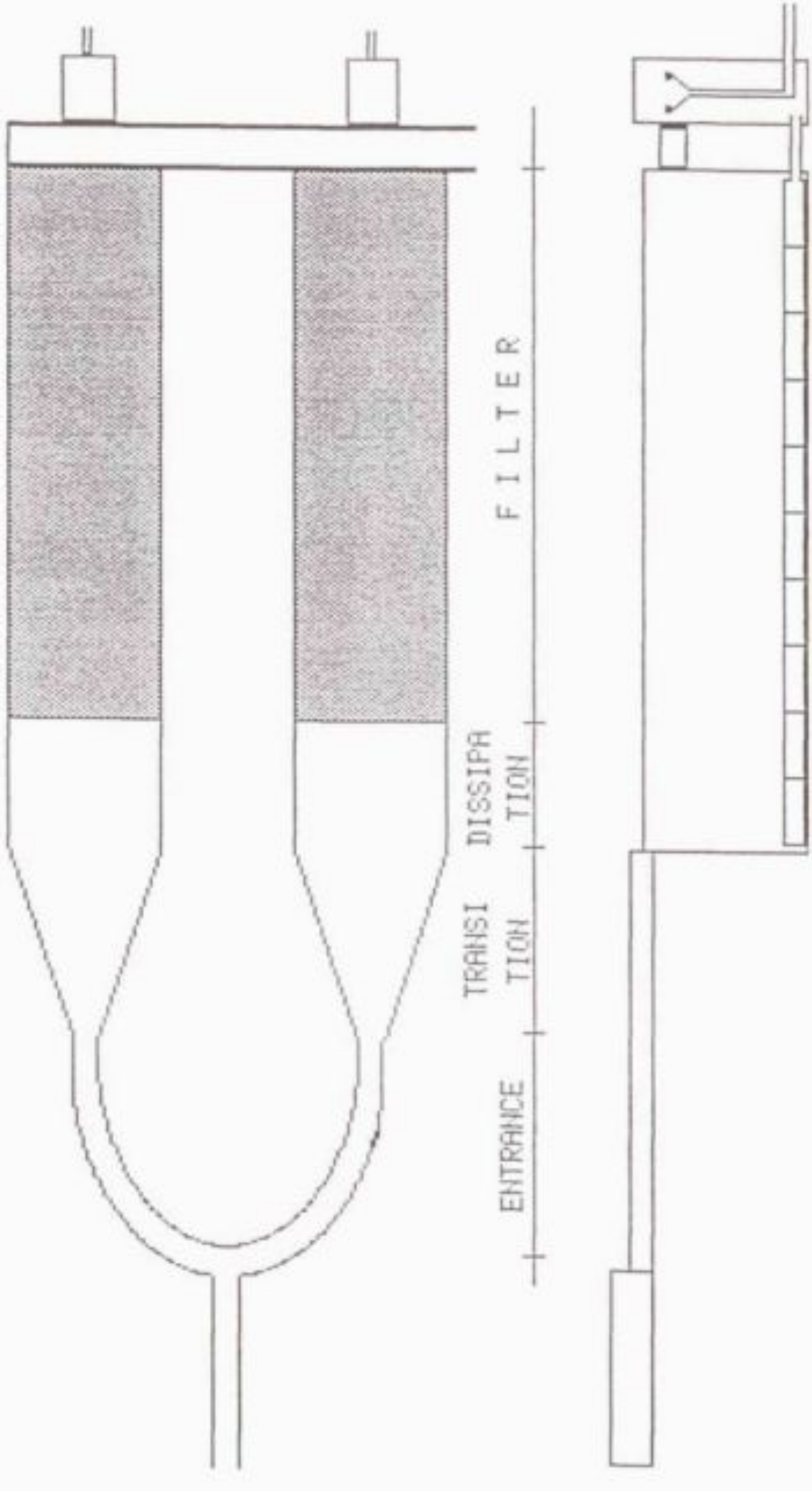


FIG. 4 - ORIGINAL LAYOUT FOR A DYNAMIC FILTER

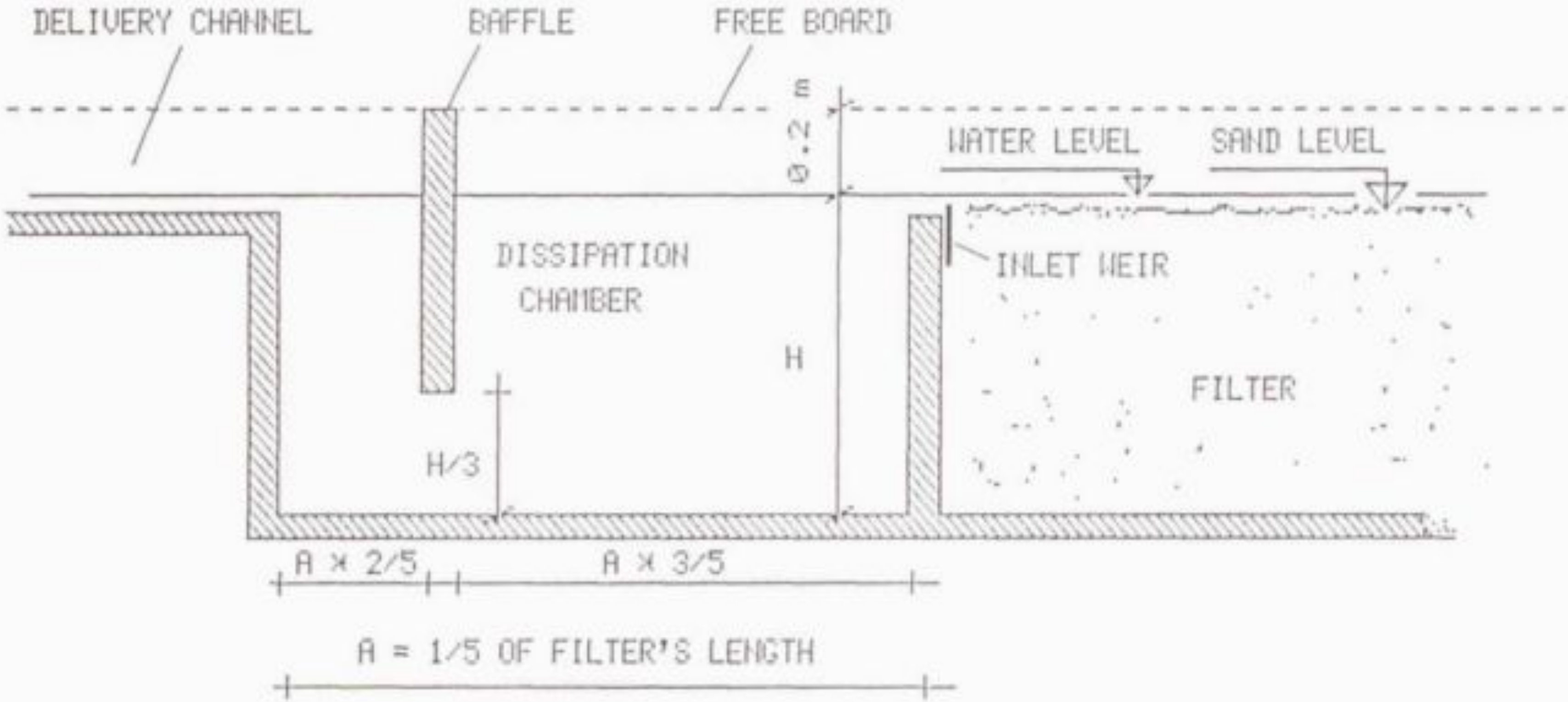


FIG. 5 - DISSIPATION CHAMBER

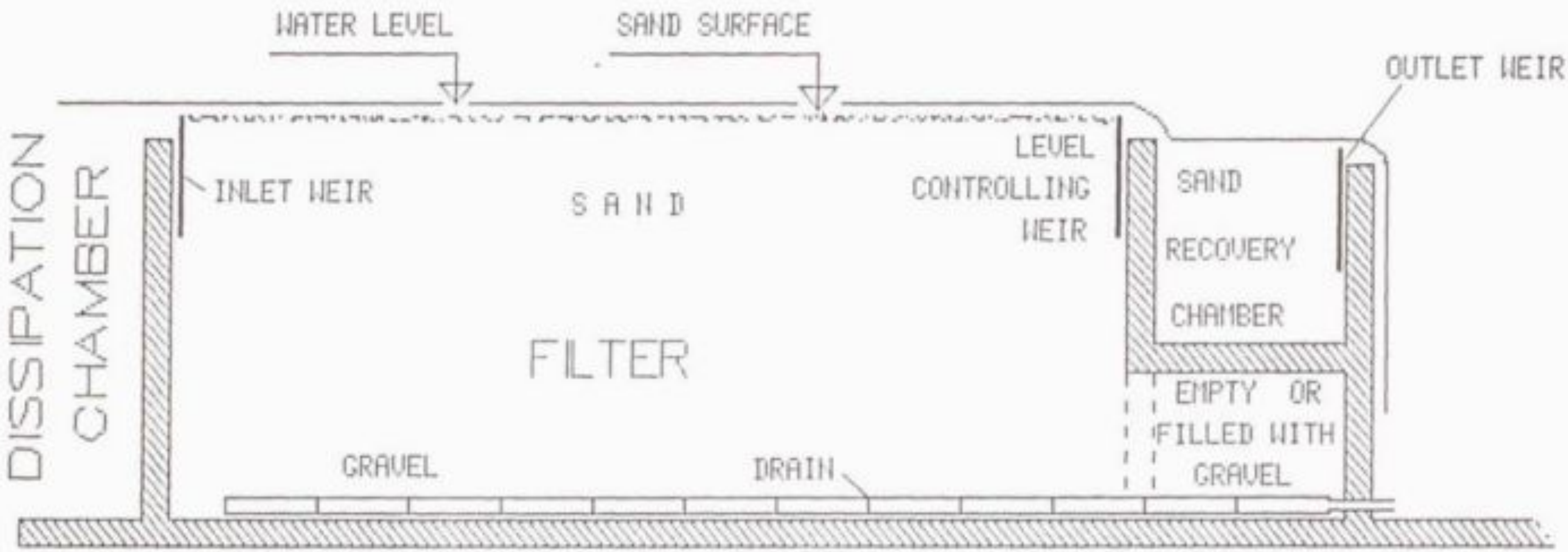

WATER LEVEL
SAND SURFACE
OUTLET WEIR
DISSIPATION CHAMBER
INLET WEIR
SAND
LEVEL CONTROLLING WEIR
SAND RECOVERY CHAMBER
FILTER
EMPTY OR FILLED WITH GRAVEL
GRAVEL
DRAIN

FIG. 6 - WEIRS

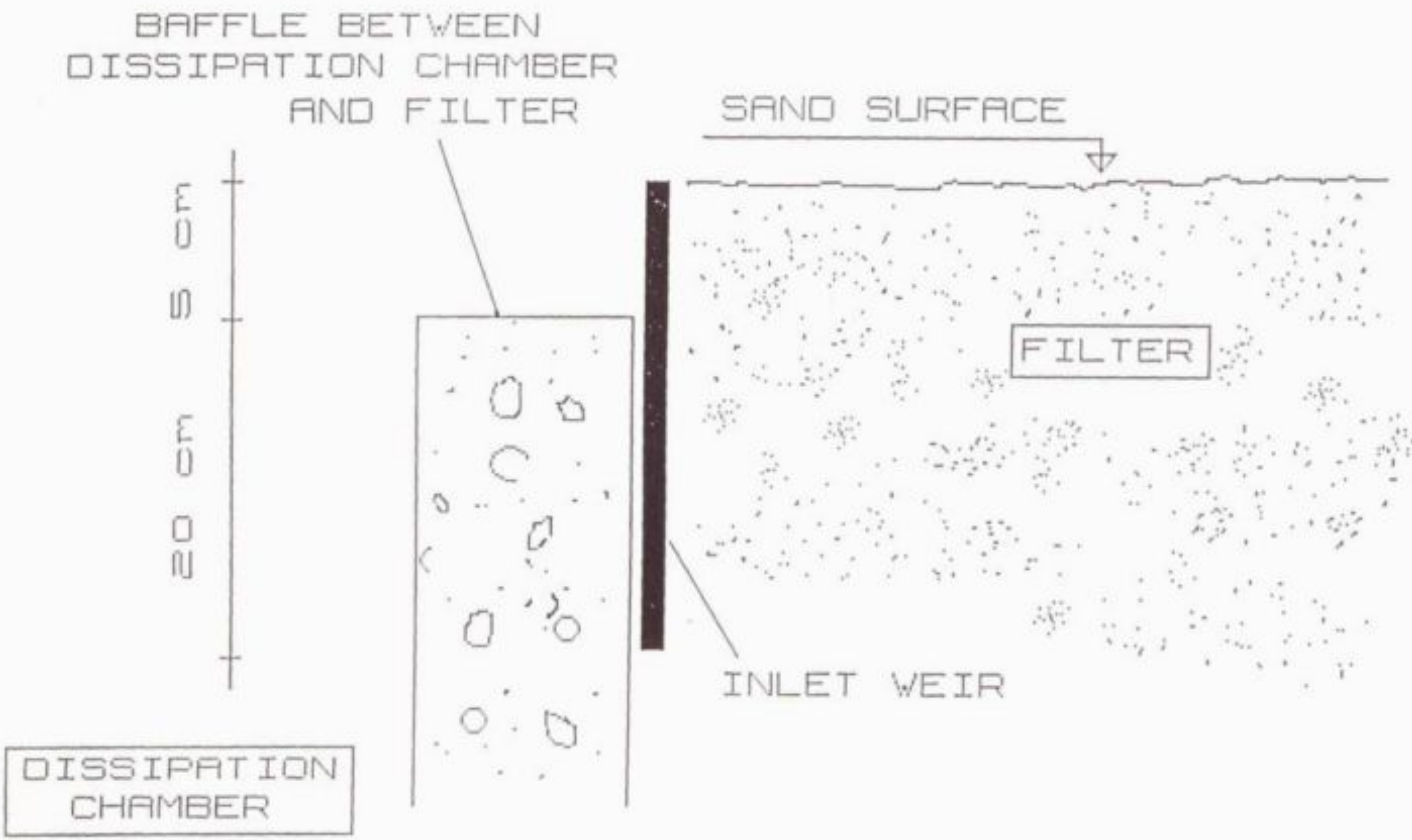


FIG. 7 - INLET WEIR

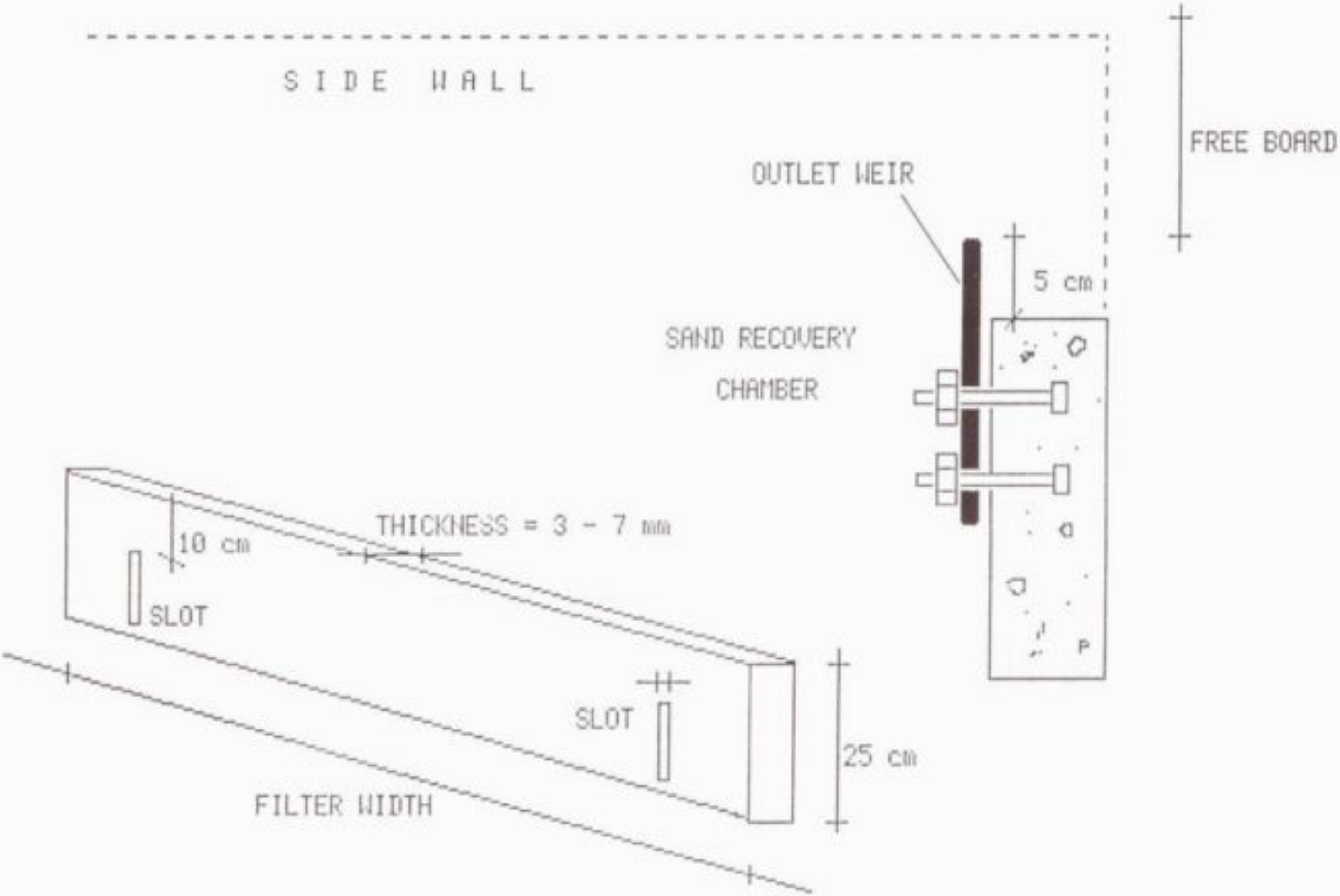


FIG. 8 - OUTLET WEIR. SLOTS TO CONTROL LEVELS

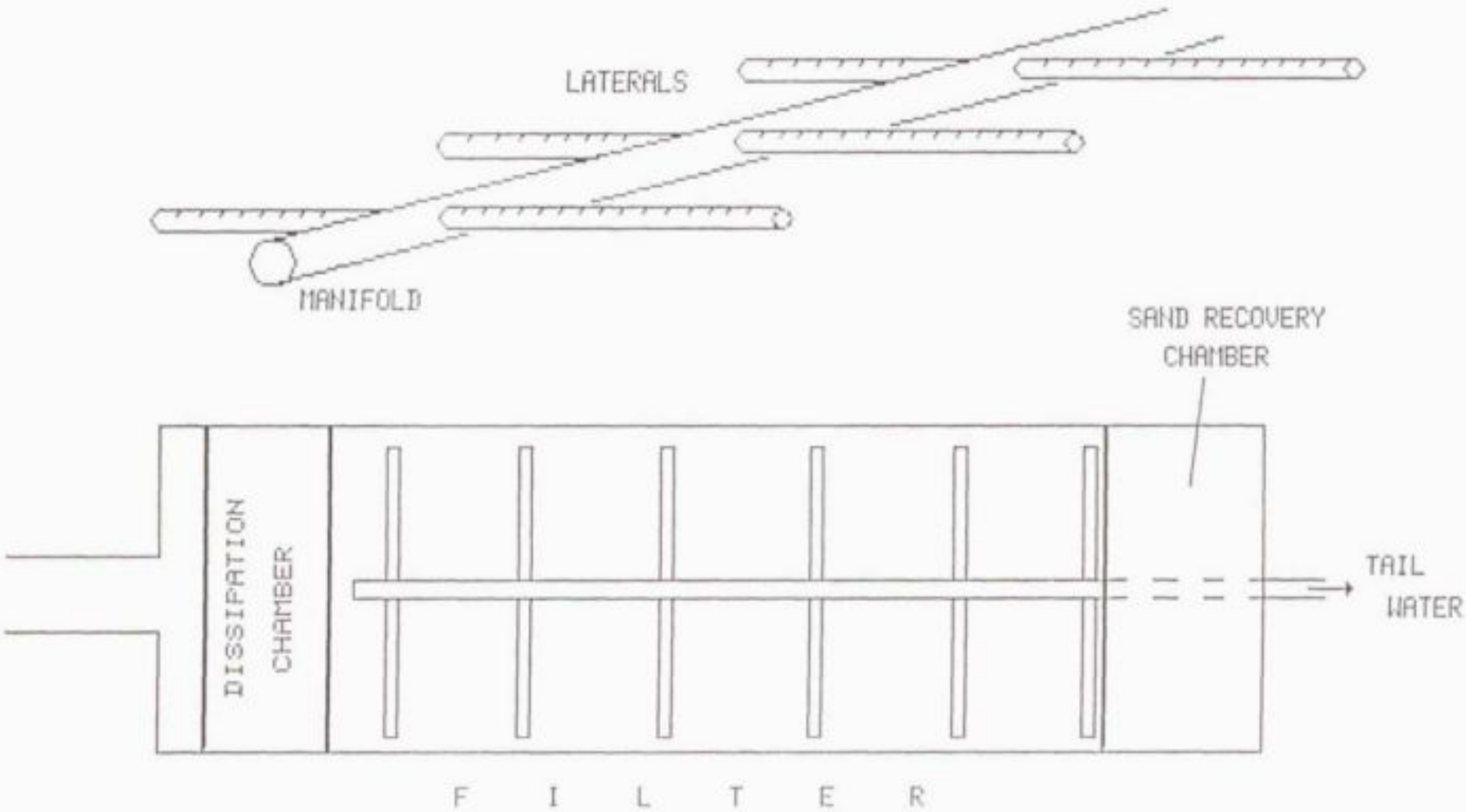


FIG. 9 - DRAIN SYSTEM WITH PIPES

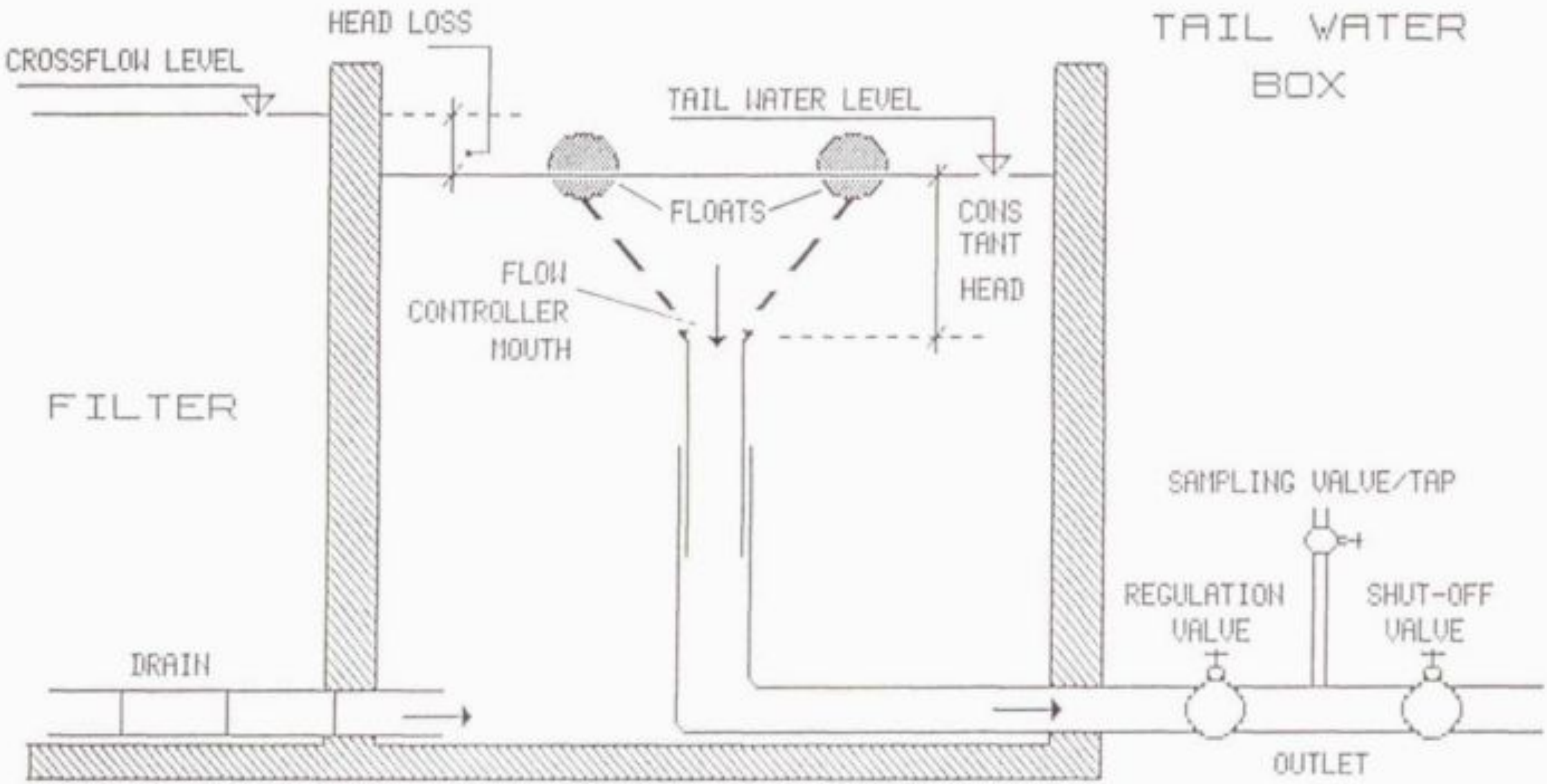


FIG. 10 - TAIL WATER BOX AND TAIL WATER CONTROLLING SYSTEM

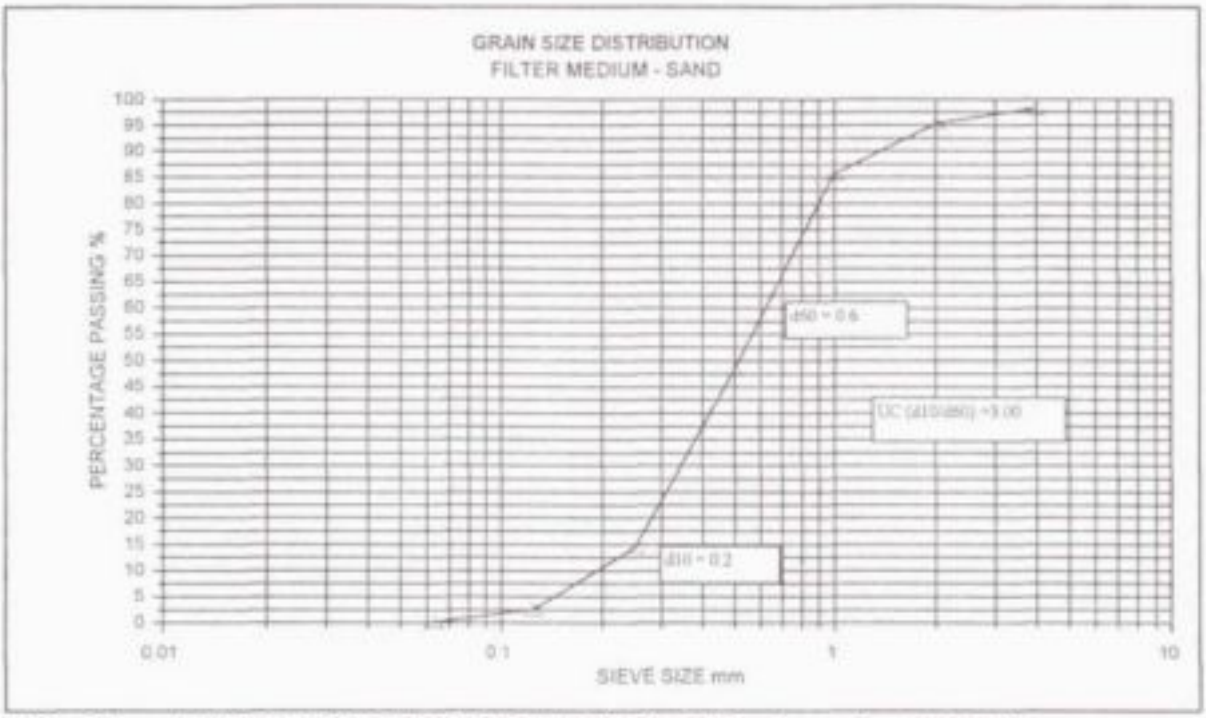


FIG.11 - SIEVE SIZE DISTRIBUTION CURVE, d_{10}, d_{60} and UC

Sieve Size (mm)	Cumulative Percentage material passing by weight (%)
4	98.4
2	95.5
1	85.7
0.5	48.3
0.25	14.5
0.125	2.6
0.063	0.2

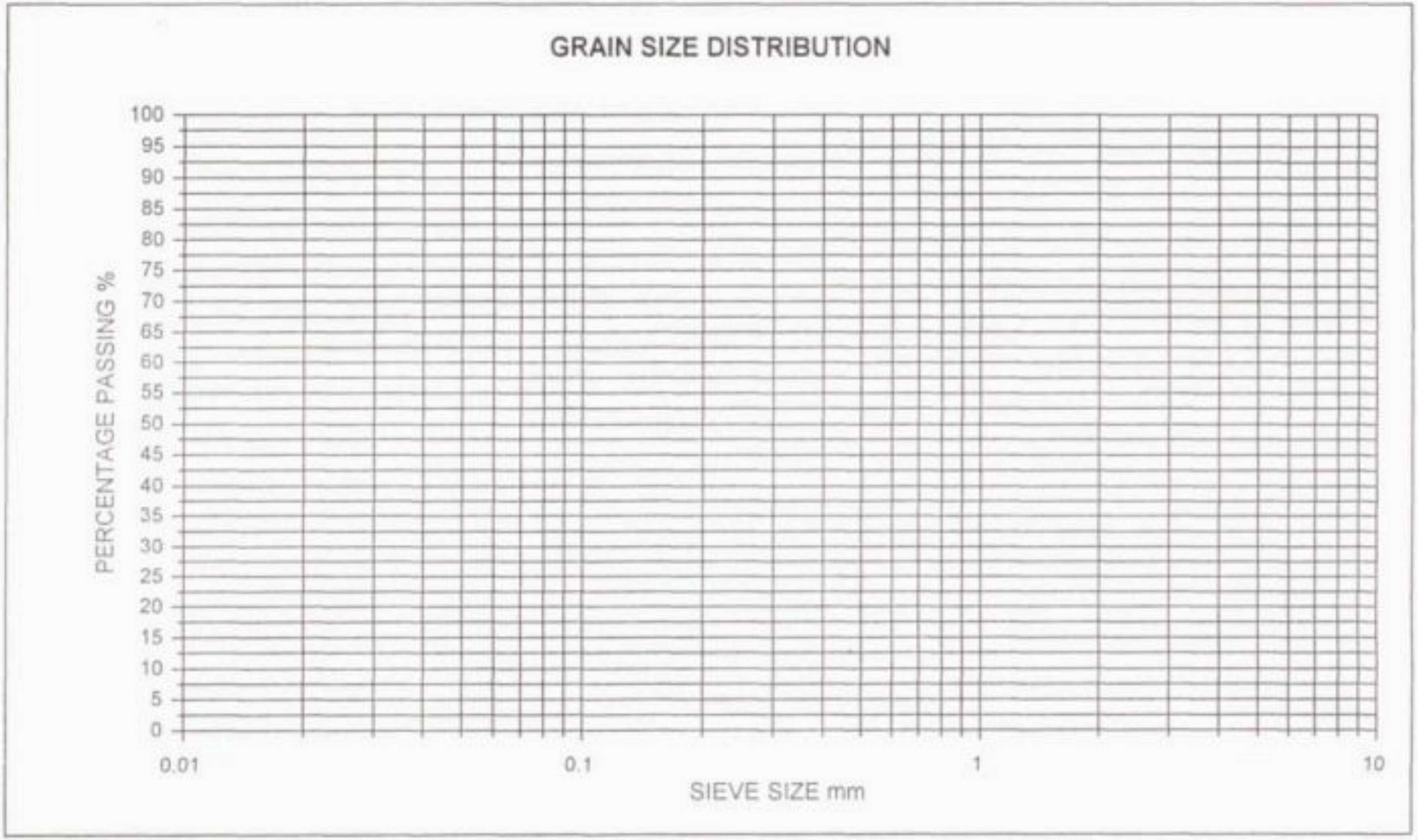


FIG. 12 - SIEVE ANALYSIS PLOTTING FORM

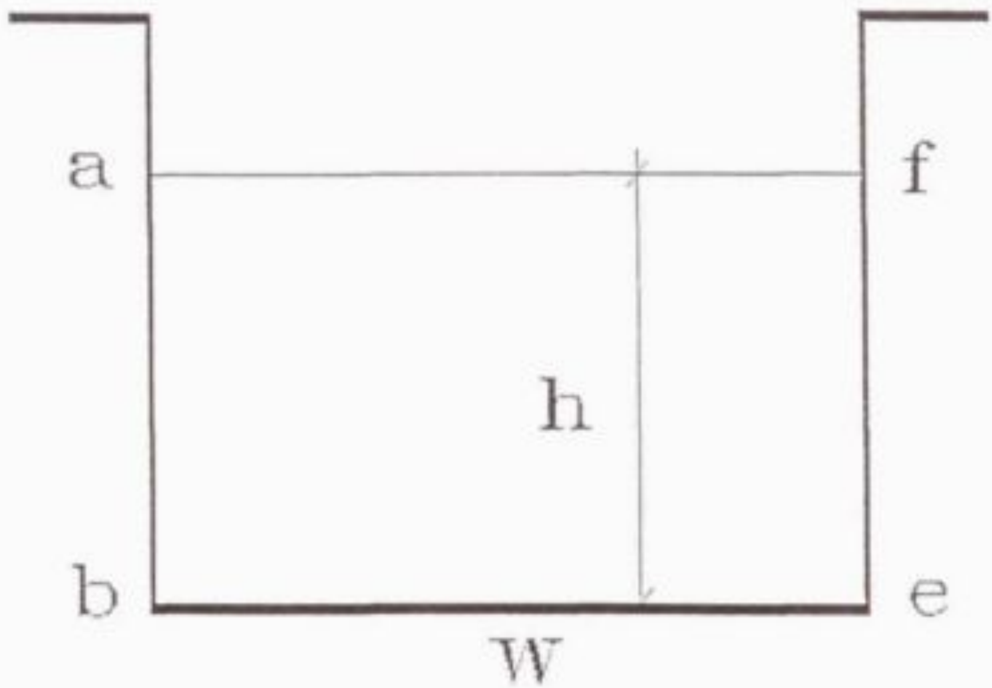


FIG. 13 - HYDRAULIC RADIUS

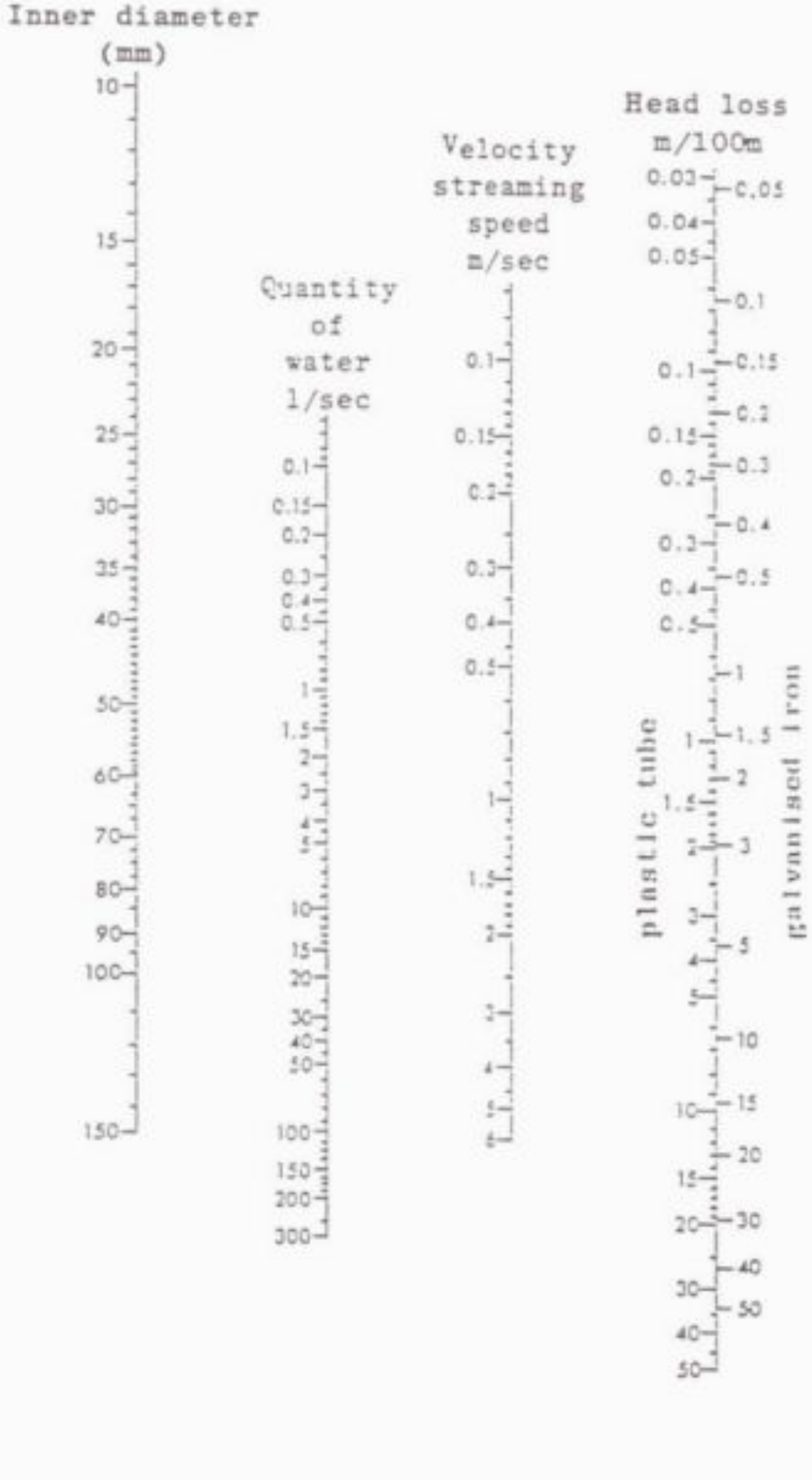


FIG. 14 - FLOW NOMOGRAPH FOR PLAŠTIC AND GI PIPE

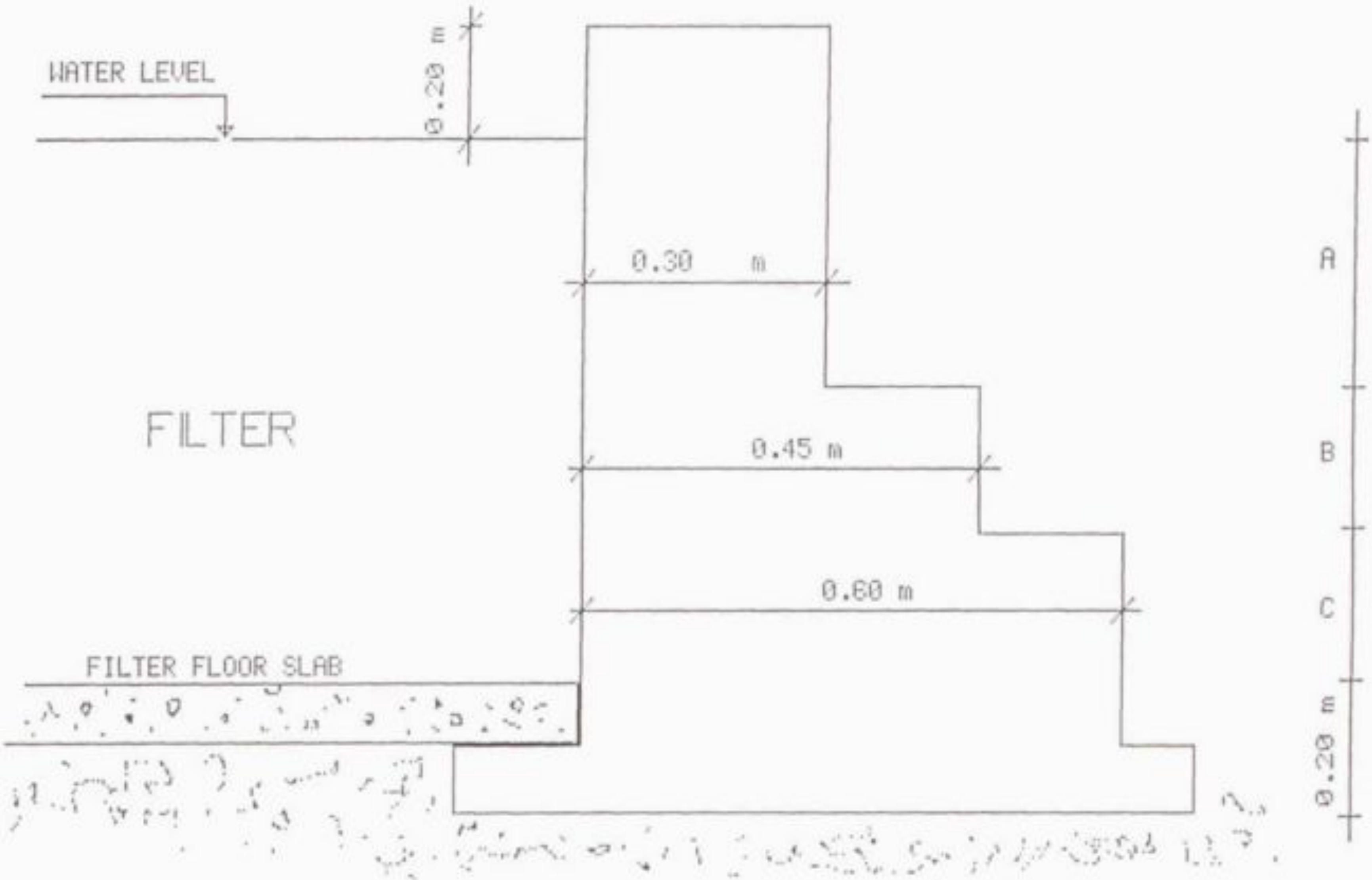
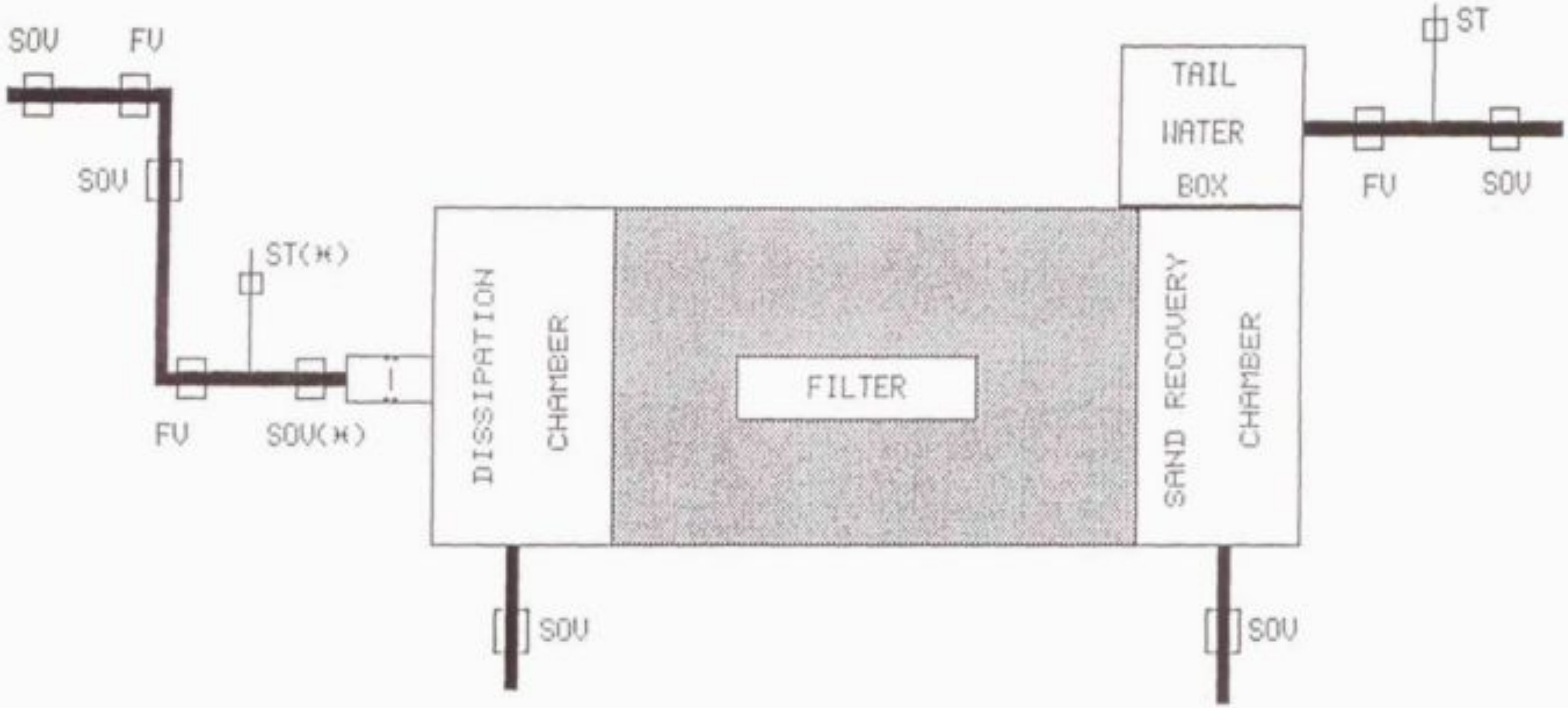


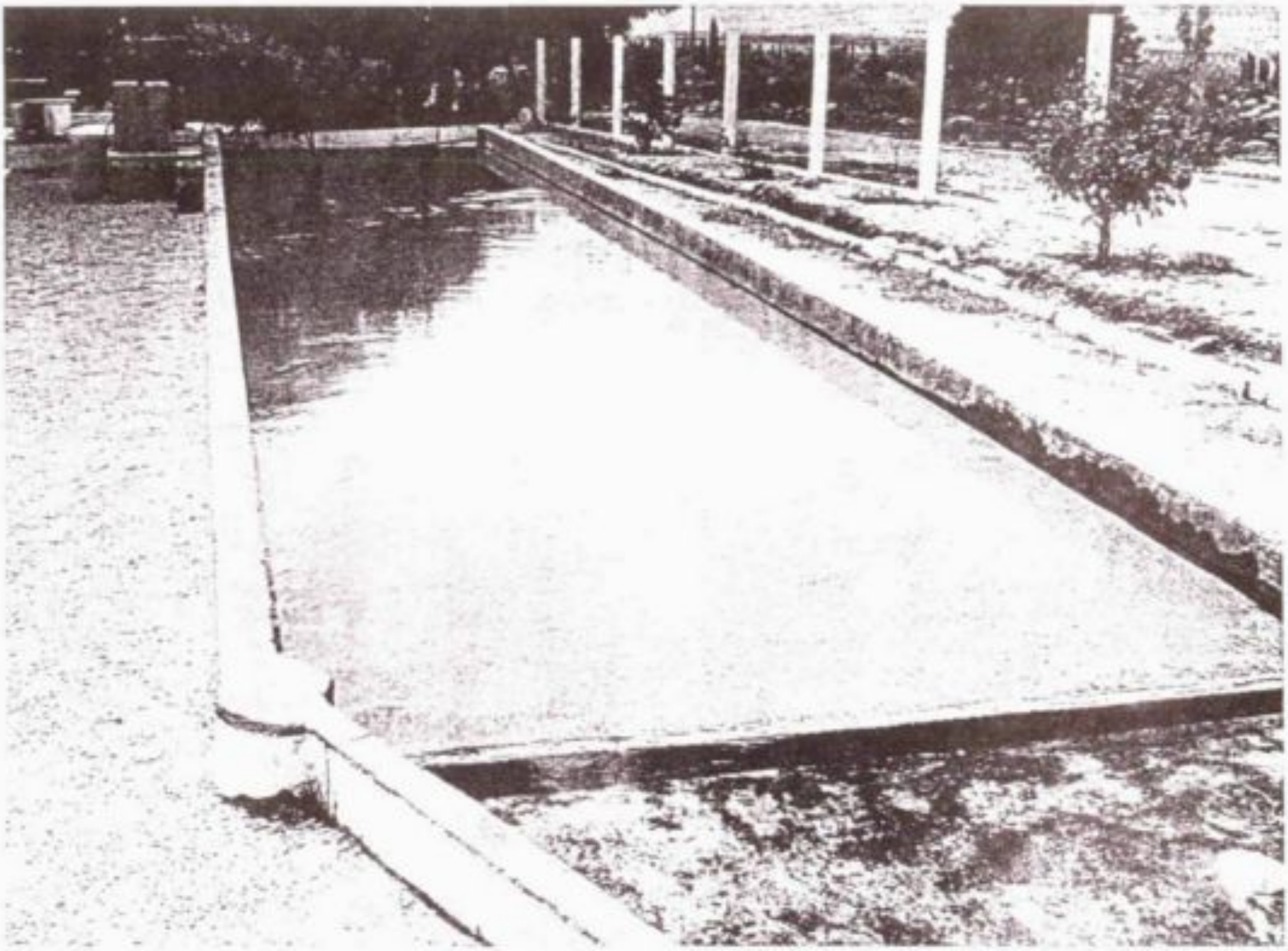
FIG. 15 - GRAVITY WALLS FOR THE FILTER BOX



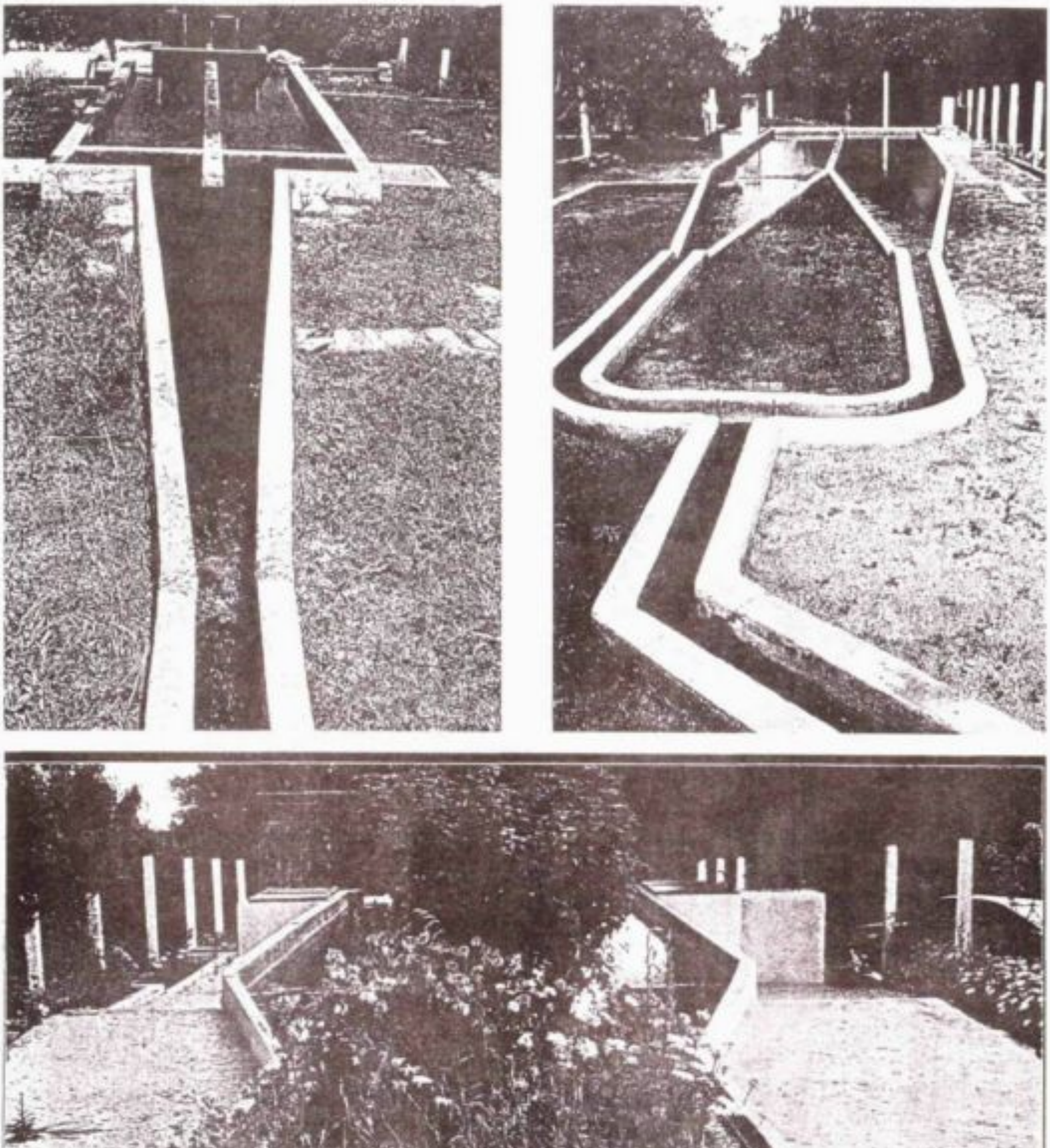
SOV = Shut-off valve
FV = Flow controlling valve
ST = Sampling tap
(*) = Optional

FIG. 16 - VALVES IN THE SYSTEM

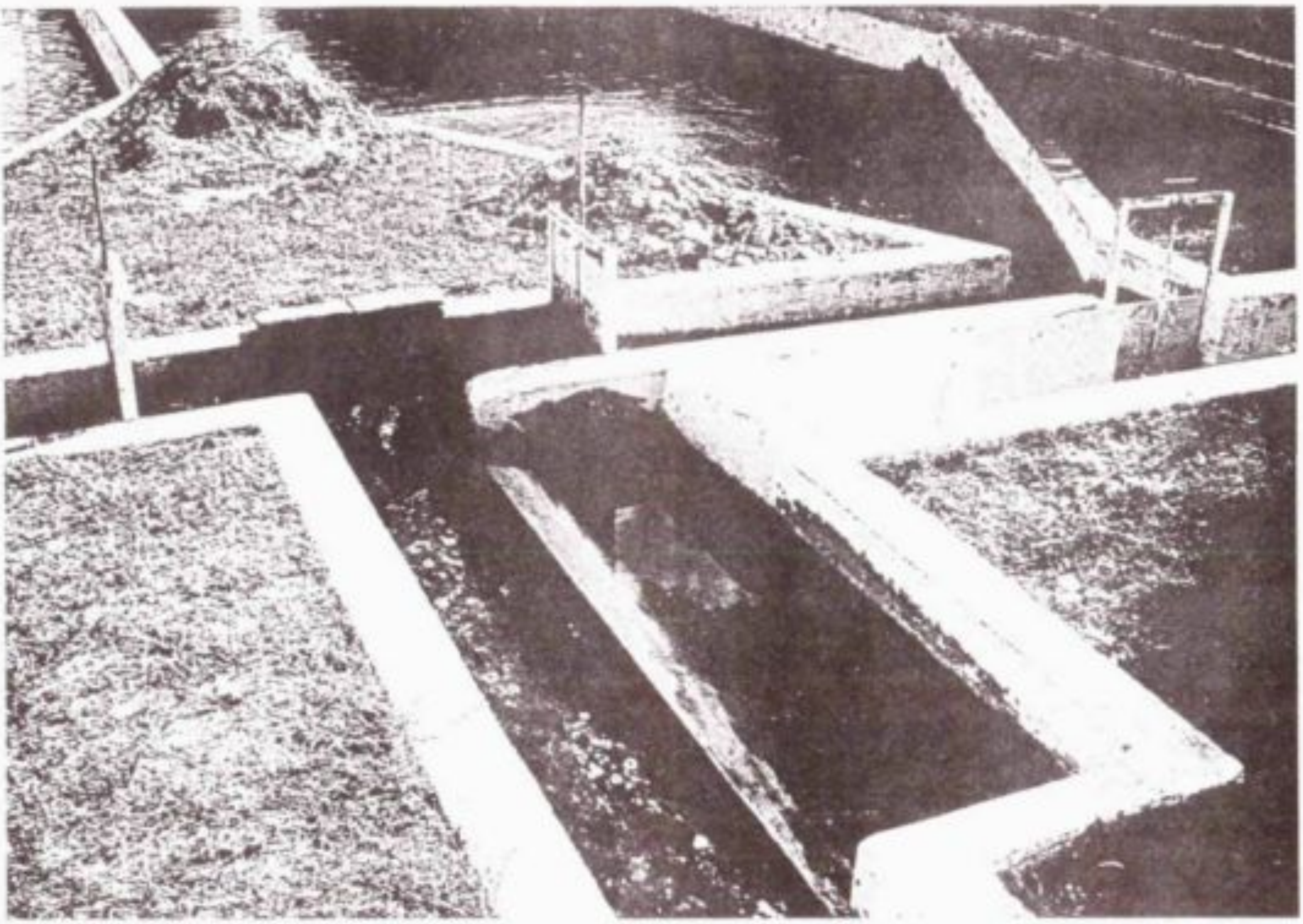
APPENDIX B
PHOTOGRAPHS



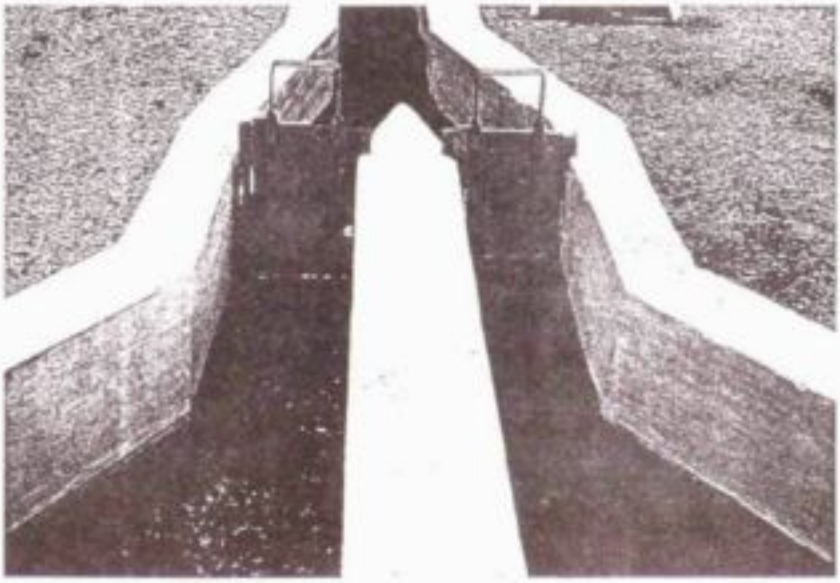
First dynamic filter built in Latin America (1969) (and still working)
Anillaco, La Rioja, Argentina

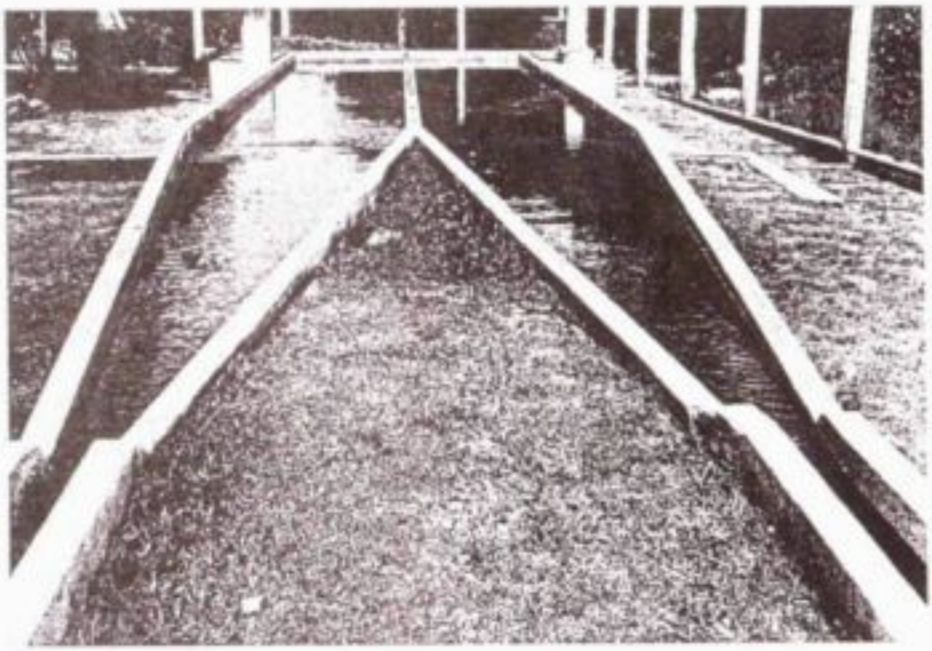


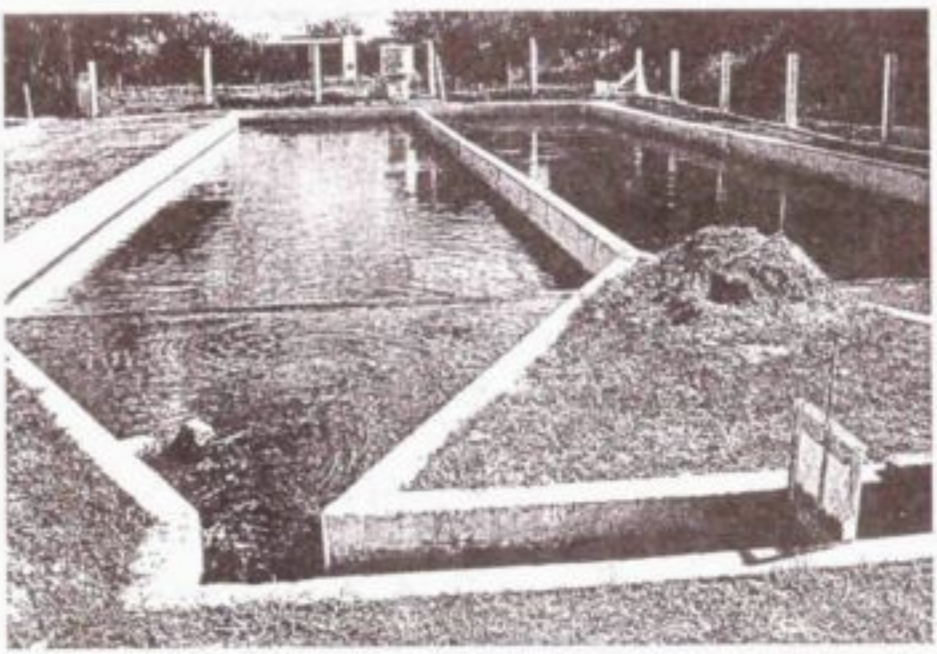
Different inlet delivery channels



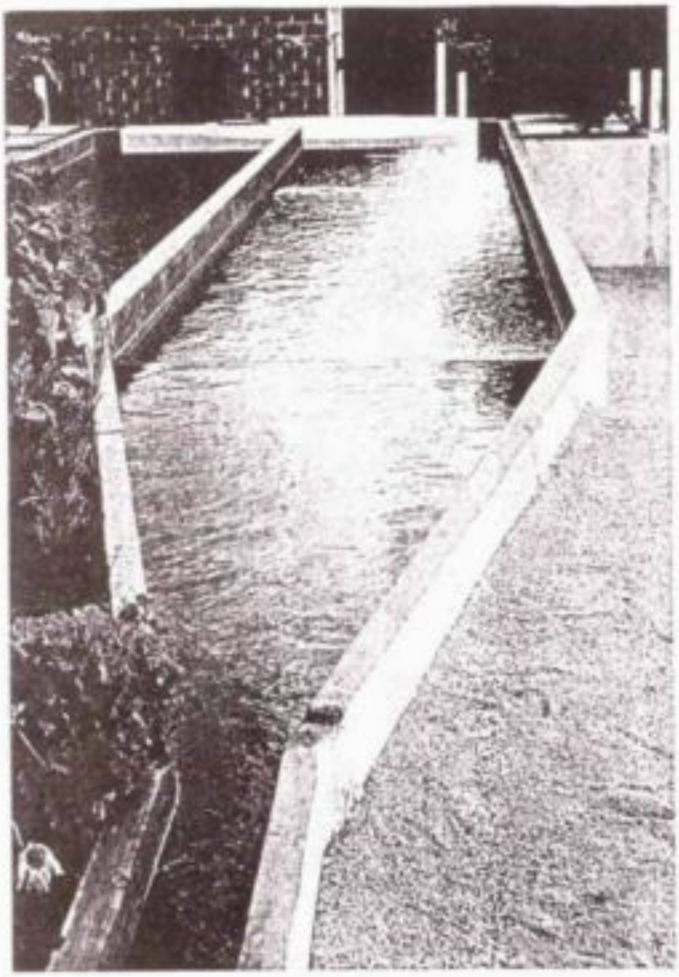
Inlet flow control utilizing sluice gates

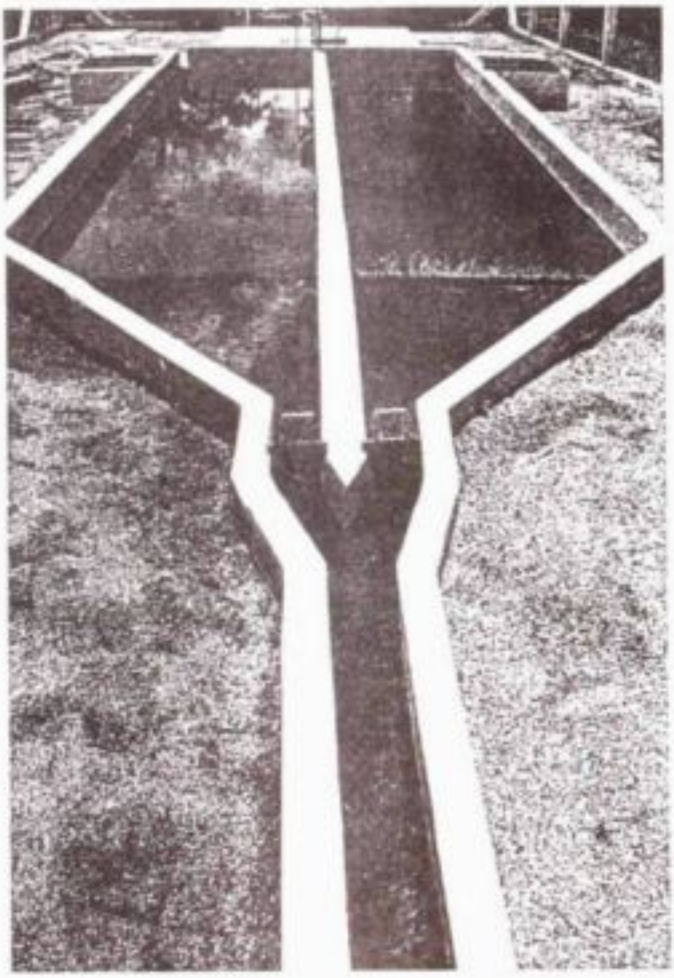


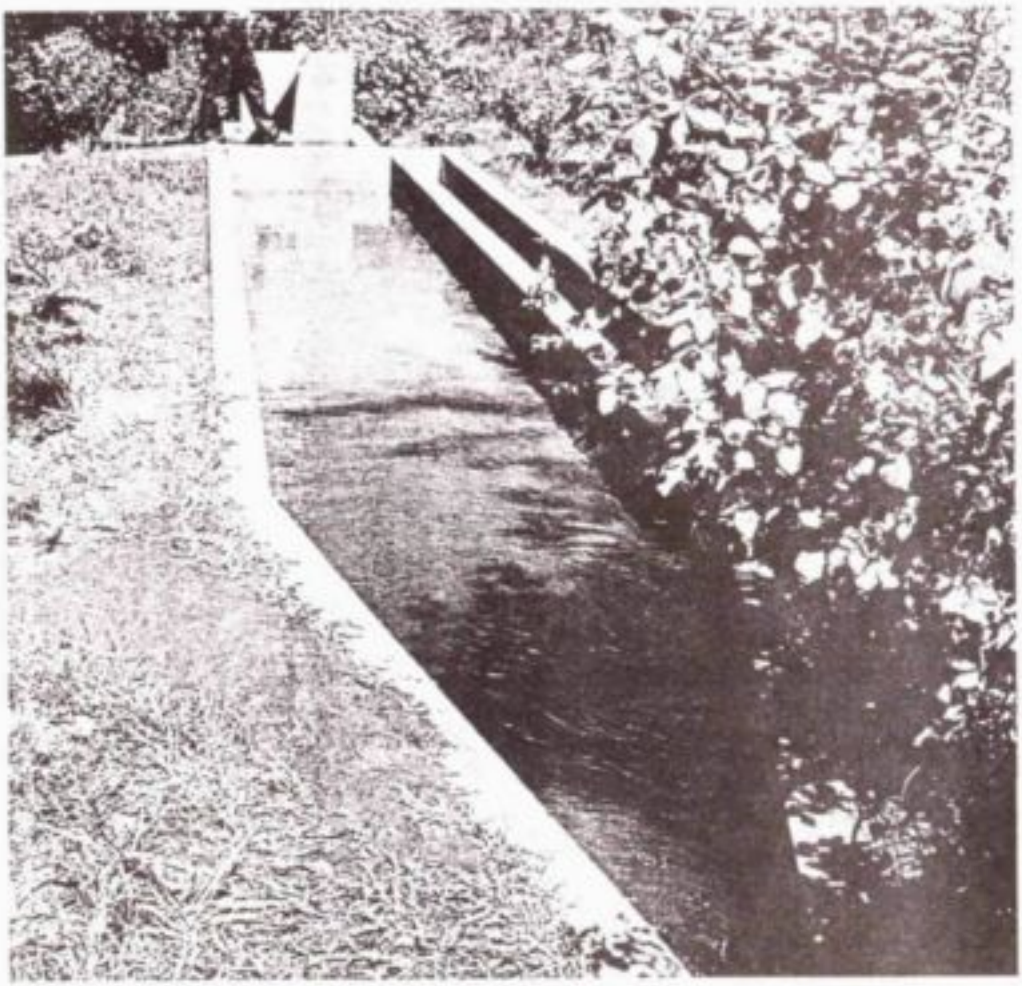




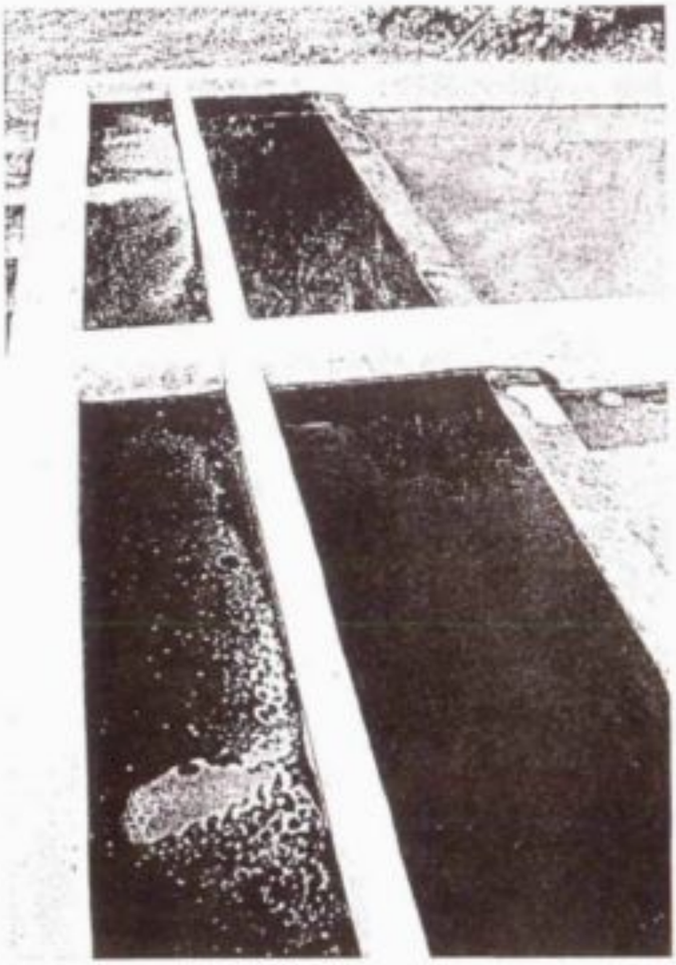
Argentine dynamic filters showing

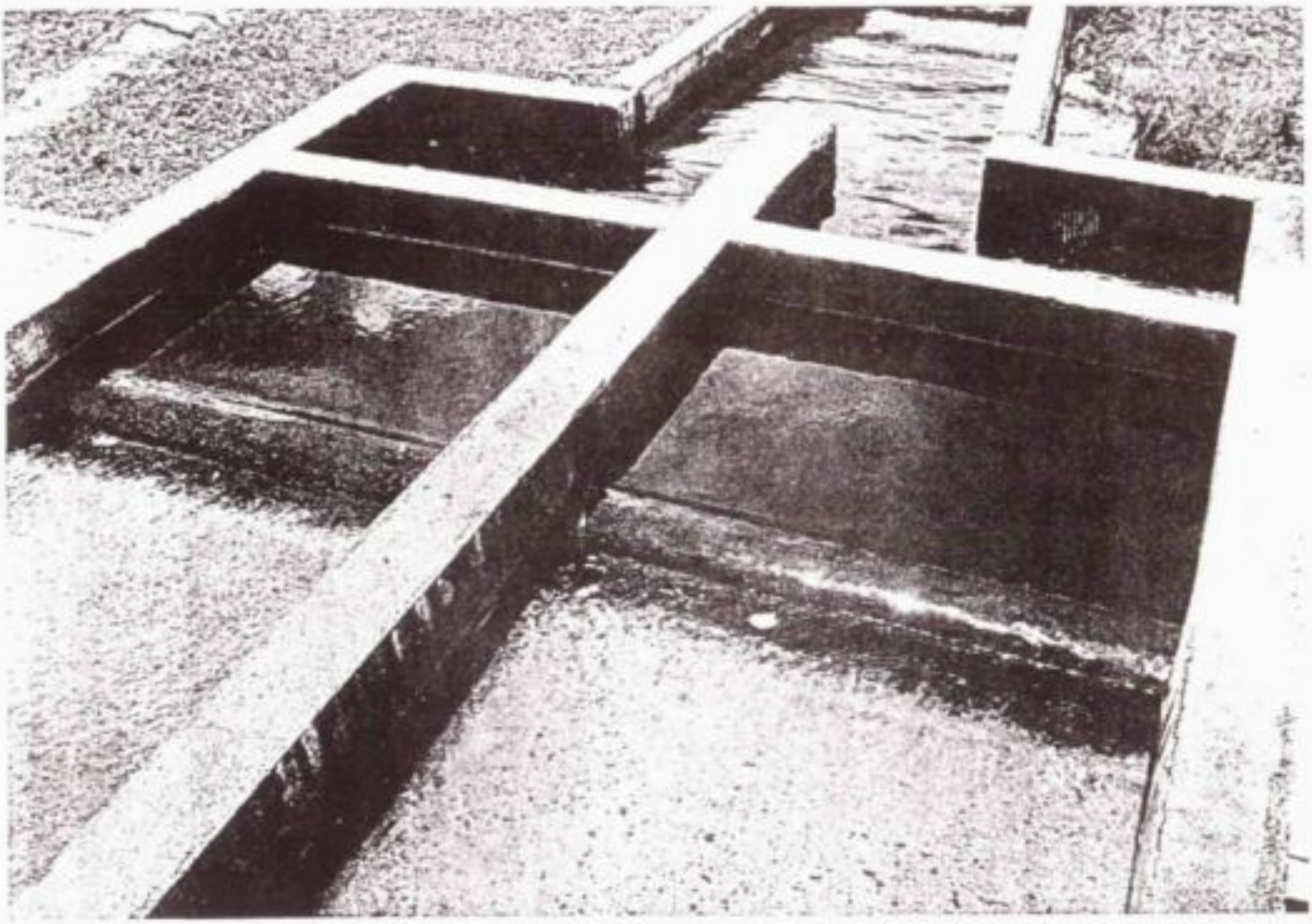




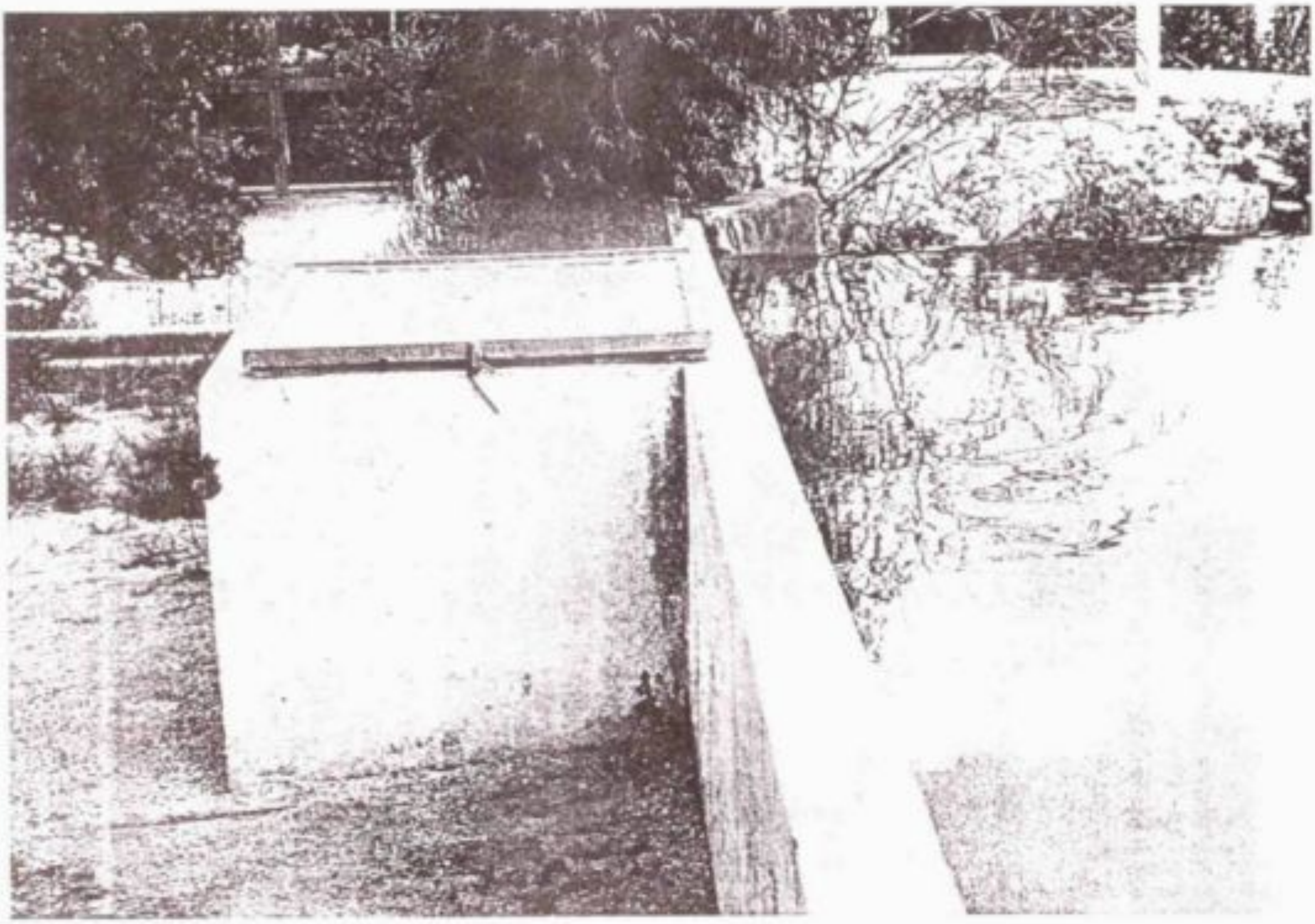


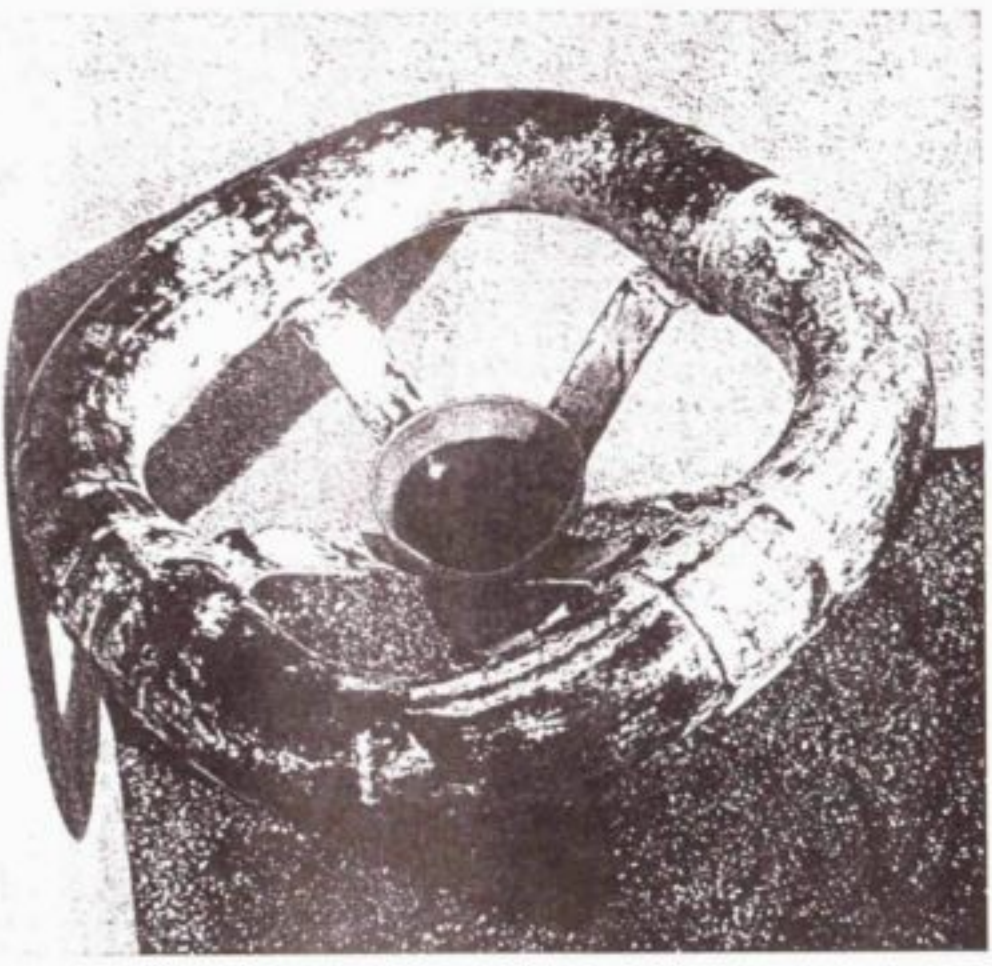
the original dissipation zone



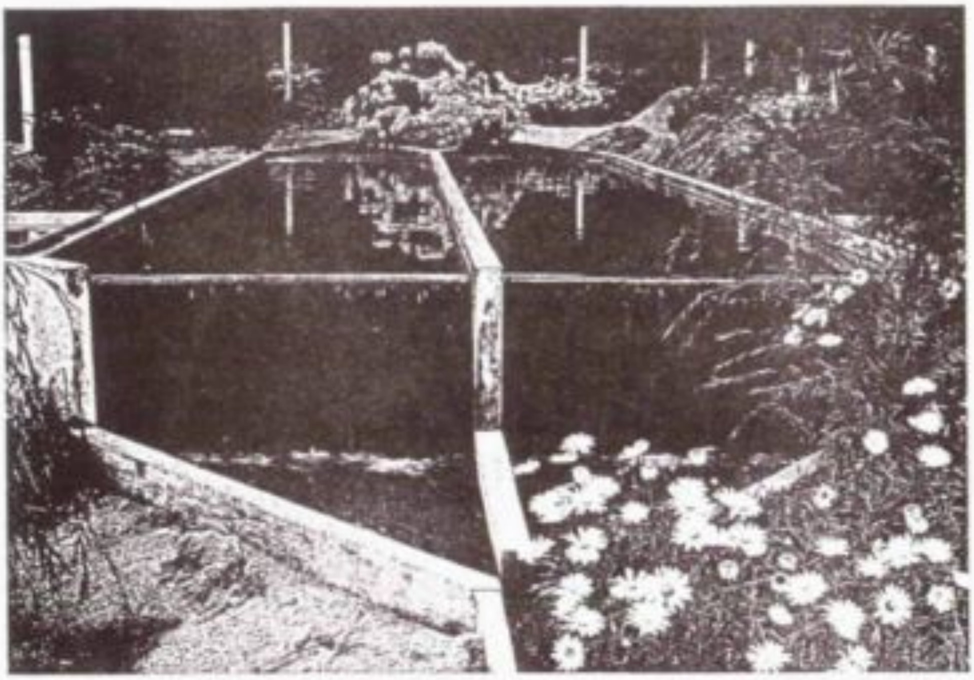


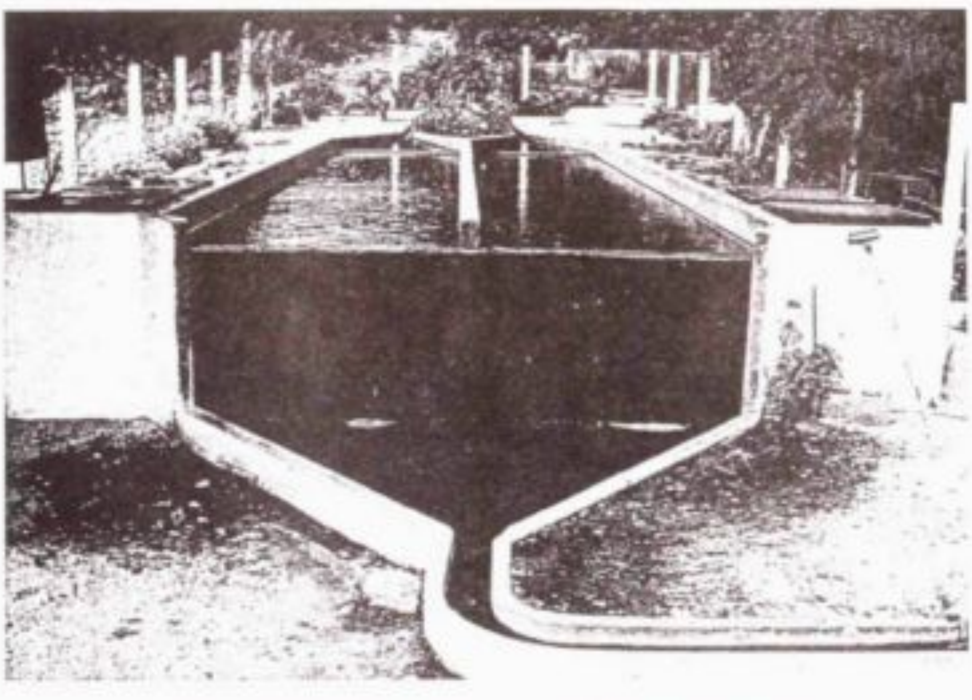
Dissipation chambers as suggested in this technical guide



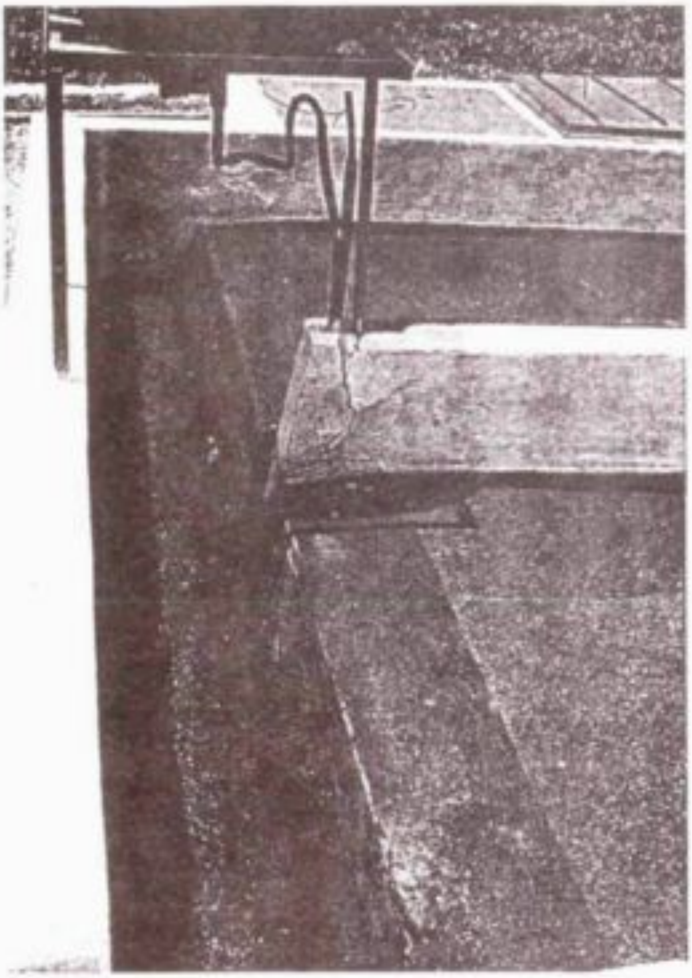


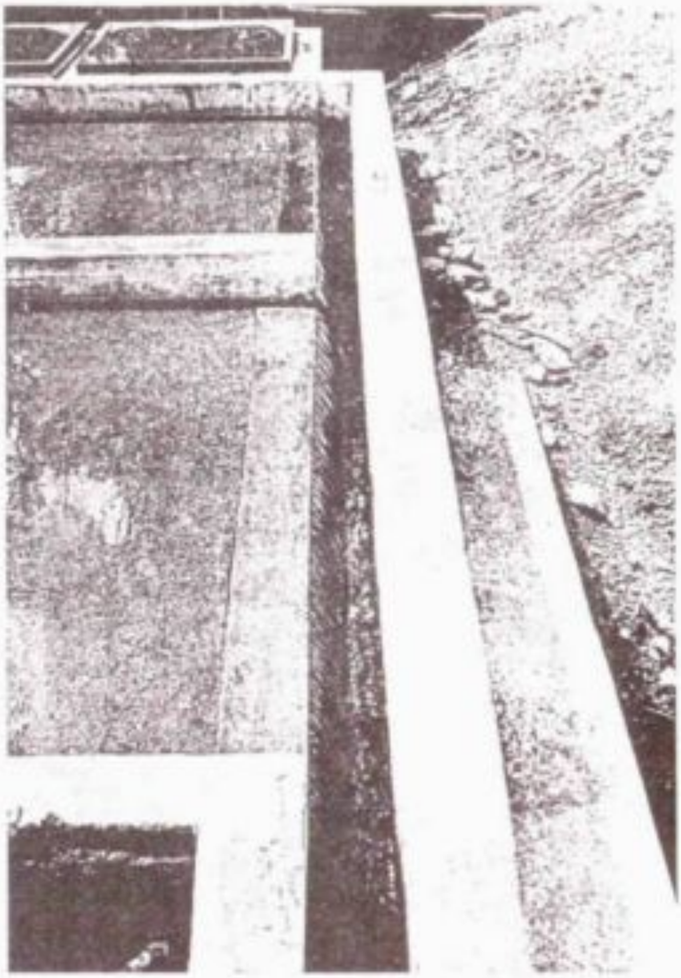
Tail water chamber and controller



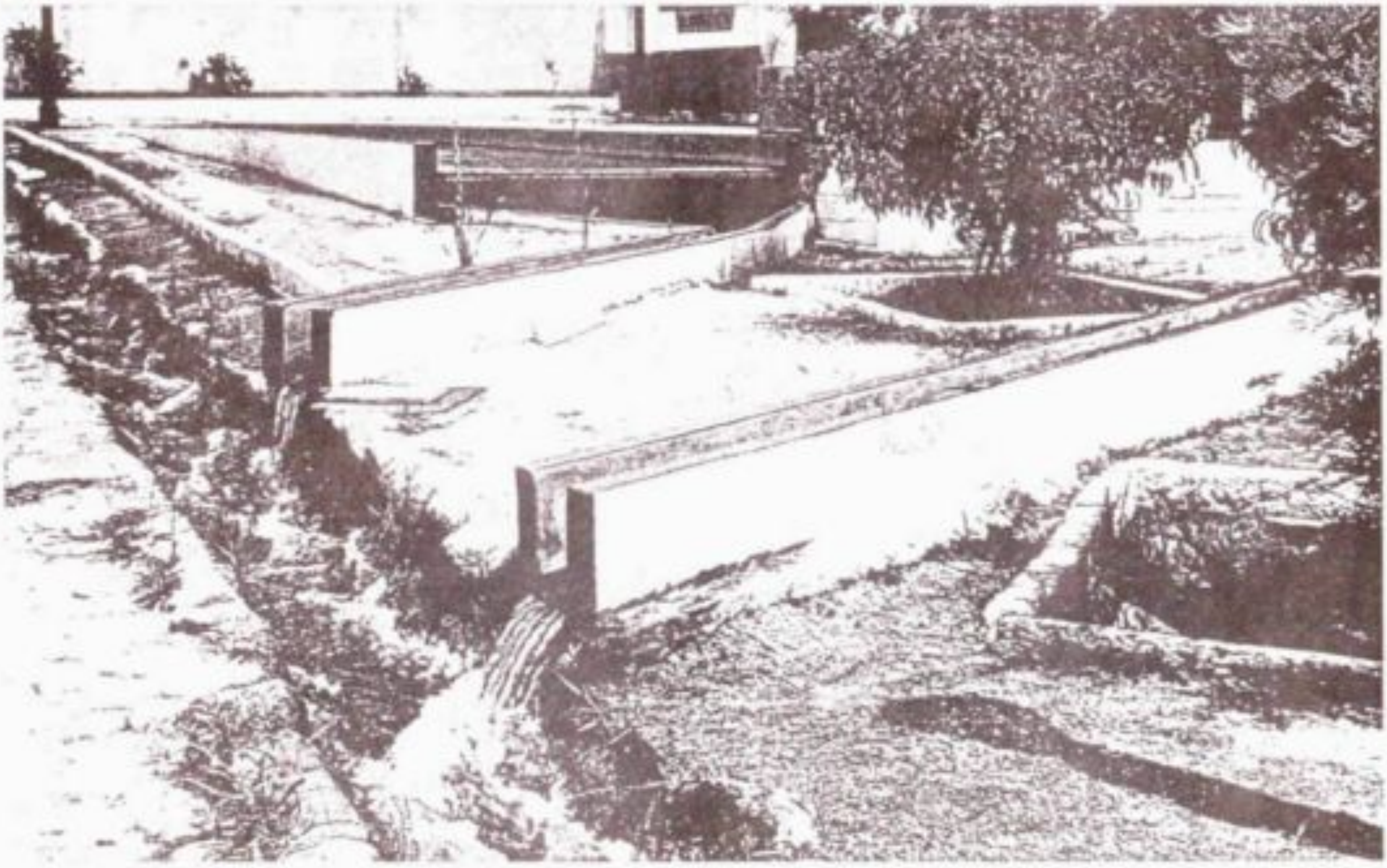


Free overflow at the end of the filter

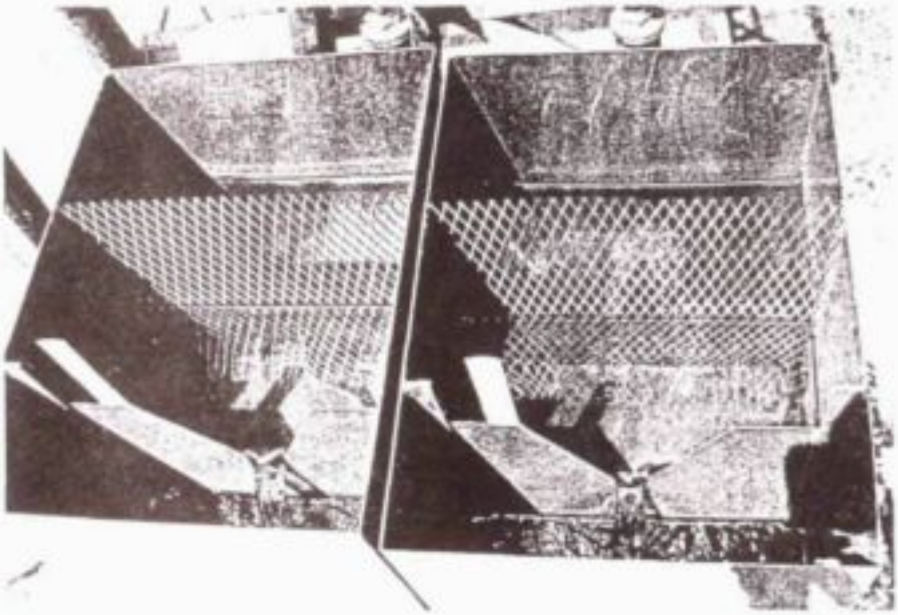




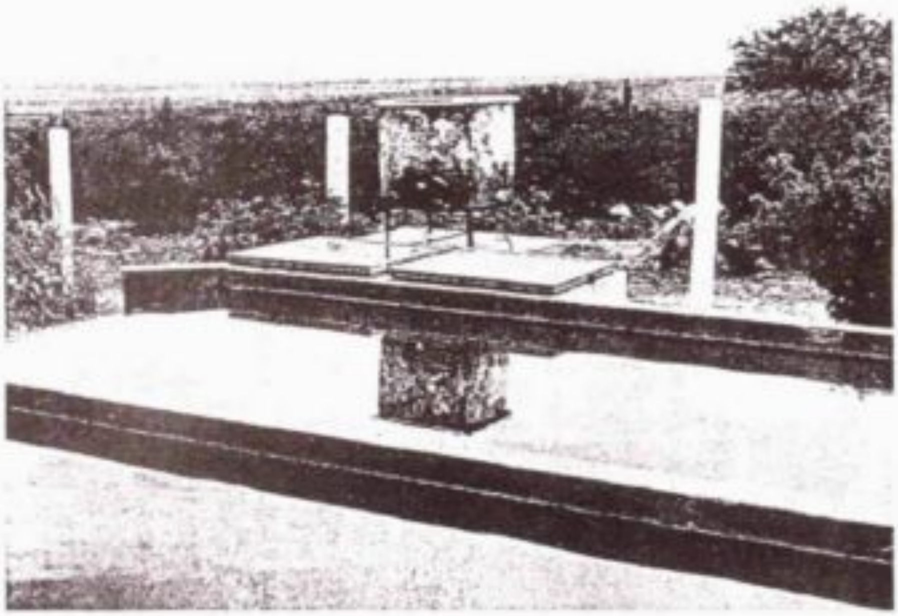
overflow into a channel ...



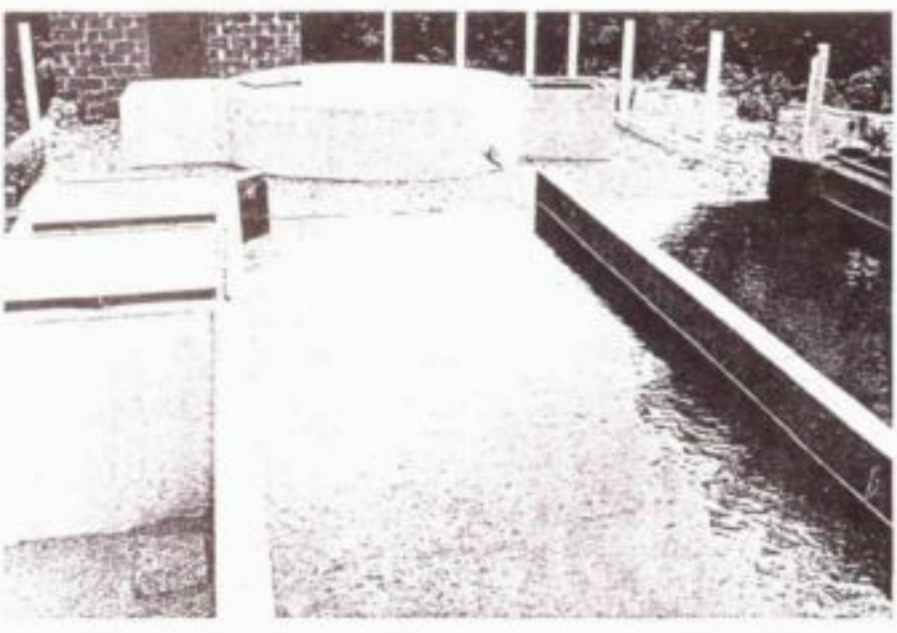
... and back into the divertion canal



V-notch (60°) measuring weirs

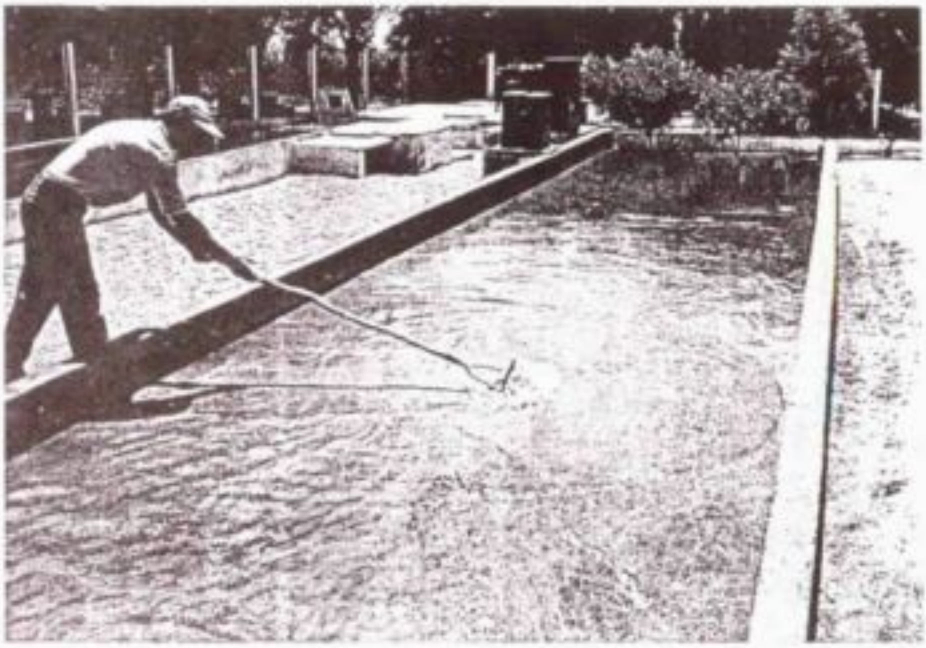


Disinfection by hypochlorite solution fed into the tail water box

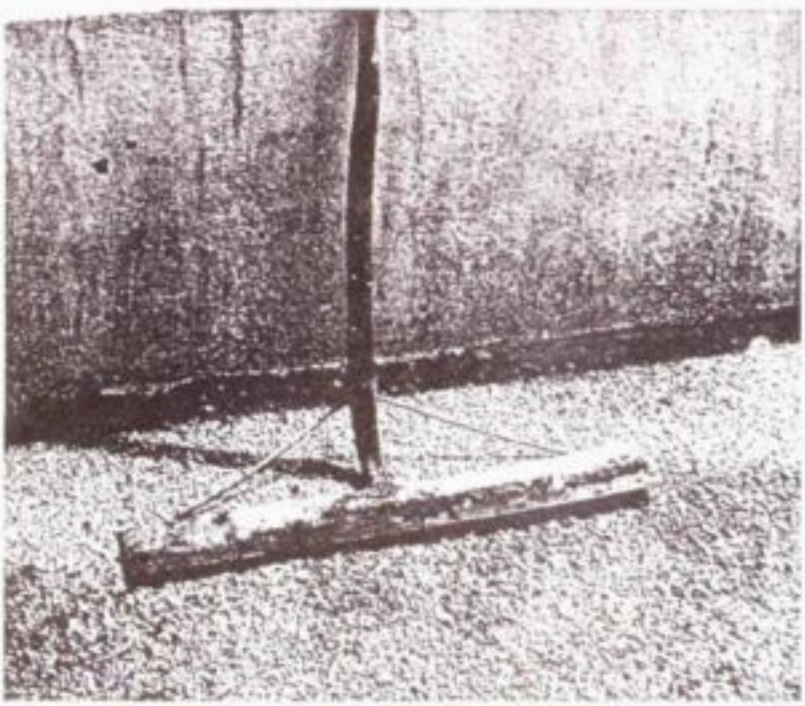


Reservoir for filtered water

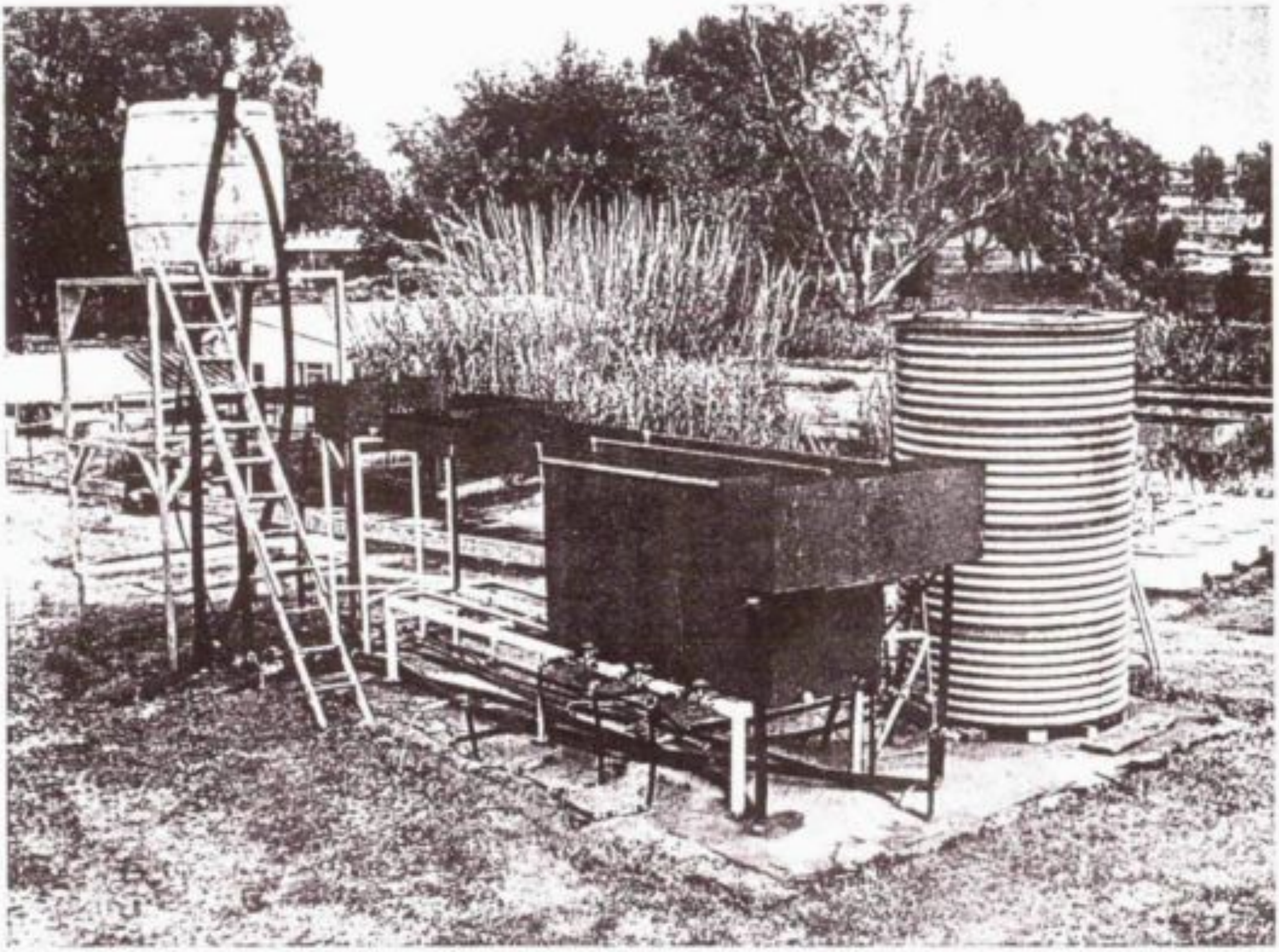
Ancillary elements



Cleaning the filter



Wooden rack



Dynamic filter unit for research. Daspoort, Pretoria, South Africa