STUDY OF A HORIZONTAL-FLOW ROUGHING FILTER

FOR PRETREATMENT PRIOR TO SLOW SAND FILTRATION

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SUMMARY

A study was made to assess the affectiviness of a simple design horizontal roughing filter as a pretreatment to slow sand filters. A pilot study using an 8 l/min flow rate was conducted over a 15 month period at Moganyaka in Lebowa. The roughing filter reduced the influent turbidity by between 70 and 85%, as well as reducing colour, iron, and bacterial counts. Slow sand filter run lengths increased from less than one month to between two and six months. For much of the time the roughing filter effluent was of an acceptable standard for drinking water without further treatment. The cost of this system of water treatment is considerably less than other more conventional means. The filters require little maintenance besides a labour intensive cleaning once per year. We believe it could have many applications in the Southern Africa context.

INTRODUCTION

This paper presents the results of a pilot plant horizontal-flow roughing filter (HRF) and slow sand filter (SSF) study which was carried out by the National Institute for Water Research (NIWR) over a 15 month period from November 1984 to February 1986. The objectives of the study were to determine the level of water treatment that could be achieved by the HRF and the increase in the periods between cleaning of the SSF due to HRF pretreatment.

Slow sand filtration is a well known water treatment process which combines both clarification and a significant reduction of pathogenic microorganisms. It is used, in particular, for small water treatment plants because it does not need skilled treatment plant operators or mechanical equipment. However, SSF does have a major disadvantage, which is that it is unsuitable where the raw water consistently has a medium to high turbidity (>10 NTU). This can cause the filters to block up within less than a month, which is unsatisfactory.

A horizontal-flow roughing filter, using gravel as a filter medium, is a pretreatment process which can be used before SSF to significantly reduce the turbidity of the influent to the SSF, with a consequent increase in the periods between cleaning of the SSF to several months. HRF pretreatment is suitable for small water treatment plants (up to 100 000 *l*/d), and is compatible with SSF because HRF also does not need skilled treatment plant operators or mechanical equipment. The HRF basically consists of a long, narrow channel filled with gravel. The water flows through the gravel, as illustrated in Figure 1, and the dirt is trapped within the gravel bed. To clean the HRF the gravel must be taken out and washed, but this should only need to be done every one to two years. This cleaning operation is the reason for the suggested capacity limitation of 100 000 *l*/d.

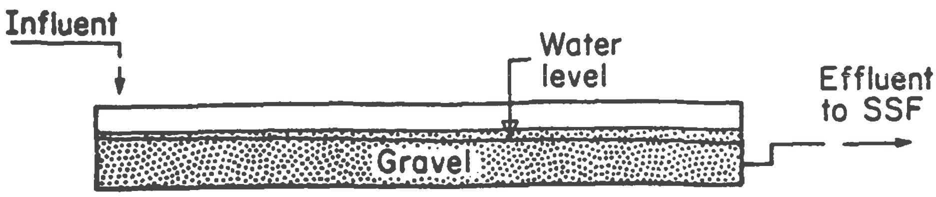

Figure 1: Horizontal-flow roughing filter (HRF)

LITERATURE SUMMARY

There is little published literature on horizontal-flow roughing filters, although the author understands that there are demonstration units currently operating in several countries. Research into the HRF process has been carried out at the Asian Institute of Technology (AIT), Thailand (Thanh and Ouano, 1977) and also through the International Reference Centre for Wastes Disposal (IRCWD), Switzerland (Wegelin, 1984 and Wegelin, Bollen and Schertenleib, 1987). These studies confirm the value of HRF in reducing the turbidity of raw water prior to slow sand filtration.

The studies referred to above were carried out for 140 days (AIT) and 67 days (Wegelin, *et al*). The study by Wegelin, *et al.* (1987) proposes 3 examples of filter configurations. One of these designs is a channel 10 m long divided into 3 sections, each section filled with a different sized gravel. The proposed grading of the gravel is from coarse (20 mm) at the inlet end to fine

(5 mm) at the outlet end and the proposed horizontal flow rate is 1 m/h. According to Wegelin (1984) 'The bulk of solid matter in the raw water will be retained by the first coarse filter packs. The last filter compartment should act as a polisher and remove the last traces of solid matter in the raw water. Each gravel pack becomes gradually loaded with retained solid matter until filter efficiency is exhausted which, under ideal HRF lay-out, should be reached by all gravel packs simultaneously'. In the same report it is stated that filter efficiency can be restored, to a certain extent, by draining the filter. However, eventually the gravel must be taken out and washed.

The study by the NIWR which is reported in this paper was a practical pilot project rather than a theoretical evaluation of the HRF process. The design of the HRF was simpler, with only pebbles and one gravel grading used, and the study was carried out over a 15 month period.

CONSTRUCTION AND OPERATION OF THE PILOT PLANT

The pilot plant used for this study was located at a small water treatment plant which serves the village of Moganyaka in Lebowa, 200 km north-east of Pretoria. The flow diagram of the pilot plant is shown in Figure 2. The raw water was pumped from the Olifants River.

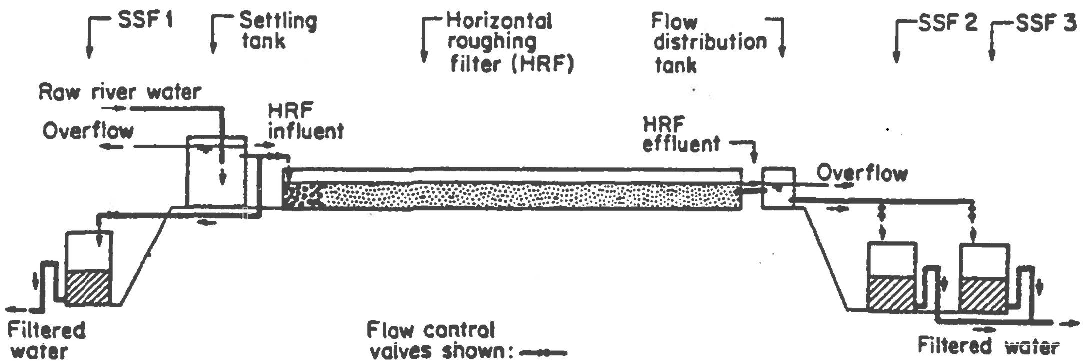

Figure 2: Flow diagram of pilot plant at Moganyaka

The HRF is shown in Figure 3. It was constructed from 1,6 mm thick (16 gauge) flat galvanized steel sheets which were turned up 30 mm at the edges. These sheets were prefabricated in a workshop and then bolted together on site. The joints between the steel sheets were sealed with commercially available Flashband bitumen tape (150 mm wide) which has an aluminium strip backing. This construction technique worked effectively, although the Flashband had to be installed carefully to prevent leaks.

The first metre of the HRF was filled with pebbles, 20 to 50 mm in size. The remaining 11 m length was filled to 650 mm depth with washed and sieved river gravel, having an effective size (d_{10}) of 1,2 mm and a uniformity coefficient (UC) of 1,9. The void ratio of this gravel was 40%.

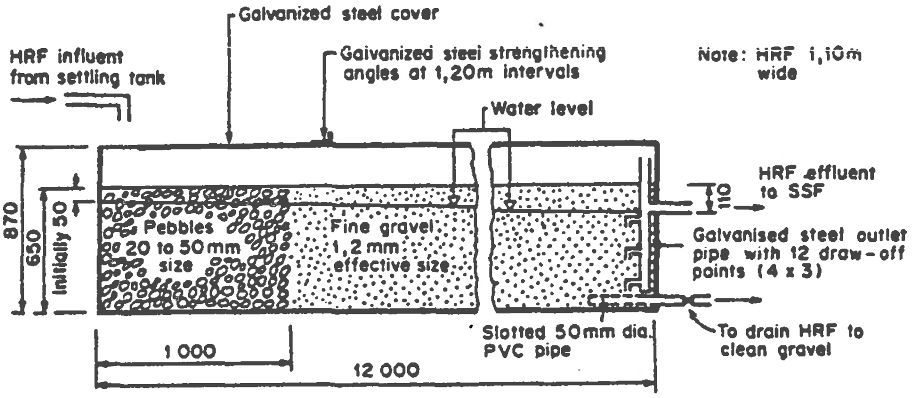

Figure 3: Longitudinal section of pilot horizontal-flow roughing filter

The settling tank and the three SSF's were constructed from standard galvanized corrugated steel tanks (4 500 and 1 800 litre capacity respectively). SSF 1 and SSF 2 were filled with fine sand (d_{10} 0,26 mm, UC 1,9, depth 700 mm), while SSF no. 3 contained coarse sand (d_{10} 0,62 mm, UC 1,6, depth 700 mm). SSF 1 was fed with water directly from the settling tank, while SSF 2 and SSF 3 were fed with the effluent from the HRF.

During the study period (November 1984 to February 1986), the pilot plant was run by the operators of the Moganyaka water treatment plant, with visits by the author approximately every two months. The only reason that the pilot plant was stopped in February 1985 was because the Olifants River dried up due to the fact that no water was being released from the Loskop Dam, which is upstream of Moganyaka, because of a drought in the region.

Raw water was pumped continuously from the river to the settling tank (24 h/d), except for a 10 day period during November 1985 when the pilot plant was stopped due to a pump failure. The settling tank had an average detention time of 40 min. The HRF was fed from this tank at a constant flow rate of 8 *l*/min (i.e. 11,5 m^3/d). The water level, in the clean gravel, was 50 mm (inlet end) to 110 mm (outlet end) below the top of the gravel bed. Therefore the flow rate was equivalent to 0,81 m/h, based on the width of the HRF (1,10 m) and the water depth at the outlet (540 mm).

Each of the SSF tanks operated at a constant flow rate of 1,7 *l*/min, which was equivalent to a downflow rate of 0,1 m/h, based on the surface area of a 1,15 m diameter tank. Each SSF was cleaned when the head loss through the filter increased to about one metre. This was one by draining the filter and carefully scraping off the schmutzdecke and the top few millimetres of sand.

CLEANING OF THE HRF

At the end of the study period the HRF was still operating satisfactorily, without any sign of turbidity breakthrough. However it was decided to clean the gravel in order to determine the method and resources needed to do it. As would be expected, the gravel at the inlet end of the HRF was choked with dirt, but it was progressively cleaner further along the HRF. It was not possible to loosen and flush out this dirt whilst the gravel was still in the HRF, and therefore the HRF was drained and the gravel was dug out of the channel, washed and then replaced. It was noted that there was a layer of dirt on the top of the gravel bed where the water had been running over the surface, but at each cross section along the HRF the gravel was dirty for the full bed depth, indicating that the water had flowed through the full cross-section of the HRF.

The washing technique was to use a concrete mixer. Each mixer load of gravel was stirred with a small amount of water and the dirty water drained off, and this procedure was repeated several times until the gravel was clean. It took one supervisor and six unskilled labourers using two mechanically driven 0,1 m^3 concrete mixers a period of ten days to clean the 8,6 m^3 of gravel and to put it back into the HRF.

The HRF blocks up slowly so that, in practice, the cleaning can be timed for a period of the year when the river water is relatively clear (i.e. low rainfall months) and can be fed directly from the settling tank to the SSF.

SAMPLING AND ANALYSIS PROGRAMME

The turbidity of the river water and of samples taken from points in the pilot plant were recorded three times per week by the plant operators.

Samples were taken during the regular two-monthly visits to the plant by the author for microbiological, non-filterable residue and chemical analyses. These analyses were carried out at the NIWR's laboratory in Pretoria.

RESULTS AND DISCUSSION

HRF and SSF runs

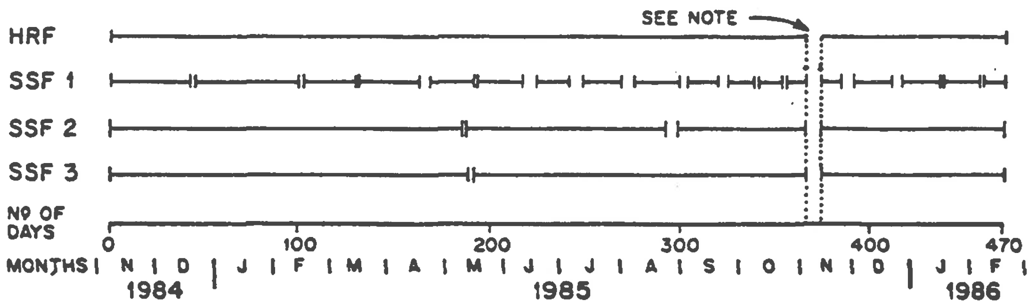

Figure 4: Operating periods between cleaning of the HRF and each SSF

Note: The pilot plant was not operating for 10 days during November 1985. All the SSF's were cleaned at this time, even though this may not have been necessary.

The HRF operated for 15 months before cleaning. SSF 1 (receiving settling tank effluent) was cleaned on 18 occasions, with operating periods between cleaning being as short as two weeks. This may have been partly due to the fact that, at least on some occasions, only the schmutzdecke was removed during cleaning of the SSF, and not all of the dirty sand immediately beneath it. This would explain the longer filter runs initially and the short filter runs during the dry months of the year when the river water was relatively clear (see Figure 5).

SSF 2 (fine sand) and SSF 3 (coarse sand) were cleaned on 4 and 3 occasions respectively, with the shortest operating period being two months and the longest six months. Therefore, despite the incomplete cleaning of SSF 1 mentioned above, it is apparent that the HRF had a very significant effect on extending the periods between cleaning of the SSF.

Head loss through the HRF

When the HRF was first started up, the water level at the inlet and outlet ends was 50 and 110 mm respectively below the level of the top of the gravel, so the head loss along the HRF was 60 mm. However, the HRF gradually blocked up from the inlet end with dirt, and after four months of operation the water level at this end was at the surface of the gravel. From then on, some of the influent water to the HRF flowed over the surface of the gravel bed until it reached cleaner gravel. After 15 months operation of the HRF, water was flowing over the first five metres of the gravel bed. However, despite this shortened length of active HRF, there was still no sign of turbidity breakthrough in the HRF effluent.

Turbidity results

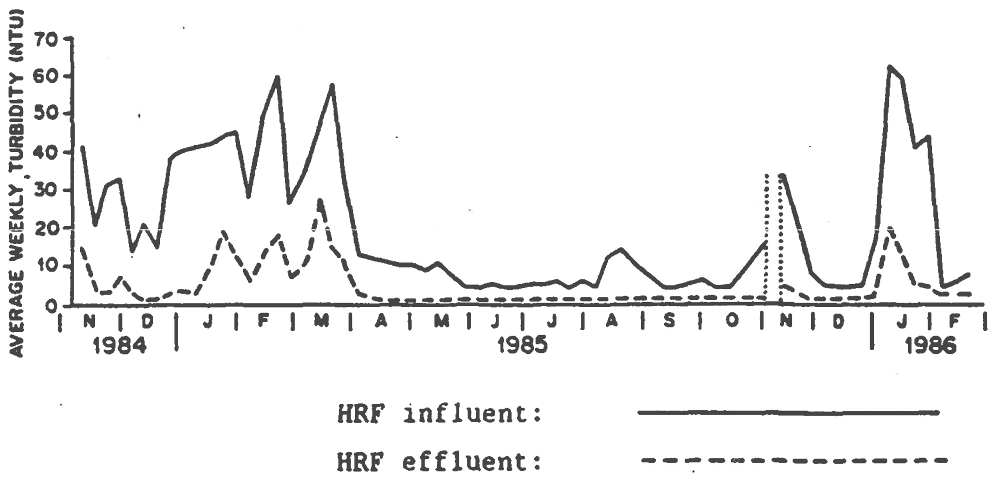

Figure 5: Average weekly turbidity of HRF influent and effluent

It can be seen from Figure 5 that the HRF influent turbidity varied widely during the wet season (October to April), with peaks up to 60 NTU. During this period the HRF effluent turbidity followed the influent peaks, but only exceeded 20 NTU on one occasion.

During the dry season (May to September) the HRF influent turbidity was generally below 5 NTU and the effluent was consistently 1 NTU or less. This provides the opportunity to take the HRF out of service for two to three weeks for cleaning and to feed the settled water directly to the SSF.

Figure 6 compares the turbidities at each stage through the pilot plant, and Figure 7 compares the turbidities of the HRF and SSF 1 effluents. These Figures summarize the results of all of the turbidity readings taken during the pilot plant study. The horizontal axis represents turbidity (1 to 100 NTU, log scale), and the vertical axis is the percentage of the total number of samples taken at each stage through the pilot plant (approximately 190). The graphs show the percentage of samples which had a turbidity equal to or greater than that indicated.

Legend for Figures 6 and 7

Raw river water:

Settled water:
(HRF & SSF 1 influent)

HRF effluent:
(SSF's 2 and 3 influent)

SSF 1 effluent:

SSF 2 effluent:

SSF 3 effluent:

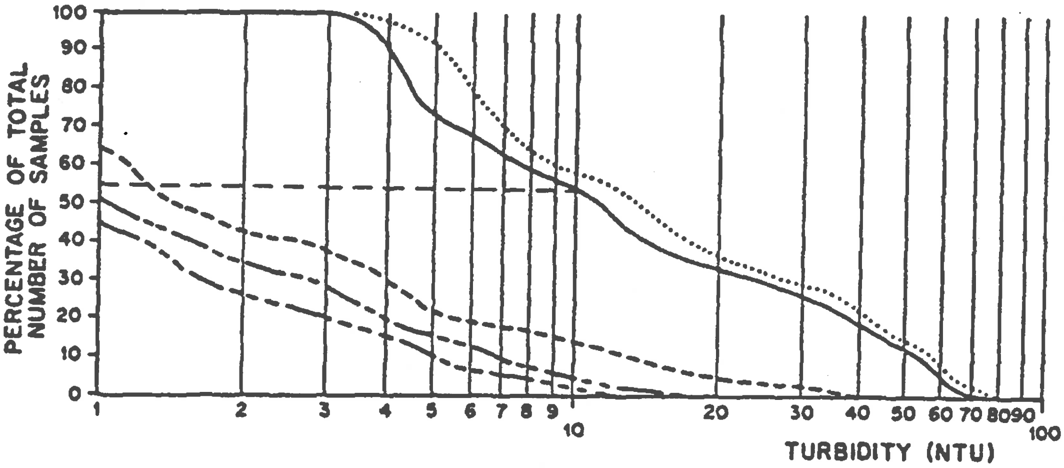

Figure 6: Comparison of turbidity results through the pilot plant

Example: 54% of all the HRF influent turbidity samples were greater than 10 NTU

Figure 6 shows that the settling tank reduced the turbidity of the raw river water by only 10 to 15%. However, there was a considerable sludge build-up on the floor of the tank, which indicated that it had substantially reduced the coarse suspended solids load which would otherwise have gone to the HRF.

The effluent from the settling tank was the influent to the HRF. The HRF reduced this turbidity by 70% to 85%, so that the effluent from the HRF was 10 NTU or greater for only 13% of the samples. SSF 2 (fine sand) after the HRF reduced the remaining turbidity in the HRF effluent by 25 to 45%, with the higher figure corresponding to the higher HRF effluent turbidity. Therefore, the turbidity of the effluent from SSF 2 was 10 NTU or greater for only 5% of the samples.

Figure 6 also compares the effluents from SSF 2 (fine sand) and SSF 3 (coarse sand), both of which received HRF effluent as their influent. It can be seen that SSF 3 gave slightly better results, reducing the remaining turbidity in the HRF effluent by 45 to 60%, so that the effluent from SSF 3 was 10 NTU or greater for only 2% of the samples. The reason for this better result was not determined during the study.

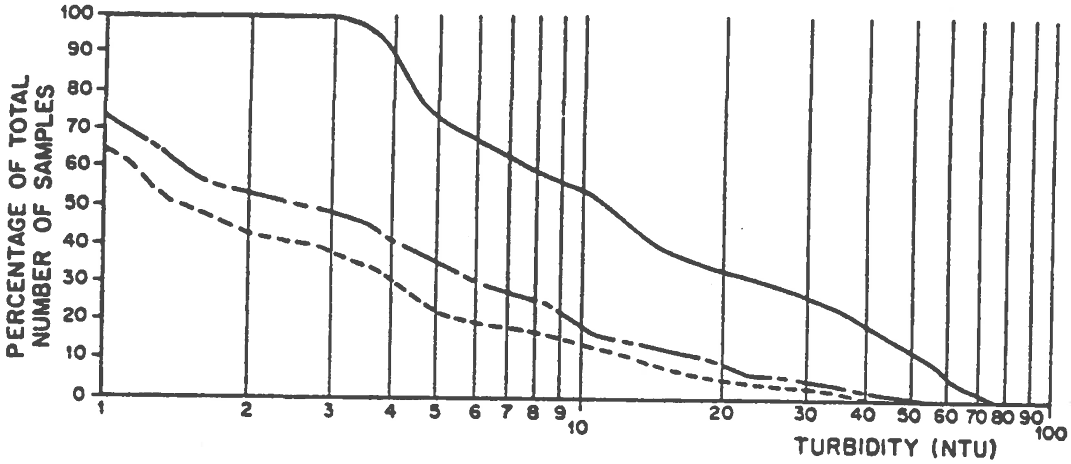

Figure 7: Comparison of turbidity results of the HRF and SSF 1 effluents

Figure 7 shows that SSF 1 was less effective at reducing turbidity than the HRF. It reduced the turbidity of the settling tank effluent by only 50 to 80%.

Non-filterable residue results

The non-filterable residue (i.e. suspended solids) analyses for the HRF influent ranged from 3 to 30 mg/*l* and of the HRF effluent from 0,4 to 3 mg/*l*. However, there were not sufficient analyses carried out to determine whether there was any relationship between non-filterable residue and turbidity.

The volatile non-filterable residue (after heating to 550 °C) of the HRF influent was consistently in the range 13 to 17%, when the turbidity was above 5 NTU. The HRF effluent had a higher volatile non-filterable residue, in the range 20 to 40 %. This indicates that the percentage of organic material was higher in the HRF effluent than in the influent.

Microbiological analyses results

Samples were taken on six occasions, and the results are summarized in Table 1.

TABLE 1: Summary of microbiological analyses results

Location of sample	Total coliforms (per 100 ml)		Faecal coliforms (per 100 ml)		Coliphages* (per 10 ml)	
	Range	Mean Average	Range	Mean Average	Range	Mean Average
Raw river water	100-300	260	60	30	0-20	7
Settled water (HRF & SSF 1 influent)	100-300	170	0- 40	20	0-20	7
HRF effluent (SSF 2 & 3 influent)	0- 3	<1	0- 3	<1	0	0
SSF 1 effluent	0- 10	4	0- 1	<1	0	0
SSF 2 effluent	0- 3	<1	0- 2	<1	0	0
SSF 3 effluent	0	0	0	0	0	0

It is apparent from these results that the HRF was very effective in disinfecting the water to a level which would cause minimal health risk, so that there was virtually no further disinfection required by the SSF.

* Coliphages are an indicator of enteric viruses (Grabow, *et al.*, 1984).

Chemical analyses results

The chemical analyses of samples of the river water were all less than the maximum permissible limits for drinking water, and generally less than the recommended limits (Kempster and Smith, 1985), except for colour and iron.

The HRF significantly reduced the colour of the raw water. For example, in one set of samples the HRF reduced the colour from 400 mg/*l* Pt to 120 mg/*l* Pt, and SSF 1 further reduced this to 40 mg/*l* Pt. This exceeds the 20 mg/*l* Pt recommended limit, but in a rural situation the colour would not be due to industrial toxic substances in the water, and therefore the water would still be safe to drink.

The HRF also significantly reduced the iron in the raw water. In one set of samples the iron was reduced from 3,6 mg/*l* to 0,85 mg/*l*, and SSF 1 further reduced this to 0,15 mg/*l*, which is well below the maximum permissible limit of 1,0 mg/*l* and close to the recommended limit of 0,1 mg/*l*.

CONCLUSIONS

The following conclusions can be drawn from this study:

1. The HRF consistently reduced the turbidity of the settled water by 70% to 85%. This increased the period between cleaning of the SSF from less than one month to between two and six months.

2. The HRF effluent was generally of an acceptable standard for drinking water, (less than 10 NTU turbidity for 87% of the samples, not more than 3 faecal coliforms/100 ml recorded and colour and iron reduced to acceptable limits). Slow sand filtration after HRF futher improved the quality of the water, but it may not be necessary in some circumstances.

3. The HRF was significantly more effective in reducing the turbidity of the settling tank effluent than direct SSF.

4. In comparing SSF 2 (fine sand) and SSF 3 (coarse sand) it appears that SSF 3 gave slightly better results. However, there was not a significant difference in effluent quality or in the periods between cleaning of each filter, although a longer study period might have shown up greater differences.

5. Cleaning the HRF necessitated taking it out of service for two weeks. However, this only needs to be done occasionally, probably annually, and as the HRF does not block up suddenly the cleaning operation can be timed for a period during the year when the river water is relatively clear and can be fed directly to the SSF. The cleaning can be done by unskilled labourers using shovels and concrete mixers.

6. Although not proven by this study, the author suggests that the design of the HRF used in the pilot plant could have been simplified as follows, without significant detriment to the HRF operation or effluent quality:

   (i) The pebbles at the inlet end of the HRF could probably be omitted, provided that there is an effective settling tank before the HRF. Once the gravel near the inlet end was choked with dirt, the water bypassed the pebbles and flowed over the gravel surface until it reached cleaner gravel. The critical factor is considered to be the void ratio of the gravel rather than the size of the voids.

   (ii) The HRF outlet design could be simplified to provide only two or three draw-off points.

   (iii) The HRF could be left uncovered. However, a cover will prevent algal growth on the surface of the gravel bed, and it can also discourage unauthorized interference with the HRF.

   (iv) The length of the HRF could be shorter than 12 metres. The optimum length will depend on the turbidity of the HRF influent and the desired frequency between cleaning. Unfortunately, the study period was not long enough to determine when turbidity breakthrough would occur in the HRF, but it appears that a length of 8 metres or less of active HRF would have been sufficient in this case to clarify the water.

7. As a result of this study, full-scale HRF's have been constructed at two small water treatment plants in Ciskei (100 000 *l*/d each) for the Department of Public Works.

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