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THE REMOVAL OF INVERTEBRATES BY SAND FILTRATION AND THE INFLUENCE THEREOF ON WATER QUALITY

Report to the
WATER RESEARCH COMMISSION
by
SCIENTIFIC SERVICES, RAND WATER
JOHANNESBURG, SOUTH AFRICA

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EXECUTIVE SUMMARY

INTRODUCTION

Although free-living organisms forms an integrated part of nature and the chemical processes which keep the ecosystem in balance, free living organisms should be absent from potable water. The organisms, which includes algae, protozoa and invertebrates, may cause adverse health effects, aesthetic problems, objectionable tastes and odours, may act as food source for fungi and bacteria and can interfere with potable water treatment and distribution.

The relation between viruses, bacteria, protozoa, algae and specific health and aesthetic effects on potable water production and quality have been studied. Very little information is, however, available on the effect of invertebrates on the production and quality of potable water.

Knowledge of the identity and abundance of invertebrates in potable water supplies is essential to determine their possible effect on potable water quality, to identify treatment options to remove invertebrates from raw water and to determine future water quality guidelines for invertebrates.

As the status of invertebrate related potable water quality in South Africa is not known, the Water Research Commission contracted Rand Water to do a basic study on the invertebrate content in Rand Water's water and to note international trends in this regard.

Organisms present in the distribution system vary in their density and composition of the population. Approximately 150 different kinds of animals have been found in British water mains. Few distribution systems are without any animals. It is, however, important to maintain the numbers of organisms as low as possible to prevent consumer awareness of their presence either directly or indirectly. Several authors state that the occurrence and persistence of invertebrates in potable water supplies is a common complaint.

The presence of organisms in potable water may be due to the penetration of unit processes or colonisation of the total purification system. Penetration of invertebrates through treatment works are the usual method of initial entry into the distribution system. The types of animals which enter in this way are those that are aquatic for the whole or part of their life cycle. Service reservoirs may also be a point of entry for flying insects gaining access through badly protected vents and overflows.

The midges (chironomids) which is an exceedingly complex family of about 3000 described species in the world, are masters in penetrating unit processes. The majority of chironomids cannot complete their life cycle in a water main, the adult midge being aerial. Chironomids adults (midges) are commonly seen flying in great numbers near water. Adult females lay a mass of eggs in the water. These eggs hatch into larvae that require about one to two months or more to reach pupation. The larvae go through four instar stages during which they wriggle and swim near the bottom sediment. The larvae are very small and

transparent during the first two stages and are practically invisible to the unaided eye. Penetration of filters by both eggs and larva occur and it is especially apparent in poorly maintained filters due to large sand particles and cracks in the filter bed. Adults may also gain entry to unprotected filter basins and reservoirs and deposit eggs directly into the purified water.

The information presented above clearly indicates the lack of knowledge regarding the presence of invertebrates in potable water and the possible effects of their presence. To address some of these aspects, this study addressed the following:

- The relationship between invertebrate population in filtered water and specific properties of filter media.
- The effect of invertebrates on water quality determinants such as turbidity and biological assimilable organic carbon (AOC).
- The effect of recycling filter backwash water on the occurrence of invertebrates on filters and in filtered water.

It is envisaged that the following could be derived from the research:

- Give an indication of the presence, type and effect on water quality of invertebrates in purified water.
- Results could be used to compile South African water quality guidelines for invertebrates.
- Indicate which water quality variables are effected by the presence of invertebrates in water and whether secondary problems can be expected i.e. increases in assimilable organic carbon concentrations, turbidity and consumer complaints.

Results can be used in the design and operation of filters and the specification for filter media i.e. procedures to optimise filter running times and backwashing procedures, selection of filter media and effect of recycled backwash water on filtrate quality.

RESULTS AND DISCUSSION

On the full scale purification plant at Vereeniging the removal of invertebrates through a sand filter containing old sand (Filter 5) was compared with that of new filter sand (Filter 113). Filter 5 is an example of a filter containing large sand particles (effective size > 1 mm) which is not properly fluidised during backwash. Filter 113 contains smaller sand particles (effective size < 0,7 mm)which is properly fluidised during backwash. The following observations made regarding the efficiency with which these

two filters removed invertebrates.

- The water before filtration at Filter 113 contained less invertebrates than the inlet to Filter 5. This may indicate that the sedimentation system of the new purification plant (the 1982 Scheme) remove invertebrates more effectively or inhibit breeding compared to that of the old system .

- The number of organisms (org/m^3) in the filtrate of Filter 113 was lower than that in the filtrate of Filter 5. If the removal efficiency is expressed in terms of the organism density in the inlet to the filter, the removal efficiency of Filter 113 is for most of the time only slightly better than that of Filter 5.

- The lower number of organisms present in the filtrate of Filter 113 may be due to the smaller effective sand size and lower uniformity coefficient compared to that of Filter 5. More effective backwash at Filter 113 compared to that at Filter 5 may also contribute to the smaller number of organisms present in the filtrate of Filter 113.

- The percentage removal could not always be correlated with the number of organisms present in the inlet to the filter.

- The invertebrate population was dominated by the Rotatoria and Cyclops. Midged larvae (Diptera) were present in higher numbers in the filtrate of Filter 5 compared to that of Filter 113, indicating possible breeding in filters. There was no notable difference in the age of the other invertebrate groups in the inlet of the filters compared to the filtrate. It was, however, obvious that the larger organisms were retained more efficiently by the sand filters.

The above results initiated a pilot plant study that was aimed at defining sand characteristics, filtration and backwash rates in relation to invertebrate removal. In spite of several technical problems experienced in the first few months the following observations could be made.

- Turbidities higher than 1 NTU in all the pilot plant runs may indicate that the filtration process was less efficient compared to Filter 113. This may explain the higher number of organisms observed in the filtrate of the different pilot plant filters compared to that of Filters 5 and 113.

- Most of the pilot plant filters, containing sand with different characteristics removed invertebrates with the same efficiency. It was only the very coarse sand that showed a lower percentage removal than the other sand filters.

- Proper disinfection of the filters and backwash of filters at the fluidisation point of the sand resulted in improved removal of the invertebrates.

- The invertebrate population was also dominated by Rotatoria and Cyclops with the Diptera present

in sufficient numbers.

The pilot plant study clearly indicated that the percentage removal of organisms can be improved significantly by proper backwash and disinfection of the filter. Filter media size less than 0,8 mm should be effective to remove invertebrates.

Proper maintenance of filters is the key to effective removal of invertebrates.

Based on the above information, a proposal regarding the setting of guidelines for invertebrates was also made. Based on the chance of consumers detecting these organisms in a glass of water, smaller numbers of organisms are recommended for the bigger and more visible organisms, compared to the small microscopic invertebrates of which more may be tolerated.

The proposed guidelines set must also take cognisance of the fact that associated with the invertebrates found, opportunistic bacteria were isolated. Fortunately, the number of invertebrates found do not contribute significantly to the assimilable organic carbon concentration.

It can, therefore be concluded that although invertebrates are aesthetically not acceptable, their nett effect on reducing water quality may be minimal.

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1. INTRODUCTION

In the natural environment there is no pure water available. All water, including rain water, has some impurities. The impurities are commonly in the form of dissolved solids or gases, suspended solids and microscopic organisms. The importance of water as a vehicle for the spreading of decease and the conveyance of hazardous substances are the main concerns in terms of supplying safe potable water. Certain other quality parameters related to aesthetics, palatability and corrosiveness or scale forming potential are also of concern. Many of these impurities are beneficial to health and form part of the essential daily dietary requirements of man. An ideal potable water would, therefore preferably contain sufficient amounts of essential elements for man's dietary requirements in the absence of any substances or organisms at concentration levels high enough to pose a health risk to the consumer or affect the palatability or aesthetics of the water.

Although free-living organisms forms an integrated part of nature and the chemical processes which keep the ecosystem in balance, free living organisms should be absent from potable water (WHO, 1993). These organisms, which includes algae, protozoa and invertebrates, may cause adverse effects on health, aesthetic problems, objectionable tastes and odours, may act as food source for fungi and bacteria and can interfere with potable water treatment and distribution (Steynberg *et al.*, 1994).

The relation between viruses, bacteria, protozoa, algae and specific health and aesthetic effects on potable water production and quality have been studied. Very little information is, however, available on the effect of invertebrates on the production and quality of potable water.

Knowledge of the identity and abundance of invertebrates in potable water supplies is essential to determine their possible effect on potable water quality, to identify treatment options to remove invertebrates from raw water and to determine future water quality guidelines for invertebrates.

As the status of invertebrate related potable water quality in South Africa is not known, the Water Research Commission contracted Rand Water to do a basic study on invertebrate content in water treated by Rand Water and to identify international trends in this regard.

2. LITERATURE SURVEY

Due to the vast variety of organisms present in water and different perceptions of the term 'invertebrates' it is important to clarify what is meant by 'invertebrates' before looking at what international trends are.

2.1 INVERTEBRATES DEFINED

The invertebrates are animals, much more complex in morphology than the protozoa and may vary in size from microscopic to macroscopic. Invertebrates found in the potable water (Evins and Greaves, 1979) include Rotifera, Copepoda, Cladocera, Malacostraca, Hydracarina, Mollusca and Diptera. Of particular concern are the parasitic helminths (flukes, tapeworms and roundworms) especially those with resistant eggs or cysts.

The five main groups of invertebrates commonly found in the Rand Water's distribution system, are Amphipods, Chironomids, Copepods, Cladocerans and Ostracods. The invertebrates play an important role in the impoundment ecology. A conspectus of the principals and lifestyles of the invertebrates is thus necessary.

2.1.1 AMPHIPODS

They are benthic organisms feeding on epiphytic growth and even dead animals and plant matter such as filamentous algae. They are thus omnivorous (Pennack, 1935; Edmondson, 1973). Amphipods have been shown to harbour bacteria (Atlas *et al.*, 1982) and to pass viable bacteria (including *Bacillus cereus*) through the gut track and out with the faecal material (Willoughby *et al.*, 1983).

2.1.2 CHIRONOMID

The adults (midges) resemble small mosquitos. The adult female midge lay a mass of eggs in the water, they hatch into small larvae and swim near the bottom sediment. Near the end of the larval stage they migrate to the surface, pupate, and stay there a few days before they emerge as adults. The larvae are frequently detected in drinking water in the spring and summer months. Their diet consists of detritus.

2.1.3 COPEPODS

They can be found as part of the plankton or benthon. Cyclops, Thermocyclops, Microcyclops, Eucyclops, Diaptomus and Metadiaptomus are the genuses found in South African waters (Kruger

et al., 1970). Their diet consists primarily of microscopic plants and animals captured while filtering the water.

2.1.4 CLADOCERANS

Species represented in South African water are *Ceriodaphnia, Diaphonosoma, Bosmina, Leydigea, Macrothrix and Moina* (Kruger *et al.*, 1970). Their diet consists of algae and bacteria. They are minute crustaceans living amongst the plankton or they forage amongst dead animal and plant debris on the bottom. Cladocerans feed on algae, protozoa and they also consume organism debris and water within their gut tracks. Most females lay their eggs which become attached to debris or are carried within the shell of the female for a period of time. Special winter eggs, produced by sexual reproduction survive the more vigorous conditions, while summer eggs hatch quickly (Pennack, 1935; Edmondson, 1973; Palmer and Fowler, 1973).

2.1.5 OSTRACODS

They are often called mussel or sea shrimps. They may be carnivorous, herbivorous, scavengers or filter feeders. They can also ingest detritus particles (Barns, 1980). They may browse in the pipe debris.

2.2 EFFECTS ON POTABLE WATER QUALITY

Organisms present in the distribution system vary in their numbers and composition of the population. Ainsworth *et al.*, (1981) reports that approximately 150 different kinds of animals have been found in British water mains, and that few distribution systems are without any animals. It is, however, important to maintain the numbers of organisms as low as possible to prevent consumer awareness of their presence either directly or indirectly. Levy (1990) states that the occurrence and persistence of invertebrates in potable water supplies is a common complaint, a statement confirmed by Flentje (1945), Levy (1984), Luczak *et al.*, (1979).

At Rand Water a Sure-Kleen inline filter capable of filtering the total volume of water passing a pipeline was installed in February 1989. During the commissioning and testing of the filter it was necessary to remove the three filter elements on four occasions. Concern was expressed regarding the large number of chironomid larvae stuck on the filter elements. The occurrence of these larvae and a complaints received during the same period from the Western and Southren part of the distribution system initiated an investigation into the presence of chironomids and other invertebrates in Rand Water's distribution system.

According to Ainsworth *et al.*, (1981) consumer complaints are considered a measure of the success or failure in maintaining low numbers of organisms, but this is no reliable measure to the extent of animal infestation in distribution systems. He therefore summarized three symptoms of

animal infestation:

- Their appearance, either because of size (*Asselus*) or by active movement (*Cyclops*).
- Discoloured water (faeces of larger animals, *Asselus* or casts of exoskeletons of some crustaceans.
- Decay of dead animals may result in tastes and odours.

Aeppli (1991), studying the appearance of invertebrates in the Zurich water supply, said that neither routine reservoir cleaning nor the addition of chlorine dioxide as a network protection agent was able to reduce populations of *Canthocamptus* (copepods) significantly. According to Zwaagstra (1982) it is evident that the elimination of organisms by chlorination in combination with coagulation, sedimentation and gravity filtration, can be attributed to the anaesthetic effect of the chlorine and thus the removal of the inactive organisms with the floc. Even when the invertebrates are totally inactivated by disinfection with chlorine and monochloroamines, they may harbour and protect bacteria from disinfection. Tracy *et al.*, (1966) theorized that microbiota, eg. coliforms become encapsulated within the microcrustacea (copepods) and are protected against normal chlorine concentrations used for disinfection. Levy (1985) speculated that bacteria associated with copepods were located internally, while bacteria flora of other invertebrates were located both internally and externally. Scanning electron microscopic studies conducted by Levy (1990), verified the presence of bacteria associated with the invertebrates.

Levy (1986) stated that the numbers of bacteria found in association with different invertebrate taxons may be expected to vary, and this variance may reflect the following considerations:

- Size as well as physical and biochemical characteristics of the invertebrate's external surface exposed to the abient water environment must be considered.
- The lifestyle of an invertebrate may predispose it to bacterial colonization. Those which actively browse in and among the bottom sediment of reservoirs and pipelines, eg. amphipods, would be exposed to higher numbers of bacteria for longer periods of time when compared to invertebrates such as copepods that live in water columns, where bacterial cells are more diffuse.
- Life expansion of an invertebrate should play a role in determining the number of permanent associates found with ambient bacteria, since contact time appears to be a factor in attachment.

Although the metazoan (many celled) animals normally associated with distribution systems are not known to cause or carry decease, they may influence the water quality by contributing to organic load entering the distribution system and they may also contribute to the colonisation of a distribution system by

invertebrate associated bacteria, in spite of residual chlorine. They may decrease the effectiveness of chlorination by increasing the chlorine demand of water (Levy, 1986). It is also known that invertebrates contribute to biological magnification by concentrating waterborne contaminants such as, pesticides, biocides, metals eg. within their bodies.

2.3 PENETRATION OF INVERTEBRATES THROUGH UNIT TREATMENT PROCESSES

The present study is aimed at investigating the efficiency of filtration as a unit treatment processes and it's ability to remove invertebrates. A brief description of some physical and chemical aspects of other unit processes such as practised by Rand Water are given as a background to clarify the concepts used later in the document.

2.3.1 WATER PURIFICATION AT RAND WATER

Rand Water abstracts virtually all of its water to be clarified and disinfected from the Vaal Dam and the Vaal River Barrage Reservoir. Vaal River Barrage Reservoir water is normally of lower quality compared to water abstracted from the Vaal Dam. This water, which contains a high proportion of treated domestic and industrial effluent contains high concentrations of algae, dissolved inorganic salts, organic material but contains low concentration of suspended matter. The Vaal Dam water is relatively unpolluted and contains high concentrations of suspended solids.

Rand Water currently applies the following conventional purification processes to produce potable water; pre-chlorination, coagulation, flocculation, sedimentation, stabilisation, filtration, disinfection, by breakpoint chlorination at the purification works and chloramination after 6 to 8 hours contact at the booster pumping stations. Each of these processes will be discussed briefly in the following paragraphs.

2.3.1.1 Coagulation and flocculation

One of the principal problems of purifying Vaal River and Vaal Dam water is the removal of the suspended matter. Suspended matter in the Vaal River water has colloidal properties and remains in suspension for long periods. The colloidal material in the Vaal River varies in diameter between 10 and 1000 nanometre and will under normal circumstances remain suspended for periods of up to 2 years. Therefore, colloidal property is in fact of greater significance than the quantity of the suspended material.

To achieve efficient removal of these solids, Rand Water uses hydrated lime for coagulation and flocculation and activated sodium silicate as an aid to flocculation. The average dosage rate of calcined lime varies between 55 and 70 mg/l as calcium oxide and the silicate dosage rate between 1 and 3 mg/l as silicon dioxide. The high pH of between

10 and 11 obtained during lime coagulation limits algal growth and is very effective towards the removal of heavy metals, some organic material, bacteria and viruses

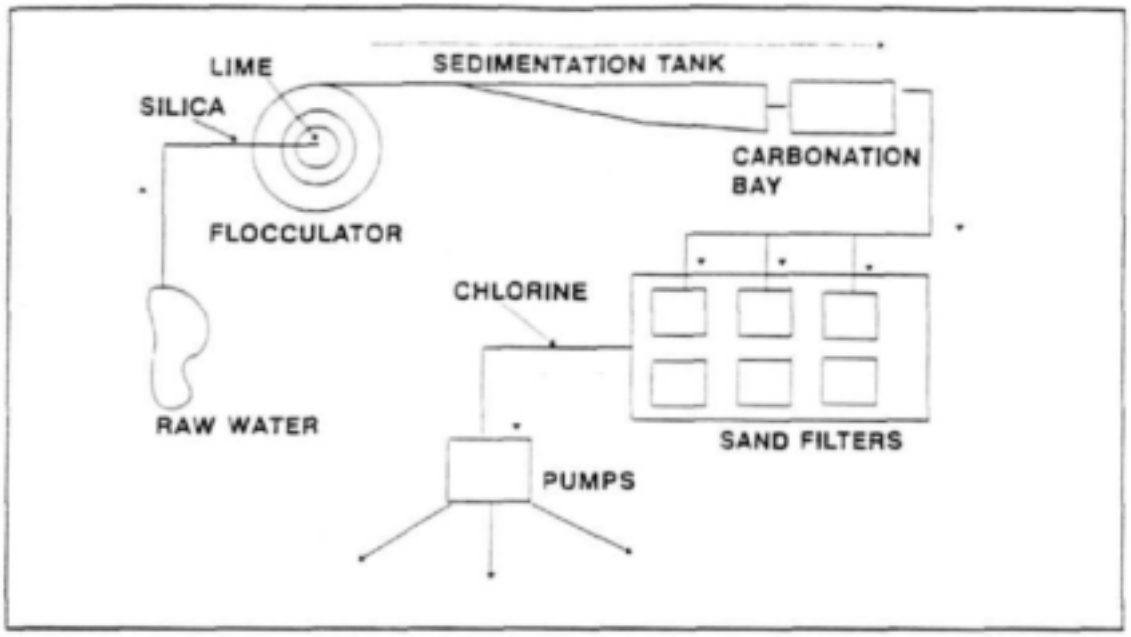

FIGURE 2.1: A diagram of a typical purification plant at Rand Water

Considering the various mechanisms which are involved during the destabilisation process with lime, rather low energy conditions are required for optimum coagulation. For lime a G value of 500 per second with a Camp Number (Gt value) of 18 000 is considered ideal in Rand Water's systems. For maximum efficiency, the lime should be added not more than 60 seconds before the point of maximum energy dissipation. The activated sodium silicate should be added prior to the lime, and it is now established practice in the Rand Water to add the silica about 15 seconds before the lime (see flocculator, Figure 2.1).

Rand Water has on occasion used high molecular weight cationic polymers as the primary coagulant. A high energy input is required to operate the systems at the optimum polyelectrolyte dosage which will prevent polyelectrolyte carry-over into the distribution system. Ideally, G values should be about 2500 per second and Gt values of 50 000. The use of polyelectrolytes appears very attractive in many ways as they are easy to handle, require less capital outlay and produce less settleable material which reduces the quantity of sludge to be removed in the sedimentation process. However, these coagulants have many disadvantages such as high dosages required for high turbidity water, flotation problems, manganese and iron deposition in the water supply pipelines and corrosion

problems. Experience has shown that the water produced by polyelectrolyte treatment is more corrosive and therefore inferior in quality to that produced using lime and activated silica. Polyelectrolytes are, therefore only used in a limited capacity.

2.3.1.2 Sedimentation

Sedimentation is the oldest known method of water purification and has been employed extensively for thousands of years. Although it is a natural phenomenon, it is aided by the addition of chemical coagulants to produce flocs which are allowed to settle in specially designed tanks from which settled sludge can be removed. Rand Water uses horizontal flow tanks (see sedimentation tank, Figure 2.1) with retention times of 4 hours and produces a water with a turbidity of 5 NTU at the outlet weirs which is considered acceptable for filtration. Some of the older purification plants have primary and secondary sedimentation tanks which increases the retention time for the sedimentation stage to 8 hours.

2.3.1.3 Stabilisation

The water after leaving the sedimentation systems has a pH value of about 10,5 and is very unstable and conductive to scale forming. To stabilise it, the pH is reduced with carbon dioxide (see carbonation bay, Figure 2.1) to a pre-determined value, normally between 8,0 and 8,4. The carbon dioxide used for stabilisation is not pure but a mixture of carbon dioxide and other furnace gases. The percentage of carbon dioxide in the lime kiln exhaust gases at the Zuikerbosch treatment plant is between 20 and 30 percent. At the Vereeniging works, the carbon dioxide obtained from the boiler flue gases has a concentration of between 8 and 12 percent.

If the concentration of carbon dioxide in the mixture is 20 percent and absorption efficiencies of 75 percent are achieved at the carbonation bays, then the volume of carbon dioxide : air mixture required for pH correction at ambient conditions is calculated as 22,5 m^3/minute per 100 Ml of water per day.

The carbonation bays are up to 3,0 metre deep and the carbon dioxide is transferred into the water through a series of PVC pipes, with 4,8 mm holes at the bottom of the pipes, under a positive pressure of 40 kPa. There are on average 13,3 holes per m^2. Absorption efficiencies vary between 70 and 80 percent.

2.3.1.4 Filtration

Rand Water uses rapid gravity sand filters (see sand filters, Figure 2.1) for the final removal of suspended material. The latest filters constructed have a fine sand layer 600

mm thick supported on a 500 mm gravel layer. Typical filter runs of between 48 and 120 hours are achieved depending on the quality of the water being filtered. The filters may be washed in any one of four instances; after a filter had been in operation for a set time; when the loss of head exceeds the preset limit; because of high turbidity in the filtrate or when filters is not producing the required volume of water. Washing of the filters is carried out by first using air to loosen the sand and then water at 32 m/h to wash away all the collected dirt. Filters are covered to exclude light to less than 25 lux to prevent algal growth on the filters. After filtration, the water normally has a residual turbidity of 0,3 - 0,5 NTU.

2.3.1.5 Primary Disinfection

The water leaving the purification works is disinfected with chlorine. The required concentration of chlorine is adjusted so that the number of bacterial colony forming units determined by the standard plate count technique after 48 hours incubation at 37°C, is less than 10 after 20 minutes contact with the chlorine. The low bacterial count will also ensure that minimal resuscitation occurs in the distribution system. Depending on the raw water quality chlorine dosage may vary between 1,5 and 4,0 mg/l to provide a free residual concentration of between 1 and 2,5 mg/l after 20 minutes contact. Pipelines in the distribution system serves as chlorine contact chambers.

2.3.1.6 Post disinfection or chloramination

Free available chlorine, although an excellent disinfectant, is consumed rapidly and may be depleted within 6 - 8 hours. To prevent bacterial aftergrowth post-disinfection is done with a bacteriostatic agent that will remain active for long periods so that the water may be protected against aftergrowth or contamination right up to the end consumer. This is achieved by dosing chlorine and ammonia at the booster pumping stations in the correct mass ratio of not less than 4:1 chlorine to ammonia as N, to form monochloramine *in situ*. The monochloramine, although less active than chlorine, will prevent bacterial regrowth for long periods.

The chlorine/ammonia dosing rates are aimed at maintaining a 0,5 to 1,0 mg/l monochloramine concentration in the water at the time it enters the municipal reticulation network.

2.3.1.7 Sludge disposal

The sludge settling in the sedimentation tanks is hydraulically scoured in the older systems and removed by pumps through a suction lift in the newer systems. The latter consists of a moving bridge spanning the sedimentation tanks with six pumps placed along its width.

each pump removing sludge at a rate of 900 l/min. Radio isotope sensors maintain the concentration of the sludge removed at between 5 and 8 percent while also determining the progress of the bridge along the length of the sedimentation tank.

The sludge consists mainly of calcium carbonate, magnesium hydroxide and complex silicates containing aluminium and iron. The total amount of sludge removed is a function of the raw water turbidity and varies between 500 - 1000 tons of dry solids per day. In the sludge thickening plant phase separation of the sludge is enhanced by the addition of between 0,6 and 1,0 kg per ton polyacrylamide which is dosed prior to passing through a static mixer. Thickened sludge at 16 to 20 per cent concentration is pumped to drying beds and the clear recovered supernatant is returned for treatment.

2.3.1.8 Additional treatment

In order to maintain the chlorophyll value in the final water to below 1 μg/l it is necessary to chlorinate the raw water when the chlorophyll values exceeds 30 μg/l. Lime addition might also be increased to reduce algal concentrations prior to sand filtration.

2.3.2 POINTS OF ENTRY FOR INVERTEBRATES

The presence of organisms in potable water may be due to penetration of unit processes or colonisation of the complete purification system. Penetration of invertebrates through treatment works are the usual method of initial entry into the distribution system. The types of animals which enter in this way are those that are aquatic for the whole or part of their life cycle. Service reservoirs may also be a point of entry for flying insects gaining access through badly protected vents and overflows (F C Viljoen - personal communication). Another possibility is submerged air valves where infested water may gain access under situations of reduced pressure in the pipes. The presence of organisms due to bad maintenance of infrastructure are most appropriately termed occurrences and are reliant on external recruitment. Animals which are aquatic for the whole of their life cycle, which enter the purification plant, colonise the distribution system and may be termed an infestation (English, 1958).

The midges (chironomids) which are an exceedingly complex family of about 3000 described species in the world, are masters in penetrating unit processes. The majority of chironomids cannot complete their life cycle in a water main, the adult midge being aerial. Chironomids adults (midges) are commonly seen flying in great numbers near water. Adult females lay a mass of eggs in the water. These eggs hatch into larvae that require from one to two months or more to reach pupation. The larvae go through four instar stages during which time their activity is restricted to the bottom sediment. The larvae are very small and transparent during the first 2 stages and are practically invisible to the unaided eye. Penetration of filters by eggs and larvae

occur and it is especially apparent in poorly maintained filters, containing large sand particles and cracks in the filter beds. Adults may also gain entry to unprotected filter basins and reservoirs and deposit eggs directly into the purified water. Ainsworth *et al.*, (1981) describes one chironomid specie which has been found in the distribution systems in south east England that is pathenogenic (females are able to produce without males). Another unusual feature of this specie is that eggs develop within the larvae and if emerging of the (normal) aerial adult is prevented, viable eggs are released. This specie can thus reproduce successfully in water mains. It is uncertain whether species with similar life cycles exist in South Africa.

2.3.3 REMOVAL OF INVERTEBRATES FROM RAW WATER

From the previous paragraphs it is evident that invertebrates may be present in potable water due to incorrect operation and maintenance of treatment units. Specific unit processes which have an impact on the number of organisms present in the potable water, will be discussed below.

2.3.3.1 Rotary strainers

Bellinger (1968) regarded rotary strainers as an important stage prior to slow sand filtration to remove invertebrates. Two examples of water works making use of these microstrainers are at the Dunkerton Springs source of Wessex Water Authority and also at Langford treatment works of the Essex Water Company.

At Dunkerton a rotary strainer of 140 μm aperture size was used. Fresh water "shrimps" as well as organisms as small as *Cyclops* were retained. Langford installed a strainer of 35 μm aperture size. Mainly Chironomidae larvae, Rotifera, and *Copepode naupli* were effectively removed. Only 60 - 70 percent Nematodes were retained.

2.3.3.2 Coagulation and sedimentation

Evins and Greaves (1979) monitoring potable water from several plants, found that coagulation and sedimentation alone are not effective in removing animals. In the case of the Staines works it was found that pre-chlorination improved the effectiveness in two instances. It was evident that in other plants, that the numbers of organisms of some species in the settled water were higher than in the raw water. Numbers of *Chironomus* larvae leaving sedimentation tanks were frequently higher, suggesting that adult midges multiply there. Benthic crustacea were generally seen to avoid sedimentation easily. Plantonic species like *Daphnia*, *Bosmina* and *Diaptomus* were much more effectively removed. Both planktonic and benthic *Cyclops* species were found in larger numbers in the settled water than in the raw water, suggesting breeding in the sedimentation tanks.

Bernhardt and Lüsse (1989) stated that in flocculation and filtration processes the removal of invertebrates is dependent on the shape, size and mobility of the individuals. Rotifers can escape from attaching flocs with the help of their rotatory organ. In order to optimize invertebrate removal (>90%), inactivation of these planktonic organisms is necessary. Chlorine, which could be undesirable because of the formation of organochlorides, ozone (1,5 - 2 mg/ℓ for 1 min), potassium permanganate (0,5 - 1 mg/ℓ for 15020 min) and the physical process of ultrasonic waves with a reaction time of a few seconds are all appropriate.

2.3.3.3 Filtration

This is the final solid-liquid phase separating stage in the purification process. The three main types of filtration (slow, pressure and rapid gravity filtration) facilitate invertebrate removal differently.

Studies done at Castle Carrock and also at Staines and Fobney (Evins and Greaves, 1979), on slow filtration, reflects that the animals found in the filtrate were the result of colonisation in the filter beds rather than animals passing through the filter. Penetration increased during the life of the filter. The pressure filters that were used in parallel to these slow filters at Castle Carrock were also not effective in removing the animals. Penetration recorded before backwash were 120 per cent and those direct after backwash 25 per cent. Colonisation was also evident in these filters. There were a variable removal of animals recorded with different flow rates. High flow rates caused cracks and channelling and therefore increased penetration, while low flow rates increases colonisation. Rapid gravity filters were reported to be the of filtration process most efficient for this purpose (Evins and Greaves, 1979). The filter media plays an important role in the removal of animals, although the source of the raw water are also considered to be an important factor (Evins and Greaves, 1979). In the rapid sand filters, sand of 0,5 mm up to 1 mm in diameter was being used resulting in an effective pore size of 100 μm up to 150 μm. The mean number of organisms found in the effluent of these rapid gravity filters prior to backwashing was 1,6 times higher than those found direct after backwashing. It is evident that there was an increase in the penetration during the life of the filter.

According to Bernhardt and Lüsse (1989), large and bulky organisms with large caudal appendages are better retained in the filter than small, compact forms of invertebrates.

2.3.4 POTABLE WATER QUALITY GUIDELINES

From the preceding information it is clear that it is desirable to supply water free of invertebrates

but this is highly unlikely to achieve. The question that needs to be answered is what is acceptable? Terms such as heavy infestation, sparse occurrences and large numbers are quoted. It is, however, not clear if the presence of these animals give rise to consumer complaints.

A complicating factor in establishing acceptable numbers is the diversity of species that may occur. One gordian (*Nematomorpha*) worm measuring 10 cm in length or one Chironomidae larvae 10 mm in length, is unacceptable and will result in consumer complaints. One hundred Nematodes (round worms) measuring 0,05 mm each, will not be detected by consumers, hence resulting in no consumer complaints.

Ainsworth *et al.*, (1981) found it convenient to record estimates of the abundance of each specie using the following log scale:

1 - 9	: +
10 - 99	: + +
100 - 999	: + + +
1000 - or more	: + + + +

This method of recording is used for 2,5 m^3 sample volumes which is then converted to organisms per m^3 of water. Evins and Greaves (1979) studied the penetration of filters by animals at fifteen different water treatment works in the United Kingdom. The mean number of invertebrates in the filtrate of the respective plants varied from nil to 240 organisms/m^3 of water with an average and median of respectively 25 and 4,5 organisms/m^3 animals. Studying the presence of animals in various filter outlets at both Rand Water's Vereeniging and Zuikerbosch works, the average and median numbers found were 19 and 3,2 organisms/m^3 respectively. Noteworthy is the low number 0,4 and 1,4 organisms/m^3, encountered in the Vereeniging No 3 and Zuikerbosch No 4 filterhouses. If this is achievable in new filters with the correct sand grading then it is indeed possible to reduce the number of animals in the potable water significantly.

In view of the fact that the animals encountered in Rand Water's water may have known health implications and in the absence of any standards in respect of invertebrates in potable water the following guidelines are used by Rand Water. This is based on the experience of Ainsworth *et al.* (1989) and studies conducted by Rand Water.

Recommended limit	20 organisms/m^3
Maximum permissible limit	50 organisms/m^3
Crisis limit	100 organism/m^3

The recommended limit set is considered the nominal water quality criteria which Rand Water will endeavour to meet at all times. Should the maximum be exceeded immediate and detailed investigations are necessary to remedy the situation. When the crisis limit is exceeded, the

treatment plant where the poor quality water is being produced must be isolated and remedial action be taken to rectify the problem.

The Netherlands (VEWIN, 1993), while excepting that invertebrates should not be present in such numbers that will cause aesthetic problems, formulated preliminary recommendations for different groups of organisms in potable water, produced from surface water. The recommendations vary from as low as 10 Chironomidae/m^3 (90 percentile leaving the purification plant) to as high as 500 Copepoda[1]/m^3 (maximum value in the distribution system).

2.4 AIMS OF THE STUDY

The information presented above clearly indicates major knowledge gaps regarding invertebrates and potable water. To address some of these aspects, this study will investigate the following:

2.4.1 The relationship between invertebrate population in filtered water and specific filter media properties.

2.4.2 The effect of invertebrates on water quality determinants such as biological assimilable organic carbon (AOC).

2.4.3 The effect of recycling filter backwash water on the occurrence of invertebrates in the water above filters and in filtered water.

It is envisaged that the following could be derived from the research:

i) Give an indication of the presence, type and effect of invertebrates on water quality in purified water.

ii) Results could be used to compile water quality guideline for invertebrates in South Africa.

iii) Indicate which water quality variables are effected by the presence of invertebrates in water and whether secondary problems can be expected i.e. increases in; AOC concentrations, turbidity and consumer complaints.

iv) Results can be used in the design and operation of filters and the specification for filter media i.e. procedures for optimal filter running times and backwashing procedures, selection of filter media, effect of recycled backwash water on the quality of filtrate.

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[1] "Nauplii and copepodieten"

3. MATERIALS AND ANALYTICAL METHODS

Several methods and experimental protocols were used to investigate the removal of invertebrates by rapid gravity sand filtration. In this chapter only the general analytical methods used throughout the project will be discussed. In Chapter 4 the specific procedure followed during each experiments were done, will be described prior to the results of the relevant experiment.

3.1 INVERTEBRATE SAMPLING

Evins and Greaves (1979) recommended the filtration of respectively 2,5 m^3 and 5 m^3 of sedimented and sand filtered water through a nylon net. During this study, the largest possible water volume was taken, varying from about 1 m^3 over a 24 hour period during the pilot plant studies to about 10 m^3 over a 40 min period during investigation on the full scale filters at the Vereeniging plant.

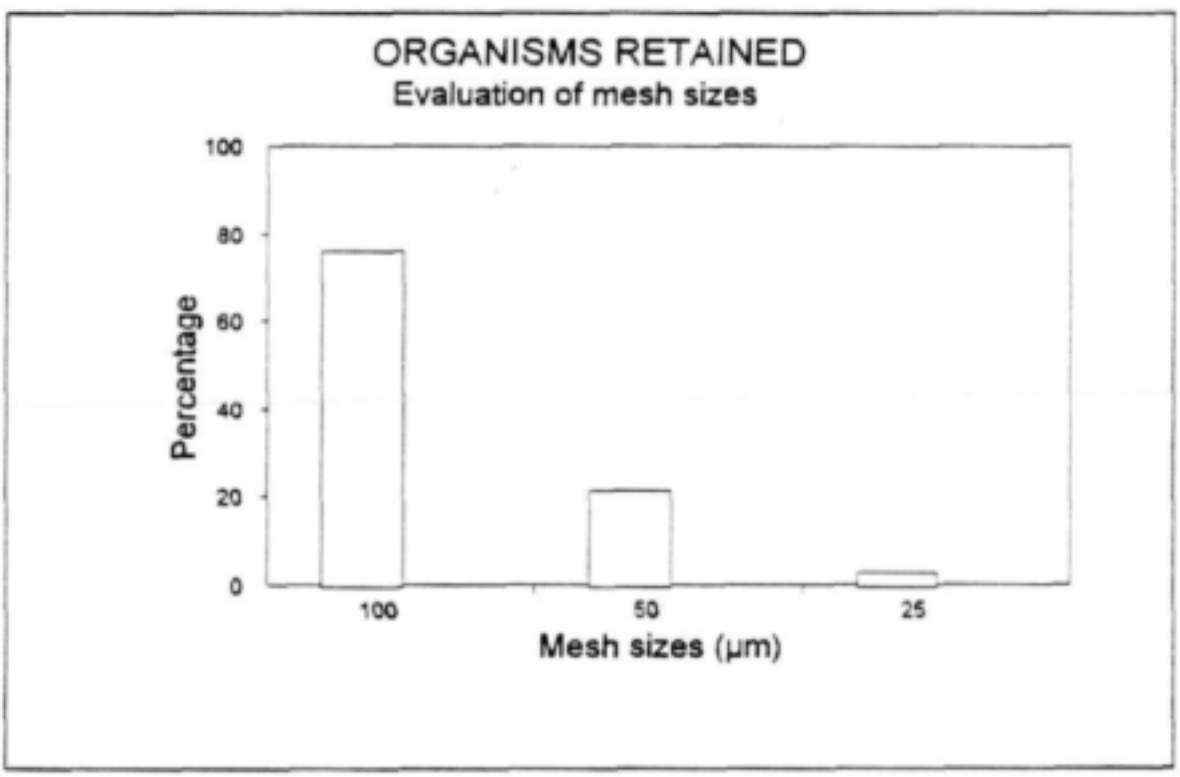


FIGURE 3.1 Invertebrates retained by each of the different nets expressed as a percentage of the total number of organisms retained by the three nets.

A critical issue was the aperture size of the nets used. Evins and Greaves (1979) used sizes varying from 84 µm to 142 µm while VEWIN (1993) used apertures varying from 30 µm to 100 µm. It was, therefore necessary to standardize on a specific aperture size should be determined for the purposes of this project.

Heavy duty nylon nets with aperture sizes of respectively 25 μm, 50 μm and 100 μm were fitted to the 100 mm outflow of the flow gauge used to record the volume during each run. The nets were fitted in series at 100 mm intervals with the 100 μm net closest to the flow gauge, followed by the 50 μm and the 25 μm nets. A total volume of 115 m^3 of sand filtered water (Filter 22 at Vereeniging) was filtered through the nets. The nets were then individually removed and placed into separate sample bottles for further analysis.

Figure 3.1 clearly indicates that the 100 μm aperture net retained about 75 per cent of the total organisms retained by the three nets. Of the 24 per cent of the invertebrates that penetrated through the 100 μm net, 21 per cent were retained by the 50 μm net and 3 per cent by the 25 μm net.

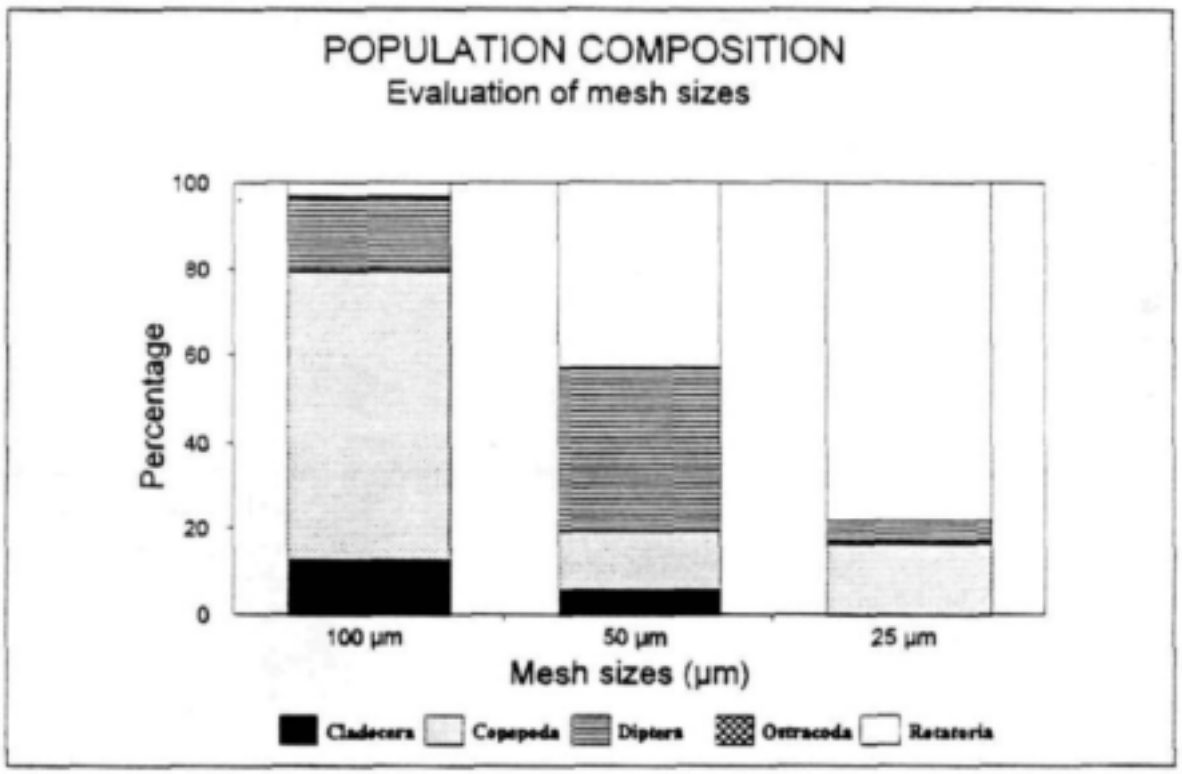


FIGURE 3.2 Population composition as a percentage of the invertebrates retained by the different nets.

Although 3 per cent of the invertebrates were retained by the 25 μm nets, 78 per cent of the invertebrates retained were Rotatoria. Figure 3.2 clearly indicates a difference in the population composition as a percentage of that retained by each net.

During the tests it was clear that the 25 μm net will clog up rapidly without the 50 μm net as prefilter. It was, therefore decided to use the 50 μm net because it will retain 97 per cent of the invertebrates bigger than 25 μm.

3.2 SAMPLE PREPARATION AND PRESERVATION

After a known volume of water had passed through the 50 μm nets, the nets were removed from the sample points or filtration apparatus, and placed into labelled plastic bottles, containing 100 mℓ of the water sampled. On arrival in the laboratory, invertebrates was removed from the net by flushing the contents of the net and the sample bottles by using distilled water, through a glass funnel, containing a 50 μm net in the neck of the funnel. The contents of this latter net was then washed into a 30 mℓ glass bottle and preserved with 70 per cent ethanol. Four drops of 0,4 per cent Rose Bengal solution was also added to colour the invertebrates, making them more visible.

3.3 ENUMERATION OF ORGANISMS

A 30 mℓ concentrated sample was emptied into a square plastic dish (120 mm x 120 mm). In some cases a standard plastic petridish (90 mm diameter) was used. To prevent distraction of the invertebrates in the counting chambers during counting, a mild detergent solution was placed in the chamber before counting. The Wild M5-stereo-microscope used for enumeration was also mounted on a movable arm, thus allowing the optics to be moved rather than the counting chamber.

All the organisms in the counting chamber were identified and counted according to the dominant groups occurring in the sample. Organism density was expressed as organisms/m^3 calculated by dividing the total count of the invertebrates by the total volume filtered during sampling.

Some of the raw water samples contained high number of organisms and a dense mixture of organic debris, that necessitated sub sampling (APHA, 1989). Statistical analysis of six sub samples, taken from the same sample indicated a coefficient variation of 1,73 per cent on an average of 1026 organisms/m^3.

3.4 TURBIDITY

The concentration of suspended material was measured by means of turbidity measurement (NTU) using a Hach Ratio Turbidity meter. Although other water quality variables such as pH and alkalinity were monitored for operational purposes, the results thereof will not be presented as it did not influence the number of organisms present in the filtrate.

4. RESULTS AND DISCUSSION

4.1 INVERTEBRATE MONITORING ON FULL SCALE FILTERS

From results obtained from Rand Water's routine monitoring of filter outlets, the filtrate of Filter 5 contained high invertebrate numbers while that of filter 113 contained relative low invertebrate numbers. Technical data of these two filters are presented in Table 4.1, the major difference being filter size, sand size, date of commissioning and backwash rate obtained.

TABLE 4.1 Physical Characteristics of Filter 5 and Filter 113 at Rand Water's Vereeniging Plant.

Characteristic	Filter 5	Filter 113
Commissioning date	1923	1992
Sand characteristics		
Effective sand size (D10)	1.2	0.63
Uniformity coefficient (D10/D60)	1.23	1.53
$CaCO_3$ - content (%)	80	0
Area Surface (m^2)	55	148.78
Filtration rate (m/h)		
Filtration calculated	-	3.5
Filtration nominal	-	4.0
Filtration maximum	-	6.0
Filter capacity (Ml/d)	-	12.5
Filter cleaning		
Filter air scouring (m/h)	-	27
Filter wash water (m/h)	10.44	32
Back wash rate required for present sand (m/h)	37.5	25
Type	Candy	Candy

The larger effective size of Filter 5 sand compared to that of Filter 113 may be attributed to "sand growing", a function of calcium carbonate precipitation onto the sand particles. This issue will receive further attention later on in this document. It also needs to be mentioned that Filter 113 is a fairly new filter (commissioned 1992) compared to Filter 5 which was build in 1923 and last renovated in 1982.

4.1.1 SAMPLING

Respectively 2,5 m^3 and 10 m^3 of water from the inlet to the filters and from the stationary water on the

filterbed (waterhead) was filtered through a 50 μm aperture net. Samples were prepared and enumerated as described in 3.2 and 3.3 respectively. Sampling took place from May 1994 to September 1994. Samples were also taken directly after commissioning the filter (0 hour) and then at 24 hour intervals up to 72 hours during filtration.

4.1.2 INVERTEBRATE NUMBERS

The invertebrate numbers recorded on different dates at 24 hour intervals at the inlet, in the water above the filter (waterhead) and in the filtrate are shown in Figure 4.1. The following comments need to be made.

a) Invertebrate numbers in the inflow (Figure 4.1A and B) did not show a general trend during a specific 72 hour period or over the several months when sampling took place. In some cases the invertebrate densities increased over the 72 hours (Figure 4.1A: 1994-05-23) or stayed the same for 48 hours and then decreased (Figure 4.1B: 1994-06-27). Comparing the densities in Filter 5 inflow with that of Filter 113 it would seem as if less invertebrates occur in the inflow to Filter 113. This may indicate more effective removal by the sedimentation process or less potential breeding spots for these insect in the new purification plant from which Filter 113 receive settled and recarbonated water for filtration.

b) Similar observations as above can be made regarding the water above the filter (waterhead). Higher numbers may occur in the waterhead compared to that in the inflow (compare Figure 4.1 A and C : 24 hours of 1994-07-04) or less may occur than in the inflow (compare Figure 4.1 B and D: 72 hours of 1994-06-27). A possible reason for this phenomenon is that the invertebrates may not be evenly spread through the water columns due to their motility and the downward velocity of the water. Sampling at different depths at different points may give more representative results.

c) Invertebrate numbers in the filtrate also vary during filter run time and over the months sampled. No distinctive trends could be detected. A graphical presentation of statistical information (Figure 4.2 A and B) of the invertebrate densities in the filtrates for the duration of the study, indicate a large variability in the density of organisms. It does, however seem as if the filtrate of Filter 113 (Figure 4.2B) contained less organisms/m^3 than that of Filter 5. This is in spite of similar percentage removal by both filters (compare Figure 4.3 A and B). The lower densities in Filter 113 filtrate may be due to lower number of organisms feed to the Filter 113 and the lower number of organisms in the waterhead of Filter 113 compared to that of Filter 5 (Compare Figure 4.1 A and B as well as Figures 4.1 C and D).

To identify factors influencing the removal of the invertebrates through rapid gravity sand filters, correlation between the percentage removal and filtration rate, filter run time and invertebrate density in the inflow were done. Only in the case of Filter 5 a significant correlation was observed between invertebrate density in the inflow and the percentage removal ($r = 0,65$; $n = 18$). No such a correlation or any other could be observed for Filter 113.

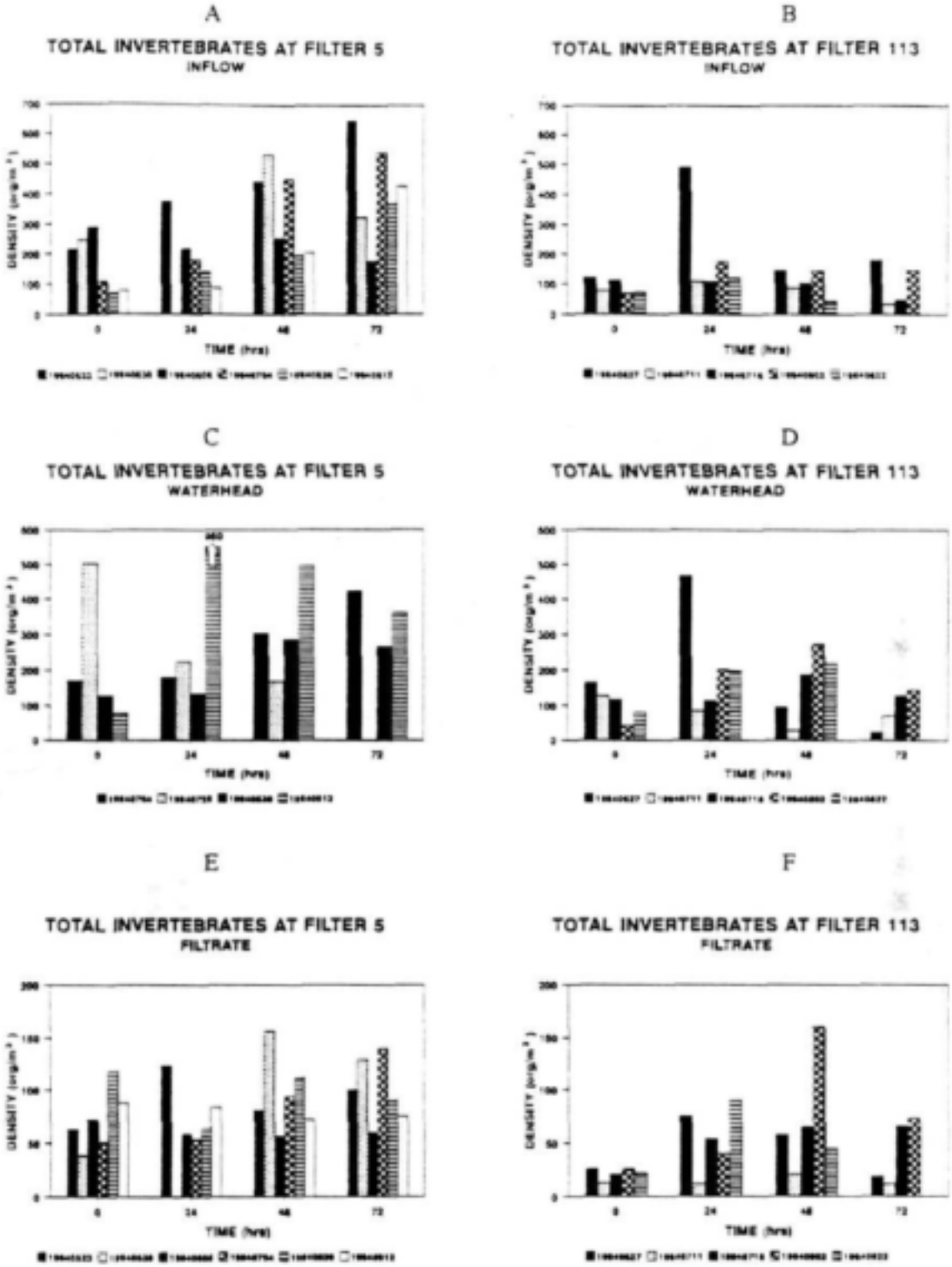
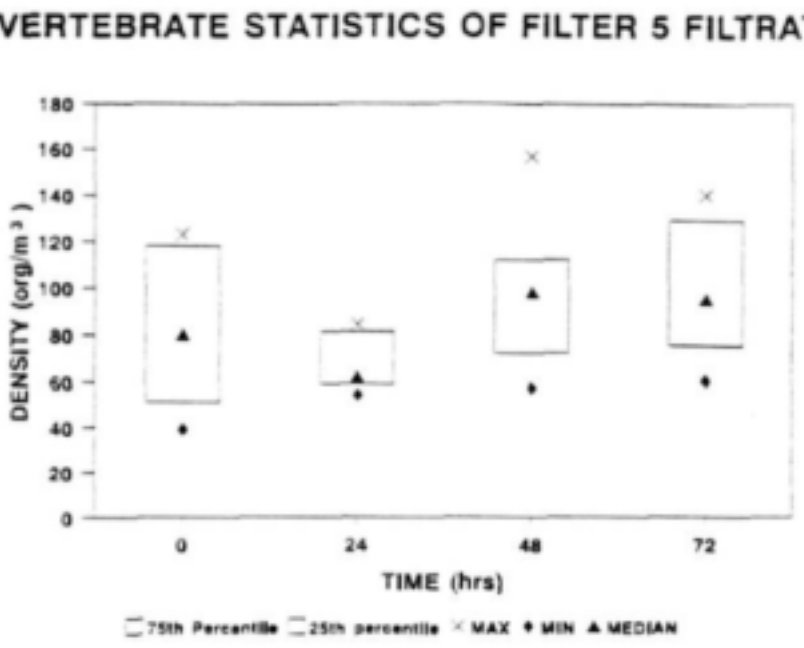


FIGURE 4.1 Total invertebrates (org/m^3) at different filter running times at the inflow (A), on top of the filter (waterhead; B) and in the filtrate (C) of the two filters studied

A



B

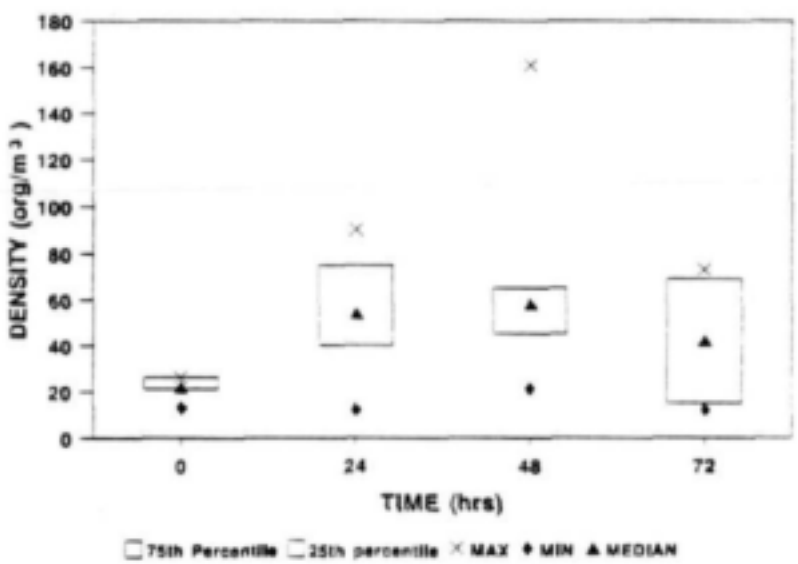
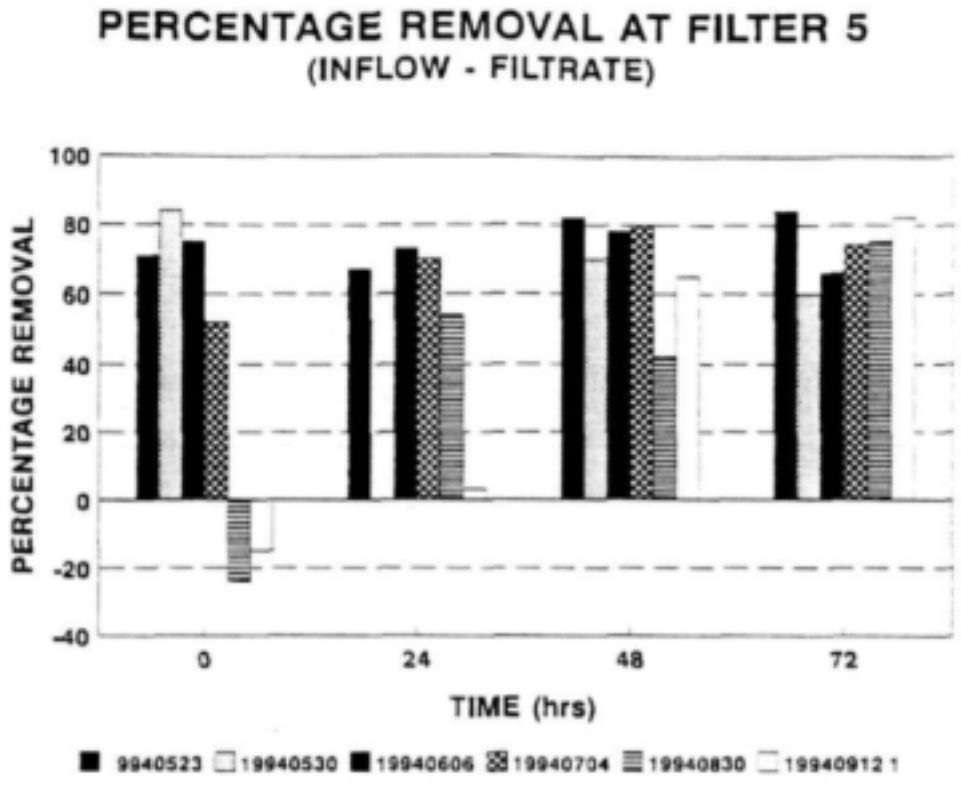


FIGURE 4.2 Graphical presentation of a statistical analysis of invertebrate numbers at specific filter hours in the filtrates of Filters 5 and 113.

A



B

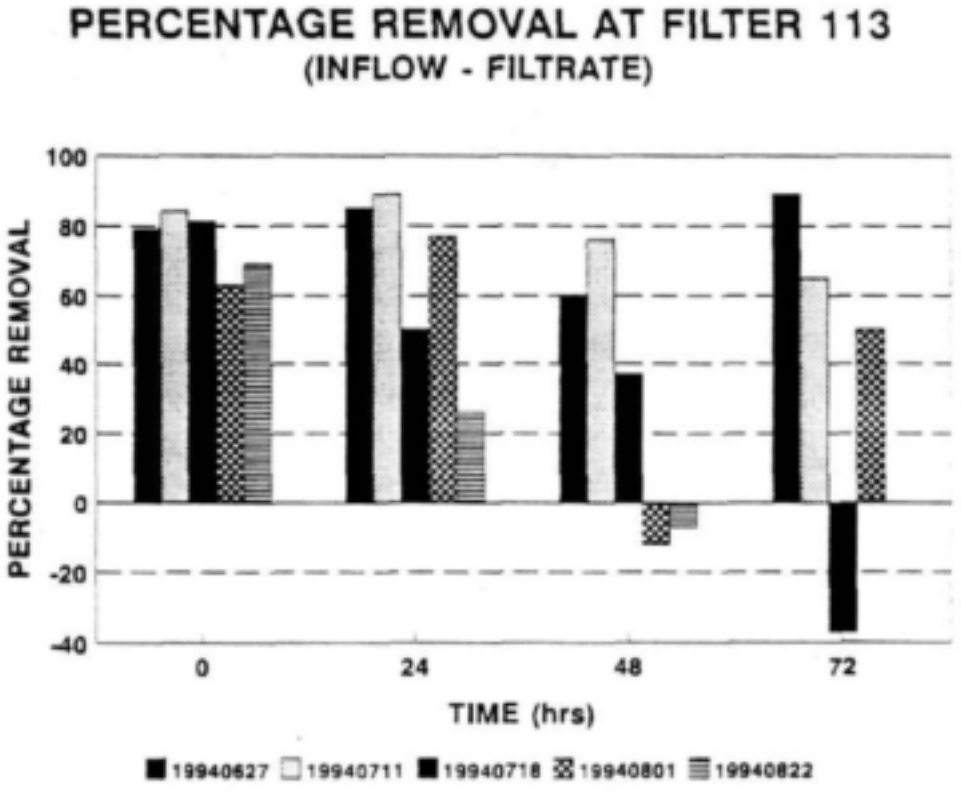


FIGURE 4.3 The percentage removal of invertebrates by Filters 5 and 113.

The lower number of organisms in the filtrate of Filter 113 compared to that in Filter 5 may be due to several other factors such as (Refer to Tables 4.1) :

- smaller effective sand size
- better uniformity coefficient and
- higher backwash rates achieved.

The significant lower organism numbers directly after backwash in the Filter 113 filtrate compared to that in Filter 5 filtrate confirms. The effective removal of invertebrates when the filterbed is fluidised during backwashing. This matter will be investigated during the pilot plant studies.

In random tests done on the number of invertebrates present in a composite backwash water sample of Filter 5 the number of organisms varied between 3820 and 8333 organisms/m^3. Before backwash 190 to 200 organisms/kg wet sand were detected, confirming that these organisms are retained by the sand. Further investigation regarding the relationship between organism numbers present in the sand prior to and after backwash, and in the backwash water needs to be done.

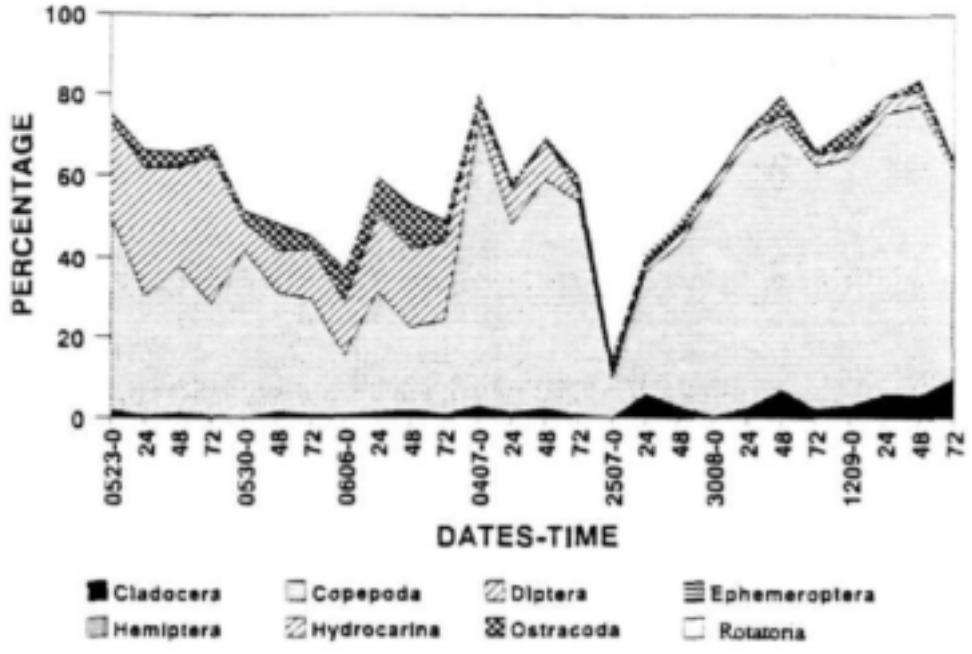
Although not experimentally investigated it can be assumed that recycling the backwash water to the raw water, just prior to coagulation can lead to organisms being retained within a closed system. This may explain the variation in invertebrate numbers at the inlet to the filters. This issue also needs further attention.

4.1.3 POPULATION COMPOSITION

Figure 4.4 clearly shows the filtrates of Filters 5 and 113 being dominated by the Copepoda and the Rotatoria. The Diptera, dominated by the Chironomidae (midged larvae) represented a larger portion of the invertebrate population of Filter 5 filtrate than that of Filter 113. It would also seem as if more Diptera was present in both filters filtrates prior to August 1994 compared to after August 1994. This may be due to the low temperatures experienced on site during June and July, resulting in low water temperatures (6°C compared to 17°C in May 1994).

In an attempt to determine wether a specific group of organisms dominate the inflow, the filtrate or were present in both the inflow and filtrate in equal numbers the number of times a specific group was present in higher numbers at a specific point was recorded and expressed as a percentage of the total number of observations. Table 4.2 indicate that the Diptera occurred for more than 50 per cent of the time in higher numbers in the filtrate than in the inflow to either filters.

A



B

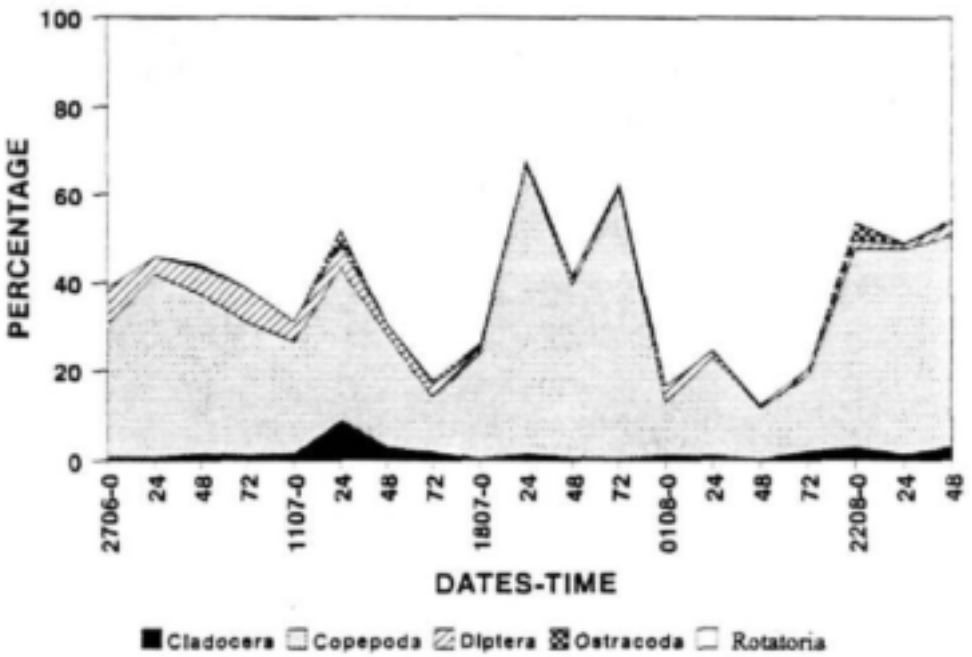


FIGURE 4.4 Population composition of invertebrates of the filtrate of Filters 5 and 113.

TABLE 4.2 **The number of times (percentage) invertebrate taxons were present in higher numbers at a specific sample point compared to the other sample points at a specific filter.**

Taxon	Filter 5			Filter 113		
	Filtrate	Inflow	Equal	Filtrate	Inflow	Equal
Cladocera	70	15	15	42	37	16
Copepoda	23	73	4	63	37	0
Diptera	54	42*	4	53	42*	5
Ostracoda	73	27	0	39	44	17
Rotatoria	42	39	19	32	58	10

This may indicate Diptera breeding in the filters. At Filter 5 the Cladocera and Ostracoda occurred more frequently in higher numbers in the filtrate than in the inflow, also indicating possible breeding in the filter. At Filter 113, Copepoda occurred more frequently in the filtrate in contrast to the frequent occurrence in the inflow of Filter 5. The only conclusion that can be made from this data is that the composition of the invertebrate population may change through the filter, indicating possible breeding of organisms above or in the filter, penetration of organisms or removal thereof.

The age of Copepoda, a dominant group in the filtrate, samples was also investigated counting young and adult life stages separately. Appendix A and B clearly show that the young life stages are not dominant at one sample point only. Observations, however indicated that Chironomidae, smaller than 2 mm are frequently observed in the filtrate. Large adults *Daphnia*-species did not occur in the filtrate but were frequently observed in the inflow and waterhead.

4.2 INVERTEBRATE MONITORING IN THE PILOT PLANT

4.2.1 GENERAL METHODS AND MATERIALS

This part of the study was aimed at defining criteria for filter media and operation of filters to achieve optimal removal of invertebrates. Six 200 mm diameter glass columns were used as experimental filters. One column was used as an inlet control contained no filter media. The remaining five columns contained 600 mm sand of different size, shape, density and chemical composition was used as filter media (Table 4.3). Each experimental filter was fitted with a filter nossle with 0,3 mm slots at the bottom of the filter. No other supporting media was used in the experimental filter.

The experimental filters were fed with water abstracted after sedimentation but prior to filtration from the filter inlet flume from station 2 at Vereeniging.

TABLE 4.3: SAND GRADING ON SIX DIFFERENT FILTER MEDIA DONE ACCORDING TO METHODS DESCRIBED BY CERONIO (1993)

Column	Density (Ps)	Equivalent diameter (deq)	Settling velocity Vt	Porosity ε	Sphericity Ø	Acid solubility %	Hydro-dynamic diameter dh	Fluidisation Vmf	Hazen effective size (d10)	Uniformity coefficient (d60/d10)
1	2,08 g/ml	1,55 mm	155 mm/s	36,7	0,552	>2	1,170	37,5	1,179	1,23
2	INLET CONTROL									
3	2,5	0,82 mm	115,2	41,2	0,503	0,176	0,669	25	0,629	1,53
4	2,5	0,86 mm	121,1	41,2	0,439	0,135	0,702	25	0,629	1,3
5	2,27	0,89 mm	97,2	35,2	0,520	0,254	0,628	-	0,706	1,4
6	2,38	0,91 mm	101,2	34,3	0,557	0,23	0,624	-	0,654	1,4

Column 1 = Carbonated sand 1,179 mm
Column 2 = Inlet control
Column 3 = Brits sand 0,629 mm
Column 4 = Brits sand 0,629 mm
Column 5 = Delmas sand 0,706 mm
Column 6 = Delmas sand 0,653 mm

Water was pumped into a storage tank from which water gravitated to the experimental filters. Flow to each individual filter was regulated with flow meters to obtain the flow required for the different experiments.

Each experimental run lasted 72 hours with sampling taking place at 24 hour intervals. Invertebrates were collected using the 50 μm mesh placed at the filter outlet pipe. These nets were removed every 24 hours. The volume of water was recorded and used to express the number of organisms per cubic metre. The samples were then prepared and invertebrates enumerated as described in 3.2 and 3.3.

At the same time the invertebrate nets were replaced, turbidity and headloss values were recorded.

The percentage removal by each sand filter was calculated by dividing the filtrate value by the value of the unfiltered sample from the control (column 2) and expressed as a percentage.

Initial tests indicated that each column is not receiving the same number of organisms. Inlets to each column were adjusted and compared to estimate the variance in the number of organisms in the inlet to the different columns (Table 4.4) and how that differs from that of the filter control (Column No. 2) containing no media (See Table 4.5).

TABLE 4.4 Variance in inlet water invertebrate counts of the different columns used.

Run No.	Invertebrates/m^3 in the inlet to Column No.						Statistics		
	1	2*	3	4	5	6	x	SD	CoV (%)
1	310	360	417	336	421	310	359	49,9	14
2	356	424	461	296	424	366	387	59,6	15

* = contain no filter media
x = Average
SD = Standard deviation of sample
CoV = Percentage variance between samples (SD/x) x 100)

From Table 4.4 it is evident that the variance in invertebrate numbers of the different inlets, is about 15 per cent. The difference between the counts of each column and the control filter (Column No. 2) is also in a similar range (except column 4 in run 2, See Table 4.5). This difference in organism numbers of each filter compared to that of the control filter is significantly larger than the two per cent variance as observed in the counting and sampling method (See section 3.3) and must be taken into account when filtration

results are evaluated.

TABLE 4.5 **Percentage difference of inlet invertebrate numbers relative.**

Run No.	Percentage difference of each column inlet to column 2 (Filter control)				
	1	3	4	5	6
1	-14	16	-7	17	-14
2	-16	9	-30	0	-14

4.2.2 EVALUATION OF DIFFERENT FILTER MEDIA

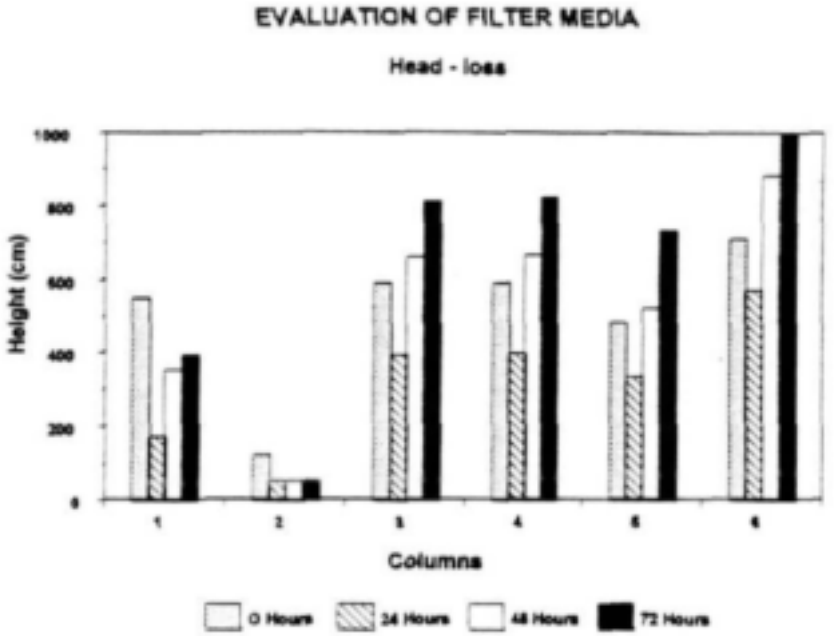
After several months of refinement to the technology to ensure that each filter receive the same water quality, it was possible to do two runs to evaluate the effect of different filter media (See Table 4.3) to remove invertebrates. Filtration rates were kept at 4 m/h (126 *l*/h) and corrected every 24 hours if necessary.

Headloss in the different columns at 24 hour intervals are shown in Figure 4.5A (run 1) and Figure 4.5B (run 2). From these figures the following is obvious.

- The increase in headloss within the first hour of commissioning is higher than the increase during the next 24 hours.

- Headloss increases after 24 hours in the filter containing coarse sand column (column 1; d10 = 1,18 mm) was about half that observed in columns 3 to 6, containing smaller sand particles (d10 = 0,629 mm to 0,706 mm).

A



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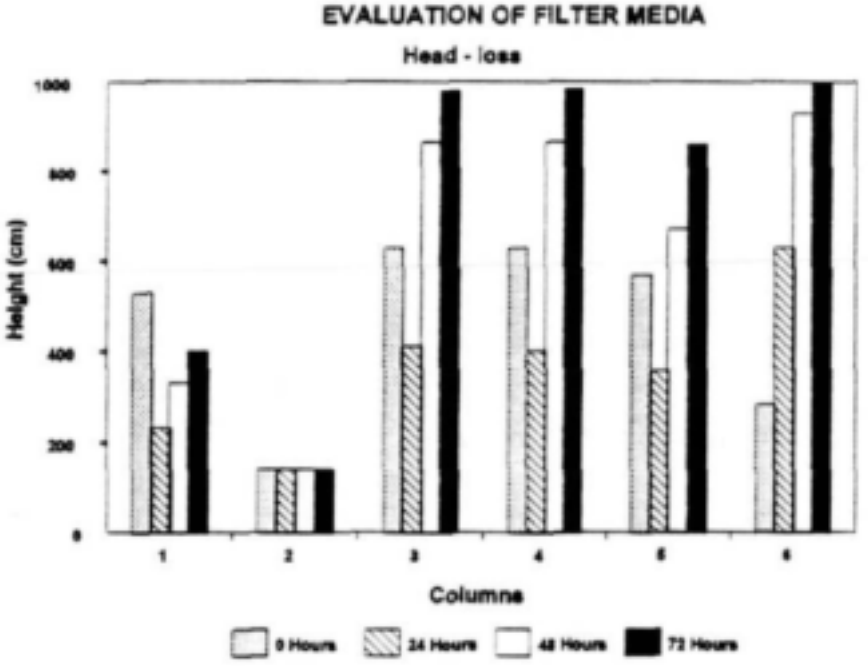
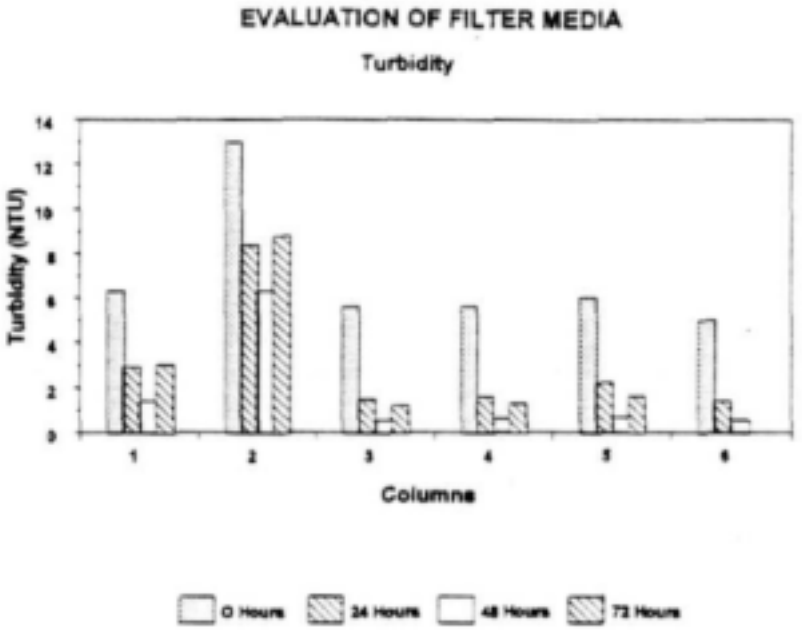


FIGURE 4.5 : Head - loss due to different filter media used during two runs (A = run 1; B = run 2) in the pilot plant study

A



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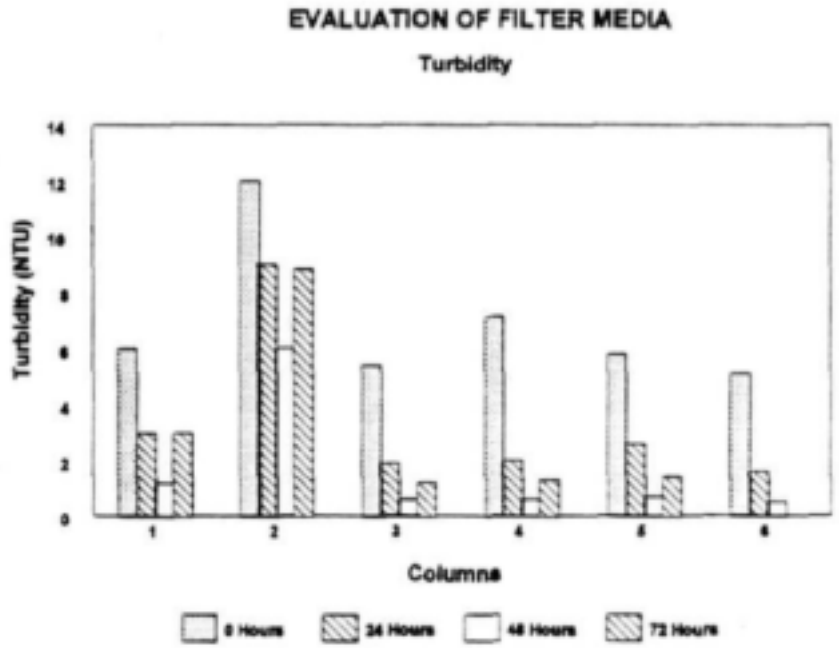


FIGURE 4.6 : Turbidity of the filtrate of different filter media used during two runs (A = run 1: B = run 2) in the pilot plant study

In both cases the headloss of column no 6 exceeded 1000 mm, resulting in a overflow of the column and termination of further monitoring of column 6.

In both runs the turbidities (Figure 4.6A and B) were the highest during the first hour of commission for the 72 hour period. That may be due to the high turbidity of the inlet water at time of commissioning which may be the result of resuspension of settled particles in the overhead tank and pipe network of the pilot plant. The lowest turbidities in the filtrate (< 1 NTU) were recorded after 48 hours running time. The filtrate turbidities increased again (> 1 NTU) at the 72 hour interval. This may not necessarily be a function of filter performance as the inlet turbidities showed the same tendencies (See Figure 4.6 A and B; column 2). The filtrate of the coarse sand filter (column 1) in both runs showed higher turbidities than columns 3 to 6 (smaller sand size).

Because samples bigger than 2,5 m^3 is recommended, samples for invertebrate analysis could only be taken 24, 48 and 72 hours after the filter runs were started. Figures 4.7A to 4.7 D indicate the following regarding invertebrate removal by the different filter media.

a) During both filter runs column 1, containing bigger sand particles, removed less organisms than the other columns. This is specifically evident during filter run 2 (Figure 4.7B) when its capability to remove invertebrates also decrease over the 72 hour period.

b) Columns 3, 4 and 5 showed the same removal efficiency during run 1 but column 5 removed less invertebrates during run 2 compared to columns 3 and 4.

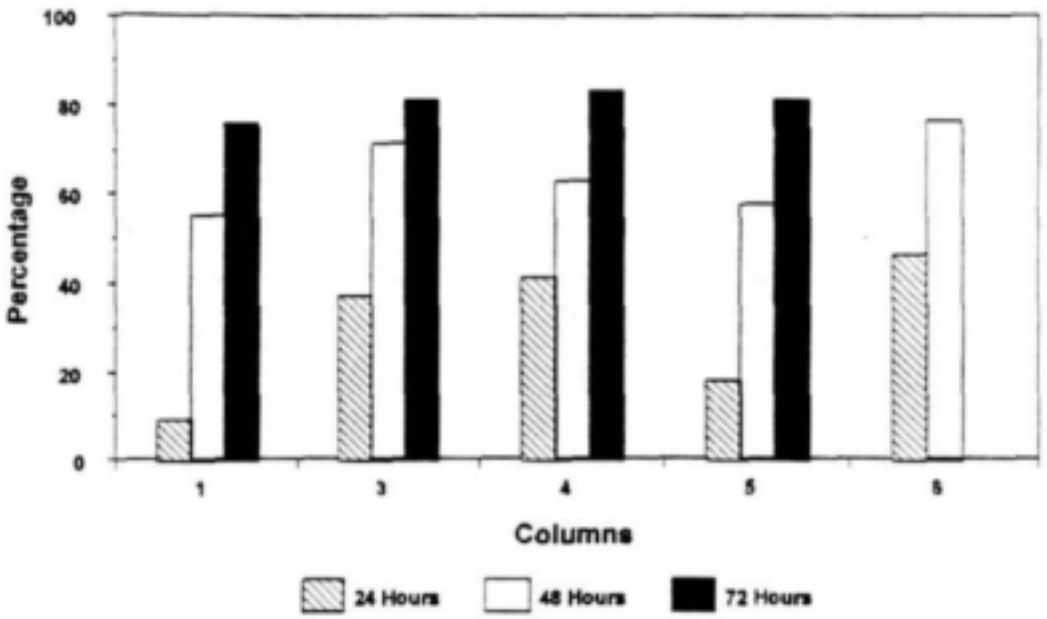
c) The number of organisms present in the filtrate were in excess of 200 org/m^3 which was for most of the time higher than that observed on the full scale filters (Compare Figures 4.7C and D with Figures 4.1 E and F). Turbidities in excess of 1 NTU (Figures 4.6A and B) where also observed when the number of invertebrates were high.

The difference in the removal of invertebrates between the two runs in the pilot plant could not be explained in terms of media characteristic, filtration rates, turbidities or headloss.

In an effort to explan the above results attention was given to proper cleaning of the filter . To investigate the latter, each column was disinfected by filling the filer columns with a 5 mg/ℓ chlorine solution for a period of two days. After two days the filters were backwashed properly for 10 minutes using potable water to fluidise the filter media. The effect of the proper preparation of the media on the removal of the organisms (Figures 4.8A to 4.8C) is evident when compared to the results obtained in run 2 (Figures 4.7A to 4.7B). From Figure 4.8A to 4.8C the following is evident:

a) The properly prepared media (Figures 4.8A to 4.8C) removed invertebrates significantly better through out the filter run, compared to the previous run 2 (Figures 4.7A and 4.7B).

A



B

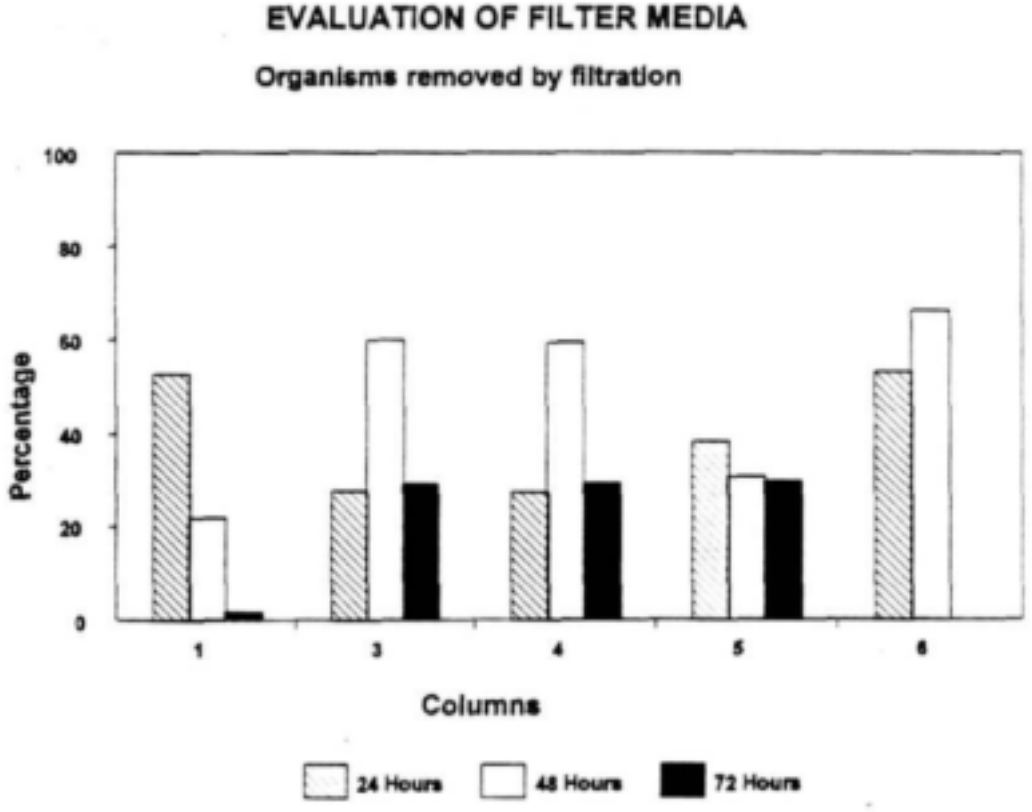
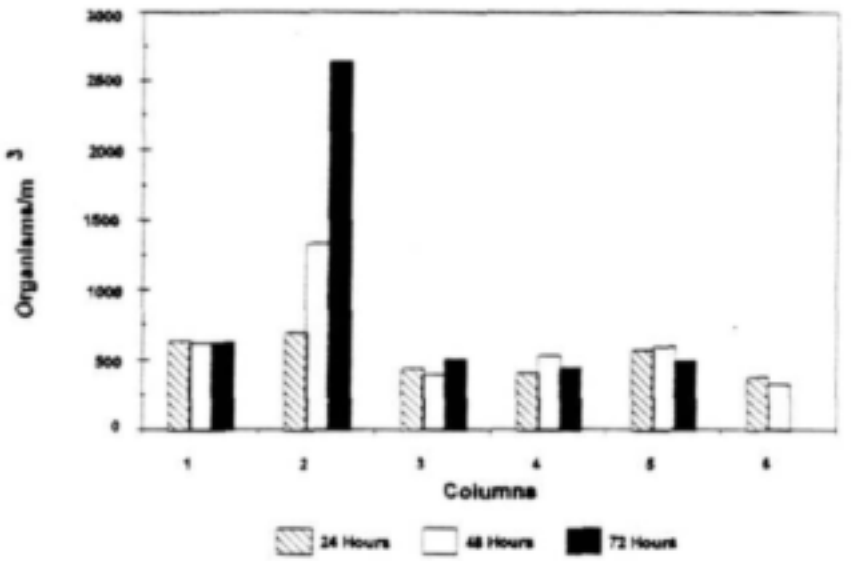


FIGURE 4.7(A & B) : Organisms removed (percentage) by different media used during two runs (A = run 1; B = run 2) in the pilot plant study.

C



D

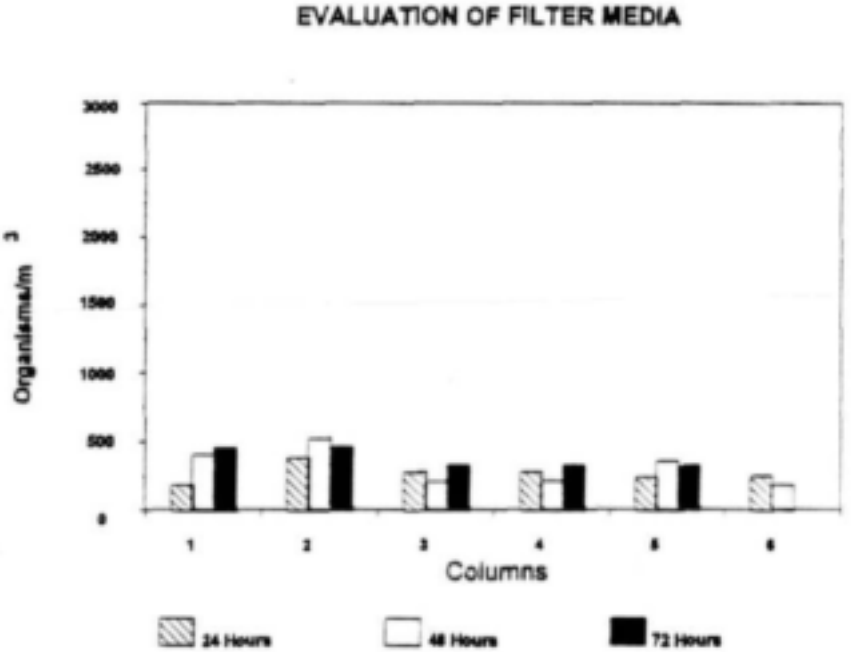
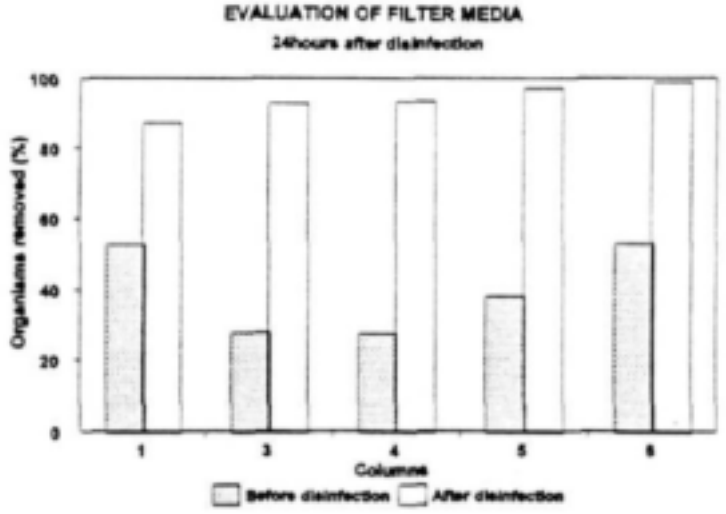
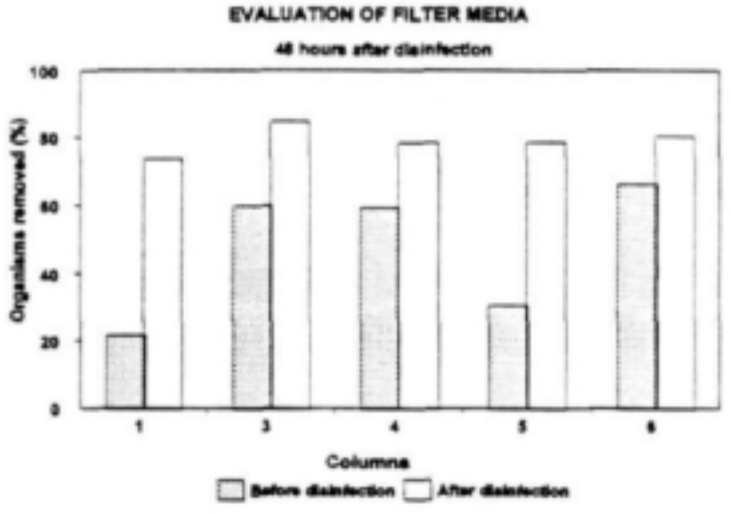


FIGURE 4.7 (C & D) : Organisms present in the filtrate of different filters containing different media during two runs (C = run 1; D = run 2) in the pilot plant study.

A



B



C

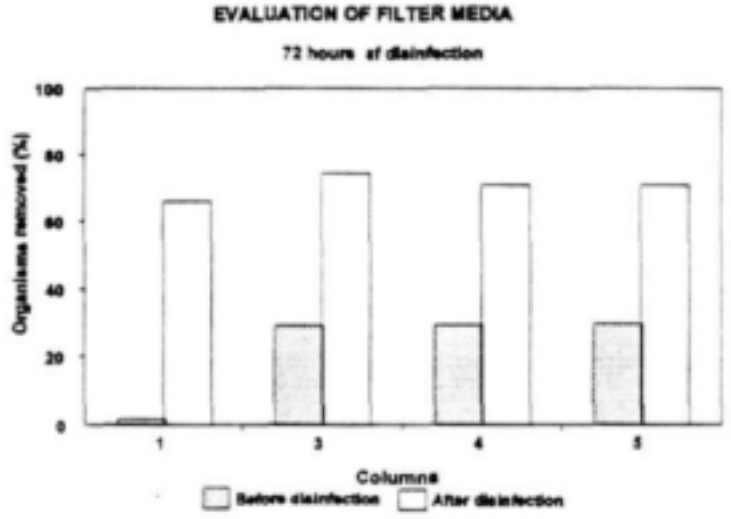


FIGURE 4.8 : Organisms removed (percentage) by different media, properly backwashed and disinfected

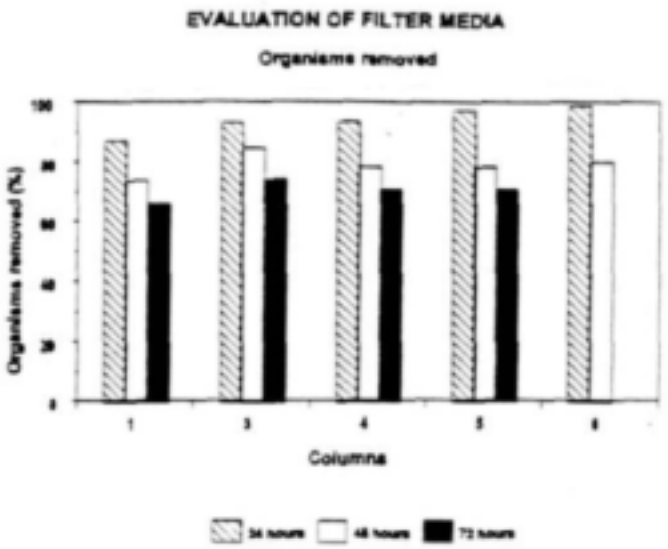


FIGURE 4.9 : Percentage organisms removed by different media during the fourth pilot plant run.

b) The decrease in removal efficiency is more linear in the properly treated media, compared to the inconsistent pattern over 72 hours of run 2.

These results strongly suggest that although large differences in the characteristics of filter media play an important role in the removal of invertebrates (Compare removal of column 1 with that of columns 3 to 6) a more important factor is the preparation and cleaning of filter media.

The improved removal of invertebrates, compared to runs 1 and 2 (Figures 4.7A and 4.7B) was confirmed during a fourth run (Figure 4.9). During this run invertebrate removal decreased with increasing filter running time similar to that observed in run 3 (Compare Figure 4.9 with the after disinfection bars in Figures 4.8A to 4.8C). These results, therefore confirmed that filter maintenance (disinfection and backwash) is of more importance than small differences in media characteristics to improve the removal of invertebrates.

4.2.3 THE INFLUENCE OF FILTRATION RATE ON THE REMOVAL OF INVERTEBRATES.

If filter maintenance (disinfection and backwash) is more important than characteristics of filter media to remove invertebrates, it may also be true that filter operation (filtration rate) may be important in removal of invertebrates. A low filtration rate may prove to be advantageous for breeding of some invertebrates inside the filter bed while a very high filtration rate may pull them through the filter.

Based on the results discussed up to now, it was decided to obtain media from Filter 5 and Filter 113, which differ in characteristics (See Table 4.1) and ability to remove invertebrates (See Figure 4.2). This step was not taken to see if results obtained in the full scale filter can be repeated in the pilot plant. The aim was to determine if vastly different media (differing notable and in their efficiency to remove invertebrate) can remove invertebrate with the same efficiency under the same operational conditions (filtration rates). Media obtained from Brits and Delmas, as used in columns 4 and 5 respectively, were also used for the same purpose. For this purpose columns in the pilot plant were set up as indicated in Table 4.6

TABLE 4.6 Filter media and column allocation for filtration rate set-up.

Media	Column Number
Filter 5	1
Filter 113	2
Inlet control	3
Brits 0,629 mm	4
Delmas 0,706 mm	5

Filtration rates selected were 3 m/h, 4 m/h and 5 m/h. Prior to this set of runs and between each filter run, the filters were disinfected and the filter media backwashed by fluidising for 10 minutes.

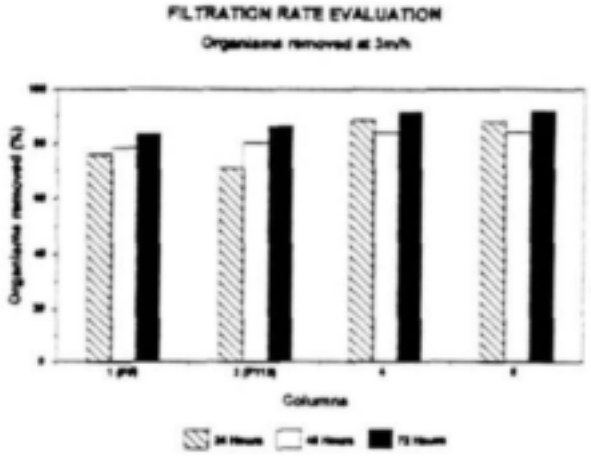
The percentage removal of invertebrates during each filtration rate run are displayed in Figures 4.10A to 4.10C. No results for invertebrate removal after 72 hours at a filtration rate of 5 m/h could be obtained, as the head-loss developed, was more than a meter, causing some of the columns to overflow. This experiment, therefore had to be terminated.

Only a small difference in the removal efficiency at the different filtration rates is visible, with that at 4 m/h run slightly better than that at 3 m/h and 5 m/h. The 5 m/h filtration rate may not only be unsuitable because of lower percentage removal of invertebrates, but also of possible other problems associated with a to high head-loss.

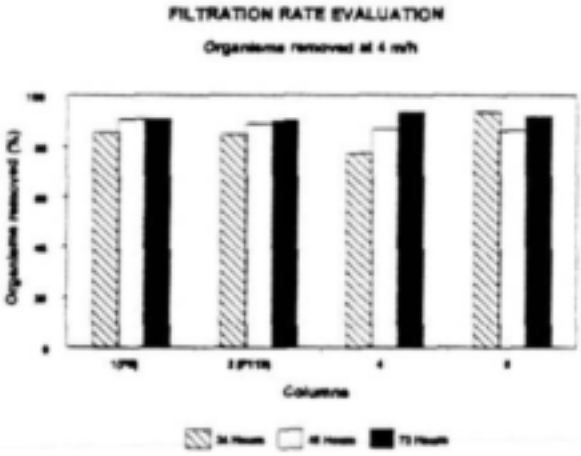
The filtration rate (3 m/h) may enhance breeding in or on top of the filter which may have resulted in the lower percentage removal at this filtration rate (Figure 4.10A) compared to the 4 m/h filtration rate (Figure 4.10B). This may specifically be true in the case of the coarser media obtained from Filter 5. Although the media of Filter 113 (column 2) and that of column 4 and 5 showed the same removal efficiency at 5 m/h (Figure 4.10C), a breakthrough of invertebrates was observed in the Filter 5 media after 48 hours. The latter may indicate that a high filtration rate through coarse media is not suitable to remove invertebrates for periods exceeding 48 hours.

The above information may, therefore suggest that of the three filtration rates investigated, the 4 m/h rate be the optimum rate to benefit long filter runs and ensure above 80 per cent removals.

A



B



C

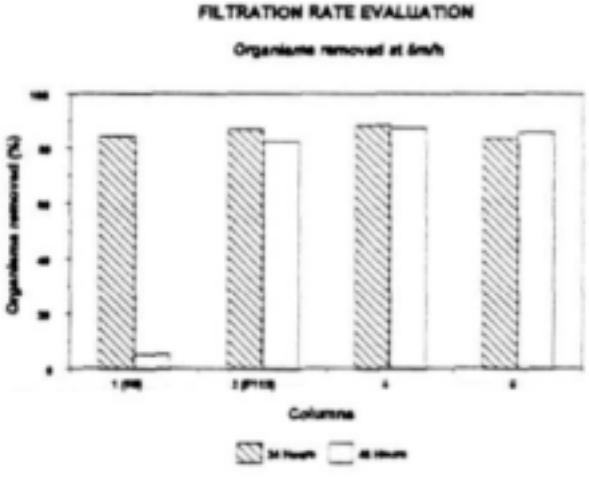


FIGURE 4.10 : **Percentage organisms removed by different media using different filtration rates (A = 3 m/h; B = 4 m/h; C = 5 m/h)**

4.2.4 THE INFLUENCE OF BACKWASH RATE ON THE EFFICIENCY OF FILTERS TO REMOVE INVERTEBRATES.

Results discussed in section 4.2.2 regarding the disinfection of filters and a proper backwashing indicated that removal of invertebrates from the filter bed before a filter run starts, is of utmost importance. It was, therefore decided to investigate the efficiency of three different backwash rates to remove invertebrates trapped in the sand.

For this purpose the fluidisation point of media obtained from Filter 5 and Filter 113 were determined. All six columns were filled with sand as indicated in Table 4.7, water filtered at 4 m/h but each column was backwashed at a specific backwash rate every 72 hours (See Table 4.7). The backwash rates were at suboptimal, optimal and above optimal rates.

TABLE 4.7 Column set-up for filters used in backwash rate experiments

Column	Sand from filter	Filtration rate (m/h)	Backwash Rate	
			m/h	% of optimum
1	5	4	30	80
2	113	4	20	80
3	5	4	37,5	100
4	113	4	25	100
5	5	4	52,5	140
6	113	4	35	140

Experiments in 4.2.3 also indicated that some of the depositated calcium carbonate on Filter 5 sand is removed. This may contribute to a reduction in effective sand size. For this purpose sand grading was done after each backwash on sand obtained from Filter 5. Three runs were done.

Figure 4.11A clearly indicates at least a 16 per cent decrease in the effective size of the sand particles from Filter 5 after the first backwash which was done at 80 per cent of the optimal backwash rate. Thereafter the effective size of the sand did not change significantly.

To enumerate organisms a inlet similar to that for each column was attached at the end of the inlet pipeline through which the same volume of water was released as for each column. The removal efficiency of each column was thus expressed in relation to this inlet sample. From Figures 4.12A to 4.12C the following can be observed.

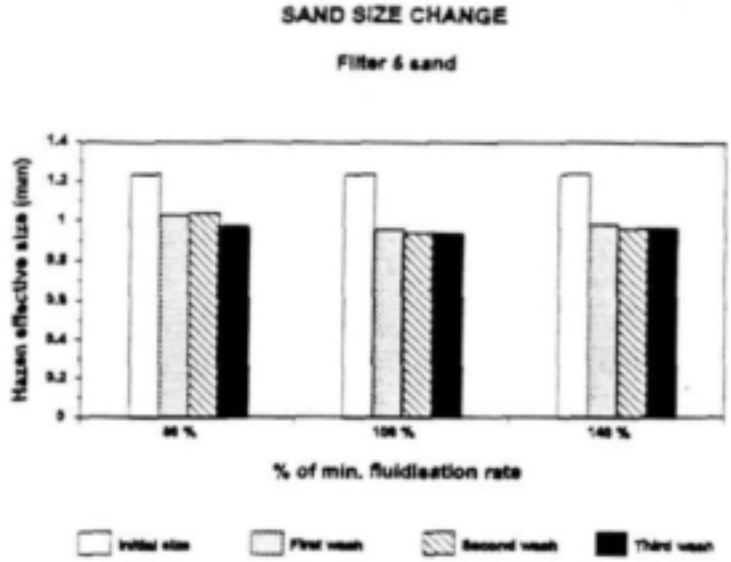


FIGURE 4.11 : Change in the effective size of calcified sand due to repeated backwashing at specific rates (percentage of fluidisation point)

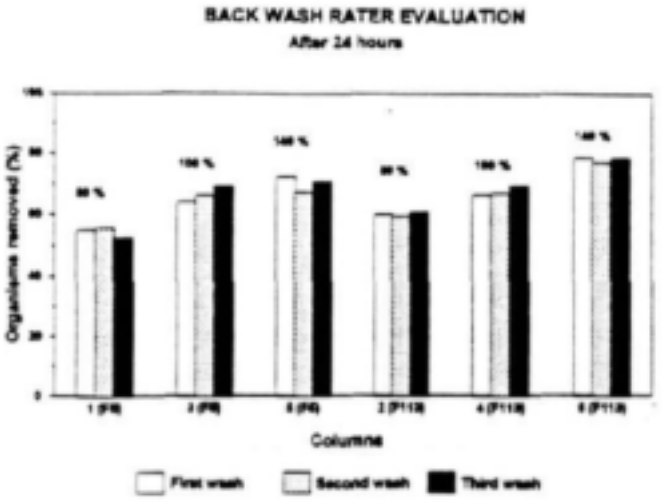
a. The smaller sand grains (Filter 113) only removed invertebrates a little better than coarser sand (Filter 5) at each backwash rate.

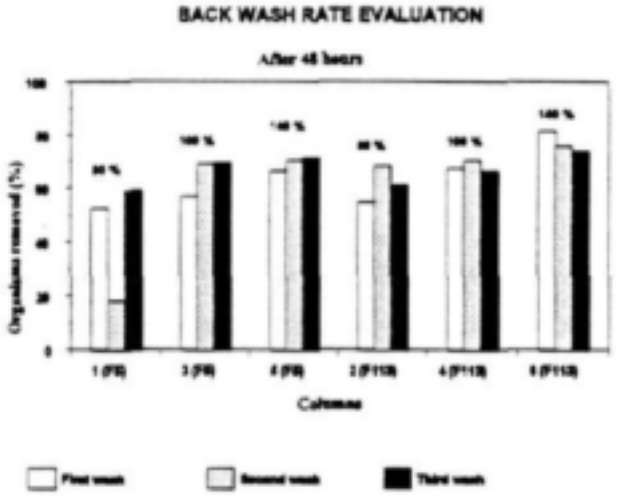
b. The percentage removal of organisms increase with increased backwash rates.

c. In most of the cases the difference in percentage removal in the three replicate runs for each column were small.

These results clearly indicate the importance of proper backwashing of a sand filter, irrespective of the sand particle size, to remove invertebrates. For effective cleaning of the filter bed, the fine sand grains in the bed should be fluidised. The backwash rate for fluidisation is *inter alia* a function of grain size. Larger grain sizes require higher backwash rates.

The grain size of Filter 5 is much larger (due to scaling) than that of Filter 113; therefore the difference in backwash rates (see Table 4.7). The results presented above indicate that the same removal efficiency for invertebrates is obtained if the backwash rates applied, result in the same degree of fluidisation. It is therefore important to ensure during the design stages of filter that the fine filter media can be fluidised under all circumstances so to guarantee efficient invertebrate removal.





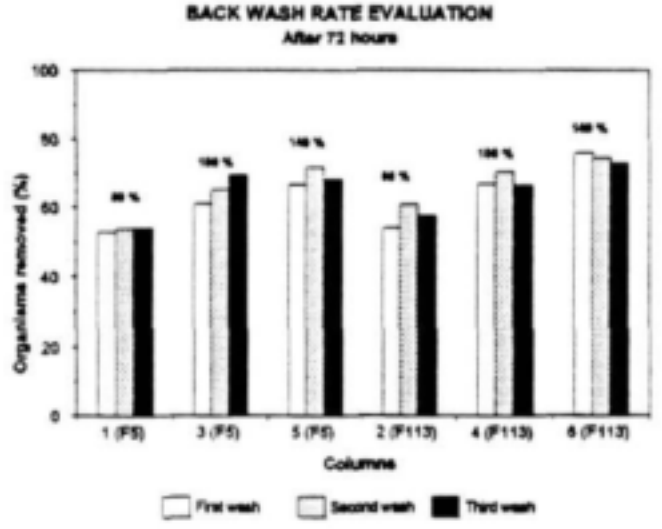


FIGURE 4.12 : Organisms removed by Filter 5 (F5) and Filter 113 (F113) sand at 24 hour intervals after back washing at 80, 100 and 140 per cent of the fluidisation point

4.2.5 POPULATION COMPOSITION

For every pilot plant run, the invertebrate population composition in the filtrates were calculated. The population composition of the runs did not differ significantly for the different sand sizes, filtration rates or backwash rates.

The composition of the invertebrate population in the filtrate of the different media in the columns of the pilot plant and during the different operational procedures indicated that the Rotatoria and Copepoda was dominant, with the presence of the Diptera easily notable. Figure 4.13 is a fear representation of the population composition of all the filter runs in the pilot plant. Managing the filtration process (maintenance and operation) does, therefore not seem feasible to prevent critical groups of organisms to penetrate the distribution system.

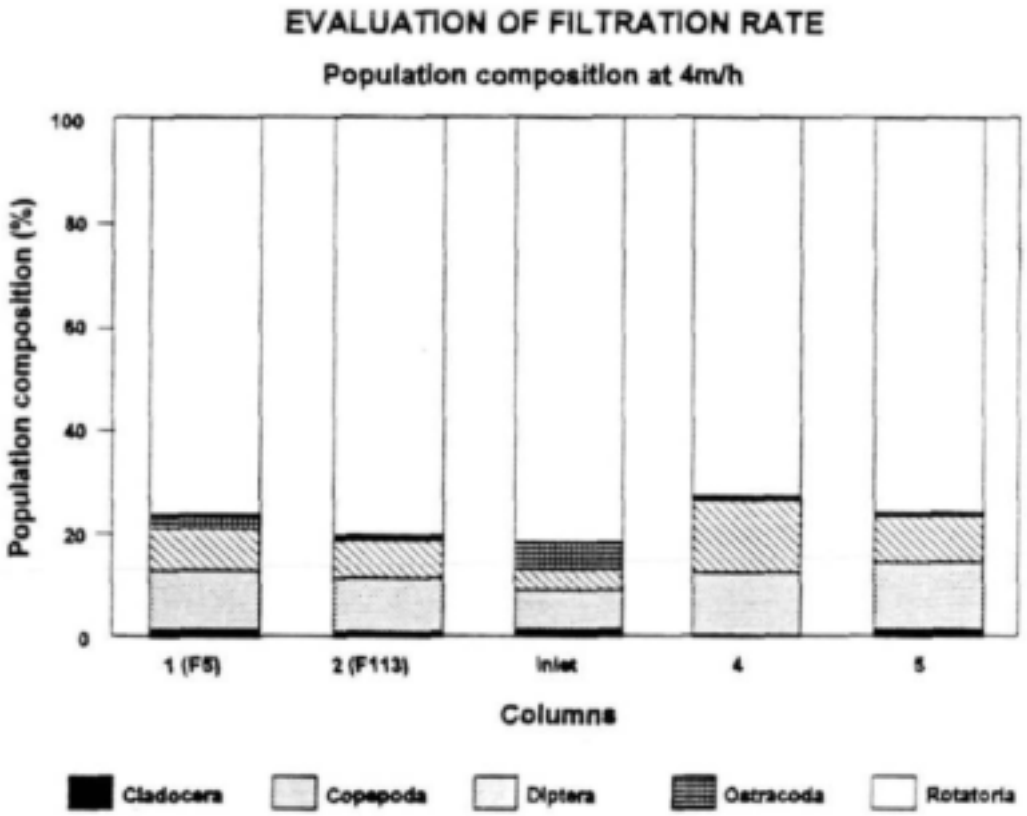


FIGURE 4.13 : **The invertebrate population composition of the filtrates of different media used in the pilot plant filters**

4.3 HEALTH RELATED ASPECTS

As mentioned in section 2.2 evidence exists regarding the associated health related aspects when invertebrates are present in potable water. It was, therefore decided to investigate these health related aspects by electron microscope studies and detailed microbiological analysis of filtered water.

4.3.1 ELECTRON MICROSCOPE EVALUATIONS

About 10 m^3 of water was filtered through a 50 μm mesh and the invertebrate sample concentrated as described in Chapter 3. Instead of preserving the sample in ethanol the concentrated invertebrates were preserved using Karnovski's preservative.

The samples were then taken to Naschem where further sample preparation scanning electron microscopy was done by Dr V L Hamilton-Attwell.

Electron microscope investigations done at 3000 times enlargement did not show the presence of any bacteria on the outer surfaces of the invertebrates. These results are contradictory to those presented by Levy (1986).

4.3.2 ISOLATION AND IDENTIFICATION OF BACTERIA FOUND INSIDE INVERTEBRATES

Samples containing concentrated organisms were rinsed three times with sterile distilled water through a 50 micron gauze and then backwashed with about five ml sterile distilled water into a tissue mill (grinder). From the pulverized suspension, dilutions were prepared and cultured on various bacteriological culture media. From these colonies, plates were made on R2A-agar, mFC-agar, Pseudomonas Isolation medium + CN supplement and Aeromonas medium (Ryan-medium). The incubation time was 24 hours. The mEndo-agar was incubated at 37 $\pm$ 1°C, the mFC-agar at 44,5 $\pm$ 0,5°C and the R2A-agar, Pseudomonas Isolation medium and Ryan medium at 28 $\pm$ 1°C.

From the isolation media, single colonies of each kind were separately streaked out on the same media to obtain pure cultures. From this purification step, media were inoculated for provisional identification. The following standard microbiological tests were done : Gram stain, catalase, oxidase, ONPG, indole and O/F reaction (MacFaddin, 1983 and Gerhardt *et al.*, 1981). The Aeromonas hydrophila medium (AH medium) was also inoculated.

Isolates that could not be placed into possible genera, were identified by means of API 20 E and 20 NE systems, supplied by Swift Micro Laboratories (Pty) Ltd.

4.3.2.1 Results

The micro-organisms isolated from the invertebrates, where they usually occur and their potential health risk for the consumer of potable water are given in Table 4.8. None of the organisms found can be considered to a high health risk for the consumer. A few of the organisms isolated are known to be opportunistic pathogens of humans. It is, however, evident that the invertebrates may contain some bacteria with a potential low risk to the consumer.

TABLE 4.8 Confirmed and identified micro-organisms isolated from invertebrates

Identified organisms or group of organisms	Natural habitat	Possible health risk for consumer
Aeromonas spp	Fresh water and sewage	Some species are pathogenic to frogs and fish
Possible *Pseudomonas* spp	Widely distributed in nature	Some species are pathogenic for humans, animals and plants
Possible *Acenetobacter* spp	Occur naturally in soil, water and sewage	Can cause nosocomial infections in humans
Pseudomonas pseudomallei	Isolated from human and animal cases of melodises and from soil and water in tropical regions, particularly Southeast Asia.	Probably a soil organism and potential pathogen, causing melodises.
Aeromonas salmonidica	Although these bacteria were isolated from natural water, their existence in river water is very short lived	It is a strict parasite (associated with salmon and trout) under natural conditions
Pseudomonas vesicularis	The type strain was isolated from a medicinal leech (Hirudo medicinalis). Other strains have been isolated from streams.	

Identified organisms or group of organisms	Natural habitat	Possible health risk for consumer
Hafnia alvei	Occurs not only in man, animals and birds, but also in natural environments such as soil, sewage and water. Also found in clinical specimens.	Seem to be **opportunistic pathogens** (Produce infections in patients with some underlying illness or predisposing factors)
Chryseomonas luteola spp	Is not found in the general environment but is primarily recovered as a saprophyte or commensal from human sources.	This **opportunistic** organism has been associated with prosthetic valve endocarditis, subdiaphragmatic abscess, postoperative infant septicemia, septicemia in patients with pancreatic abscess and granulomatous hepatitis, and peritonitis in patients undergoing continuous ambulatory peritoneal dialysis.
Sphingomonas paucimobilis	Isolated from water sources, plants, air, hospital equipment, pharmaceuticals, and human clinical specimens.	This opportunist has been implicated in **human infections** of community-acquired and nosocomial origins, including meningitis, urinary tract infection, peritonitis during ambulatory peritoneal dialysis, multiple skin granuloma, splenic abscess, empyema following orthotropic cardiac transplantation, postoperative and posttraumatic wound infections, and septicemia in patients with chronic leg and pulmonary embolism.

4.4 OTHER INVERTEBRATE RELATED WATER QUALITY ASPECTS

Not only do invertebrates harbour micro-organisms but they also may act as a food source for different micro-organisms after they have died and if present in specific numbers may not be aesthetically acceptable. It was, therefore decided to further investigate these two aspects.

4.4.1 INVERTEBRATES AS FOOD SOURCE FOR MICRO-ORGANISMS

Invertebrates killed during the purification process or in the distribution network, may act as a source of nutrients for different micro-organisms. To test the validity of such a statement, it was decided to determine the assimilable organic carbon (AOC) in invertebrate suspensions using the AOC analyzer and method as described by Link *et al.* (1992), with *Pseudomonas fluorescens* (P17).

As source of invertebrates, 80 m^3 of Filter 5 filtrate was filtered through a 50 μm mesh as described in Chapter 3. In the laboratory the invertebrates were split into two groups i.e. Group C containing all invertebrates except Diptera and Group D that only contained Diptera. Two sets of samples were taken i.e. on 31 August 1994 and 7 September 1994. The samples were concentrated on the same day, but the groups or organisms split, counted and resuspended into 3 x 10 $m\ell$ dechlorinated tap water, on the next day.

One of the 10 $m\ell$ samples was pulverised in a tissue mill and added to 400 $m\ell$ dechlorinated tap water. This solution was used to determine the AOC concentration. The other two 10 $m\ell$ samples were covered with a watch glass and kept in the dark at 25°C. At two week intervals these samples were collected and prepared for AOC analysis. The purpose of the standing time of the samples was to simulate possible die-off of invertebrates in a pipeline that may result in carbon compounds becoming available to bacteria only after a specific time period.

The numbers of the organisms used in the 400 $m\ell$ container used for the AOC analysis are shown in Table 4.9. It must be pointed out that the number sampling dates and dated on which samples were analysed of organisms present in the suspension was much higher than the numbers recorded during this project or on the full scale plant.

TABLE 4.9 Invertebrate numbers

Invertebrate group	DATES				Density (org/m^3)
	Sampled	Analysed			
1.1 Diptera only (D)	31-08-194	01-09-94	15-09-94	29-09-94	$9,5 \times 10^4$
1.2 Other (C)	"	"	"	"	$2,5 \times 10^5$
2.1 Diptera only(D)	07-09-94	08-09-94	22-09-94	11-10-94	$4,3 \times 10^4$
2.2 Other (C)	"	"	"	"	$2,2 \times 10^5$

4.4.2 RESULTS

The results as displayed in Table 4.10 indicate the following:

- Only in the first week of analyses did the Diptera samples show a lower growth rate (μ) than the sample containing all other invertebrates, indicating a more assimilable substrate present in higher quantities (f). This may be due to the lower number of organisms present in the Diptera group. Analysis on the same samples done after two weeks, not only indicate a lower growth rate (μ) and lower concentration of carbon sources available (f), but also that the AOC values of the two groups of differed slightly. The increase in the growth rate (μ) and substrate quantity (f) in both invertebrate groups in the 6th week of this experiment, may be due to a secondary carbon source becoming available due to continued microbial brake down of organic material.

- The lower μ and f values for the sample batch collected on 7 September 1994 may also be because of lower organism numbers compared to samples taken on the 31 August 1994, although this difference became less evident in the second and third analysis period.

Table 4.10 clearly indicate that organisms present at such high numbers are responsible for assimilable carbon in water. A comparison of the growth rate and growth factor of samples containing high numbers of invertebrates with that of the Vaal Dam and potable water, indicate the notable contribution invertebrates in high numbers can make to AOC (Table 4.11). It can be assumed that invertebrates present at densities less than 10^9 organisms/m^3 will have no visible contribution to AOC concentrations.

4.4.3 AESTHETIC PROBLEMS ASSOCIATED WITH INVERTEBRATES

The only aesthetic problem associated with the presence of invertebrates in water is whether they are visible by the naked eye. Only one red Chironomidae larvae, 10 mm long, 1 mm in diameter is enough to convince consumers that the water is not fit for use. On the other hand, 200 small Rotatoria or Cyclops per m^3 is not visible for the naked eye and will, therefore not be offensive to the consumer.

4.5 POTABLE WATER QUALITY STANDARDS

As mentioned in section 2.3.4 water guidelines for invertebrates by different organisations varies considerably despite the fact that the World Health Organisation states that potable water should not contain any living organisms (WHO, 1993).

From the information presented above, it is evident that a single organism (Chironomidae larvae) may be responsible for an aesthetic complaint, while many small transparent invertebrates may not even be visible to the consumer. It would also seem as if the invertebrates in the filtered water do not contain any harmful bacteria, but may contribute to the presence of opportunistic pathogens.

TABLE 4.10 Summary of the results obtained for the two different groups of invertebrates on their possible contribution to the assimilable organic compounds in drinking water.

	1		2	
	C	D	C	D
	01-09-94		08-09-94	
μ	0.4532	0.3137	0.2142	0.1453
f	18.06	5.44	23.43	8.21
DOC_o	3.2	2.5	4.8	4.0
DOC_t	4.0	3.5	3.4	3.4
DOC_s	-0.8	-1.0	1.4	0.6
	15-09-94		22-09-94	
μ	0.1339	0.1853	0.0832	0.0957
f	3.78	5.3	3.4	3.6
DOC_o	4.3	3.9	3.4	3.6
DOC_t	3.8	3.6	3.4	3.6
DOC_s	0.5	0.3	0	0
	28-09-94		11-10-94	
μ	0.1644	0.1584	0.2101	0.1664
f	7.96	6.35	9.11	5.3
DOC_o	3.7	3.4	3.7	4.0
DOC_t	3.7	3.7	4.1	3.8
DOC_s	0	-0.3	-0.4	0.2

μ (growth rate) is a parameter for the substrate quality - how available the substrate is for assimilation by bacteria.

f (growth factor) is an indication for substrate concentration.

DOC_o and DOC_t is the dissolved organic carbon content of the water sample respectively at the start and end of the experiment.

$DOC_s = DOC_o - DOC_t$: this value give an indication of how much of the DOC initially available in the water sample, is assimilable by bacteria and can give rise to regrowth/after growth in that water.

TABLE 4.11 A comparison of growth characteristics of bacteria in samples containing high number of invertebrates with that of other samples.

Sample	Growth Rate (μ)	Growth Factor (f)
Diptera only (D)	0,31 - 0,14	8,21 - 5,44
Other (C)	0,45 - 0,21	18,06 - 23,43
Vaal Dam water	0,20 - 0,07	8,39 - 3,21
Potable water	0,23 - 0,09	13,03 - 2,89

Taking all these factors into account it is obvious that a single series of guideline values applied for all invertebrates in potable water is to simplistic. The following approach in setting guidelines is proposed.

4.5.1 GUIDELINE FOR MACROSCOPIC INVERTEBRATES

Macroscopic invertebrates, like the midget (Chironomidae) larvae are responsible for most of the invertebrate related water quality complaints received in general. In setting guidelines for these organisms, Rand Water calculated the theoretical percentage of the water its supplies that people will drink. Calculations indicated that 0,7 per cent of the water Rand Water supplies may be directly used as potable water. Table 4.12 indicates the possibility of 1 organism/m^3 to be present in the two litres of water consumed per capita per day.

TABLE 4.12 The risk involved for invertebrates being noticed by consumers if present at in a specific number/m^3

Organisms/m^3	Risk (%)	Rand Water guideline
1	0,7	Recommended limit
4	2,8	Maximum permissable limit
7	4,8	Crisis limit
10	13,1	
100	50,5	
300	87,8	

Based on the information presented above, Rand Water has adjusted its guideline to that indicated in Table 4.12. Rand Water has also, based on experience gained from other invertebrate monitoring programmes, implemented a second invertebrate guideline which includes all the invertebrates, except the Diptera.

These limits are as follows:

Recommended limit	:	20 org/m^3
Maximum permissible limit	:	100 org/m^3
Crisis limit	:	250 org/m^3

The latter set of guidelines is based on the fact that this low number of organisms will not contribute significantly to AOC or a health risk in the potable water.

CHAPTER 5

CONCLUDING REMARKS

Potable water should be safe, palatable and aesthetically appealing. It should contain no chemical substances that is deleterious to health and be free of pathogenic organisms. Although invertebrates occurring in South African water are not known to be pathogenic, this study has clearly indicated that they may act as carriers for other potential pathogens. Different types of invertebrates present at different concentrations may be visible to the consumer, resulting in water quality complaints. It is, therefore of paramount importance that these organisms be removed by water purification plants. This study investigated the removal of invertebrates by rapid gravity filtration. The results of this study can be summarised as follows.

On the full scale purification plant at Vereeniging the removal of invertebrates through Filter 5 with old filter sand, was compared with that of new sand filter (Filter 113). Filter 5 is an example of a filter containing large sand particles (> 1 mm) which are not properly fluidised during backwashing. Filter 113 contains sand particles of less than 0,7 mm which are properly fluidised during backwashing. The following observations were made regarding the removal efficiency of invertebrates by the two filter's media.

- Water before filtration the at Filter 113 contained less invertebrates than the inlet to Filter 5. This may indicate that the sedimentation stage of the new purification system (the 1982 system) removed invertebrates more effectively than that of the old system.

- The numbers of organisms (org/m^3) in the filtrate of Filter 113 was less than that in the filtrate of Filter 5. If the removal efficiency is expressed in terms of the number of organisms in the inlet to the filter, the removal efficiency of Filter 113 was for most of the time only slightly better than that of Filter 5.

- The higher removal efficiency of Filter 113 may be due to the smaller effective sand sizes and better uniformity coefficient compared to that of Filter 5. More effective backwashing at Filter 113 compared to that at Filter 5 may also have contributed to the lower number of organisms present in the filtrate of Filter 113.

- No relationship could be found between the removal efficiency of the filters and the number of organisms in the filtrate.

- The invertebrate population was dominated by the Rotatoria. Midget larvae (Diptera) were present in higher numbers in the filtrate of Filter 5 compared to that of Filter 113, indicating possible breeding taking place in Filter 5. There was no notable difference in the age of the other invertebrate groups present in the inlet to or the filtrate of the filters. It was, however, obvious

that the larger organisms were retained more efficiently by the sand filters.

The above results initiated a pilot plant study that was aimed at defining sand characteristics, as well as filtration and backwash rates in relation to invertebrate removal. In spite of several technical problems experienced the following observations could be made.

- The efficiency of the pilot plant filters for turbidity removal was less than that of Filter 113. This may explain the higher number of organisms observed in the filtrate of the different pilot plant filters compared to that of Filter 5 and 113.

- Most of the pilot plant filters, containing sand with different characteristics removed invertebrates with the same efficiency. It was only the filter containing very coarse sand that showed lower percentage removal than the other sand filters.

- Proper disinfection of the filters and backwashing of filters at the fluidisation point resulted in improved removal of the invertebrates.

- The invertebrate population was also dominated by Rotatoria and Cyclops with the Diptera present in sufficient number.

The pilot plant study clearly indicated that the percentage removal of organisms can be improved significantly by proper backwashing and disinfection of the filter sand size less than 0,8 mm that should be sufficient to remove invertebrates.

Proper maintenance is the key to effective removal of invertebrates.

Based on the above information, a proposal regarding the setting of guidelines for the presence of invertebrates in potable water was made. Based on the chance of people detecting these organisms in a glass of water, smaller numbers of organisms are recommended for the larger and more visible organisms, compared to the small microscopic invertebrates of which more can be tolerated.

CHAPTER 6

RESEARCH NEEDS

This study was the first of its kind for South Africa and should only be regarded as a pilot study. Several questions is still not answered and would need further research. The following aspects have to be addressed are:

6.1 INVERTEBRATE POTABLE WATER GUIDELINE PROTOCOL

A protocol based on health and aesthetic aspects, risk analysis and efficiency of technology to remove invertebrates should be compiled to guide managers in setting water quality standard.

6.2 INTERACTION BETWEEN FILTRATION FORCES AND INVERTEBRATES

Results from this project suggest that certain invertebrates may breed inside the filter and that larger species do not penetrate. The relationship between this phenomenon and mechanisms of filtration needs further research (e.g. How do eggs attach themselves to sand, thereby resisting removal by backwashing?). This would also involve studying the depth of penetration of invertebrates and the eggs.

6.3 INVERTEBRATE REMOVAL AND RETURN OF FILTER BACKWASH WATER

This study has clearly indicated that proper backwashing contributes significantly to the efficiency with which invertebrates are removed. If the filter backwash water is returned to the purification system, at which point should it be introduced to prevent a build-up of these organisms in the plant? The optimum backwash rate and time need to be determined to ensure maximum removal of invertebrates with the minimum volume of water.

6.4 SAMPLING OF INVERTEBRATES ON AND IN FILTERS

A special sampling protocol have to be developed to quantify organisms in the water on top of the filter. Special sampling techniques have to be developed to quantify invertebrates retained by the sand filter. This could perhaps allow the calculation of invertebrate mass balance that could give more clarity of the interaction between invertebrates and sand filters.

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APPENDIX A: THE PERCENTAGE YOUNG *COPEPODA* IN SAMPLES TAKEN AT DIFFERENT TIMES AND SAMPLE POINTS OF FILTER 5.

Date	Hours	Inflow	Waterhead	Filtrate
4/7	0	42	44	51
	24	45	50	54
	48	54	56	61
	72	49	52	52
25/7	0	48	44	43
	24	41	52	41
	48	40	39	34
	72	-	-	-
30/8	0	42	40	51
	24	25	36	22
	48	39	22	0
	72	44	41	47
12/9	0	42	49	49
	24	33	16	60
	48	46	1	49
	72	48	33	68

APPENDIX B: THE PERCENTAGE YOUNG *COPEPODA* IN SAMPLES TAKEN AT DIFFERENT TIMES AND SAMPLE POINTS OF FILTER 113

Date	Hours	Inflow	Waterhead	Filtrate
27/6	0	48	67	69
	24	64	57	74
	48	76	62	75
	72	63	64	66
11/7	0	67	61	70
	24	75	71	44
	48	78	63	79
	72	46	58	54
18/7	0	68	62	80
	24	50	65	37
	48	58	36	45
	72	33	58	46
1/8	0	54	37	70
	24	66	57	76
	48	48	42	49
	72	55	46	53
22/8	0	60	53	48
	24	47	43	50
	48	72	37	58
	72			