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Family scale rural water treatment plant: intermittent slow sand filtration

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The second step : The delivery pipe.
The delivery pipe provides the hydraulic control for the system. Onto the threaded end of the collection pipe (protruding from the side of the filter, at the bottom of the tank) is threaded a T piece with a drainage stopper secured. The T piece is tightened in such a way as to ensure that the final position of the delivery pipe, which is threaded into the T, is vertical along side the filter section of the drum. An elbow is then threaded onto the top of the delivery pipe so that the lower edge of the inside of the elbow is 40mm below the rim of the filter section of the drum. This level determines the equilibrium level of the supernatant above the filter. A 2mm hole is drilled in the top of the elbow so as to provide an air entry point to avoid siphoning water out of the filter if a hose is attached to the delivery pipe. An adapter may be threaded to the elbow to allow a short length of hose to be connected which will make collection of the filtered water easier.

The third step: Placing the filter sand.
Coarse gravel or builders stone should be placed around the collection pipe to act as a graded filter medium which will prevent sand entering the collection pipe. Alternatively the collection pipe can be wrapped in filter fabric. Filter sand is then placed in the drum to a depth of 510mm. The sand used in the filter may be any clean river sand. Uniform grading is ideal but not essential. Sand should be sought from sources where it is unlikely to have been polluted with faeces or other waste.

5.4 Operation

5.4.1 Commissioning

Once the filter has been constructed, the filter section must be filled with water. Approximately 50 l is required. Once the water surface rises above the level of the outlet pipe, water from the bottom of the filter will begin to flow out of it.

The biological action of the filter will begin to affect the quality of the water only after 7 to 14 days. This process may be assisted by "seeding" the filter with a twig of algae from a local stream which is likely to contain the microbes required.

5.4.2 Daily use

The plant is designed so that it will operate most effectively if a daily routine is established. A simple routine of pouring 50 l (Two 25 litre containers) of "raw" water into the reservoir at the same time each day is recommended. When the water is poured into the reservoir it begins to flow into the filter at a rate determined by the reservoir outlet valve. The incoming water displaces the water from the previous cycle which flows out of the delivery pipe. It will take 2 to 3 hours for 50 litres to displace the treated water. The treated water is collected in a clean receptacle. In field plants, families sometimes use the reservoir to store untreated water and open the reservoir outlet tap when they need treated water.

5.4.3 Maintenance

Maintenance of the plant is minimal. Occasional washing out of the reservoir is recommended which is a simple exercise.

The length of run before the top of the filter becomes so blocked that operation is impeded, depends largely on the concentration of suspended material in the raw water. Much of the suspended load is removed in the reservoir.

The pilot plant was operated daily for six months before there was a need to scrape the top of the filter. Scraping the filter requires that the water level is reduced so that the top layer of sand is firm and unsaturated. This is achieved by loosening the drainage plug on the collection pipe T-piece. Only the top 5 - 10mm are removed by carefully scraping the surface of the sand. The only instruction which needs to be given to a user is to remove the dark coloured layer of sand.

6. TESTING PROGRAMME

6.1 Introduction

A test programme was designed to measure the effectiveness of the plant. The programme began on 1 December 1986 and was concluded on 2 July 1987. During this period the plant was run continuously with daily loading, except for certain periods which are discussed below. During the test period the raw water and the treated water were tested daily except for the aforementioned periods.

Raw water was collected from a tributary of the Sand Spruit running through the suburb of Norwood in Johannesburg. The catchment includes a number of parks but is mainly urban. The water quality of the stream is very poor as indicated by the test results. The stream flow is perennial. Water was collected mainly in the evenings between 16h00 and 18h00 in two 20 litre plastic buckets.

One problem experienced in the pilot plant was the breeding of mosquitoes. This was solved by introducing two small goldfish into the supernatant. (This may not be practical in field plants).

The effective size (ES) of the filter sand used in the pilot plant was d_{10} = 0,0'mm. The d_{60} = 0,28mm. The uniformity coefficient (UC) of the sand is d_{60}/d_{10} = 4. This is high, indicating a low porosity which is typical of unsieved river sands.

The plant was situated outside where it received direct sunlight, although the reservoir provided some shade for the filter surface.

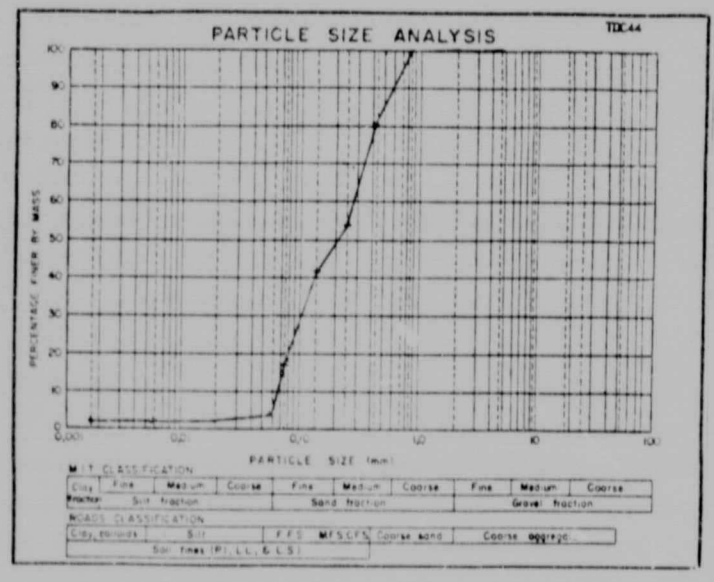


Fig 5.3 Sieve analysis of pilot filter sand.

6.2 Tests

Tests conducted on the raw and treated water are summarised in Table 6.1.

Table 6.1 Tests and units

Test	Units	Abbreviation
turbidity	Napthalmic Turbidity Units	NTU
temperature	Degrees Centigrade	°C
conductivity	milli Seamen per meter	mS/m
f-coliform	bacteria colonies per 100ml	counts/100ml
total plate counts	bacteria colonies per ml	counts/ml
dissolved oxygen	dissolved O_2 in mg/l	mg/l

6.2.1 Turbidity

Turbidity tests were conducted on raw and treated water with the use of a HACH turbidity meter. Readings were made directly in NTU.

6.2.2 Temperature

Water temperature was measured by a 1/2 degree mercury thermometer and, later in the programme, by a Hanna digital thermometer.

6.2.3 Conductivity

Conductivity was measured using a Hanna digital conductivity meter. The conductivity was measured in order to estimate the total dissolved solids.

6.2.4 Faecal coliform bacteria

Faecal coliform bacteria was measured to determine the level of faecal pollution in the raw water and the effectiveness of its removal from the treated water. Coliform bacteria are indicators of the possible presence of pathogenic bacteria. Two methods were used to determine the F-coliform count.

The first technique was spreading a 0,1 ml sample onto the surface of a standard 90mm diameter petri dish containing fresh mFC agar. Raw water samples were diluted using successive 10% dilutions. 0,1ml samples were spread on the agar using a flame sterilized glass spreader. Pipettes were sterilized by heating to 180 °C for a period of at least 30 minutes. The prepared petri dishes were then incubated at 44 °C in a

thermostatically controlled incubator for 24 hours. Colonies were counted at the end of the incubation period. Plates containing between 30 and 300 colonies were counted and factored up to account for dilution.

It became apparent that the afore mentioned technique of determining the F-coliform count was too coarse to test the very low counts in the treated water. This is because counts are reported per 100ml but only 0,1ml samples are used. The second technique used was therefore the micro-filter technique using Millipore equipment. This involves placing 100ml of water in a funnel and passing it through a 47mm diameter sterile filter supported on porous glass base. The filter is then placed, using sterile tweezers, on m-FC agar in a 47mm petri-dish and incubated as above.

For determination of faecal coliform bacteria, it is not necessary to autoclave the agar medium during preparation but it is necessary to autoclave the equipment. This was done in a pressure cooker at about 121°C for a minimum period of 20 minutes. Sufficient agar was prepared for a week at a time.

6.2.5 Total plate count

The total plate count test provides an indication of the presence of all types of bacteria in the water, many of which would not be pathogenic. Because all bacteria are counted, it is important to autoclave all equipment and to conduct all work under aseptic conditions.

Methods similar to those for the determination of the F-coliform were used to determine the total plate count. TPC will necessarily be higher than any other specific bacteria counts. Greater dilution is therefore required.

Plate count agar medium was prepared and autoclaved before being distributed into petri dishes. Incubation was at 25 °C for a minimum period of 24 hours. TPC was made in units of counts per ml.

6.2.6 Dissolved oxygen determination

Dissolved oxygen tests were conducted on samples collected from small plastic tapping tubes inserted through the walls of the filter section of the test plant. The tubes are at varying depths in the filter and permitted water to be removed from the filter when required. Samples were carefuliy collected so as to ensure that no oxygen was entrained during collection and to exclude oxygen from the sample once it had been collected.

Dissolved oxygen was then determined using the Azide modification of the Winkler titration method which produced consistent results.

6.3 Routine testing

The plant was tested daily. Raw water was placed in the raw water reservoir after being collected from the same location each day. The plant was then allowed to operate for half an hour to an hour before sampling the raw and treated water for testing. (It must be noted that, because of the 24 hour retention period, the previous day's raw

water results should be compared with the present day's treated water results).

The first test was the turbidity of both raw and treated water. Thereafter raw water dilutions were measured using 10ml pipettes. One ml of full strength water was added to 9ml of autoclave deionized water. This was then thoroughly mixed and the process repeated with a new pipette so that there were then dilutions of 1:1, 1:10, 1:100 etc. Finally a new pipette was used to take 0,1 ml of each dilution and deposit it on a petri dish, starting at the most dilute and moving to the least dilute. This was done for both the TPC and F-coliform bacteria dishes. Using a flame sterilized glass spreader, the sample was then spread on the dishes, again going from least dilute to most dilute. The dishes were then inverted, labelled and placed in an incubator.

A similar procedure was followed for the treated water save that dilution was not required.

For testing of raw water using the Millipore micro filter technique, a 1,0ml or 0,1ml sample was placed in autoclaved de-ionized water and filtered. After passing the water through the filter, the filter flask was washed down with autoclaved water which was also filtered so as to ensure that all water passed through the filter. The micro filter paper was then removed from the porous glass filter assembly and placed on a prepared 47mm diameter petri dish with the contaminated surface upwards in such a way as to ensure that there was no air entrapped between the agar and the filter paper. The dishes were then inverted, labelled, and placed in an incubator.

The micro filter technique used for the treated water was the same as that used for testing the raw water except that, because the bacteria concentrations were so low, full 100ml samples were used for the F-coliform determinations, and 1,0 ml for the total plate count.

After the petri dishes had been prepared, pH and conductivity of both raw and treated water were measured. The temperatures of both were also recorded.

The final activity of each day's tests was counting the colonies on the already incubated petri dishes. After completion of the tests all equipment was cleaned and where necessary autoclaved in preparation for the following day.

6.4 Recovery test

An important element of the design of the plant is that it needs to be resilient and capable of recovery if abused. The most sensitive feature of the plant is the "schmutzdecke" where the biological action takes place.

To test its ability to recover if it is abused, the plant was dried out on two consecutive days. The water level was reduced to below the sand surface which meant that the schmutzdecke was completely dried out. The plant was then operated as normal in order to asses its ability to recover and the period which this requires. The results are discussed at item 7.4 below.

6.5 Stagnation test

In order to assess the effect of a prolonged period of stagnation on treated water quality, the plant was left standing for a period of 12 days. During this time no water

was displaced from the body of the filter. The results are discussed below under item 7.5.

6.6 Introduction of charcoal layer

In order to test whether charcoal improves the performance of the filter, a layer of charcoal 100 mm thick was placed 200 mm below the sand surface.

So that the inclusion of a charcoal layer could be replicated in the field, special charcoal was not used. Charcoal generated from a wood fire was crushed and placed in the filter after removing sand to a depth of 300 mm. After 100 mm of charcoal had been placed in the filter a 200 mm layer of sand was replaced in order to counter the buoyancy effects of the charcoal. The results of this test are recorded under item 7.6.

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7. RESULTS

7.1 Introduction

A full record of all test results is presented in Appendix A. Results were recorded in a file and then captured on a computer. The results, which are discussed in detail below, indicate that the plant is effective in reducing bacteria and turbidity.

7.2 Tests

It should be noted that in some instances the bacteria counts of treated water appear to be very high. These represent occasions when the plant had not been run continuously, as a result of which the "schmutzdecke" died off.

7.2.1 Turbidity

Table 7.1 Results - turbidity

	Raw	Treated	WHO Standard *
Count	43	43	
Mean NTU	9.48	0.38	0.5 recommended
Maximum NTU	42.0	11.00	5.0 maximum
Minimum NTU	2.0	0.19	
Std. Dev.	9.21	0.52	

* Guidelines for drinking water quality (WHO 1984)

The treated water had a mean turbidity of 0.38 which is extremely low. This indicates that there is likely to be a correspondingly low bacteria level in the water. Johannesburg tap water gave a reading of 0,5 NTU.

Appearance of the water is important to the consumer because it plays a major role in the subjective assessment of water quality. There is a correlation between raw water turbidity and treated water turbidity (see Fig 7.1)

After rainstorms the raw water turbidity increased markedly up to as high as 42 NTU. It is interesting to note in Figure 7.2 that when the turbidity was low, the conductivity (total dissolved solids) was high but after rain, when the water was highly turbid, the conductivity was low.

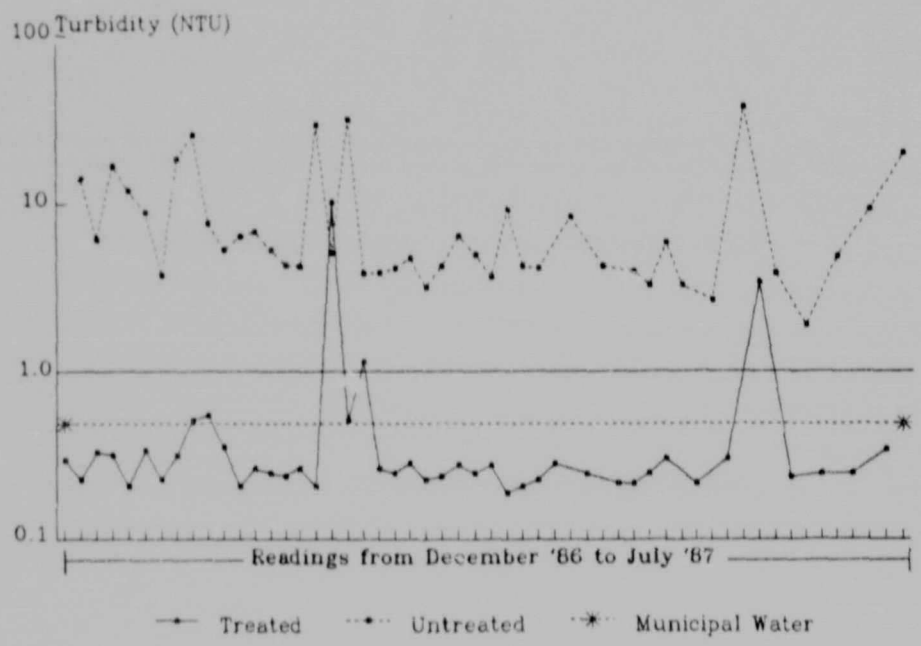


Fig. 7.1 Raw water and treated water turbidity

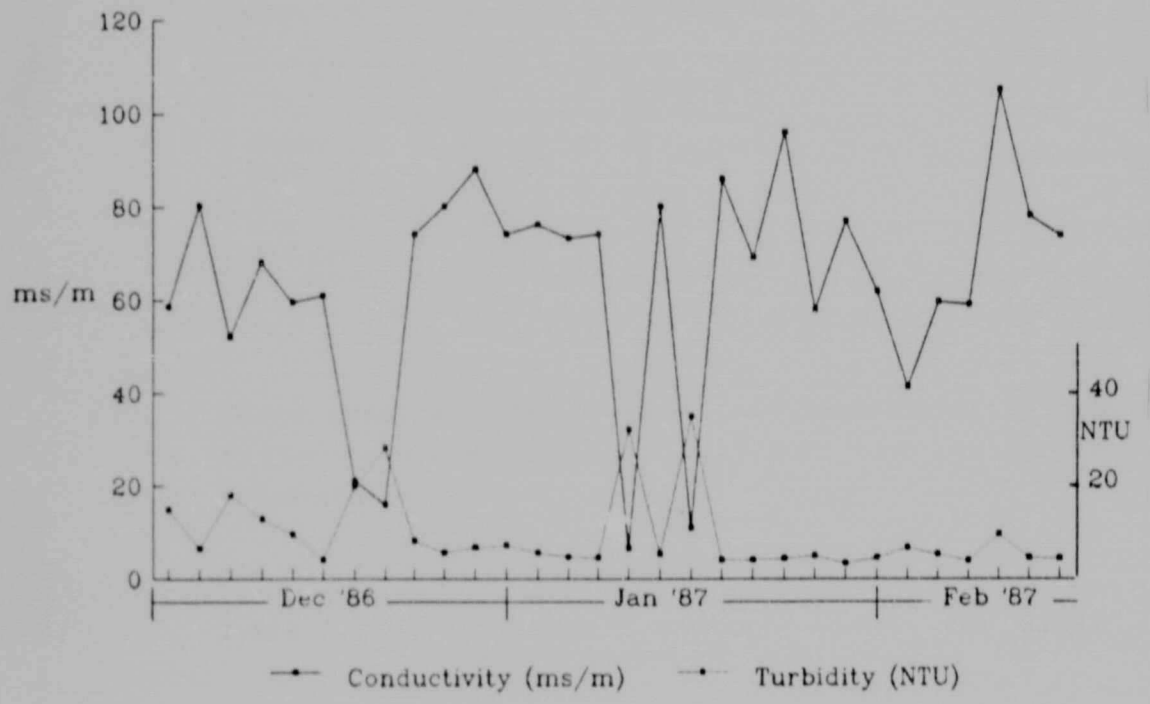


Fig. 7.2 Raw water conductivity and turbidity

7.2.2 Temperature

Table 7.2 Results - temperature

	Raw	Treated
Count	43	43
Mean °C	19.29	18.69
Max °C	25.0	24.0
Min °C	8.4	8.2
Std Dev	3.73	3.8

These results indicate that the temperatures in the filter were slightly lower than the raw water temperatures.

Table 7.3 Results - summer & winter raw water temperature and F-coliform

	Raw water	
	°C	F-coliform
Summer Mean	21.05	2.7×10^5
Winter Mean	14.75	5.7×10^3
Diff/Ratio	6.30	47.4

Table 7.3 indicates that the faecal coliform concentration is higher during summer when the temperatures are higher.

7.2.3 Conductivity

Table 7.4 Results - mean conductivity

		Raw	Treated
Total period	mS/m	59.6	59.02
Summer	mS/m	64.61	62.88
Winter	mS/m	45.4	47.80

The conductivity of the water was not significantly affected by the filter. This indicates that the filter has little effect on dissolved solids.

7.2.4 Faecal coliform bacteria

Raw-water F-coliform bacteria counts were higher during the summer months than during winter. This is due to the higher summer temperatures and can be seen both in Table 7.3 and Figure 7.3. These results indicate a severely polluted source.

The F-coliform counts were much lower in the treated water. Indeed only the more sensitive micro-filtration technique could detect F-coliform bacteria in the treated water. The mean count is 1,6 counts/100ml which indicates an order of magnitude reduction of $3,3 \times 10^3$ for the winter months and $1,15 \times 10^5$ for the entire period. The faecal coliform count should be zero for potable water (WHO Guidelines for drinking water quality, 1984) but where chemical disinfection is not a sustainable option 1.6 is a significant improvement.

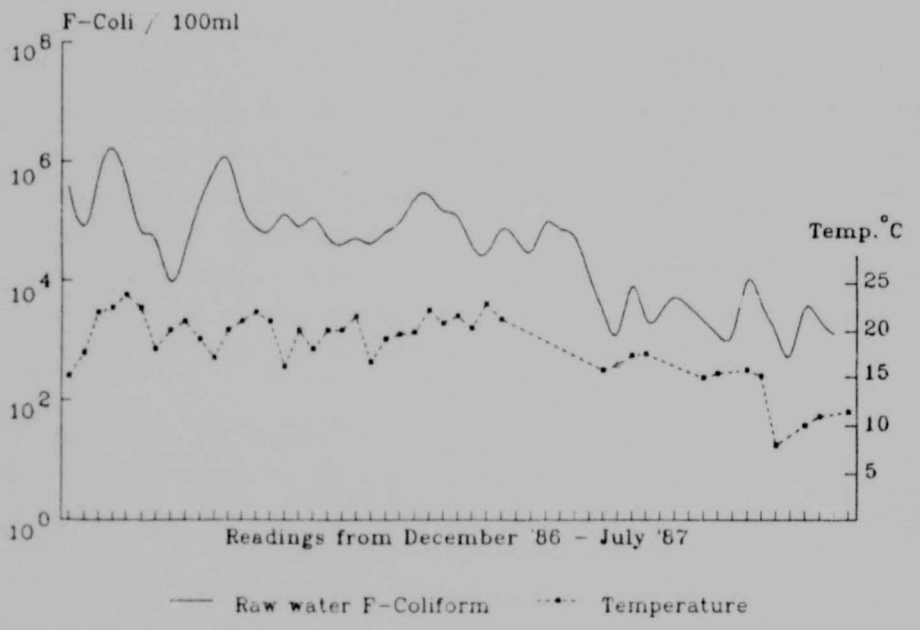


Fig. 7.3 Raw water F-coliform and temperature

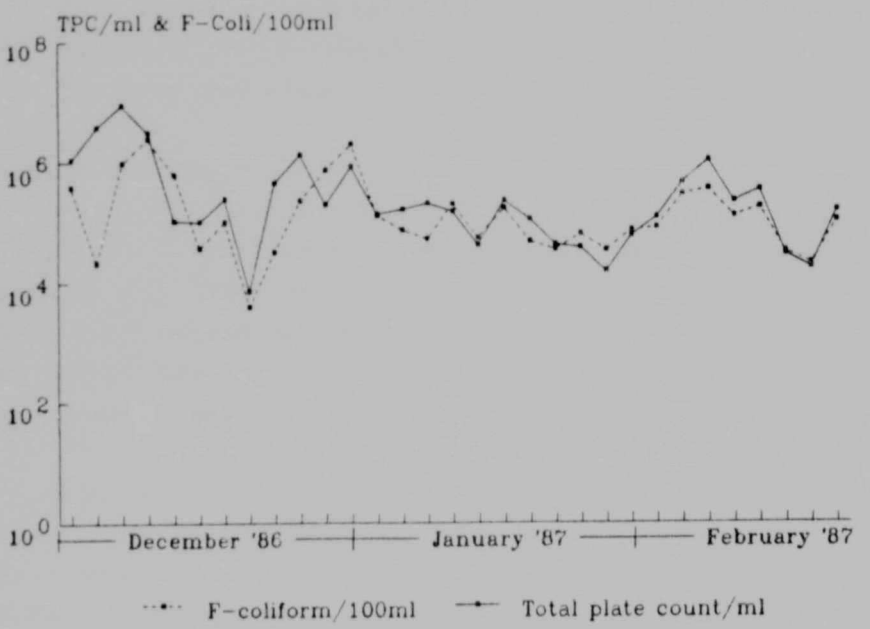


Fig. 7.4 Raw water F-coliform and total plate count

7.2.5 Total plate count.

As with the F-coliform count discussed above, the raw water TPC colony counts may be expected to vary with season. As can be seen from Figure 7.4 the F-coliform and TPC correlate with each other and with temperature. The reduction in TPC produced by the filter is of the order of $4{,}65 \times 10^3$, with mean counts of $7{,}53 \times 10^5$ raw and $1{,}61 \times 10^2$ treated.

7.2.6 Dissolved oxygen

The results of the dissolved oxygen determination are shown in appendix A5. The dissolved oxygen in the raw water was 6,50 and 6,56 mg/l. The dissolved oxygen profile indicates that the dissolved oxygen is reduced from 6,56 mg/l to less than 0,15 mg/l.

The results indicate that the dissolved oxygen is utilized in the metabolism of bacteria in the filter. The profiles also indicate plug-flow.

7.3 Routine testing

It will be noted from the test results that when routine testing has been carried out, the results are consistent. There are occasions when the results indicate a weekly or two weeks testing period. During these periods the plant was operated daily but only tested occasionally.

One major concern with the results is the inadequacy of the first method of testing the treated water for faecal coliform. However the test results for the micro-filter method are conclusive.

7.4 Recovery test

On 28, 29/1/87 the surface of the filter (the schmutzdecke) was dried out and allowed to stand unshaded in the sun. The surface became completely dry. The results of subsequent tests over a period from 30/1/87 to 8/2/87 (10 days) indicate the plant's ability to recover. The results show that initially there was very little difference between the treated water and raw water quality. However the plant recovered within a period of 10 days to produce normal good quality treated water. The F-coliform results are very coarse because the spreading plate method was used, but the TPC results provide a clearer indication of plant operation. This test was not conclusive but it did serve to indicate that the plant will recover naturally from any abuse it may suffer.

7.5 Stagnation test.

From 2/3/87 to 13/3/87, a period of 12 days, the plant stood unattended. Because of small leaks at the dissolved oxygen tapping points down the side of the filter, 16 litre had to be added to the filter to bring the volume up to the hydraulic controlled outlet level. This means that some 35-40 liters remained in the body of the filter. The treated water was clear and sweet to the taste. There was no evidence of anaerobic bacterial activity or the characteristic smell of hydrogen sulphide, although no specific tests were conducted to prove this. The important conclusion is that in terms of the subjective assessment of the ordinary user, the plant had not suffered any ill effects in the stagnation period and had not "gone bad".

7.6 Charcoal layer TDS reduction

The plant was run for a week after placing the charcoal layer. There was no apparent effect on the conductivity readings - the treated water results remained very close to the raw water results. This indicates that finely crushed charcoal does not reduce the total dissolved solids.

8. FIELD PILOT PLANTS

8.1 Lekhema, Winterveld

A family in Lekhema in the Winterveld (30 km North West of Pretoria), whose only water source was a polluted shallow well constructed by sinking two 210 l drums into the ground, were approached to establish a drum filter at their home. The filter was placed inside the kitchen of the household and the wife was instructed how to operate it.

The filter was established on the 12 December 1986. Results of the test conducted at the plant are given in Appendix B1.

The results were positive but not as good as the control pilot plant. The following reasons are presented for this: The establishment of the "schmutzdecke" was very slow. This was because the plant was inside the house in a position which received very little light. The plant should be placed out of doors. Local sand was used which may have been directly polluted - it is suggested that a "plug" of chlorine be passed through the filter to provide initial sterilization. This can be done with a household disinfectant.

The plant was nevertheless well received in the household. The reservoir was used as a water storage facility and the filter was operated when water was needed. The following comments were made :-

The taste of the water was greatly improved.
The water was cooler - (indoor filter).

The testing programme was restricted by the remoteness of

the site. The use of the plant was discontinued in the winter months because the family could not get sufficient water!

8.2 Mafefe continuous flow pilot filter

8.2.1 Introduction

The Mafefe district is situated in the North Eastern Drakensberg, some 100 km south-east of Pietersburg. The population comprises 11 500 people living in 27 villages. The mining of asbestos, which commenced in the area around 1920 and continued until 1965, has had a wide ranging effect on the area. Asbestos constitutes a major environmental health hazard with some 80% of the population suffering from serious respiratory ailments.

The removal of asbestos from the water is important because, although asbestos polluted water does not constitute a threat to health if it is drunk, it is a problem when used for washing clothes. When the clothes dry, fibers are released into the atmosphere and inhaled.

8.2.2 Design

The most appropriate water treatment method for this area appears to be slow sand filtration. The streams are fast running and carry a heavy silt load during the rainy season. Pretreatment will therefore be necessary, using horizontal roughing filters. However, before full scale plants can be designed it was considered necessary to test the methodology with the use of a pilot plant.

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