Australian Water & Wastewater Association
10th Federal Convention. Sydney. 1983.

THE APPLICATION OF THE SLOW SAND FILTRATION PROCESS TO THE TREATMENT OF SMALL TOWN WATER SUPPLIES

BY

B.A. BOWLES, W.M. DREW and G. HIRTH,

STATE RIVERS AND WATER SUPPLY COMMISSION OF VICTORIA.

SUMMARY The history of slow sand filters and the design considerations for a pilot study are briefly described together with details of the construction and commissioning of a pilot plant at Yarrawonga, Victoria (Study Phase I). Preliminary results from the first operational phase (Study Phase II), including operational characteristics and the effect of filtration on chemical, bacteriological and biological parameters are also presented. The future operation of the plant (Study Phase III) is discussed. The results obtained so far indicate that, with a suitable form of prefiltration, slow sand filters are capable of producing a water of good quality in all respects from a raw water supply containing high concentrations of algae.

1. INTRODUCTION

Slow sand filters are used extensively in a number of countries such as the United Kingdom, the Netherlands, other parts of Europe and some developing countries, for the removal of micro-organisms and to improve the general physico-chemical properties of waters intended for domestic supplies.

In developed countries, slow sand filtration is used only after rapid sand or microstrainer filtration; however, in many developing countries it provides a single-step treatment for raw waters with turbidity not exceeding 50 NTU.

Because of the simplicity of the process and its potentially low costs of operation and maintenance, a pilot study using four small experimental filters is being undertaken at Yarrawonga, Victoria, by the Ministry of Water Resources, to evaluate the application of the process to Victorian town water supplies.

2. HISTORICAL

The origins of slow sand filtration are lost in the dim mists of time, but as far as is known, the sand filter designed and built by John Gibb in Paisley, Scotland, in 1804, was the first such filter for the treatment of water for use by the public (Baker, 1949). Following from improvements on Gibb's design by Robert Thom in 1827, and James Simpson in 1829, by 1851 the advantages of sand filtration were so evident, that Parliament required the filtration of all river water supplied to London (Huisman & Wood, 1974).

A most convincing proof of the effectiveness of slow sand filtration was provided in 1892, by the experience of two neighbouring cities, Hamburg and Altona, which both drew their drinking water from the River Elbe, the former delivering it untreated, while the latter filtered the whole of its supply. When the river water became infected with cholera organisms, Hamburg suffered from a cholera epidemic which caused

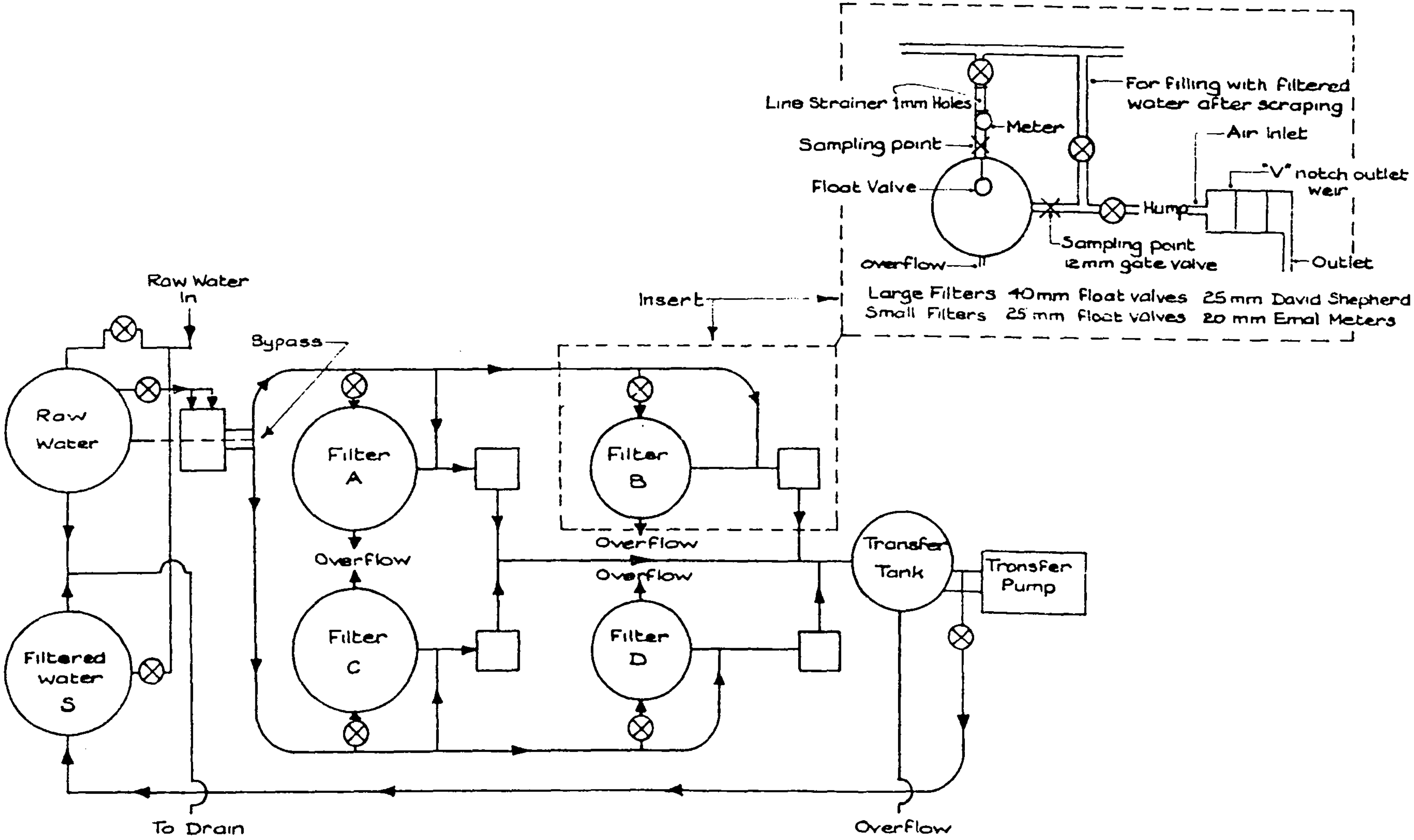

Fig. 1: Plan of Pilot Plant

more than 7 500 deaths, while Altona escaped almost unscathed, notwithstanding the fact that Altona's water intake was downstream of Hamburg. Subsequent waterborne epidemics in many parts of the world confirmed this experience. In every case, infection was almost entirely confined to people drinking unfiltered water (Hazen, 1895; Huisman & Wood, 1974).

At that time, modern methods of disinfection were quite unknown, so that the protection afforded the public against waterborne pathogens was almost entirely dependent on the efficient operation of the sand filters. Following the introduction of chlorination during the early 1900's, and the development of chemical coagulation followed by the smaller "rapid" sand filters (about 100 times as fast as the slow filters), the slow sand filters tended to fall from favour.

As an example of those still surviving, some four-fifths of London's drinking water is still treated by slow sand filtration, although nowadays, the sand filtration is third in a four-stage process of purification:-

(i) long-term storage in large reservoirs,
(ii) rapid sand filtration or microstraining,
(iii) slow sand filtration, and
(iv) disinfection by chlorination.

During the last decade or two, there has been a revival of interest in slow sand filters, especially for the treatment of water for small communities, and in developing countries where local materials can be used and where the necessary skills for construction, operation and maintenance usually lie within the resources of the local community. The success of many of these installations, especially in conjunction with the public-health safeguard provided by post-chlorination, has renewed consideration of the suitability and economic viability of slow sand filtration for small town water supplies in Victoria.

3. SITE SELECTION AND DESIGN OF PILOT PLANT

As community expectations rise, and as dwindling supplies of natural water are increasingly affected by development of one sort or another, there is a growing need for water treatment for town water supplies throughout the State. In particular, towns in the northern part of Victoria, especially those drawing their raw water from the River Murray, usually experience a run of highly coloured and turbid water during the winter-spring period.

It was therefore proposed that the pilot plant be located on the Murray, within a few hours' drive of Melbourne, preferably beside an existing conventional treatment plant. Such a site was selected at Yarrawonga, beside Lake Mulwala, an on-river storage on the Murray. An additional factor in site selection was the work already done by Dr. Bowles, a member of the project team, for her doctoral thesis "Phytoplankton Populations of the River Thames" which includes detailed comparisons with levels of phytoplankton in the River Murray (Bowles, 1978).

At the same time, Caldwell Connell Engineers Pty. Ltd., were engaged as "desk" consultants for the project, and a number of eminent biologists, scientists and engineers were invited to join a Project Reference Panel to overview the design and progress of the study.

It was agreed that four separate filter units should be provided (two large, two small), they should be circular, of concrete, readily transportable, and the two large units wide enough to receive sunlight directly onto the sand layer for a few hours each day, even in mid-winter, at that latitude of 36^{o} south. The general arrangement of the four open-topped filters (with provision for roofing later on if required), together with two covered tanks at the southern end (one for raw water and one for filtered water) and a partly buried transfer tank at the northern end, is shown in Fig. 1.

Two of the filter units, A and B, contain 1 metre of washed river sand approximating to the WHO specification for slow sand filters (Huisman & Wood, 1974 and Van Dijk and Oomen, 1978), while filters C and D contain a coarse sand washed and graded from the same source. The sand gradings are shown in Table I.

TABLE I

Sieve No.	Fine Sand Filters A & B % passing	Coarse Sand Filters C & D % passing
8 mm	-	100
4 "	-	97
2 "	-	65
1.2 mm	100	36
600 microns	83	6
300 "	32	1
150 "	8	1
75 "	2.4	0.5

The concept of "effective size" of the filter sand, introduced by Hazen as long ago as 1892 (Hazen, 1895), is the size of grain such that 10% by weight of the particles are smaller than itself, and 90% larger than itself. This value cannot be measured but is the diameter on the mechanical analysis graph corresponding to the 10% passing line, and is best referred to as the d_{10} value. Similarly, the d_{60} value is read off at the 60% line. These values for the fine and coarse sands, compared with values suggested in WHO publications, are given in Table II.

The shape factor for the sand grains has been assessed as 0.85 (worn) for the fine sand, and 0.75 (angular) for the coarse sand, on a scale which ranges from 1.00 (spherical) through 0.9 (rounded) to 0.65 (broken).

The total height of each filter is 2.75 m, having an initial water depth of 1 m, filter sand 1 m, and graded gravel to a depth of 450 mm, surrounding slotted underdrains (Fig. 2).

TABLE II

Parameter	WHO Suggestion (Huisman & Wood, 1974)	Fine Sand (Filters A & B)	Coarse Sand (Filters C & D)
d_{10}	0.15 to 0.35 mm	0.16 mm	0.70 mm
d_{60}	0.2 " 1.0	0.45 "	1.8 "
$U_c = \frac{d_{60}}{d_{10}}$	1.5 " 3.0	2.8	2.6
Porosity (% voids)	-	39%	33%

U_c = Uniformity coefficient

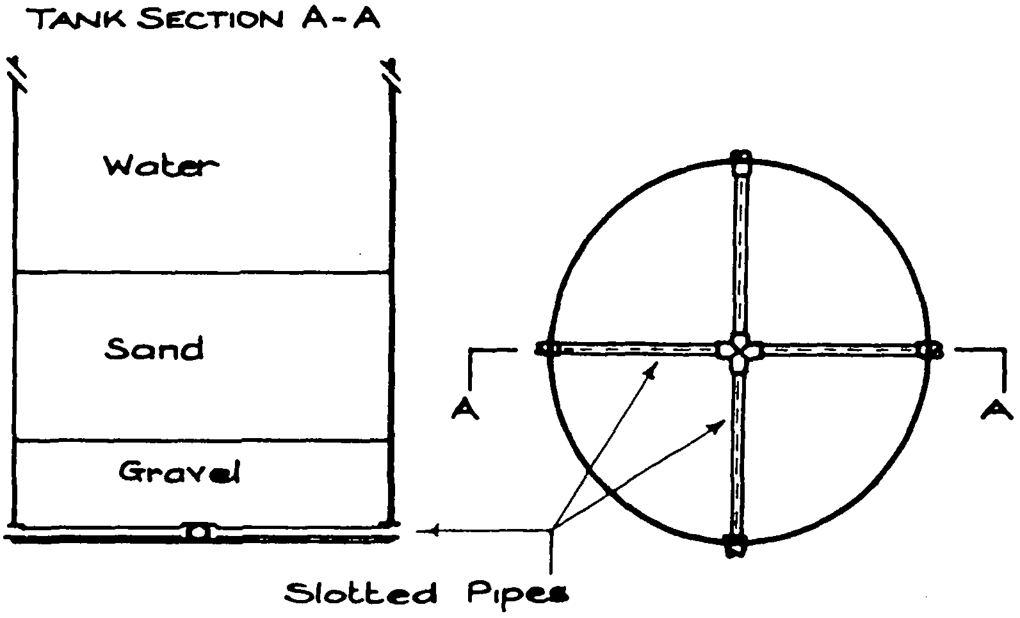

Figure 2: Diagramatic section through a slow sand filter

Plastic polyethylene pipe with screwed hand-tight connections is used throughout to facilitate changeovers to different modes of operation. Pumps and piping are designed for filtering rates up to 0.5 m^3/m^2.hr (i.e. 0.5 m/hr), but to date the flow rate has been fixed at 0.1 m/hr for the fine filters and up to 0.15 m/hr for the coarse filters.

Because the site is flat, constant head for the filters is provided by continuous pumping to a float valve in each filter. The flow rate is controlled by an outlet valve, leading to a hump which maintains water level above the sand (in the event of a power failure), and prevents negative heads under the filter skin, thus avoiding air binding in the filter sand. In addition to a V-notch weir at each outlet, all flows into each filter are metered through ordinary domestic meters.

The area of each of the two large tanks is 7 m^2, and the two small ones 3 m^2, each giving discharges of 11.7 L/min and 5.0 L/min respectively at a downward filtering rate of 0.1 m/hr. Each filter has only two manometer tappings, one in the supernatant water and one in the gravel underdrain.

4. COMMISSIONING (PHASE I)

The plant was commissioned in mid-January 1982, when raw water was run directly on to all four filters in parallel (i.e. A and B, fine sand and C and D, coarse sand) at a controlled outflow rate of 0.1 m/hr. On site testing was performed for colour, turbidity, electrical conductivity, pH and dissolved oxygen on the raw and product waters. Laboratory algal counts were made on samples taken from the same locations.

It was found that although the colour, turbidity and algal counts were not unusual for that time of year (i.e. mid-summer) for Lake Mulwala water, the fine filters (A and B) blocked within a week. On the other hand the coarse filters (C and D) ran for approximately four weeks before blocking. Scraping of the fine filters on a weekly basis enabled them to run for a total time of five weeks.

The commissioning phase (designated Phase I) was terminated after five weeks because of the unacceptably short runs achieved for the fine filters. It was obvious that some form of pretreatment was necessary to achieve adequate run times.

Some typical results for Phase I were:-

TABLE III

Filters	Colour (Apparent Pt/Co)	Turbidity (JTU)
A & B (fine sand)		
Raw water	90, 80	29, 17
Filtered water	5, 5	1.5, 2.5
C & D (coarse sand)		
Raw water	80, 100	20, 19
Filtered water	10, 10	2.0, 1.6

With the experience gained during commissioning it was decided to make alterations to the flow of water through the plant and to use the coarse sand filters (i.e. C and D) as prefilters for the fine sand filters (A and B).

This change to the flow pattern (see Fig. 3) and the intended mode of operation led to a new phase of operation (designated Phase II) which effectively became the first experimental phase.

5. EXPERIMENTAL (PHASES II and III)

5.1 Phase II Operation of Filters

This phase began in late February, 1982, when raw water pumped from the raw-water tank R was directed first to coarse filters C and D in parallel, then by gravity to the transfer tank T, pumped back to the filtered water tank F, and finally to the fine filters A and B in parallel.

This mode of operation, with filters C and D acting as prefilters, enabled three runs, each of 10 weeks, to be

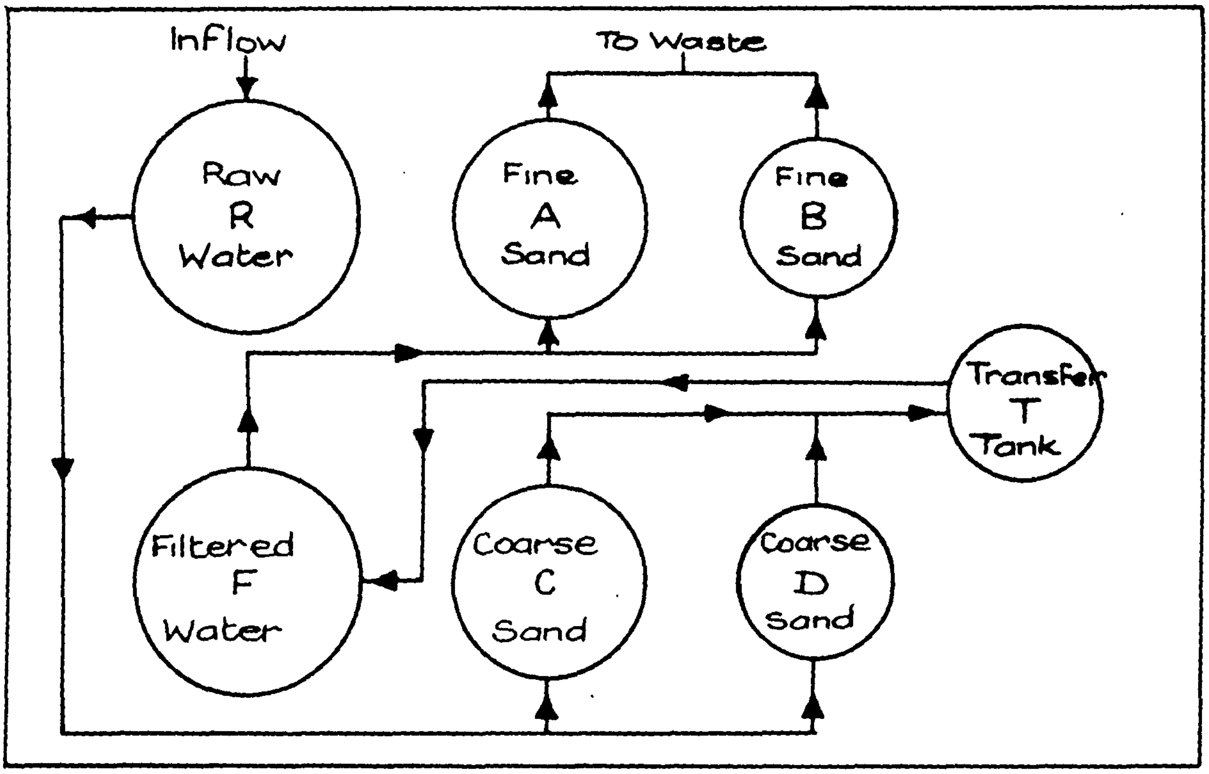

Figure 3: Direction of flow through the plant in Phase II

achieved for the fine filters A and B. During each of these periods of operation (i.e. 10 weeks) the coarse filters had to be scraped at intervals of between two and six weeks. At the commencement of Phase II filters A and B were given a 'ripening'period of several weeks at 0.05 m/hr, before increasing to 0.1 m/hr, while C and D had to be run at 0.15 m/hr or greater, to ensure that the transfer pumps always had adequate water while the plant was essentially unattended for up to 5 or 6 days per week.

Phase II ceased at the end of September 1982, after 31 weeks in which three separate runs were completed with fine sand filters (A and B). The results obtained are discussed in Section 6.

5.2 Sampling Procedures

5.2.1 Physico-chemical measurements

Samples were collected throughout the plant of:-

- raw water
- filtered water from coarse filters C and D
- filtered water from fine filters A and B.

In addition, head loss measurements were made on each filter. The parameters measured were:-

- colour
- turbidity
- pH
- dissolved oxygen
- electrical conductivity.

5.2.2 Bacteriological measurements

Standard bacteriological techniques were used to collect samples from the outlets of both fine sand filters (i.e. A and B) during the three filter runs of Phase II. At the commencement of the study, the inlets to the filters were sampled at the float valve inflow, but owing to difficulties with collection, these points were replaced by sampling points on the rising pipes of the inlets. Still later, they were replaced by a single sample on the outlet of the tank used to store the water produced by the coarse sand filters. Samples were collected weekly, except on those four occasions when the plant was not fully operational (e.g. during scraping or because of a power failure).

The following bacteriological parameters were routinely measured:-

- *E.coli*
- coliforms
- *Aeromonas hydrophila*
- *Pseudomonas aeruginosa*
- 22 and 37°C plate count
- total background population.

The results of coliform and *Aeromonas* counts in filter A are presented in this paper (see Section 6.2).

5.2.3 Biological measurements

Biological changes in the sand itself and also in the water produced by the filters were both investigated.

The algal, protozoan and invertebrate populations of the sand were investigated using a "micro-core" technique. Cores, 10 mm diameter and filled with clean sand, were planted in the filters after scraping and successively withdrawn during the course of a filter run. At the end of each run, additional large sand cores (40 mm diameter) were also collected by forcing a core barrel into the filter bed.

Water samples from various parts of the pilot plant were collected at weekly intervals for algal determinations and particle size/frequency distribution measurements.

The following parameters were measured on the sand cores:-

- algal numbers
- protozoa concentrations
- rotifer concentrations
- concentrations of other invertebrates.

On water samples, measurements were made on the following:-

- algal numbers
- invertebrate numbers
- particle numbers and sizes (using a Coulter Counter Model ZB with a 260 μm orifice).

5.3 Phase III

In this phase (current at the time of preparing this paper) changes to the sampling and testing programme have been initiated to optimise data collection and to concentrate on those parameters of most significance. A swimming-pool filter with automatic backwash has been introduced to provide an alternative to using the coarse filters for prefiltration. The flow diagram (Fig. 4) incorporating the swimming pool filter, indicates that this filter has been introduced whilst still retaining as a control the coarse filters to supply one of the fine filters. Further phases will hopefully include a horizontal prefiltration arrangement and possibly some additional alteration to flow paths throughout the plant. At this stage, however, only those steps actually taken to modify the sampling programme and the plant operation will be discussed. Future plans will be discussed in Section 8.

5.3.1 Physico-chemical programme for Phase III

Electrical conductivity and pH, show very little variation throughout the plant and are not being measured intensively in this phase. However, if significant changes are made in the plant operation, raw water quality changes, or if new sand is introduced, then intensive monitoring is to be reintroduced.

Colour and turbidity are the most significant measurements as their reduction is a direct measure of the effectiveness of the plant. These measurements continue to be made throughout the plant and relatively intensively.

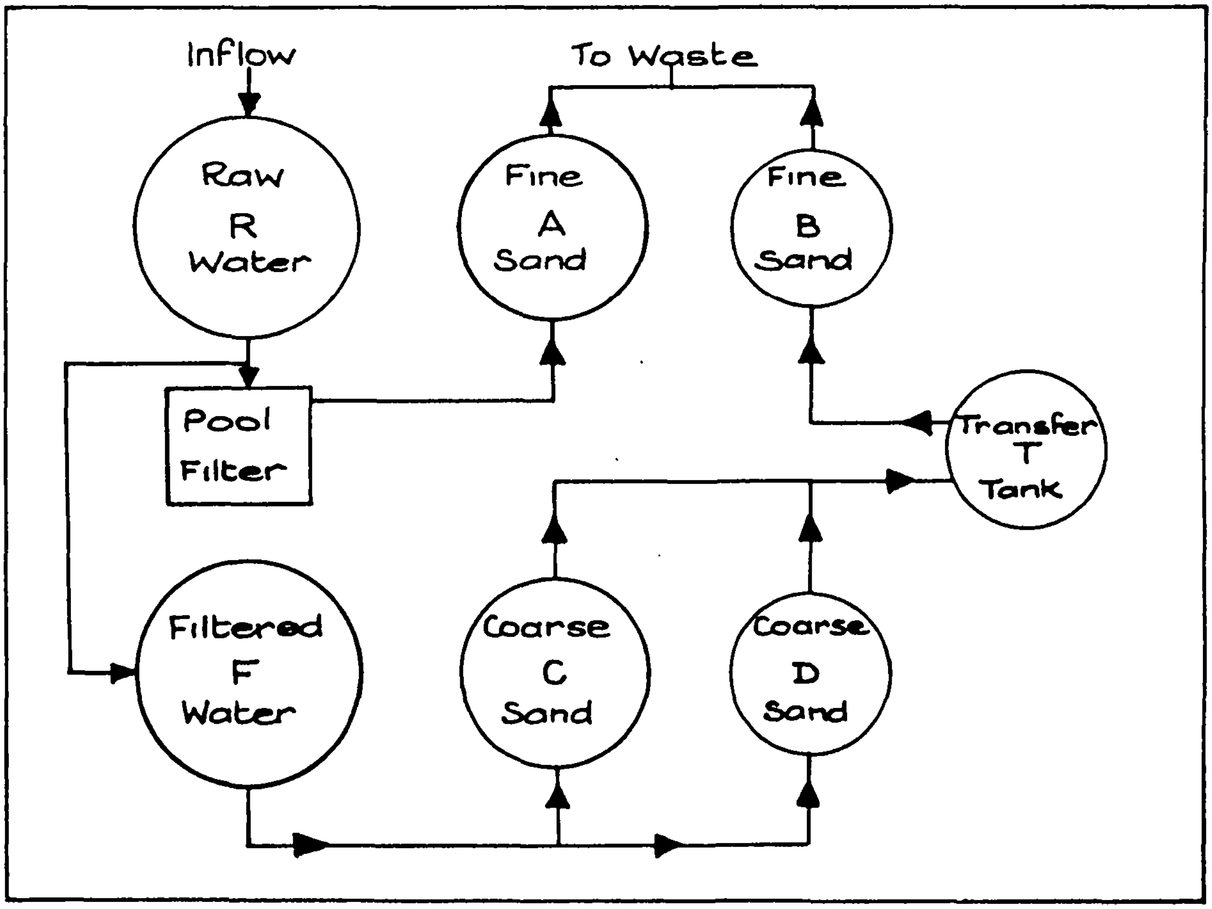

Figure 4: Direction of flow through the plant in Phase III.

Dissolved oxygen concentration, unless measured intensively over 24 hour periods, does not indicate diurnal cycles of production by algae and uptake by the aquatic biota of the filters. During Phase III, intensive measurements of these changes are being made on the water above the sand and in the outflow. As dissolved oxygen concentration in the outflowing water is a good indicator of health of the organisms in the filters, regular measurements will be maintained at the outflows of the fine filters.

5.3.2 Bacteriological programme for Phase III

In accordance with the flow arrangements to the fine filters, the bacteriology of the inputs and outlets of these filters, and the two holding tanks F and T are being investigated. The parameters currently being measured are *E.coli*, coliforms, *Aeromonas*, *Pseudomonas* and a 37°C plate count. Further, if future results indicate little differences between the holding tanks and the respective inlets to the filters, sampling of the inlets will be discontinued.

5.3.3 Biological programme for Phase III

Algal numbers are being determined using a rapid counting technique on the inflows, supernatant water above the sand, and in the outflows of the fine filters. These counts will be used to establish the input loadings from both the supplied water and from algal growth, as well as the efficiency of the filters with respect to removing algae. Algal counts are supplemented by particle size/frequency measurements obtained by Coulter count. This latter technique permits the exact size, volume and concentration in the respective samples to be measured.

Estimates of the density of algal mats on the surface of the sand in the two fine filters are to be made by measurements of dry weight and loss on ignition at 500°C at the end of each filter run. The depth of penetration of organic material into both the coarse and fine sand filters is being estimated by the analysis of sand cores collected at the end of each run.

Build up of protozoa, algae and small invertebrates in the fine sand filters are being investigated using micro-cores planted in the filters at the beginning of each run and withdrawn and analysed successively during the run period.

6. RESULTS AND DISCUSSION (Phase II)

The results presented in this section relate mainly to Phase II; Phase I results having been considered under Section 4, and Phase III results are not available at the time of writing.

6.1 Physico-chemical Results

6.1.1 Temperature

As expected, water temperatures are consistent with the seasonal changes. During this phase, the warmest water was found in March (24-26°C) and the coolest in July (5-6°C). Figure 5 is a plot of temperature data for filter A and is typical of the other filters; the outlet water is frequently cooler than the supernatant water by 1 to 2°C.

6.1.2 Dissolved oxygen

The inlet and outlet of both fine and coarse sand filters have had very similar dissolved oxygen concentrations throughout this phase. On most occasions, over 10 ppm dissolved oxygen was found. The single daily measurements of dissolved oxygen were not sufficient to indicate any diurnal changes in concentration which might be expected to occur as a result of algal production on the surface of the filters.

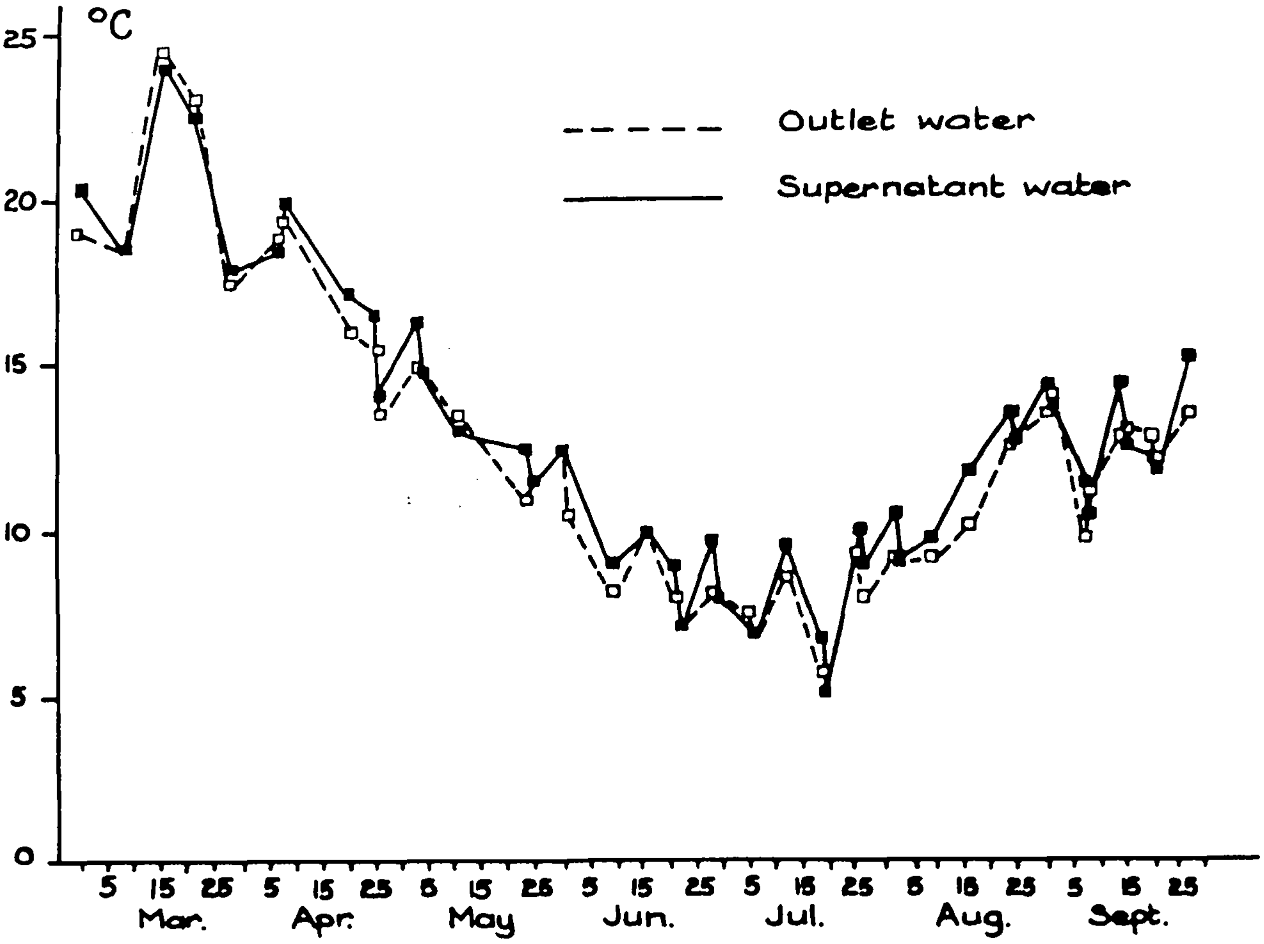

Figure 5: Temperature changes in the supernatant and outlet water of filter.

The outlet water of the coarse filters was consistently of a lower dissolved oxygen concentration than the raw (inlet) water and the greatest differences occurred when the head loss was at its highest.

6.1.3 pH and electrical conductivity

In general, the pH changed by only 0.2-0.4 pH units as a result of filtration. Since June 1982, the pH of the outlet water of the coarse sand filters has been lower than the raw (inlet) water, while the reverse effect occurred in the fine sand filters.

The high pH values experienced in September in the fine sand filters could be the result of algal production.

Filtration has had very little effect on the electrical conductivity of the water which has remained within 60-100 µS/cm throughout Phase II.

6.1.4 Colour

All colour measurements during Phase II were made without filtration or centrifugation and are therefore more truly termed 'apparent colour'. The coarse filters caused a decrease in

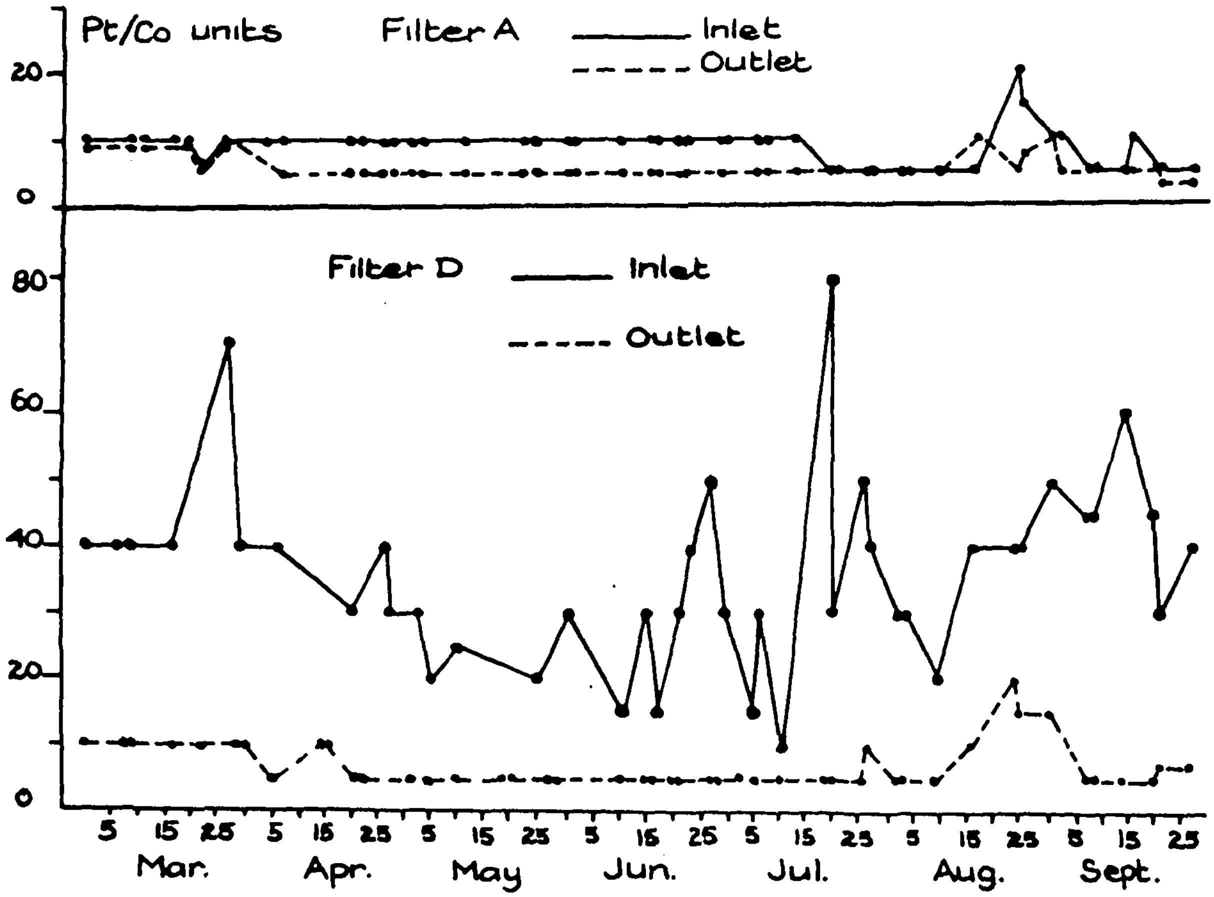

Figure 6: Changes in colour caused by coarse and fine sand filtration.

water colour from between 10-80 Pt-Co units to values of 5-10 Pt-Co units in most cases. A further decrease in water colour from 5-10 Pt-Co units to 5 Pt-Co units resulted from fine sand filtration. The results from filters D and A are shown in Figure 6.

6.1.5 Turbidity

Turbidities ranging from 3-28 NTU in the raw water were decreased to about 1 JTU by the coarse filters, on most occasions (Fig. 7). After the initial maturation period in March-April when outlet turbidities were higher than those of the inlet, the fine sand filters decreased turbidity from 1 JTU to about 0.5 JTU (Fig. 7).

6.1.6 Head loss

The coarse filters, which have received raw water during this phase, have had only very short "runs" before the head loss seriously affected the flow rates and the filters had to be scraped (Fig. 8).

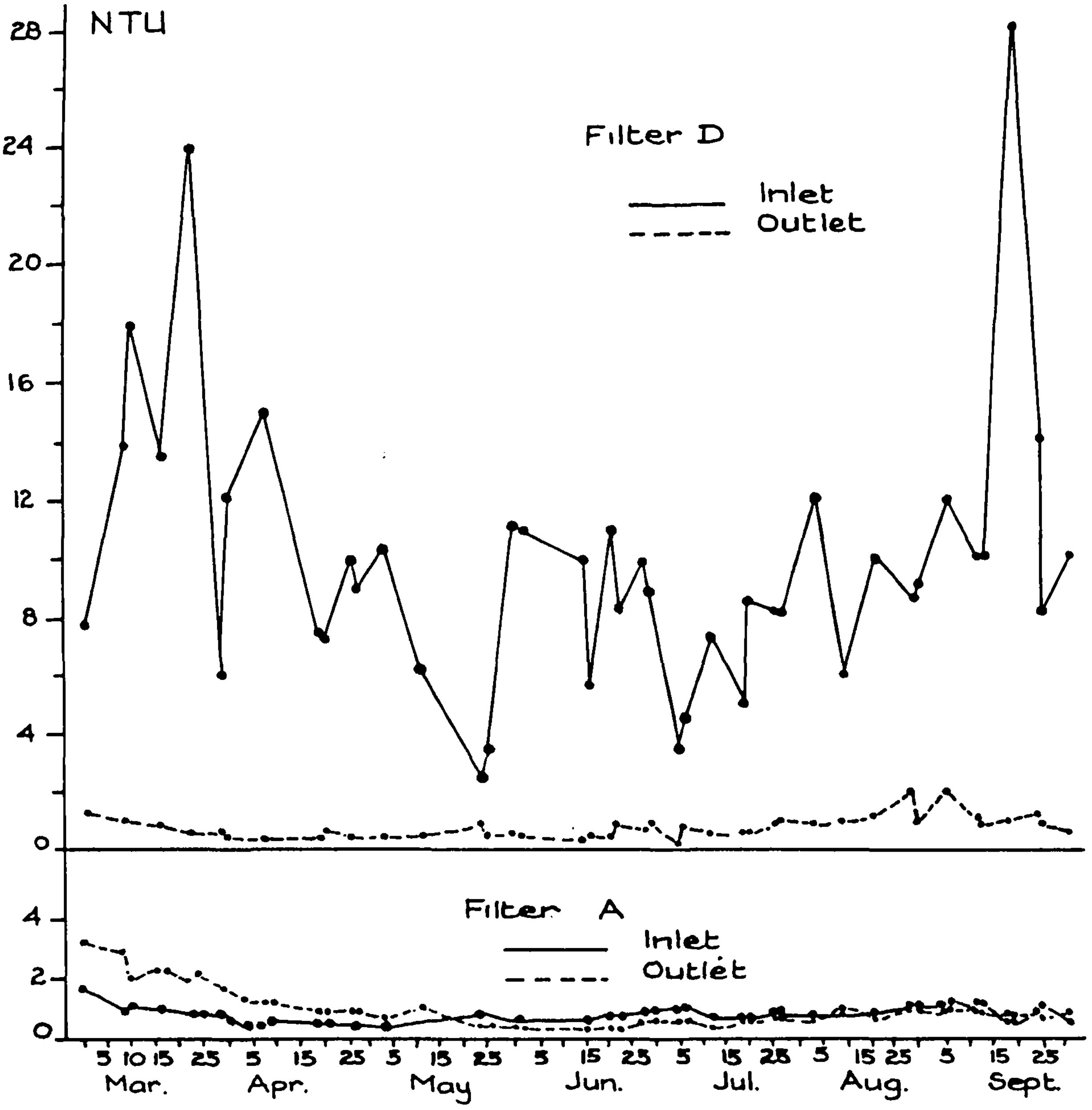

Figure 7: Changes in turbidity caused by coarse and fine sand filtration

Initially the removal of 1 cm of sand was sufficient to reduce head loss to near zero, but toward the end of Phase II, 2 cm had to be removed from the coarse filters. The longest run on the coarse filter, of five weeks duration, occurred in May-June and corresponded to a period of low turbidity in the inlet water. On other occasions, especially toward the end of this phase, the coarse filters have required scraping every two weeks.

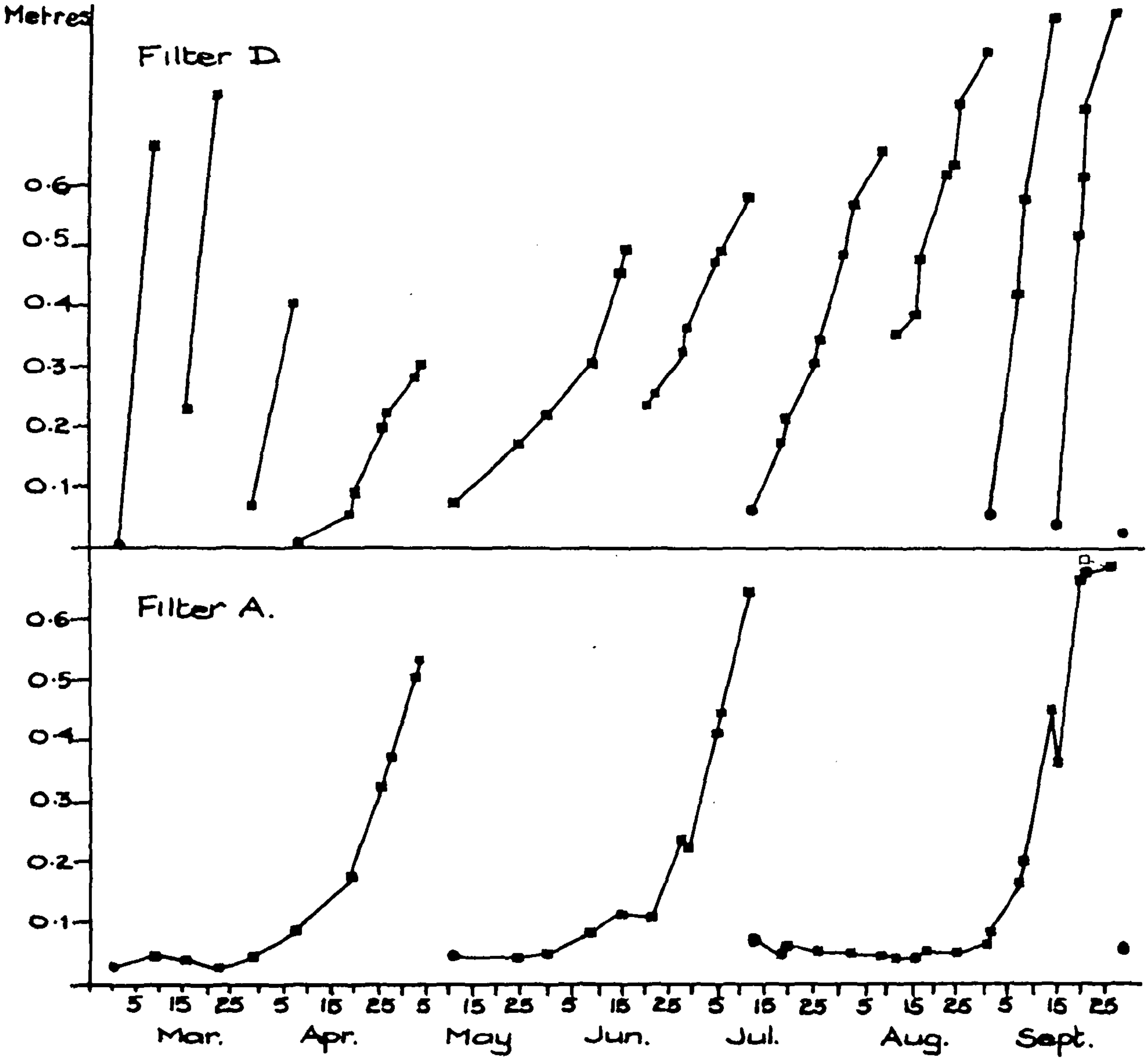

Figure 8: Changes in head loss in coarse and fine sand filters.

Very low turbidity in the pre-filtered inlet water from filters C and D has allowed the fine filters (A and B) to run for 10 weeks duration. Filter A consistently produced an exponential response to head loss with time, the rapid increase in head loss occurring some 40 days after filtration began (Fig. 8).

6.2 Bacteriological Results

The results of coliform and *Aeromonas* counts in filter A (fine sand) have been used as the basis for the following discussion.

Coliform numbers were used as a means of indicating bacterial removal by

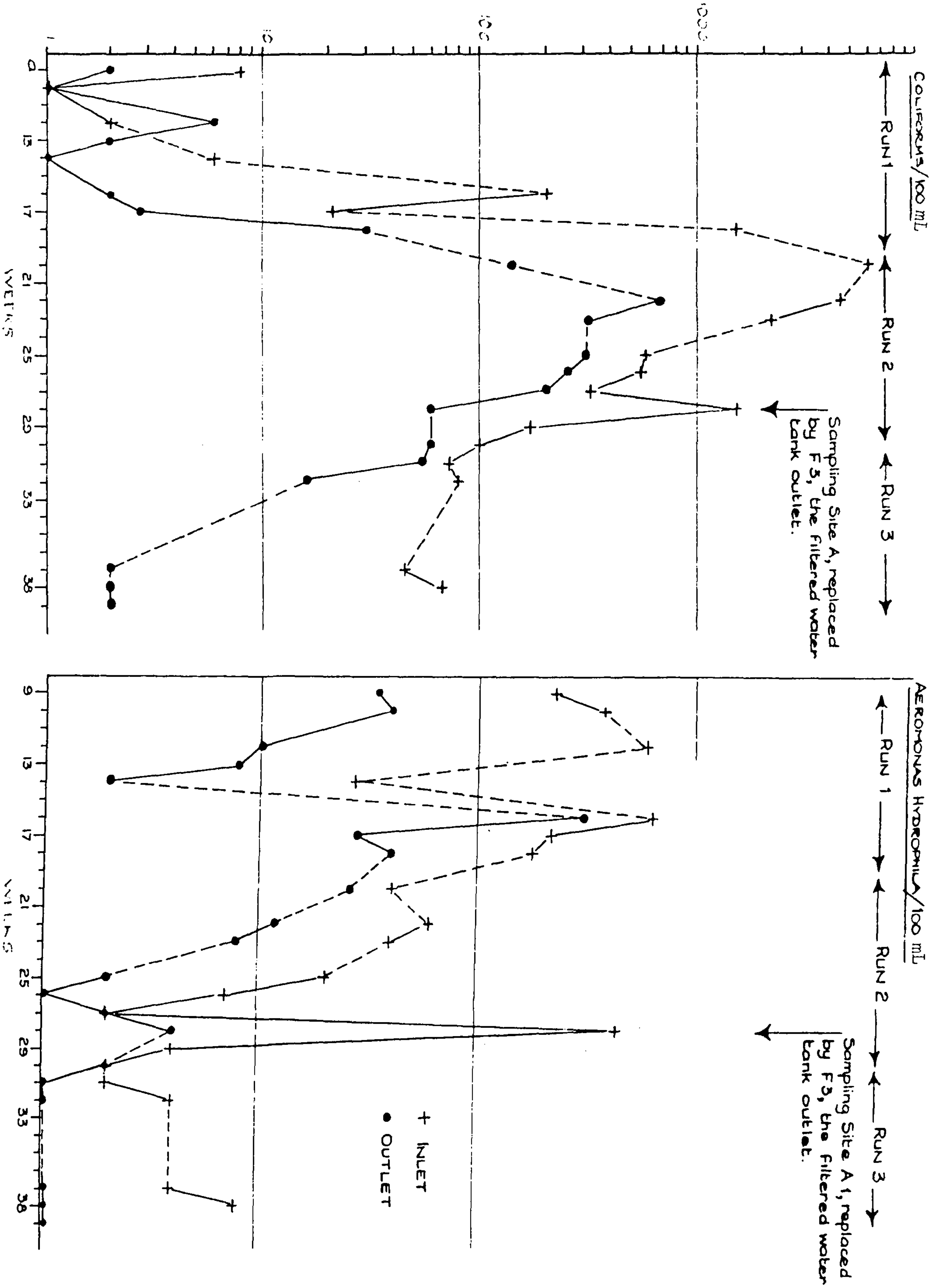

Fig. 9: The Bacteriology of Fine Sand Filter A

the filters as *E.coli* was very rarely present, even in the raw water, during Phase II. Except in initial stages of Phase II, coliform numbers invariably decreased after filtration through fine sand. In June, July and August (corresponding to weeks 19 to 32 in Fig. 9) there was least reduction in numbers; presumably this was because water temperatures were low and grazing protozoa populations were at their least active. Since September, the removal of coliforms has been more effective.

Aeromonas hydrophila is an aquatic bacterium which occasionally causes an ulcerative disease in fish, and has, very rarely, been known to infect man. As *Aeromonas* is a natural component of the freshwater bacterial flora, it was doubtful whether filtration could cause a reduction in numbers; and it seemed possible that numbers might even increase as a result of growth within the filters. However, the results so far indicate that *Aeromonas* was removed by filtration, although not, perhaps, as effectively as coliforms (Fig. 9).

6.3 Biological Results

Sand samples

Melosira granulata which was abundant in the raw water during winter and spring was mainly removed by the coarse sand filters. The skin which formed on the fine sand filters during winter consisted mainly of the *Melosira* which had penetrated the coarse sand, and two other diatoms, *Navicula* sp. and *Nitzschia acicularis*. In spring as the temperature and solar radiation increased, a thick mat of the green filamentous alga *Zygnema* sp. developed on filter A, and to a lesser extent on filter B. The *Zygnema* mat extended as long streamers into the water above the sand and formed dense patches on the water surface. Despite this, there were no indications that the surface of the sand had been lifted by the algal filaments.

When the fine filters were drained for scraping and had partially dried, the algal skin compacted to a thickness of ∿2 mm. This skin could be "rolled up" and removed.

Sand cores illustrated the development of a sand flora and fauna which was most abundant just below the skin surface, still abundant at a depth of 10 mm, but decreased rapidly over a depth of 80 mm. Below 80 mm very few organisms were present. The top 10 mm contained, as well as *Zygnema*, two motile diatoms, *Navicula* sp. and *Nitzschia acicularis* which are very commonly found in sand filters and are capable of moving through the sand. The presence of many protozoan species was also recorded; small flagellates being most abundant and ciliated species were also common but amoeboid protozoa were rare. The flora and fauna of the fine sand filters resembled in many respects the typical slow sand filter populations found in Thames Water Authority filters (Bowles personal communication) except that in the English situation the skin is formed by *Melosira varians* in spring and the green algal *Cladophora* during summer.

Water samples

Algae were uncommon in the outflow from the fine sand filters during this period, being predominantly restricted to small flagellates and *Nitzschia acicularis*. This species is a fine needle shape organism known for its filter penetrating capabilities (Thames Water Authority, unpublished). *Nitzschia acicularis* numbers commonly ranged between 0 and 20 cells/mL in the outflows of the fine sand filters. Total particle numbers in the filtered water were also low, being very similar to a distilled water background.

7. CONCLUSIONS

The following conclusions have been drawn from the commissioning phase (Phase I) and the first experimental phase (Phase II) of this study.

. The water quality results from Phase II of the study are encouraging. With the aid of roughing filters it has proved possible to produce a high quality treated water from the fine sand filters A and B with a run length of ten weeks between cleaning periods. Simple scraping of the fine sand filters was sufficient to restore head losses to their initial level.

. The fine sand filters A and B have developed a characteristic slow sand filter flora and fauna and have operated as true biological filters. The removal of particles, including bacteria and algae would appear to occur within the top 80 mm of the sand bed. Despite high concentrations of algae in the raw water in the latter part of Phase II, there have been very few algae in the treated water and its overall particle content has also been low. No taste and odour problems have occurred.

. Although there were insufficient numbers of *E.coli* for observations on the effects of fine sand filters to be made, the removal of coliforms and other natural aquatic bacteria indicated that, had *E.coli* been present, its numbers would certainly have been decreased as a result of filtration.

. The physico-chemical quality of the treated water was good, its apparent colour being 5 Pt/Co units and its turbidity 1.5 to 2.5 JTU. These levels were measured at the detection limits of the field instrumentation. However, due to lack of rain, the ability of the filters to treat highly coloured or turbid water has not yet been tested.

. The quality of water produced by fine sand filters was therefore satisfactory in all respects. In a full scale operation, the main purpose of chlorination would be to ensure disinfection throughout the reticulation system, rather than treatment of the filtered water. Owing to the low level of bacteria and other particulate material in the treated water it is expected that chlorination costs could be low, full chlorination easily achieved, and taste and odour problems resulting from the chlorination of algae minimal.

. Additional work is required to determine the most effective means of prefiltering water prior to treatment by fine sand filtration.

8. FUTURE WORK

Having established broad operational criteria for slow sand filters under the conditions found at Yarrawonga, it is proposed that Phase III and subsequent phases will be used to assess various pre-filtration options, together with establishing the upper limits for flow rate through the fine filter beds.

During this phase, fine sand filter B will be used as a control for experiments conducted on fine sand filter A. Additionally, if the pretreatment section of the plant has sufficient capacity, filter D will be resanded with fine sand and also be used experimentally. The effectiveness of shading the filters as a means of decreasing surface algal growth and increasing run length (hence decreasing cleaning costs in a full scale operation), and of the relationship between high rate filtration and head loss on shaded and unshaded filters will be investigated. In addition, attempts will be made to make preliminary economic comparisons with more conventional treatment plants, although this will be difficult because of the small scale of the current pilot plant.

The study is scheduled to be concluded at the end of 1983 (on-site experimental work concluding mid-1983) with the cost of the study estimated to be $200 000 approximately by the time of completion.

ACKNOWLEDGEMENTS

The authors wish to thank Mr. J. Mann, Director of Water Resources, Ministry of Water Resources and Water Supply, Victoria for his interest in, and for arranging the funding for the project, and R. Gocs, S. Phillips, D. Welsh and A. McNeill for providing engineering and analytical information. In addition, the authors are grateful to the State Rivers and Water Supply Commission, Victoria for permission to prepare this paper.

REFERENCES

BOOK

BAKER, M.N. (1949). The Quest for Pure Water, The American Water Works Association, Inc.

HAZEN, A. (1895). The Filtration of Public Water-Supplies. John Wiley and Sons.

HUISMAN, L. & WOOD, W.E. (1974). Slow Sand Filtration. World Health Organisation, Geneva.

MONOGRAPH

VAN DIJK, J.C. and OOMEN, J.H.C.M. (1978). Slow Sand Filtration for Community Water Supply in Developing Countries. WHO International Reference Centre, Technical Paper No. 11.

THESIS

BOWLES, B.A. (1978). Phytoplankton Populations of the River Thames. Ph.D. Thesis, London University.