Pilot Plant Studies on Slow-Sand-Filtration and Up-Flow-Roughing Filtration in Mozambique

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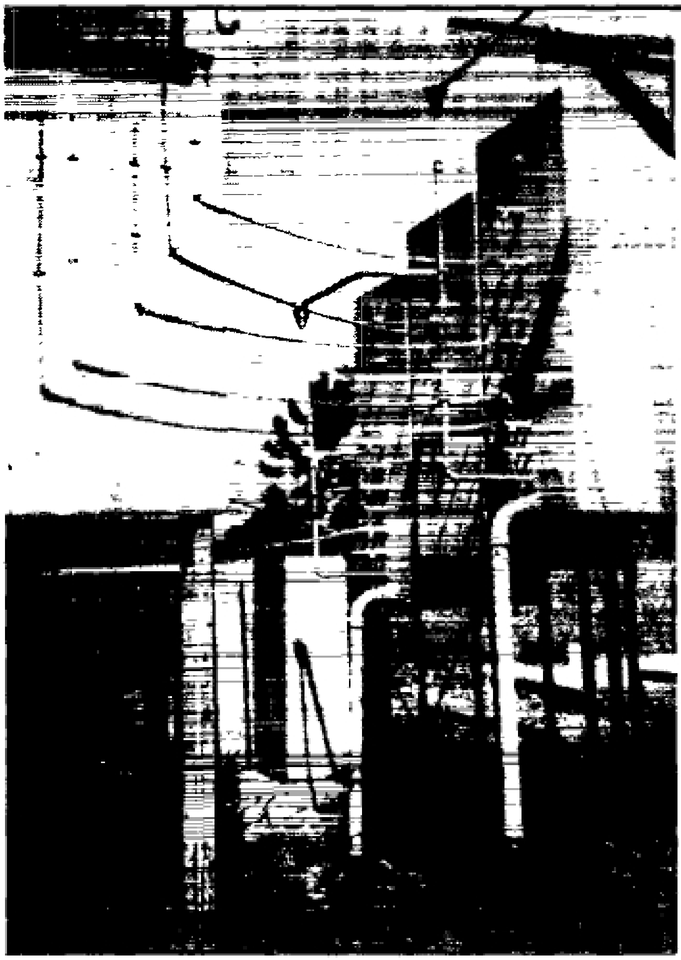

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PILOT PLANT STUDIES ON SLOW-SAND-FILTRATION AND UP-FLOW-ROUGHING-FILTRATION IN MOZAMBIQUE

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SUMMARY

In Mozambique there exists little knowledge concerning surface water treatment for drinking water. Although most of the existing problems are related to organization and operation rather than to technical matter, the chosen technology must be appropriate for local circumstances, which also take the human factor into account.
Therefore, in 1989 a research project was started to investigate the possibilities of the implementation of slow-sand-filtration with up-flow-roughing-filtration in Mozambique.
The main objectives of the research programme were:

- to demonstrate that slow-sand-filtration with up-flow-roughing-filtration can be a good alternative for treatment of surface water for small communities in Mozambique.
- to gain experience with the design process, construction, maintenance and operation of drinking water treatment plants.

These objectives were reached by literature review and by the construction and installation of a pilot plant.
The monitoring and operation of the pilot plant took place once or twice a week. The monitoring of the pilot plant was carried out by checking specific water quality parameters, the flow rates and the resistance of the filter-bed.
During the operation and installation of the pilot plant some difficulties were encountered, of which the following can be remarked:

- Interruptions in the pumping system and low pressure in the raw water main to which the raw water supply pipe was connected. The storage tank in practice did not function adequately due to its low capacity and trapped air in the supply pipe after interruption could extend the interruption period.
- Because a separate drainage system for cleaning the up-flow-roughing-filter units was made, the raw water inlet system was never flushed and therefore clogging occurred in the distribution system.
- Due to the high dirt content of the sand for the slow-sand-filter the sand was washed manually. In case of application of slow-sand-filtration at larger scale either other sand should be chosen or more attention should be paid to the washing process and alternative methods should be found.
- For cleaning the slow-sand-filter the supernatant water must be drained. However, due to the difference in permeability between the top layer and the rest of the filter-bed, retardation occurred with respect to the lowering of the water level. In the beginning this effect was not taken into account with the result that the rest water level dropped well below the recommended level.

From the monitoring data it can be concluded that with filtration rates of 0.5 m/h and the applied grain sizes of the gravel/crushed stone (coarse gravel: 3/4" - 1 1/2", medium gravel: 3/8" - 3/4", fine gravel: 3/16" - 3/8"), one multi-layer up-flow-roughing-filter of 1 m height has sufficient capacity for pre-treating raw water without high turbidity levels and will be

sufficiently flexible to receive higher turbidity loads (upto 100 NTU). In addition it can be concluded that, when dealing with raw water with high turbidity levels, an up-flow-roughing-filter filled with only coarse gravel will show signs of break-through of suspended matter after a month of operation. In the up-flow-roughing-filters with other configurations no significant decrease in the effluent water quality was observed during at least two months of operation.
During peak loads the removal of suspended solids (SS) by the up-flow-roughing-filters is percentage-wise significantly higher than the removal of turbidity, which indicates the removal of larger particles through sedimentation. With low turbidity and SS values in the raw water, the removal of SS is percentage-wise lower than the removal of turbidity. This may be due to the fact that in this period a major part of the solids are colloidal matter and thus predominantly other processes than sedimentation take place such as adsorption and biochemical activity.

Only after about 7 - 9 months of running the slow-sand-filter, the filter-bed succeeded in removing the majority of the turbidity and suspended solids. From that time the effluent quality was constantly good with turbidity values mostly below 1 NTU, even during relatively high influent turbidities (25 - 30 NTU).
The maturation of the filter has never been complete (due to the many interruptions of the raw water supply). Therefore, it is probable that the effluent water is not totally free from pathogenic organisms.
Acceleration of the maturation process could be achieved by starting-up the slow-sand-filter just before a period with high turbidity levels in the influent water, or by using artificial feeding material.
In order to achieve in practice total maturation of slow-sand-filters a constant flow through the filter should be guaranteed. Therefore, if a community depends on pumped raw water supply, a raw water reservoir should be included in the design.
If maturation is not complete post-chlorination of the effluent water should always be applied.
During the monitoring period, abundant algae growth was not observed. Nevertheless, it was noticed that the slow-sand-filter was rapidly clogged (after 1 month) mainly during the first period. This can be explained by the fact that relatively fine filter material had been used, d_e = 0.1 mm.

The project resulted in some fundamental discussions with DNA/PRONAR about the technological choice for surface water treatment, which are a basis for further development of strategies in this field.
After the experiments with the pilot plant, a design for the rehabilitation of a drinking water treatment plant was made, based on existing infrastructure. The proposal is to transform the sedimentation tank into an up-flow-roughing-filter and to improve the existing rapid-sand-filters.
In addition, in 1992 a research programme is started related to the performance of the compact surface water treatment plants, which are presently used for small community water supply.

RESUMO

Em Moçambique pouco conhecimento existe no concernente ao tratamento de águas de fontes superficias para o consumo doméstico. Embora a maior parte dos problemas existentes têm características organizativas e operacionais. Para além dos já conhecidos problemas técnicos, constata-se presentemente que as technologias aplicadas devem ser apropriadas às condições locais, incluido o factor humano. Por esta razão, iniciou-se em 1989 um projecto de investigação sobre a aplicação de filtração lenta com pré-filtração por arrastamento de fluxo ascendente.
Os principais objectivos do programa de investigação eram:

- demostrar que o tratamento de água de origem superficial, por filtração lenta com filtração por arrastamento, pode constituir uma alternativa atraente para a realidade Moçambicana, particularmente em pequenas comunidades..
- obter experiência em aspectos de dimensionamento, construção, operação e manutenção de instalações de tratamento de água superficial.

Para se alcançar estes objectivos, no estudo a realizar foram efectuados estudos bibliográficos e, posteriormente construida uma estação piloto. Após concluida, foram analisados alguns parâmatros de qualidade de água, a resistência do leito filtrante e os caudais a serem tratados. O controle e operação da estação piloto foi feito uma ou duas vezes por semana.
Durante a operação e instalação da estação piloto foram observadas algumas dificuldades, dos quais se citam:

- Paragens na bombagem e pressões baixas na conduta de água bruta a qual o tubo de alimentação de água foi ligado, provocavam frequentemente interupções na alimentação de água bruta à estação piloto. O reservatório na prática não funcionou adequadamente por razões de capacidade reduzida e ár incluso no tubo de alimentação o que podia aumentar o período de interupção ainda mais.
- Porque sistemas separados de drenagem foram aplicados para a limpeza dos pré-filtros por arrastamento, os tubos de alimentação de água bruta foram nunca limpos e portanto entupiram-se facilmente
- A areia utilizada para o filtro lento apresentava muito poeira, o que obrigou a uma lavagem manual da mesma. No caso de aplicação da filtração lenta em escala maior, recomenda-se a escolha de uma outra areia ou dar mais atenção à procura de soluções de lavagem mais eficientes.
- Durante o processo de limpeza do filtro lento, a água supernatante deve ser drenada. Porém, porque a permeabilidade da camada superior é naquele momento inferior à permeabilidade do resto do leito filtrante, verificou-se uma retardação no que respeita ao rebaixamento do nível de água. No início este efeito não foi tomado em conta o que resultou num rebaixamento excessivo do nível de água até a baixo do nível recomendado.

Dos dados tirados da instalação piloto pode-se concluir que um único pré-filtro com velocidades de filtração de 0.5 m/h, uma altura total de 1 m e de multi-camadas com diferentes granulometrias (brita grossa: 3/4" - 1 1/2", brita média: 3/8" -

3/4", brita fina: 3/16" - 3/8") pode suficientemente melhorar a qualidade de água do rio com teores de turvação não muito elevados e poderá ser suficientemente flexível para receber teores de turvação relativamente grandes (até 100 NTU). Em paralelo conclui-se que no caso de água bruta com altos teores de turvação, um pré-filtro de fluxo ascendente com uma única camada de brita grosseira apresenta sinais de deterioração do efluente após um mês de operação. Nos pré-filtros com outras configurações não se verificou deterioração do efluente durante um período de operação de pelo menos dois meses.
Durante períodos em que a água bruta tinha teores altos de turvação, nos pré-filtros de fluxo ascendente a remoção de sólidos suspensos (SS) era superior à remoção da turvação (em termos percentuais), o que significa que principalmente as partículas maiores são removidas por processos de sedimentação. Durante períodos em que os teores eram menores, a remoção de SS era em percentagens inferior à da turvação, o que implica que nestes casos processos como adsorpção e actividade bioquímica desempenham o seu papel na remoção de material coloidal.

Somente, após 7 - 9 meses de funcionamento, o leito filtrante do filtro lento conseguiu remover maior parte da turvação e sólidos suspensos. A partir desta altura a qualidade do efluente era constantemente boa, com teores de turvação na maioria dos casos inferior a 1 NTU, mesmo durante os períodos em que os teores de turvação no afluente eram relativamente altos (25 - 30 NTU).
Porém, é de notar que a maturação do filtro lento nunca foi completa daí que é provável que no efluente do filtro ainda se verificasse a presença de organismos patogénicos.
O processo de maturação poderia ser acelerado por arrancar o filtro num período com altos teores de turvação ou pela utilização de produtos de alimentação artificiais.
Na prática, para se conseguir a maturação total do filtro lento, um caudal constante de água bruta aos filtros deve ser garantido. Daí que um reservatório de água bruta deve ser incluido em projectos para comunidades que dependam de alimentação por bombagem.Enquanto a maturação não fôr completa, entá torna-se necessário a pós-cloração do efluente.
Durante o período de controle não se verificou um crescimento abundante de algas. Mesmo assim, notou-se uma colmatação rápida (após 1 mês) do filtro lento, principalmente durante os primeiros meses. Este fenómeno pode ser explicado pelo facto de que a areia escolhida para o filtro lento era muito fina (d_e = 0.1 mm).

O projecto resultou em algumas discussões fundamentais com a DNA/PRONAR sobre a escolha de tecnologias para o tratamento de água superficial, como base para o desenvolvimento de estratégias neste área. Como resultado, após os experimentos com a instalação piloto, fez-se um projecto para a reabilitação de uma estação de tratamento, baseado na infraestutura existente. A proposta apresentada foi a de transformar o tanque de sedimentação num pré-filtro por arrastamento de fluxo ascendente e o melhoramento do dimensionamento dos filtros rápidos existentes. Para além disso, começou-se em 1992 um programa de investigação relacionado com a eficiencia das estações compactas utilizadas actualmente para abastecimento de água em pequenas comunidades.

I INTRODUCTION

In Mozambique there exists little knowledge concerning surface water treatment for drinking water. Rehabilitation, installation, operation and maintenance of the existing treatment plants is carried out without the necessary capacity of anticipation in order to avoid irregularities, decrease operation costs, increase the treatment efficiency and maintain an acceptable effluent quality.
Although most of the existing problems are of an organizational and operational rather than of a technical character, the chosen technology must be appropriate for local circumstances, which also take the human factor into account.
In order to improve the knowledge about treatment processes, it is necessary to create conditions for technicians to experiment with certain parameters which are important for design, construction, operation and maintenance.
Therefore, in 1989 the Civil Engineering Department of the Engineering Faculty of the Eduardo Mondlane University, technically supported by the Sanitary Engineering Department of the Delft University of Technology, started a project on the possibilities of the implementation of slow-sand-filtration with roughing-filtration in Mozambique. The project was financially supported by the Dutch (DGIS) and Swedish (SAREC) Governments and consisted of a literature study phase (Jan/Feb 1989) and a pilot plant phase. The pilot plant was installed in May 1990 and monitored until April 1991.
For the present project a very old technology was chosen, which, with the recent developments in low-cost pre-treatment, can be very appropriate for drinking water treatment for small communities in developing countries.
However, "Because slow-sand-filtration is supposedly 'simple' it may not get the degree of attention it deserves in terms of design and operation. The design may be relegated to more junior staff with little input from senior, more experienced staff. As slow-sand-filtration can be operated by semi-skilled staff (again cited as an advantage of slow-sand-filtration) there is the danger these operators will suffer from lower status and reward and hence receive less training than their more skilled counterparts. In developing countries where resources are limited there is an obvious tendency to put more resources into the more 'difficult' and challenging projects with the result that they are often successful. The 'simple' projects conversely, often fail due to lack of resources. (..). slow-sand-filtration is in danger of falling into this category of 'simple', hence neglected technologies" (T.F. Ryan, (5)).
The purpose of the present research project is to deal with the mentioned danger and this report is a reflection of the activities within and results of that project.
In chapter 2 the context of the project is described, while in chapter 3 a descripton of the pilot plant and its functioning is given. The results obtained from the pilot plant studies are analyzed in chapter 4 and because the research project is part of a series of activities developed in the field of drinking water treatment, in chapter 5 follow-up activities and strategies are mentioned.

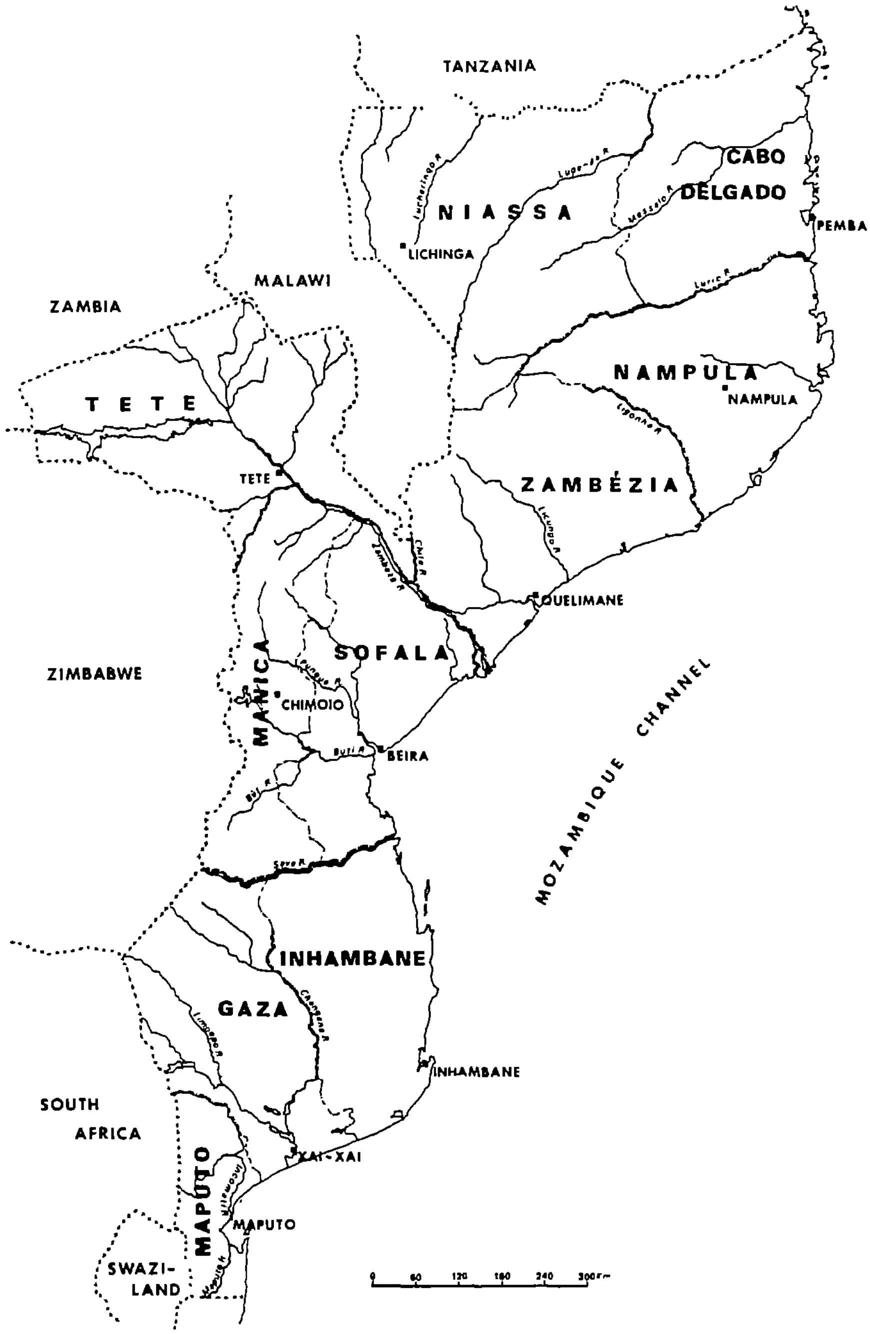

Figure 2.1 Map of Mozambique

II THE RESEARCH PROJECT

2.1 Present situation in surface water treatment in Mozambique

In the Mozambican drinking water practice, surface water is frequently used as a source. This water needs treatment before being distributed to the city or village. There are many different water treatment systems, but the most common is: coagulation/flocculation - sedimentation - filtration - chlorination.
At the moment most of the Mozambican cities and villages use rapid-sand-filtration as a basis for water treatment. In smaller communities compact treatment plants based on pressure filters are being installed. The plants usually do not function very well, due to lack of skilled personnel and chemical products for operation and equipment for maintenance and repairs.
The pre-treatment process is conventionally done by coagulation-flocculation and sedimentation. This type of pre-treatment needs a considerable input of chemicals, which, for developing countries is not very suitable.

2.2 Approach of surface water treatment research

Most of the surface water treatment systems in Mozambique date from before Mozambican Independence from Portuguese colonialism. Before Independence, the systems were designed, constructed and operated by Portuguese engineers, who subsequentely left the country. Since then the systems have been run by Mozambican operators, who had their training on-the-job without having a theoretical background.
Most of the systems fell into disrepair during the eighties. In 1987 the National Directorate for Water Affairs (DNA) started an identification programme aimed at finding the origins of the problems. The Civil Engineering Department of the Eduardo Mondlane University (EMU) was linked to that programme via technical visits which were executed by the staff and students. The identification resulted in an inventory of constraints which hampered the performance of the treatment plants. Apart from financial, organizational and operational problems, the systems seemed to be not always technically appropriate for local circumstances. Although in the larger cities (>100.000 inhabitants) the problems already occur (only the city of Maputo has a well functioning treatment plant), it is obvious that in small communities the constraints will be more serious and therefore ask for a different approach.

Before coming to a national strategy for the improvement of the water treatment systems in small communities some research needed to be carried out first. The research was carried out by the Civil Engineering Department of the Eduardo Mondlane University in close cooperation with the National Program for Rural Water supply (PRONAR), the Department for Water supply and Sanitation of DNA and the national installation enterprise (Hidromoc) (see annex I).

In order to gain more experience with design, operation, construction and maintenance of treatment plants the Civil Engineering Department of the EMU started the research programme in 1989 with a literature review at the International reference Centre for Water and Sanitation (IRC) in The Netherlands (see annex II) and continued with the construction (1989/1990) and monitoring (1990/1991) of a pilot plant in Mozambique (subject of the present report).

In a second stage of the research programme a design for the rehabilitation of a water treatment plant was made based on the experiences and the results of the pilot plant. During the implementation of this project attention will be given to the construction by local contractors and the training of operators. The plant will be monitored after half a year of functioning in order to be able to analyze the chosen design and approach for implementation.
In the mean time a detailed analysis of the existing compact water treatment plants (mainly installed in small communities) is being carried out in order to be able to compare the performance of the different plants with respect to technical, operational and financial aspects.

2.3. System choice

The main part of a surface water treatment plant is the filtration step. Basic options for filtration are slow-sand-filtration (SSF) and rapid-sand-filtration (RSF). More sophisticated filtration systems are, in the Mozambican reality, not appropriate.
The advantage of rapid-sand-filtration in relation to slow-sand-filtration, is that the former occupies less land and can treat water with a higher degree of turbidity.
The disadvantage is that rapid-sand-filtration needs more skilled personnel, energy and equipment since the washing-system is more complicated. The obtained water quality is inferior to water from slow-sand-filtration and the treatment process needs more (imported) chemicals.
Apart from these problems it is possible to obtain good results with slow-sand-filtration, since simple pre-treatment methods to decrease the turbidity are available. Therefore, the slow-sand-filtration process was used during the research experiments.

In Mozambique it is noticable that only a few plants can guarantee a 24 hour per day supply. Therefore a storage capacity has to be introduced. To have an extra buffer, the possibility of declining rate filtration has to be considered. Filters with a constant high water level, which is regulated downstream of the filter, (outlet controlled filters) are more suitable for this way of filtration.

For decreasing the turbidity pre-treatment units are necessary. Because slow-sand-filtration has the advantage of being scarce in equipment and rather robust in terms of operation, the pre-treatment unit must have the same characteristics. Roughing-

filtration satisfies these requirements as an alternative to the conventional coagulation-sedimentation process.
The type of pre-treatment chosen in the project is up-flow-roughing-filtration (URF), because of the advantages it seems to have over the other types of roughing-filtration:

- Dynamic roughing filtration depends to a large extend on local situations and therefore it is less suitable for a project aiming at a standardization of design.
- Unless a great deal of research is done to develop horizontal-roughing-filtration, it is considered that large areas are required for this type of pre-treatment and this would make this alternative more expensive.
- Down-flow-roughing-filters are difficult to clean by flushing, requiring frequent removal and washing of the filter medium.
- Up-flow-filters seem to be more efficient during the flushing process and require less space. The design of the underdrain system, however, requires special attention.

2.4. Research objectives

The main objectives of the research programme were:

- to demonstrate that slow-sand-filtration with up-flow-roughing-filtration can be a good alternative for treatment of surface water for small communities in Mozambique.
- to gain experience with the design process, construction, maintenance and operation of drinking water treatment plants.

The objectives were reached by:

- literature review in order to learn from the experiences with SSF and URF in other countries.
- construction and installation of a pilot plant, including pre-treatment processes and slow-sand-filtration, near Maputo at the Umbelúzi treatment plant.
- training of technicians in operation and monitoring.
- monitoring and operating the pilot plant while functioning under different conditions.
- analyzing the sampling data and presenting the results in a scientific report.
- informing DNA and students and demonstrating the treatment process.

2.5 Boundary conditions

The project has been totally carried out by personnel of the Civil Engineering Department of the Eduardo Mondlane University, supported by national institutes related to water affairs, in the in the Mozambican context. Even the pilot plant was constructed by local means through the national installation enterprise, Hidromoc.

The pilot plant was installed at the Maputo treatment works and connected to its raw water main. Therefore, the installation was dependent on the raw water quality (and its variations) of the Umbelúzi river and the available pressure in the raw water main.

The climate in Maputo can be characterised by a hot (temperature 25 - 35 °C), rainy season (with high intensity showers) from December until March and a cool (temperature 15 - 25 °C), dry season from April until November. During October low intensity rainfall can occur.

The research project was part of the training programme for the staff and the supporting personnel. The main participants were one ex-patriate expert (MSc.), one junior lecturer (BSc.) and one medium level laboratory technician. During the construction they were assisted by technicians from the national installation enterprise (Hidromoc), the Maputo water works and the Faculty of Engineering of the EMU.
The research work is not the only task of the university staff and therefore only 20% of the time could be spent on the project.

The laboratory technician was inexperienced and therefore it is possible that the sampling data are not totally reliable. This was aggravated by electricity cuts, which affected the analysis procedures.

III DESCRIPTION OF THE PILOT PLANT

3.1. Localization and lay-out of the pilot plant

The pilot plant is situated at the treatment works of the Maputo water company about 30 km from Maputo. The site was chosen because of the short distance in relation to the Faculty of Engineering of the Eduardo Mondlane University and the facilities it offers in terms of installation, water intake and water analysis.

The pilot plant consists of:

- One storage tank of 1 m^3 with a balancing tank for flow regulation.
- Three units for testing pre-treatment performances with up-flow-roughing-filtration which can be connected in series or in parallel and can consist of one or more layers of gravel of varying thickness and grain size and can function under varying flow rates.
- one unit for testing slow-sand-filtration.

The pilot installation is supplied with raw water from the Umbelúzi river by a tube of PE (1"). The tube is connected to the raw water main of the Maputo treatment plant slightly downstream of the pumps.

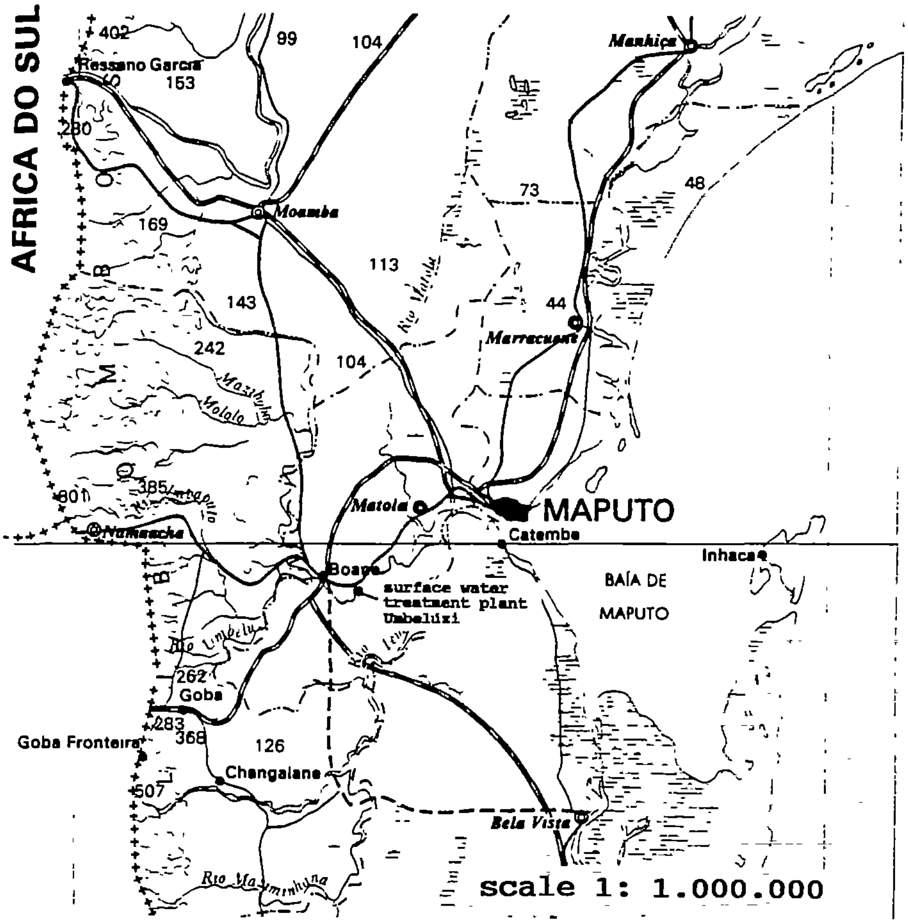

Figure 3.1 Location of Maputo treatment works (Umbelúzi)

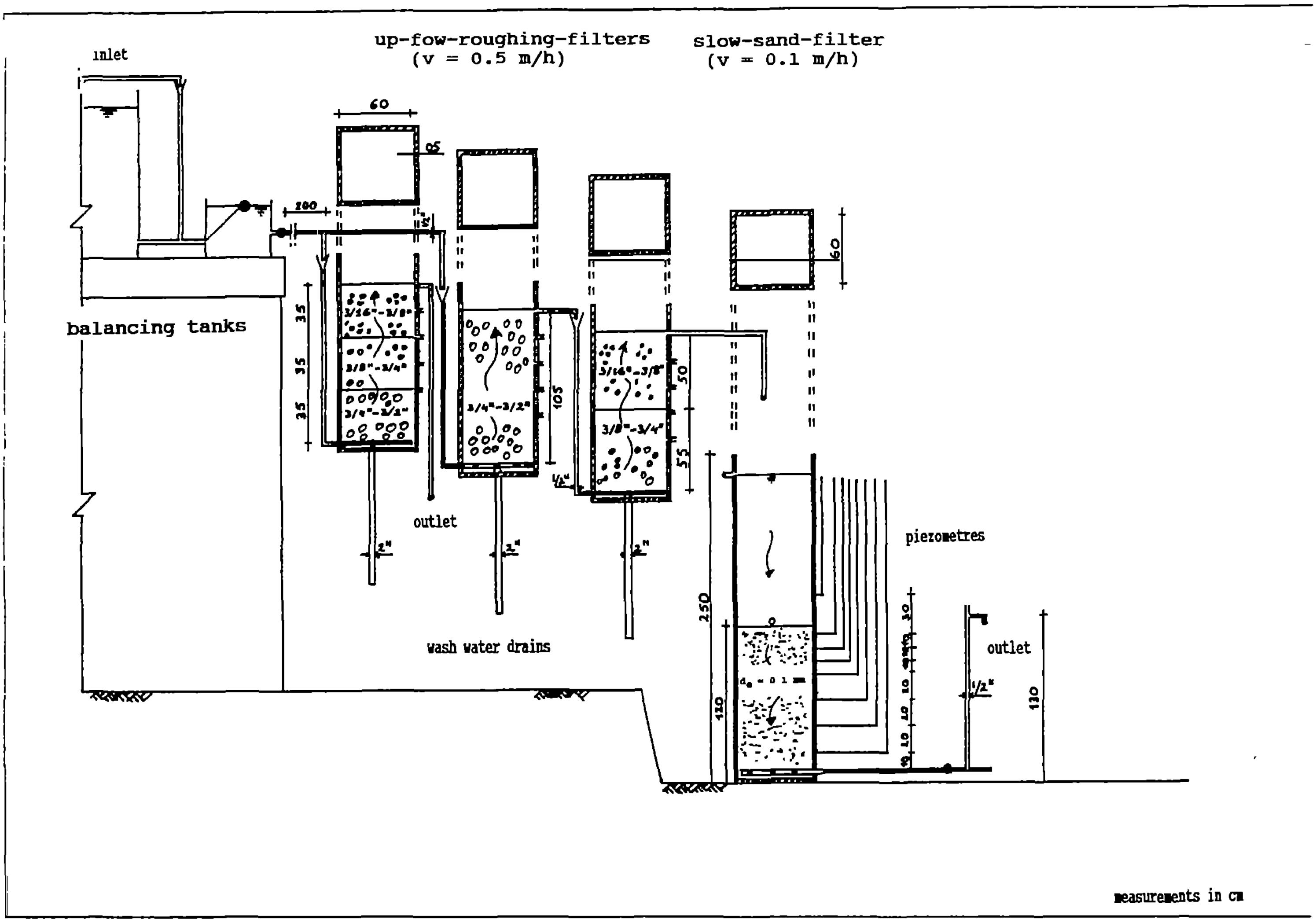

Figure 3.2 Lay-out of pilot plant

Construction details of the pilot plant (see figure 3.2):

- The tanks and units were made from iron platework and constructed by the local installation enterprise, Hidromoc.
- The pre-treatment units are 1 m high with a section of 0.6 x 0.6 m^2. The SSF unit has the same cross-section dimension, but is 2.5 m high.
- The pre-treatment units were constructed with various outlet-tubes at different heights to create possibilities to decrease the height of the inlet structure, when swallower filter-beds are applied.
- The pre-treatment units were installed 15-20 cm above each other to guarantee flow from one unit to the other including after clogging of the filter-bed.
- The pre-treatment units have separate raw water distribution and wash water drainage systems at the bottom: a small diameter (1/2") perforated pipe (openings of 3 mm) to avoid clogging for distribution and a large diameter corrugated pipe (2") for drainage.
- From the last pre-filter unit the water flows into the supernatant water of the SSF unit, which was constructed half underground.

- The SSF unit is supplied with a drainage system of 2" corrugated PVC tube, covered with jute to prevent sand from escaping.
- The storage and balance tank was constructed in such a way that:
  - a constant flow can be guaranteed (floating ball)
  - by-pass to different pre-treatment and treatment units can be guaranteed
  - the storage tank does not cut off turbidity peaks
- Piezometers were installed at the filter units at different heights and are made of transparent tubes.
- The piezometers were fitted with a T-piece to guarantee dripping of water from it, to prevent clogging.
- Apart from the tanks a drainage system to waste was constructed and a platform to wash the sand and gravel.

3.2. Operation of the Pilot Plant

During the experiments one pre-treatment unit was connected parallel to the other two units, which in their turn were connected in series. The latter units supplied the SSF unit with pre-treated water.

For URF testing, the first unit (Pre-filter 1) was filled with coarse, medium and fine gravel (crushed stone) in three layers of 0.35m each, the others were filled respectively with one 1m layer of coarse gravel (Pre-filter 2) and two 0.5 m layers of medium and fine gravel (Pre-filter 3).

The gravel size chosen for the project depended on the availability at the local market:

coarse gravel: 3/4" - 1 1/2"
medium gravel: 3/8" - 3/4"
fine gravel: 3/16" - 3/8"

On top of the pre-filters a layer of course gravel was placed in order to avoid either clogging of the outlet tube or the build-up of supernatant water in which algae could grow.
The gravel applied had already been washed at the quarry.

Filter rates of 0.5 m/h were applied.

For SSF testing, the unit was filled with a layer (with a thickness of 1 m) of fine sand with an effective diameter (d_e) of 0.1 mm (see figure 3.3) and a uniformity coefficient (U) of 2. The sand applied was collected in the neighbourhood of the plant.

The filter rate applied was 0.1 m/h, while the supernatant water level was kept constant about 1 m above the top of the filter-bed, controlled at the outlet of the filter by a valve. Excess pre-filtered water was constantly drained by an overflow.

The pilot plant operated between May 1990 and April 1991. Only the performance of the SSF unit was monitored until November 1990. From November 1990 until April 1991 regular monitoring of the pre-filter units was carried out as well.
During the period in which the pilot plant was functioning, notes were taken about the operation process related to cleaning after clogging and irregularities, mainly in the raw water supply (see Annex III).

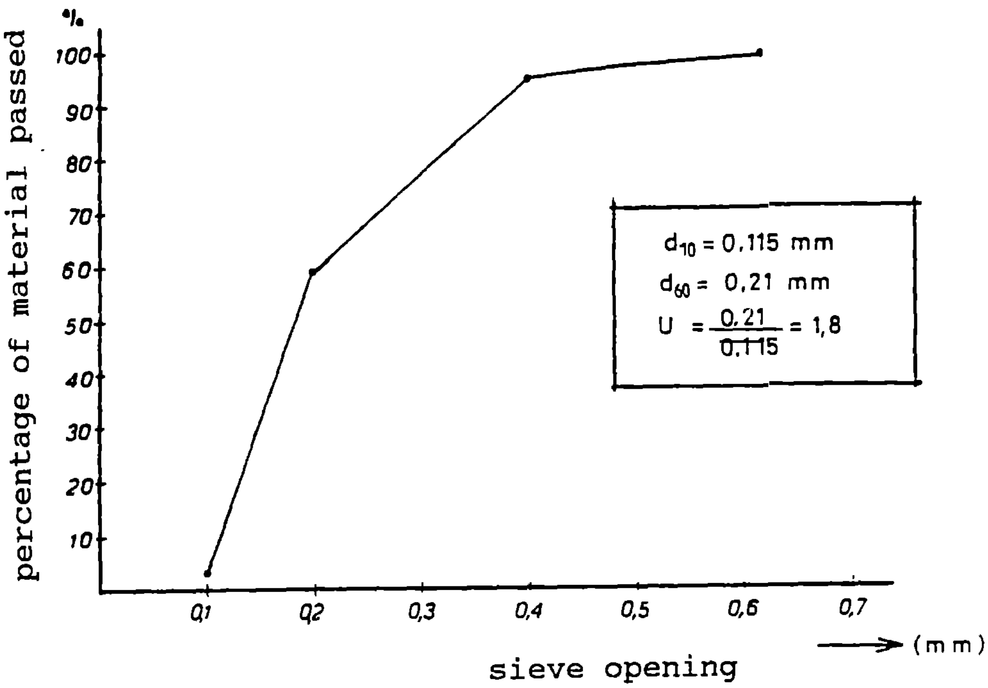

Figure 3.3 Sieve curve of applied sand for Slow-sand-filtration

3.3. Monitoring the pilot plant

The monitoring of the pilot plant was carried out by checking specific water quality parameters, the flow rates and the resistance of the filter-bed.
The main purpose of the roughing-filters is to reduce the turbidity of the influent water of the slow-sand-filter and therefore only suspended solids concentration and turbidity were measured.
Slow-sand-filtration was monitored by measuring turbidity and suspended solid concentration for analysis of the physical water quality. In addition nitrate, nitrite and ammonium was measured to check whether the filter-bed was mature. (In a mature filter-bed all ammonium, present in the influent water, should be transformed into nitrate). The concentration of dissolved oxygen was measured to check whether the concentration of organic matter

in the influent water was not too high, causing anaerobic conditions in the filter-bed.
General parameters such as pH, electrical conductivity and temperature completed the water quality analysis.
Filter-bed resistance for both the roughing-filters and the slow-sand-filter could give an indication of the maximum filter-run length.

The monitoring of the pilot plant took place once or twice a week by a laboratory technician of the Civil Engineering Department of the Eduardo Mondlane University. Due to the distance between the site and the university and the other tasks of the technician more frequent monitoring was not possible.

It would have been interesting to check the pilot plant for algae removal and the removal of pathogenic organisms. Due to the inexperience of the technician and the lack of adequate equipment, these measurements were not carried out (only once the effluent of the slow-sand-filter was checked for E-coli's).

The determination of micro-pollutants such as heavy metals and pesticides was not part of the research. On one hand because of the reasons mentioned above (lack of equipment and experience) and on the other hand because in Mozambique industry and agriculture is not seriously developed and only in special cases will these parameters be relevant.

Table 3.1. Monitoring programme of the pilot plant

	raw water	Pre-filter 1	Pre-filter 2	Pre-filter 3	Slow-sand-filter
turbidity	x	x	x	x	x
suspended solids	x	x	x	x	x
temperature				x	x
pH				x	x
dissolved oxygen				x	x
nitrate (No_3^-)				x	x
nitrite (No_2^-)				x	x
ammonia (NH_4^+)				x	x
Conductivity				x	x
Head loss		x	x	x	x
Flow rate		x	x	x	x

x = monitoring once or twice a week

Moreover, notes were taken about the operation of the pilot plant, related to cleaning (after clogging) and irregularities (mainly in the raw water supply) (see annex III).

The results of the water quality measurements are represented in tables in annex IV and diagrams in annex V

3.4. Functioning of the pilot plant in practice

During the operation of the pilot plant some difficulties were noticed, which were not foreseen during the conception period. For future studies it could be of importance to be aware of these constraints and therefore in this paragraph they are mentioned.

During the conception period it was assumed that the construction and installation of the pilot plant would take about three months. However, in practice it took about a year. This was mainly due to the fact that the installation was totally built at a Mozambican enterprise (Hidromoc), with bureaucratic procedures, without any experience with this type of installation and sometimes with a shortage of materials. In addition, the installation of the plant was carried out with personnel of the university, who were not full-time available for the job (only one or two days a week).

Relatively fine sand, which was available in the neighbourhood of Maputo, was chosen for filling the slow-sand-filter. The sand was found at a site along the Umbelúzi river, although it was not part of the river bed. Washing of the sand was carried out following the procedures described in "Slow sand filtration for community water supply"(8) with a shovel and hose. Due to the high dirt content of the sand, however, this procedure did not function and a more intensive method had to be used. Because the amount of sand was not very large (0.36 m^3) washing was done by hand, using a bucket and mixing the sand with clean water.
In the case of application of slow-sand-filtration on a larger scale either other sand should be chosen (with a lower dirt content and a larger effective diameter) or more attention should be paid to the washing process and alternative methods should be found.

In order to avoid a separate pumping unit for the pilot plant it was intended to use the pumping capacity of the Maputo water treatment for the raw water supply for the pilot plant. Therefore a raw water supply pipe (of a 1" diameter) had to be connected directly upstream from the pumping station, in order to avoid the raw water from containing chlorine which is dosed for the pre-treatment process of the Maputo treatment plant.
After connection of the raw water supply pipe to the storage tank hardly any water flowed. It was discovered that trapped air in the supply pipe blocked the flow and therefore a T-piece with a valve was installed on a relative high point for frequent removal of air.
Interruptions in the pumping system and low pressures in the raw water main to which the raw water supply pipe was connected

caused frequent interruption of the raw water supply to the pilot plant (see annex III). The storage tank, which was intended to prevent interruption of the supply of raw water to the pilot plant, did not, in practice, function adequately due to the low capacity (detention time of about 2 hours). Interruption of the raw water supply could last for a longer period and trapped air following the interruption could extend this period.
In practice it was therefore impossible to increase the filter velocities of the pre-filters above 0.5 m/h, which limited the research possibilities.
In order to be more independent of the raw water supply system of the Maputo treatment works it would have been better to install a separate raw water pump for the pilot plant (although more expensive).

From the balancing tank a 1/2" pipe was connected to the up-flow-roughing-filter units. These pipes were frequently clogged due to algae growth and settled matter. In addition, the distribution system of influent water into the up-flow-roughing-filter units was made of 1/2" pipe. Because a separate drainage system for cleaning of the units was made of 2" pipes, the inlet system was never flushed and therefore clogging also occurred in the distribution system. It was therefore necessary to drain not only water from the drainage system, but also from the distribution system during the cleaning process.

The cleaning procedure of the slow-sand-filter was carried out following the instructions in the literature (8). First the supernatant water was drained from the filter and afterwards the water level was lowered to 5 cm below the filter-bed surface before scraping off a small top layer. However, due to the difference in permeability between the top layer and the rest of the filter-bed, retardation occurred with respect to the lowering of the water level. In the beginning this effect was not taken into account with the result that the rest water level was well below the recommended 5 cm (and therefore back-filling of the filter was necessary).

The control (operation) of the pilot plant was carried out by the laboratory technician of the Civil Engineering Department of the Eduardo Mondlane University. It was done on the same lines as the monitoring of the pilot plant (once or twice a week). Due to the irregularities of the raw water supply and other constraints during operation it was in fact not adequate enough. Although, this was foreseen and therefore it was planned that operators from the Maputo water treatment plant should also be integrated in the operation programme of the pilot plant, in practice this did not work out, because the working discipline of the operators at that time was rather poor. Nevertheless, it would have been worthwhile to have given more attention to this aspect. There were additional problems for the laboratory technician in the operation phase during the holiday period (December/January) and during flooding. Although the rainy period can be the most interesting if high river discharges occur, access to the treatment plant at that time is very difficult.

The pilot plant was installed in order to test its operation under different conditions and periods with raw water with high concentrations of suspended solids were especially interesting. Unfortunately this only occurred during one small time interval in 1991. This was due to the fact that since 1988 a reservoir has been operating upstream from the water intake point to avoid flooding during the rainy season and to guarantee a minimum flow in the Umbelúzi river during the dry season. In addition, the rainy season 1991/1992 was extremely dry. Somehow this affected the the experiments.
Due to the fact that the pilot plant did not function under laboratory conditions it was in practice not possible to work with (artificially) dosed suspended solids in order to simulate high turbidity levels.

IV RESULTS AND DISCUSSION

4.1 Raw water quality

The water quality of the Umbelúzi river is generally constant and good with respect to the parameters measured. Only during a short period in March 1991 were relatively high peaks of turbidity (100 NTU) and suspended solid concentrations registered. This was due to large amounts of water spilling from the reservoir upstream from the water intake. This took already place in February 1991, but due to inaccessibility of the site at that time no measurements are available.
For the period May - October 1990 no raw water data with respect to turbidity and suspended solids are available, because during that period the pre-filters were not adequately monitored, although they were in operation. At that time, however, the values were expected to be rather low.

Table 4.1 Ranges of raw water quality parameters

	turbidity (NTU)	suspended solids (mg/l)	temperature* (°C)	pH*	conductivity* (µS/cm)
May 1990	-	-	19.5 - 23	7.64	355 - 367
June 1990	-	-	15.5 - 20.5	7.71-8.15	361 - 371
July 1990	-	-	15.5 - 20.5	7.02-7.87	364 - 374
August 1990	-	-	17.7 - 22.9	7.5 - 8	351 - 383
September 1990	-	-	19.5 - 22.9	6.93-7.62	345 - 359
October 1990	-	-	23	7.5	375
November 1990	5.6 - 17	2.6 - 7.6	18.9 - 27.5	7 - 8.5	369 - 390
December 1990	-	-	-	-	-
January 1991	-	-	-	-	-
february 1991	-	-	-	-	-
March 1991	20 - 100	6.8 - 44.3	24.8 - 28.9	7	372 - 389
April 1991	4.2 - 5.6	5.2- 6.4	23	7	399

* data obtained from measurements on slow-sand-filter assuming that these parameters do not change during the pre-filtration process.

4.2 Pre-filtration by up-flow-roughing filtration

For the analysis of the up-flow-roughing-filters, periods are noticable in which the turbidity and suspended solid concentration values are low (November 1990 and mid March until mid April 1991) and in which these values are high (end of February until half March 1991).

Table 4.2. Average removal of turbidity and suspended solids by pre-filters (based on data from annex IV)

	Pre-filter 1	Pre-filter 2	Pre-filter 3	Pre-filter 2 + 3
SS (high concentrations)	66.6%	42.8%	62.9%	78.8%
SS (low concentrations)	77.7%	35.8%	45%	69.1%
SS (average)	69.6%	41.1%	58.1%	76%
turbidity (high values)	50%	26.2%	55.3%	67%
turbidity (low values)	82%	59.4%	59.7%	83.6%
turbidity (average)	58.2%	33.8%	55.9%	70.8%

The effluent quality of the roughing-filters when relatively high peak loads occur is reasonable (< 60 NTU for one unit and < 30 NTU for two units in series), although not always in the advised range (< 20 NTU). However, these peak loads occur in a short period of time during the year.

During the filtration experiments it was not possible to analyze the clogging process. Before the start of the period with high turbidity values the filters were cleaned and during a period of two months the filters operated without further cleaning.
From the data in annex IV it can be concluded that only pre-filter 2 shows signs of break-through of suspended matter after a month of operation. Suspended solids removal by the pre-filter is decreasing and the removal of turbidity even becomes negative. This can mean that particles with a small size are present in the effluent increasing the turbidity of the water.
In the other pre-filters no significant decrease in the effluent water quality was observed in the period under consideration.
Head loss measurements were not a good indicator for the clogging of the filter. Due to the small diameter pipes used in the distribution system of the pre-filters, clogging of the underdrain system occurred first.

Although the measurements of the suspended solid concentration are not very reliable, it can be concluded that during peak loads the removal of suspended solids (SS) is in percentages significantly greater than the removal of turbidity. This

confirms the hypothesis in the literature (6) that mainly larger (suspended) particles are removed in the roughing-filters through the sedimentation process which takes place in the pre-filters. During low turbidity and SS values in the raw water, the removal of SS is in percentages lower than the removal of turbidity. This may be due to the fact that in this period a major part of the solids are colloidal matter and thus mainly other filtration processes than sedimentation are taking place such as adsorption and biochemical activity.

N.B. These conclusions are based on the fact that if two samples have the same suspended solids concentration, the sample with the largest amount of small size particles will have a higher turbidity.

Analyzing the removal rates it can be concluded that pre-filter 1 has a rather high efficiency considering the fact that the retention time of the water in pre-filter 1 is half of the retention time in pre-filter 2 and 3 together. This means a considerable reduction in filtration area and construction costs. Considering the circumstances (not very high turbidities and short periods of higher turbidity rates), it is concluded that a filter with much coarse material (and thus a high storage capacity of sludge), is not needed and even not advisable.
For filtration rates of 0.5 m/h and the applied grain sizes, one multi-layer filter has sufficient capacity for pre-treating the raw water and will be sufficiently flexible for receiving higher turbidity loads.

4.3 Slow-sand-filtration

4.3.1 Removal of turbidity and suspended solids

The removal rates can be analyzed by considering 3 periods in which the filter was functioning more or less constantly:

- period of 7 months (May - November 1990) with relatively low turbidities
- period of 1/2 month (end of February - half March 1991) with relatively high turbidities
- filtration period of 1 month (half March - half April 1991) with relatively low turbidities

Table 4.4. Average removal of suspended solids and turbidity by slow-sand-filter (based on data from annex IV)

		average turbidity removal	average suspended solids removal
1st period	May 1990	13.3%	30.6%
	June 1990	26.3%	59.8%
	July 1990	23.3%	-1.2%
	August 1990	42.2%	13%
	September 1990	28.6%	42.1%
	October 1990	-	13.5%
	November 1990	52.9%	-31.8%
2nd period	end February - half March 1991	96%	100%
3rd period	half March - half April 1991	100%	80.3%

Analyzing the data it can be concluded that during the starting-up period the removal rates of turbidity and suspended solids were very low. During some months the removal of suspended solids was even negative, which can indicate the fact that relatively large particles came into suspension during the filtration process (apart from the fact that it can be the influence of the low accuracy of the measurements).
This phenomena can be explained due to the fact that the dirt content of the sand was rather high. (The sand remained dirty even after thorough washing efforts). This dirt had to be washed out, and, in addition, the maturation process took time with the consequence that colloidal organic matter could not be removed. After about 7 - 9 months of running, the filter-bed succeeded in removing a major part of the turbidity and suspended solids.
From that time the effluent quality was constantly good with turbidity values mostly below 1 NTU, even during high influent turbidities (25 - 30 NTU).

It must be mentioned that part of the irregular pattern of the effluent quality is due to the many water and energy cuts the pilot plant was dealing with (see annex II). Therefore the plant was frequently functioning as a "declining rate filter". In literature (8) it is mentioned that the effluent of these filters suffer due to hydraulic shock loading.

4.3.2 Dissolved oxygen removal

From the results of dissolved oxygen concentration in the effluent of the slow-sand-filter (see annex IV/V), it can be concluded that the influent water does not contain too much organic matter which suffers biochemical degradation. Therefore, the effluent contains sufficient oxygen to avoid bad odours and colour. Twice the effluent contained more oxygen than the saturation concentration, which is very unlikely to occur and must be due to an analysis error.

In the supernatant water of the slow-sand-filter the dissolved oxygen content was twice above the saturation concentration, but these values are not realistic, because at the same time in the effluent over-saturated water was also measured.
Twice the supernatant water when measured was saturated, which can be due to reduced algae growth in the influent and supernatant water and re-aeration during the inlet of the water into the filter.
Algae growth is not likely to be too abundant, because over-saturation in the supernatant water is considered not to occur. In addition, if algae growth were significant it should have been possible to register a dramatic drop in the oxygen concentration in the supernatant water during the night (which was not noticed during an incidental check) and the effluent should contain less oxygen than measured.

4.3.3 Maturation of the filter-bed

The maturation of the filter-bed is normally measured through the capacity of removal of pathogenic organisms.
During the project the maturation of the filter-bed was only measured through indirect methods related to the capacity to remove organic matter (turbidity, suspended solids) and to transform ammonium into nitrate.

With respect to the removal of turbidity and suspended solids the maturation period of the filter was about 7 - 9 months (see 4.3.1). This is much more than given in literature (8), in which periods from 1 - 3 weeks are mentioned. This ripening period could be so long due to the initial high dirt content of the sand and the low turbidity of the influent water in the starting-up period. With low concentrations of suspended matter the organic matter content will also be low and thus the bacteria in the sand will hardly be fed and thus grow slowly.
In addition, the irregular operation pattern of the pilot plant

will influence the maturation process, because with an interruption of the filtration process bacteria will die.

It was observed that the ammonium concentration in the effluent of the filter was never zero, which is an indication that the maturation of the filter was never complete.
Therefore, it is probable that the effluent water is not totally free from pathogenic organisms (which was confirmed by an incidental check).
An interesting fact is that after a long time of stagnation of the pilot plant a high concentration of ammonium in the influent and the effluent was observed (17/10/'91). This indicates degradation of organic matter (including bacteria) in both the pre-filters and the slow-sand-filter and thus the maturation must be re-started.

Acceleration of the maturation process could be achieved by starting-up the slow-sand-filter just before a period with high turbidity levels in the influent water, or by using artificial feeding material.
In order to achieve total maturation of slow-sand-filters a constant flow through the filter should be guarateed.
In Mozambique only about 3% of the small communities are supplied by a gravity fed raw water supply system and therefore have the possibility of guaranteeing a 24 hour per day supply.
If a community depends on pumped raw water supply, either a raw water reservoir should be included in the design or declining rate filtration should be accepted. The latter case is not favourable for the performance of the SSF units and therefore post-chlorination of the effluent water should always be applied.

4.3.4 Length of filter-run

It was observed (see annex III) that the slow-sand-filter was rapidly clogged mainly during the first period (after 1 month). This can be explained by the fact that relatively fine filter material was used, $d_e = 0.1$ mm, while in the literature (8) it is advised to use sand with $0.15 < d_e < 0.3$ mm.
In addition, the high dirt content of the sand could have contributed to this.

After the maturation of the filter, when degradation of the incoming organic matter could be guaranteed the filter-run time increased (from 1 month to approx. 2 months).
The improved functioning of the roughing-filters could have had an additional effect on the filter-run time by reducing the algae content of the incoming water (although overall incoming turbidity was not lower than before).

V IMPACT OF STUDY AND CONTINUATION

5.1 Training and awareness

One of the objectives of the pilot plant was to provide training. Experience was gained in design of the treatment plant, in the organization of its construction and in its operation and maintenance. The staff of the Civil Engineering Department of the Eduardo Mondlane University mainly benefited from that part, although an engineer of the Maputo water company was also closely involved.
A final year civil engineering student worked for half a year (May - October 1990) on the pilot plant and some third year civil engineering students were involved in the monitoring process during a practical period of three weeks in July 1990.
The plant was used for demonstration and instruction during field visits of fifth year civil engineering students following the sanitary engineering course, third year physical planning students following the course of hydraulic infrastructures and staff members of PRONAR, working in the section "Small-systems-water-supply".
The pilot plant thus has shown its value mainly for training (design and operation) and familiarisation purposes (excursions).

The project resulted in some fundamental discussions at DNA/PRONAR about technology choice for surface water treatment, which are a basis for further development of strategies in this field.

5.2 Strategy development and follow-up

After the experiments with the pilot plant and after analysis of the results, a second phase in the project was planned. In this phase a full scale treatment plant should have been designed, constructed and operated in order to gain experience in design and construction and to study the process of operation and maintenance (including training). Moreover, a better comparison in terms of performance and costs between the already existing compact treatment plants of Hidromoc and the slow-sand-filters could thus be made.
It was planned that the full scale plant based on slow-sand-filtration with up-flow-roughing filtration should be built and located in the neighbourhood of Maputo to facilitate the monitoring of the plant and the training of the operators.
The location chosen for the implementation of the project was Umpala, a small village about 30 km from Maputo, which has a small distribution system with public standposts serving a population of about 7000 people. The population should benefit directly from the plant and could participate in operation and maintenance.
The plant should have been financed partly by the research project and partly by the National Programme for Rural Water supply (PRONAR). The design as well as the supervision of the construction and the monitoring of the plant would be carried out by the research team. Construction, operation and maintenance

would be under the responsibility of PRONAR.
However, after several meetings between the involved parties, it was concluded that such a project would not be feasible due to the fact that it was doubtful if the population would be sufficiently dependent on the system, when other alternative sources were available (groundwater e.g.). In addition, overloading of the staff and financial problems played a role.

The second alternative was to analyze an existing treatment plant and to rehabilitate it to conform with the objectives of the project. The advantage of such an approach is that the importance will be more evident and therefore funds will become available. In addition some operation experience is present. However, in terms of monitoring and training problems could arise, due to the longer distance from Maputo. Through PRONAR it was suggested to concentrate on the drinking water treatment plant in Nhamatanda, located in the centre of the country and rehabilitated in 1989 without success due to design errors.
Although it is not possible to implement all aspects of the project on the Nhamatanda case (for example the slow-sand-filter component), it has been a good opportunity putting part of the obtained knowlegde into practice. Moreover, Nhamatanda is relatively easy to reach and therefore monitoring of the project is possible.
The design for the rehabilitation of the drinking water treatment plant in Nhamatanda (which has a capacity of 50 m^3/h) is based on the existing infrastructure. The proposal is to transform the sedimentation tank into an up-flow-roughing-filter and to improve the existing rapid-sand-filters. The rehabilitation would be executed by a local contractor, supported by staff of the CED/UEM and Hidromoc.
The project was appraised by PRONAR/DNA in 1991 and finances obtained through UNICEF. Due to a delay in the supply of imported material, by the end of 1992 the execution of the works had not yet started.

At present, locally produced (by Hidromoc/Krueger), compact treatment plants based on pressure filtration are installed in several small communities. These compact plants are considered to have advantages over other treatment systems by being relatively cheap with respect to investment, being easy to install (and construct) and requiring only one pumping station, pumping water directly from the surface water through the plant to a water tower.
However, the long-term performance of these plants, management, operation & maintenance, costs and data about treatment efficiency are seldom evaluated.
Therefore, in 1992 the Civil Engineering Department of the UEM, started a research program related to that subject being part of the MSc-thesis work of one of the staff members.
The results of this study will be used for more detailed discussions about technology choice for water treatment plant rehabilitation in small communities.

In Mozambique many treatment plants are out of order due to lack of maintenance, rehabilitation funds and access difficulties. Due to an increase of investment in Mozambique by bilateral, multilateral and Non-governmental donors and a significant improvement in the war situation, some of the plants can be rehabilitated. Efforts should be made to rebuild the existing, mainly rapid-sand-filter-plants using more appropriate technologies. To promote and coordinate these efforts, PRONAR/DNA should establish a strategy and train staff to do design work, to give technical assistance during construction and to train operators. In addition, running plants should be constantly monitored to improve the design, construction and operation methods.

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LIST OF ABBREVIATIONS AND SYMBOLS

CED	Civil Engineering Department of the EMU
DAS	Department for Water supply and Sanitation of DNA
d_e	Effective grainsize diameter of granular material
DGIS	Directorate General for International Cooperation, The Netherlands
DO	Dissolved oxygen concentration
DOsat	Dissolved oxygen saturation concentration
DNA	National Directorate for Water Affairs of Mozambique
DUT	Delft University of Technology
EAM	Maputo Water Company
EC	Electrical Conductivity
EMU	Eduardo Mondlane University
IRC	International Reference Centre for water and sanitation, The Netherlands
NTU	Nephelometric turbidity unit
PRONAR	National Programme for Rural Water supply of Mozambique
SAREC	Swedish Agency for Research Cooperation
SS	Suspended solids concentration
SSF	Slow-sand-filtration
RSF	Rapid-sand-filtration
U	Uniformity coefficient of granular material
URF	Up-flow-roughing-filtration

ANNEXES

ANNEX I TEAM EXECUTING THE PROJECT

Design, supervision and analysis of data
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Water quality monitoring and operation
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ANNEX II HIGHLIGHTS OF LITERATURE REVIEW

The first phase of the project was to study existing literature on Slow-Sand-Filtration and low-cost pretreatment methods (see bibliography), to increase the chance of success. During the study phase a resume was made which is represented in the next paragraphs.

1. SSF can work for turbidities lower than 10-20 NTU with occasional peaks of higher turbidity. If this in practice is not the case, pretreatment is necessary.
2. SSF is working optimally when a constant flow of 24 hours per day can be guaranteed.
3. SSF can be hindered by growth of algae and if this is the case something has to be done against it.
4. The flow rate of SSF can be controlled on the outlet or on the inlet.
5. The outlet structure of SSF has to be constructed in such a manner that negative heads in the filter-bed do not occur.
6. Means for backfilling the SSF unit have to be integrated in the project.
7. SSFs normally have a layer of 1.0-1.2 m of sand (with a minimum of 0.6 m) with an effective size of the grain of 0.20-0.35 mm and an uniformity coefficient of 2-3.
8. Flow rates for SSF are from 0.1 m/h (conventional) until 0.3 m/h.
9. The maximum level of the supernatant water should be approximately 1 m of height.
10. The inlet structure has to be constructed in such a way that the bed will not be disturbed.
11. Drainage of supernatant water, ripening water, filter-bed water and overflow water has to be considered.
12. Building materials, foundation technique, shape and underdrain system of the plant depend on local situations.
13. The purpose of a SSF Pilot Plant is to test the grain size of the sand locally available, to test different flow rates (apart from the conventional 0.1 m/h), to test declining rate filtration and to investigate the algae problems (apart from other problems which may occur).
14. Washing the sand before using it as filter-bed material is very important.
15. Sharing the experiences during the study and construction phase with other persons/institutions involved, is important (caretakers, decision-makers, constructors).
16. If pretreatment is necessary, the technology has to be selected. Pilot plants for testing the method have to be installed (number of units, flow rates, filter material, bed height).
17. For low-cost pretreatment before SSF, Roughing Filtration can be applied with success. Roughing-Filtration can be subdivided into:
    - Dynamic roughing filtration
    - Horizontal roughing filtration
    - Up-flow roughing filtration
    - Down-flow roughing filtration

18. Up-flow-roughing-filters should consist of an underdrainage system to distribute equally water over the filter and to drain flush water to waste and an upper drainage system to collect pre-filtered water.
19. Little information about flow rates, grain sizes, and filter-bed depths on up-flow-roughing-filtration is available. As a start one can take a filter-bed of about 1 m, with three units in series, flow rates up to 1 m/h and grain-sizes varying from 35 mm till 4 mm (15-25; 8-15; 4-8 mm). The optimum combination has to be checked in the pilot plant. Flushing rates of 4 - 6 m/h are recommended and during flushing it is advisable to open and close rapidly the drainage system to introduce shock waves and thus to improve flushing efficiency.
20. To avoid algae growth on the surface of the gravel-bed, the water level should be below the top of the filter-bed.
21. The purpose of a demonstration plant is to test the pilot results on a larger scale, to gain experience with the design and construction of a SSF-plant, to gain experience with operation/maintenance, to train personnel and to evaluate and correct errors which have been made.

ANNEX III OPERATION DETAILS OF THE PILOT PLANT

26/06/'90	Pilot plant functioning, regulation of flow.
28/06/'90	Pilot plant functioning, regulation of flow.
02/07/'90	Interruption in functioning of pilot plant due to low pressure in raw water main (break-down of pump).
06/07/'90	Cleaning of slow-sand-filter and regulation of flow.
09/07/'90	Pilot plant functioning, regulation of flow.
25/07/'90	Cleaning of slow-sand-filter and regulation of flow.
27/07/'90	Pilot plant functioning, regulation of flow.
30/07/'90	Pilot plant functioning, regulation of flow.
29/08/'90	Cleaning of slow-sand-filter and regulation of flow.
05/09/'90	Pilot plant functioning, regulation of flow.
12/09/'90	Pilot plant functioning, regulation of flow.
13/09/'90	Pilot plant functioning, regulation of flow.
09/10/'90	Cleaning of slow-sand-filter, regulation of flow not possible due to problems with raw water pumps.
13/10/'90	Regulation of flow.
17/10/'90	Pilot plant functioning, regulation of flow.
18/10/'90	Changing the gravel in the pre-filters.
26/10/'90	Starting-up the pre-filters
30/10/'90	Cleaning the pre-filters
20/11/'90	Interruption of functioning of slow-sand-filter due to clogged pipe, the pre-filters were functioning, regulation of flow.
22/11/'90	Interruption of functioning of pilot plant due low pressure in raw water main to Maputo treatment plant.
11/12/'90	Regulation of flow.
13/12/'90	Interruption of functioning of pilot plant due low pressure in raw water main to Maputo treatment plant.
20/02/'91	Cleaning of pilot plant site.
26/02/'91	Cleaning of slow-sand-filter and pre-filters, regulation of flow.
27/02/'91	Pilot plant functioning, regulation of flow.
05/03/'91	Pilot plant functioning, regulation of flow.
07/03/'91	Pilot plant functioning, regulation of flow.
12/03/'91	Pilot plant functioning, regulation of flow.
14/03/'91	Pilot plant functioning, regulation of flow.
09/04/'91	Cleaning of slow-sand-filter
11/04/'91	Pilot plant functioning, regulation of flow.
18/04/'91	Pilot plant functioning, regulation of flow, problems with inlet of raw water due to low pressure in raw water main.
23/04/'91	Interruption in functioning of pilot plant due to closed valve, regulation of flow.

ANNEX IV TABLES WITH WATER QUALITY DATA FROM PILOT PLANT

Table IV.1 Water quality data, Pre-filter 1

	influent		effluent		removal rates	
	SS (mg/l)	turbidity (NTU)	SS (mg/l)	turbidity (NTU)	turbidity (%)	SS (%)
06/11/'90	-*	5.6	-*	3.1	44.6	-
08/11/'90	2.6	14	0.95	3	78.6	63.5
13/11/'90	7.2	17	1.4	2.1	87.6	80.6
20/11/'90	7.6	17	0.4	1.5	91.2	94.7
27/11/'90	5.8	12	0.6	1	91.7	89.7
26/02/'91	cleaning					
28/02/'91	37.25	101	14.6	56	44.6	60.8
05/03/'91	22.8	51	10.6	26	49	53.5
07/03/'91	16	29	4.4	14	51.7	72.5
12/03/'91	7	20	0.8	9	55	88.6
14/03/'91	12.8	20	1.6	5.4	73	87.5
28/03/'91	6.4	5.6	2.2	1.1	80.4	65.6
11/04/'91	5.2	4.9	2.2	1.9	61.2	57.7
15/10/'91	cleaning					
17/10/'91	9.5	2.9	4.88	1.5	48.3	48.6
28/11/'91	8.87	5.7	0	0.8	86	100

* doubtful data

Table IV.2 Water quality data, Pre-filter 2

	influent		effluent		removal rates	
	SS (mg/l)	turbidity (NTU)	SS (mg/l)	turbidity (NTU)	turbidity (%)	SS (%)
06/11/'90	6.3	5.5	-*	4.5	18.2	-
08/11/'90	3.4	11	1	3.4	69.1	70.6
13/11/'90	5.8	15	4.8	2.9	80.7	17.2
20/11/'90	6.2	13	4.2	3.1	76.2	32.3
27/11/'90	4.6	11	1.6	2.1	80.9	65.2
26/02/'91	cleaning					
28/02/'91	44.25	100	25.2	66	34	43.1
05/03/'91	23.8	51	16.6	39	23.5	30.3
07/03/'91	12.6	27	8.2	23	14.8	34.9
12/03/'91	6.8	19	2.2	16	15.8	67.6
14/03/'91	11.8	17	4.6	14	17.6	61
28/03/'91	6	3.8	5	4.6	-21.1	16.7
11/04/'91	6.4	4.2	4.2	5.2	-23.8	34.4
15/10/'91	cleaning					
17/10/'91	3.5	2.3	0.37	2	13	89.4
28/11/'91	9	6.1	1.37	2.1	65.6	84.8

* doubtful data

Table IV.3 Water quality data, Pre-filter 3

	influent		effluent		removal rates pre-filter 3		removal rates pre-filters 2 +3	
	SS (mg/l)	turbidity (NTU)	SS (mg/l)	turbidity (NTU)	turbidity (%)	SS (%)	turbidity (%)	SS (%)
06/11/'90	-*	4.5	0.53	2	55.6	-	63.6	91.6
08/11/'90	1	3.4	0.67	1.4	58.8	33	87.3	80.3
13/11/'90	4.8	2.9	2.67	1.5	48.3	44.4	90	54
20/11/'90	4.2	3.1	1.9	2.4	22.6	54.8	81.5	69.4
27/11/'90	1.6	2.1	2.13	1.2	42.9	-33.1	89.1	53.7
26/02/'91	cleaning							
28/02/'91	25.2	66	12.93	27	59.1	48.7	73	70.8
05/03/'91	16.6	39	4.67	20	48.7	71.9	60.8	80.4
07/03/'91	8.2	23	3.47	13	43.5	57.7	51.9	72.5
12/03/'91	2.2	16	0	8	50	100	57.9	100
14/03/'91	4.6	14	0	2.6	81.4	100	84.7	100
28/03/'91	5	4.6	3.87	1.5	67.4	22.6	60.5	35.5
11/04/'91	4.2	5.2	0.2	0.4	92.3	95.2	90.5	96.9
15/10/'91	cleaning							
17/10/'91	0.37	2	0.75	0.9	55	-102.7	60.9	78.6
28/11/'91	1.37	2.1	0	1	52.4	100	83.6	100

* doubtful data

Table IV.4.1 Water quality data, Slow-sand-filter

	influent		effluent		removal rates	
	SS (mg/l)	turbidity (NTU)	SS (mg/l)	turbidity (NTU)	turbidity (%)	SS (%)
10/05/'90	16.8*	15	11.2*	13	13.3	33.3*
29/05/'90	-	18	2.8	20	-11	-
30/05/'90	2.8	15	2.4	13	13.3	14.3
05/06/'90	4.8	12	2.6	11.7	2.5	45.8
07/06/'90	5.2	9	0.43	5	44.4	91.7
09/06/'90	cleaning					
11/06/'90	6.13	8	2.67	4.1	48.8	56.4
26/06/'90	3.23	7.1	1.34	7.7	-8.5	58.5
28/06/'90	5.73	8	3.07	4	50	46.4
04/07/'90	7.66	13	4.82	11	15.4	37.1
06/07/'90	cleaning					
09/07/'90	3.56	15	2.53	8	46.7	28.9
17/07/'90	3.33	10	2.53	8	20	24
19/07/'90	7	-	3.2	-	-	54.3
23/07/'90	4.11	10	4	7	30	2.7
25/07/'90	cleaning					
27/07/'90	2.22	6	3.78*	3.5	41.7	-70.3*
30/07/'90	4	7.4	6.45*	6.1	17.6	-61.3*
03/08/'90	0.44	3.6	0.33	2.4	33.3	25
06/08/'90	3.22	3.5	2.33	2.2	37.1	27.6
09/08/'90	5.55*	1.5	5.44*	0.5	66.7	2*
13/08/'90	2.78	2.3	2.33	1.2	47.8	16.2
29/08/'90	cleaning					
11/09/'90	-	4.1	-	3.5	14.6	-
13/09/'90	0.8	1.1	0.53	0.5	54.5	33.8
17/09/'90	8.75*	3	5*	2.5	16.7	42.9*
20/09/'90	0.53	0.9	-	0	100	-
27/09/90	-	0	-	0	-	-
09/10/'90	cleaning					
17/10/'90	2	0	1.73	0	-	13.5

* doubtful data

Table IV.4.2 Water quality data, Slow-sand-filter (continued)

	influent		effluent		removal rates	
	SS (mg/l)	turbidity (NTU)	SS (mg/l)	turbidity (NTU)	turbidity (%)	SS (%)
06/11/'90	0.53	2	2.27	0.6	70	-328.3*
08/11/'90	0.67	1.4	2.27	0.7	50	-238.8*
13/11/'90	2.67	1.5	0.4	0.5	66.7	85
20/11/'90	1.9	2.4	2.67	1.6	33.3	-40.5
27/11/'90	2.13	1.2	2.8	0.6	50	-31.5
26/02/'90	cleaning					
28/02/'91	12.93	27	0	1.5	94.4	100
05/03/'91	4.67	20	0	0	100	100
07/03/'91	3.47	13	0	0.8	93.8	100
12/03/'91	0	8	0	0	100	-
14/03/'91	0	2.6	0	0.5	80.8	-
28/03/'91	3.87	1.5	0.8	0	100	79.3
09/04/'91	cleaning					
11/04/'91	0.2	0.4	0	0	100	100
15/10/'91	cleaning					
17/10/'91	0.75	0.9	0	0.6	33.3	100
28/11/'91	0	1	1	0.3	70	-

* doubtful data

Table IV.4.3 Water quality data, Slow-sand-filter (continued)

	influent			effluent			
	NH_4^+ (mg/l)	NO_2^- (mg/l)	NO_3^- (mg/l)	NH_4^+ (mg/l)	NH_4^+ removed (%)	NO_2^- (mg/l)	NO_3^- (mg/l)
10/05/'90	0.35	0.13	1.69	0.45	-28.6	0.08	2.59
29/05/'90	0.6	0.11	1.01	0.28	53.3	0.08	0.68
30/05/'90	0.31	0.6	0.76	0.24	22.6	0.06	0.68
05/06/'90	0.34	0.07	0.62	0.3	11.8	0.54	0.96
07/06/'90	0.2	0.06	1.01	0.2	0	0.07	0.73
09/06/'90	cleaning						
11/06/'90	0.24	0.07	0.95	0.28	-16.7	0.12	0.48
26/06/'90	0.36	0.06	0.69	0.3	16.7	0.07	0.75
28/06/'90	0.03	0.04	0.57	0.29	3.3	0.04	0.81
04/07/'90	0.37	0.05	0.81	0.4	-8.1	0.05	1.03
06/07/'90	cleaning						
09/07/'90	0.37	0.04	0.63	0.18	51.4	0.04	0.63
17/07/'90	0.18	0.04	0.51	0.18	0	0.04	0.63
19/07/'90	0.04	0.16	0.81	0.19	-375	0.03	0.55
23/07/'90	0.19	0.03	1.12	0.21	-10.5	0.05	0.45
25/07/'90	cleaning						
27/07/'90	0.15	0.03	0.75	0.31	-106.7	0.04	0.57
30/07/'90	0.2	0.06	-	0.19	5	0.06	-
03/08/'90	0.17	0.04	1.07	0.18	-5.9	0.04	0.93
06/08/'90	0.23	0.08	0.38	0.19	17.4	0.07	0.38
09/08/'90	0.14	0.05	0.59	0.17	-21.4	0.06	0.51
13/08/'90	0.12	0.03	1.63	0.23	-91.7	0.2	0.34
29/08/'90	cleaning						
11/09/'90	0.13	0.03	2.15	0.17	-30.8	0.05	1.09
13/09/'90	0.14	0.02	1.78	0.16	-14.3	0.03	1.25
17/09/'90	0.16	0.02	1.19	0.13	18.8	0.02	0.84
20/09/'90	0.12	0.01	1.37	0.11	8.3	0.01	1.09
27/09/'90	0.09	0.01	5.44	0.09	0	0.02	1.69
09/10/'90	cleaning						
17/10/'90	0.18	0.01	2.22	0.18	0	0.02	1.81

Table IV.4.4 Water quality data, Slow-sand-filter (continued)

	influent			effluent			
	NH_4^+ (mg/l)	NO_2^- (mg/l)	NO_3^- (mg/l)	NH_4^+ (mg/l)	NH_4^+ removed (%)	NO_2^- (mg/l)	NO_3^- (mg/l)
06/11/'90	0.25	0.03	1.44	0.21	16	0.02	1.72
08/11/'90	0.17	0.02	1.81	0.17	0	0.01	1.5
13/11/'90	0.39	0.03	0.91	0.39	0	0.02	0.97
20/11/'90	0.1	0.02	0.78	0.29	-190	0.01	0.53
27/11/'90	0.14	0.14	0.84	0.07	50	0	0.78
26/02/'91	cleaning						
28/02/'91	0.39	0.15	3.09	0.08	79.5	0.04	1.63
05/03/'91	0.4	0.11	2.14	0.15	62.5	0.02	1.66
07/03/'91	0.27	0.06	1.32	0.14	48.1	0	1.55
12/03/'91	0.09	0.03	1.1	0.07	22.2	0.01	1.55
14/03/'91	0.15	0.02	1.97	0.06	60	0.01	1.04
28/03/'91	0.1	0.02	0.37	0.09	10	0	0.67
09/04/'91	cleaning						
11/04/'91	0.08	0.02	10.29*	0.05	37.5	0.04	-
15/10/'91	cleaning						
17/10/'91	11	-	0	7.05	35.9	-	0
28/11/'91	0.1	-	0.56	0.09	10	-	0.5

* doubtful data

Table IV.4.5 Water quality data, Slow-sand-filter (continued)

	influent					effluent				
	EC (µS/cm)	pH	T (°C)	DO (mg/l)	DO sat (mg/l)	EC (µS/cm)	pH	T (°C)	DO (mg/l)	DO sat (mg/l)
10/05/'90	367	-	23	29.5*	8.7	366	-	21.5	30.2*	8.9
29/05/'90	361	7.98	18.5	6.9	9.5	363	7.73	19.5	5.6	9.3
30/05/'90	355	7.64	19.5	7.5	9.3	354	7.56	19	5.1	9.4
05/06/'90	361	7.89	20.5	8.7	9.1	360	7.5	19.5	7.8	9.3
07/06/'90	-	8.15	-	-	-	-	8.03	-	-	-
09/06/'90	cleaning									
11/06/'90	368	7.71	16.9	8.9	9.7	380	7.32	17.5	2.9	9.6
26/06/'90	370	7.96	15.5	8.5	10.1	369	7.85	17.5	7.1	9.6
28/06/'90	371	7.96	17.5	8.8	9.6	373	7.87	17.9	7.1	9.5
04/07/'90	374	7.87	16	9.3	10	372	7.76	16	6.8	10
06/07/'90	cleaning									
09/07/'90	364	8	21	8.3	9	363	7.05	18	6.5	9.5
17/07/'90	364	7.04	16.2	8.7	10	363	7.05	18	6.5	9.5
10/07/'90	359	7.01	18.9	8.2	9.4	358	7.02	19.8	6.5	9
23/07/'90	368	7.02	15.5	10.1	10.1	365	7.02	16.7	7.3	9.8
25/07/'90	cleaning									
27/07/'90	366	-	18.5	8.3	9.5	362	-	19	7.6	9.4
30/07/'90	365	-	20.5	12.9*	9.1	346	-	20.5	11.5*	9.1
03/08/'90	351	-	19	8.6	9.4	365	-	21	7.7	9
06/08/'90	358	7.5	22.9	8.4	8.7	363	7	21.5	7.6	8.9
09/08/'90	-	8	-	-	9.3	-	7	-	-	9.1
13/08/'90	383	7.5	17.7	7.1	9.6	380	7	20.3	3.8	9.1
29/08/'90	cleaning									
11/09/'90	345	7.06	22.9	7.9	8.7	355	7.78	22.4	7.3	8.8
13/09/'90	348	6.93	22.2	7.3	8.8	356	6.95	23.4	6.4	8.6
17/09/'90	346	7.62	22.6	7.2	8.7	355	7.76	23.9	5.9	8.5
20/09/'90	356	7.04	19.5	9.2	9.3	354	7.05	17.1	9	9.7
27/09/'90	359	7.26	22.9	6.2	8.7	367	7.54	25	6.2	8.4
09/10/'90	cleaning									
17/10/'90	375	7.5	23	4.5	8.7	356	7	24.5	5.8	8.4

* doubtful data

Table IV.4.6 Water quality data, Slow-sand-filter (continued)

	influent					effluent				
	EC (µS/cm)	pH	T (°C)	DO (mg/l)	DO sat (mg/l)	EC (µS/cm)	pH	T (°C)	DO (mg/l)	DO sat (mg/l)
06/11/'90	371	7	18.9	7.5	9.4	373	7	22.8	6.3	8.7
08/11/'90	369	7	23	7.5	8.7	376	7.5	21.5	7.2	8.9
13/11/'90	377	8	27.5	6.3	8	378	7.5	28.9	4.7	7.8
20/11/'90	390	7	27	4.7	8.1	417	7.5	26.9	2.2	8.1
27/11/'90	378	8.5	26.3	7.1	8.2	377	7	25	5.6	8.4
26/02/'91	cleaning									
28/02/'91	387	7	27.9	5.6	7.9	395	7	28.5	4.3	7.8
05/03/'91	372	7	28.9	5.6	7.8	373	7	31	4.5	7.5
07/03/'91	378	7	28	5.3	7.9	379	7	27.7	4.9	8
12/03/'91	379	7	24.8	6.9	8.4	381	7	26.5	5.5	8.1
14/03/'91	387	7	26.5	5.7	8.1	383	8	27.9	6.8	7.9
28/03/'91	389	7	27	5.9	8.1	393	7	23.5	4.8	8.6
09/04/'91	cleaning									
11/04/'91	399	7	23	5.7	8.7	404	7	22.5	7.7	8.8
15/10/'91	cleaning									
17/10/'91	416	7	24	-	8.5	427	7	21.9	-	8.8
28/11/'91	432	7	30.9	-	7.5	433	7.05	-	-	-

ANNEX V GRAFICS WITH WATER QUALITY DATA FROM PILOT PLANT

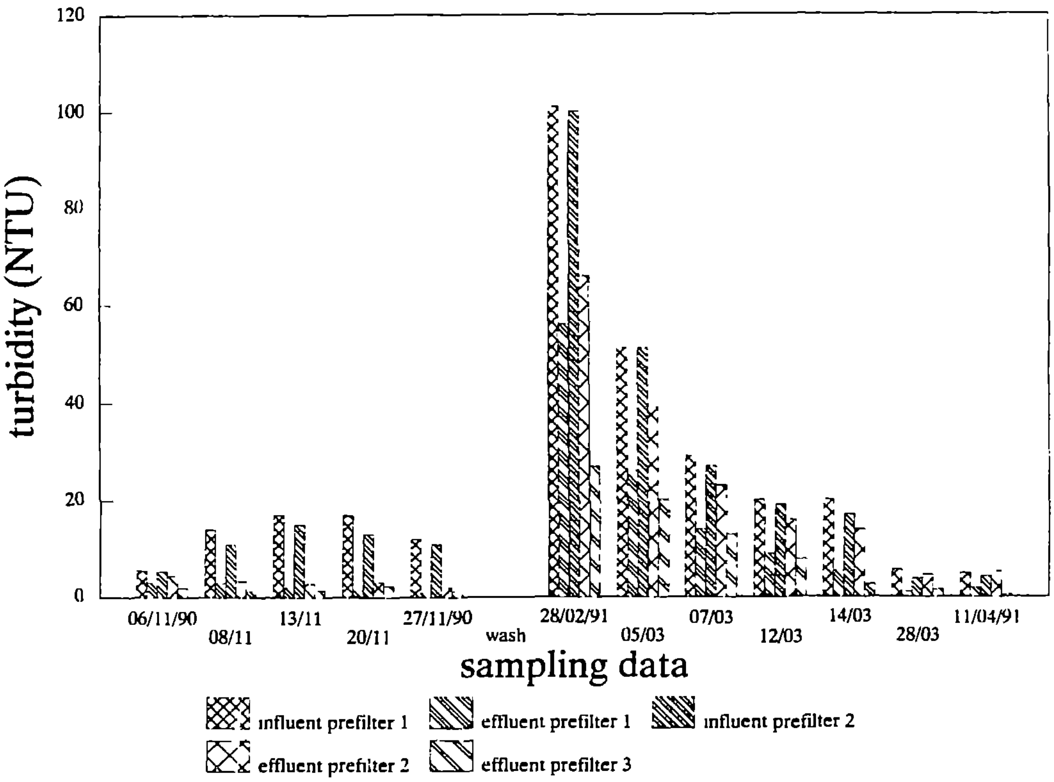


fig.V.1 Pre-filters, turbidity (Nov '90 - Apr '91)

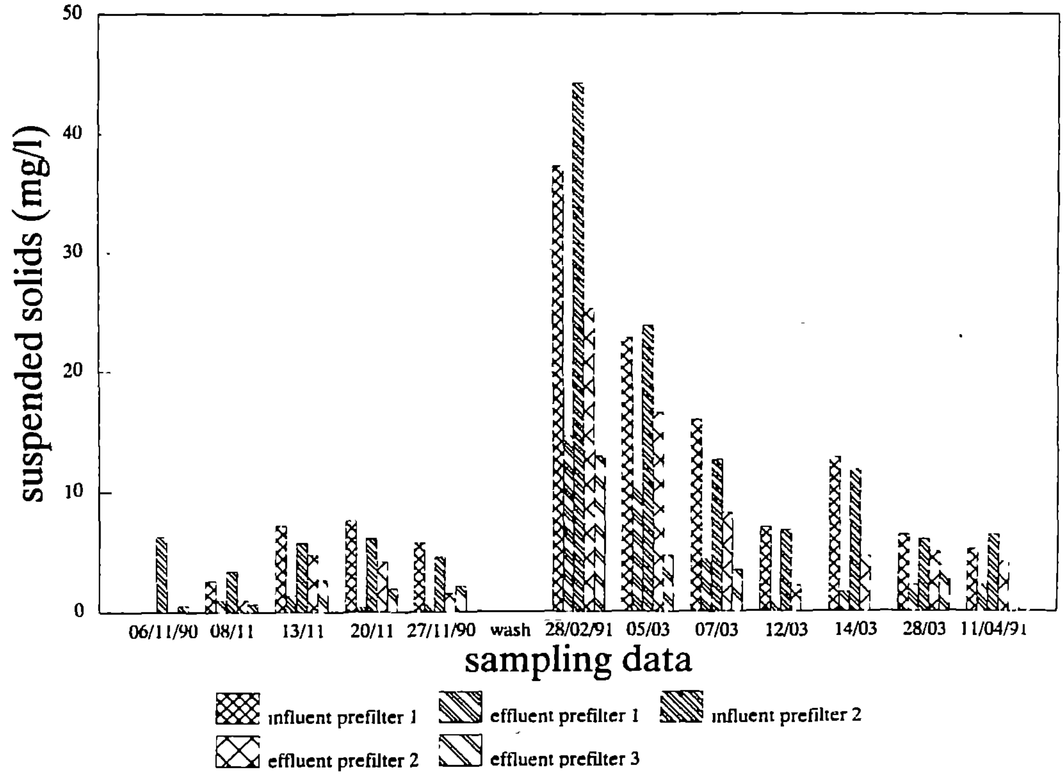
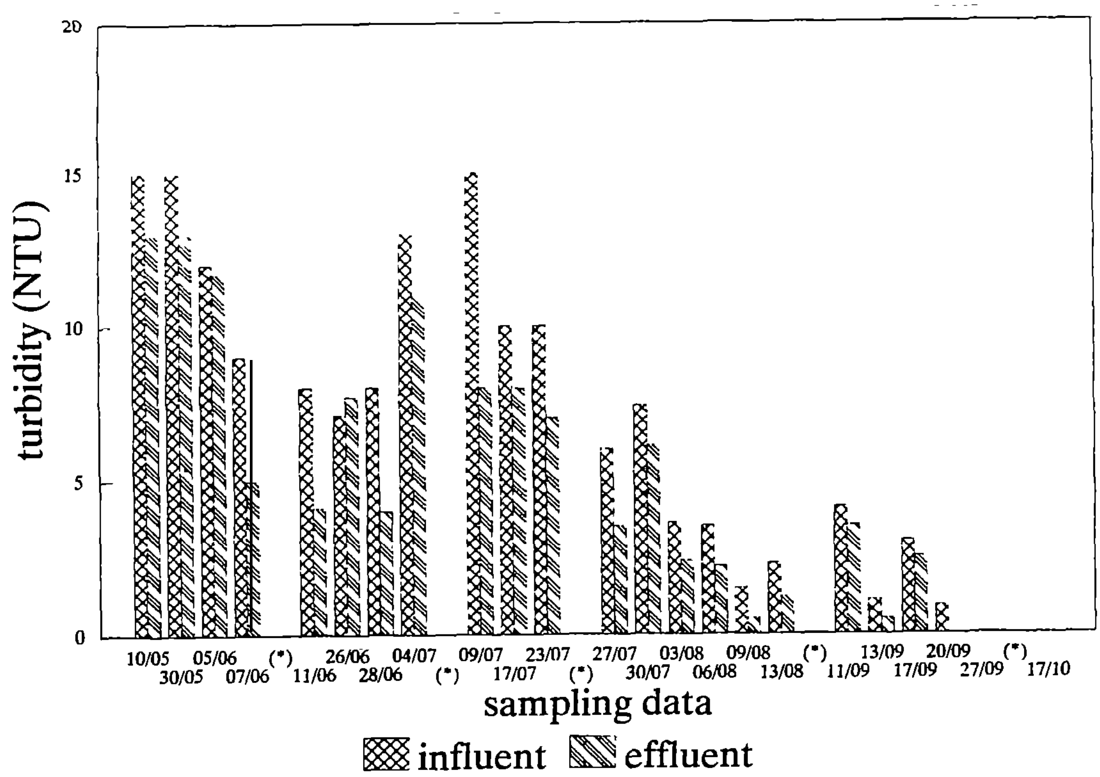
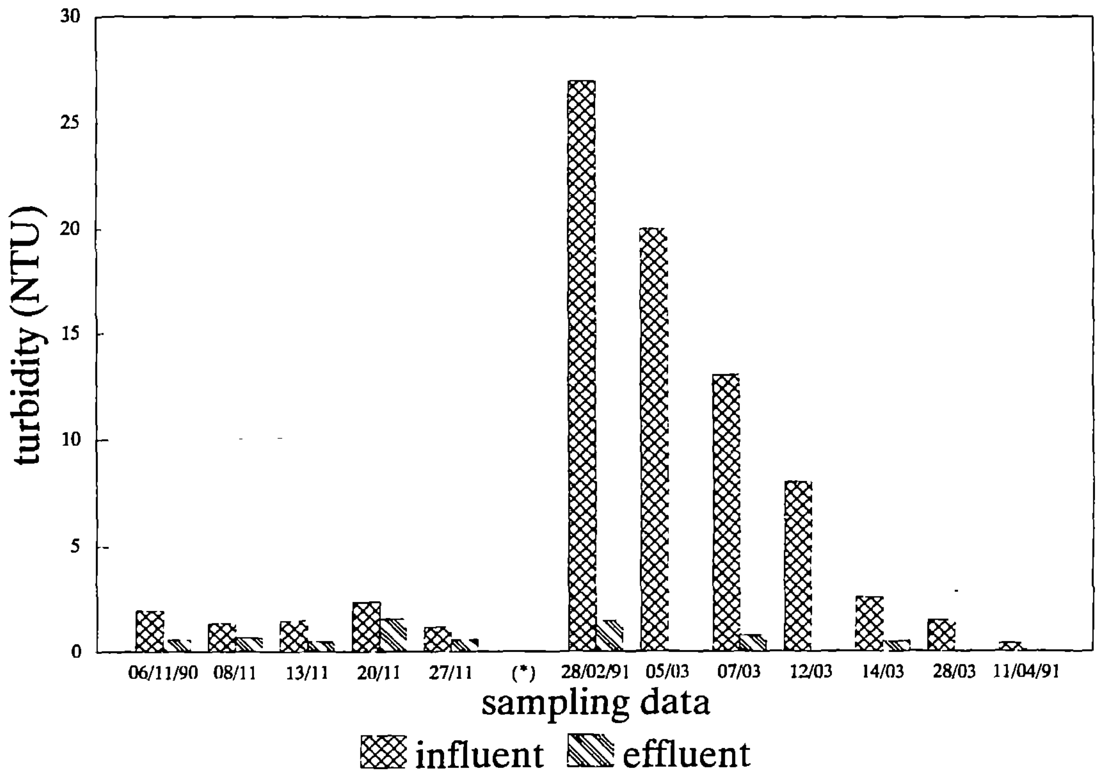


Fig.V.2 Pre-filters, suspended solids concentration (Nov. '90 - Apr '91)



(*) cleaning of slow-sand-filter

Fig.V.3.1 Slow-sand-filter, turbidity (May - Oct '90)



(*) cleaning of slow-sand-filter

Fig.V.3.2 Slow-sand-filter, turbidity (Nov '90 - Apr '91)

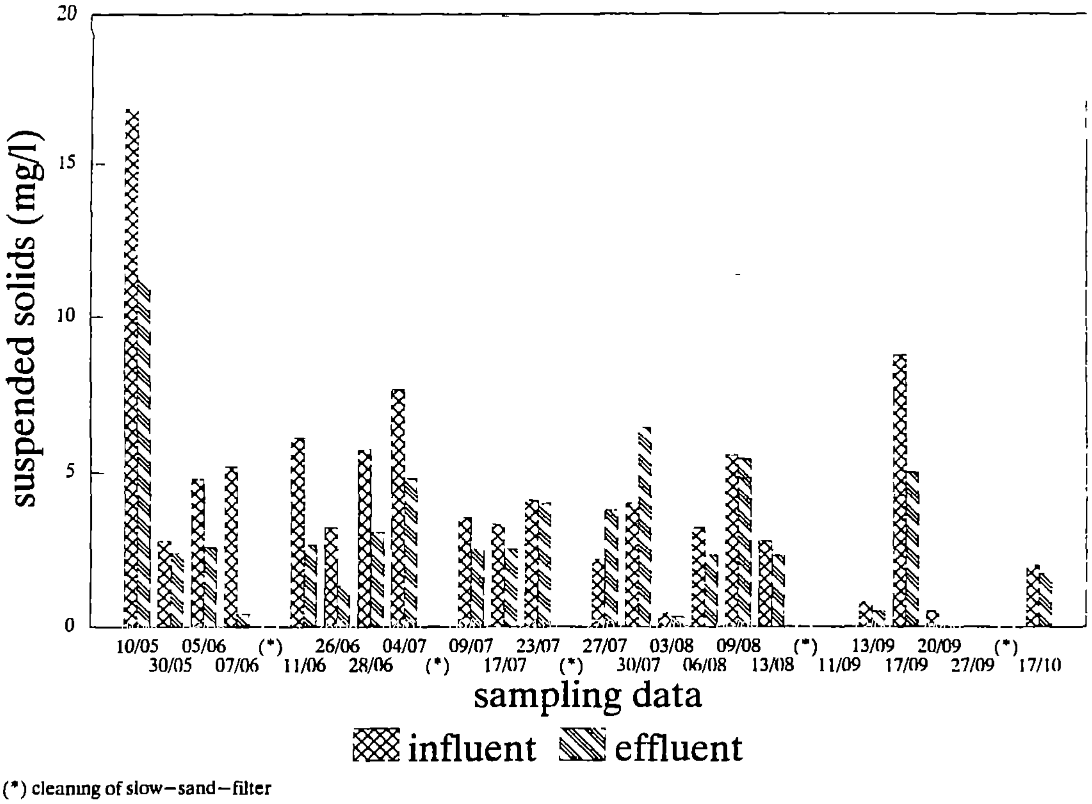


Fig.V.4.1 Slow-sand-filter, suspended solids conentration (May - Oct '90)

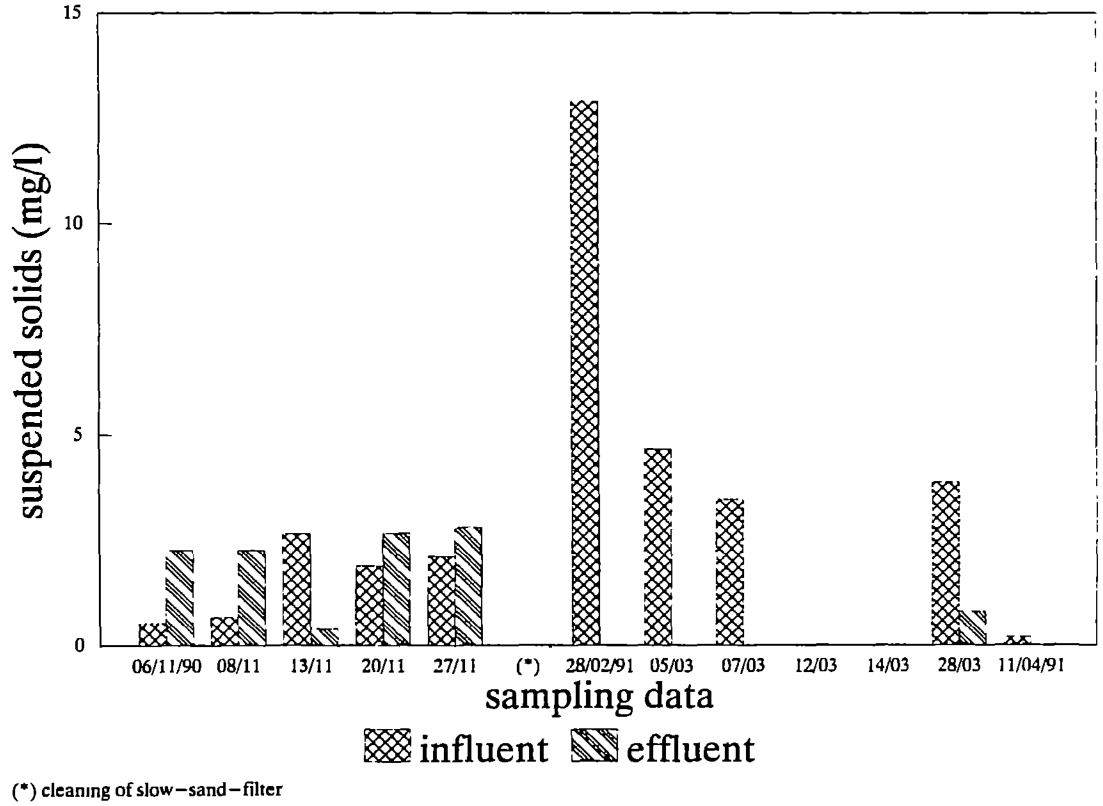


Fig.V.4.2 Slow-sand-filter, suspended solids concentration (Nov '90 - Apr '91)

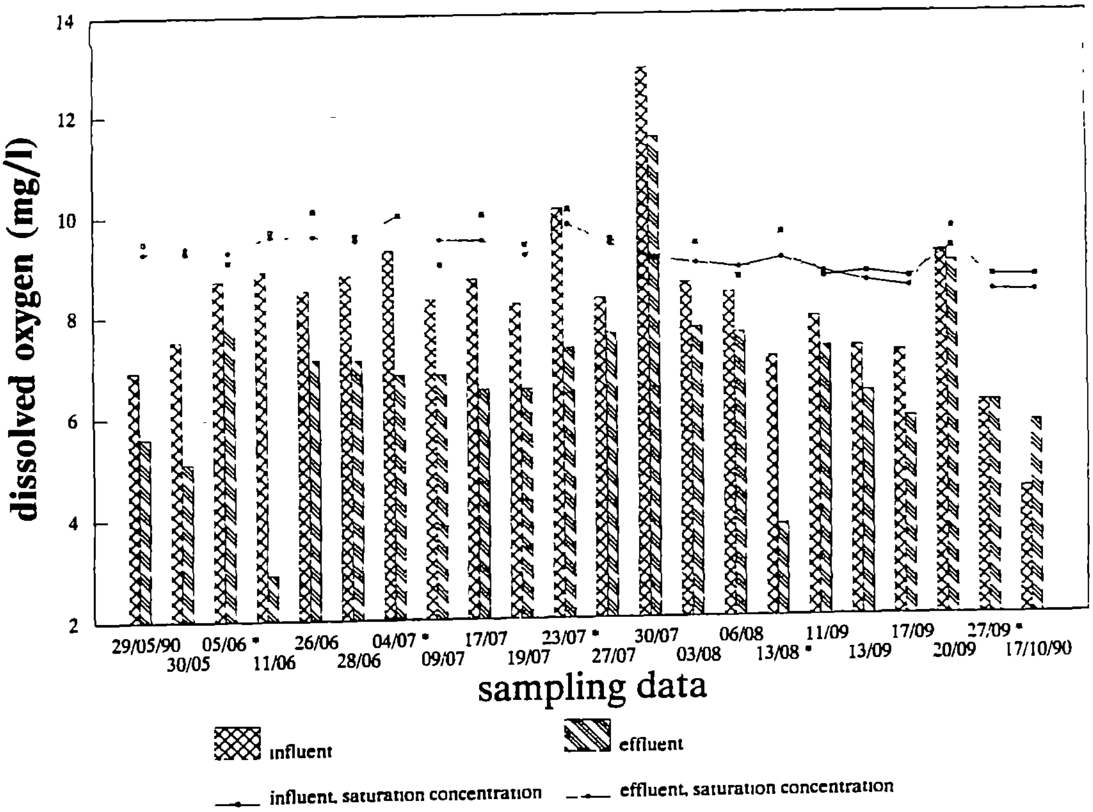


Fig.V.5.1 Slow-sand-filter, dissolved oxygen concentration (May - Oct '90)

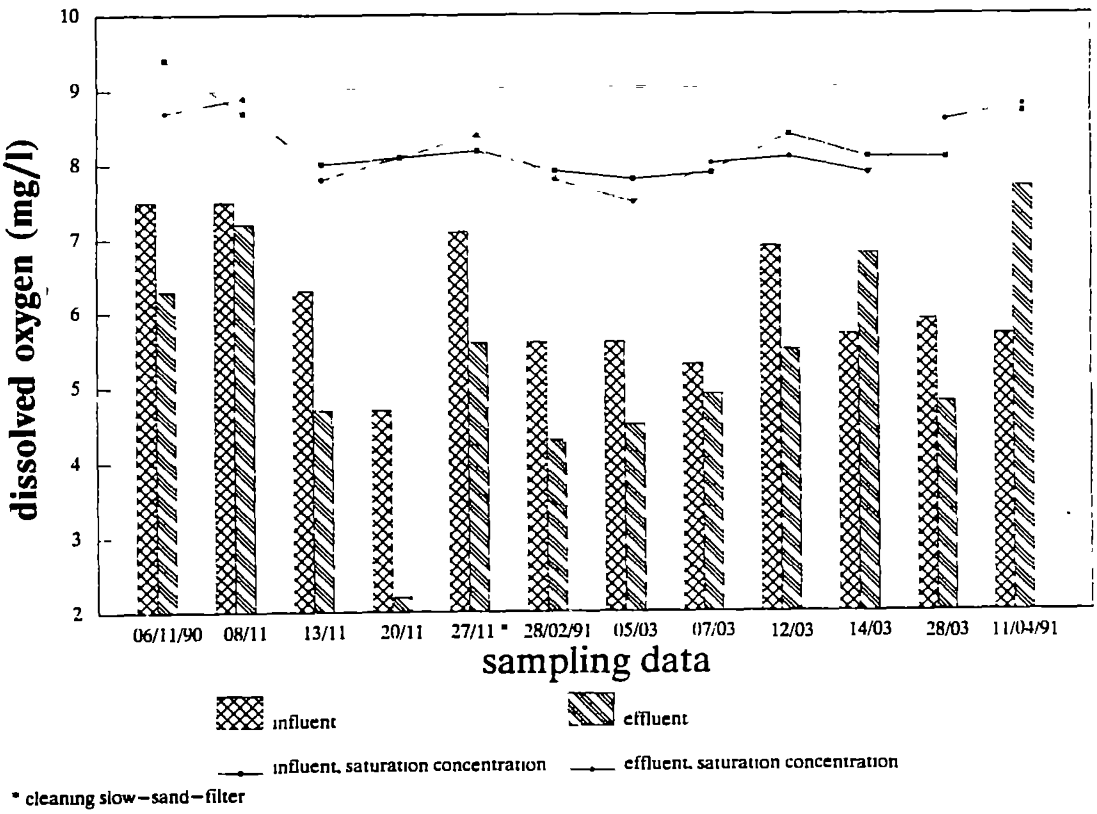


Fig.V.5.2 Slow-sand-filter, dissolved oxygen concentration (Nov '90 - Apr '91)

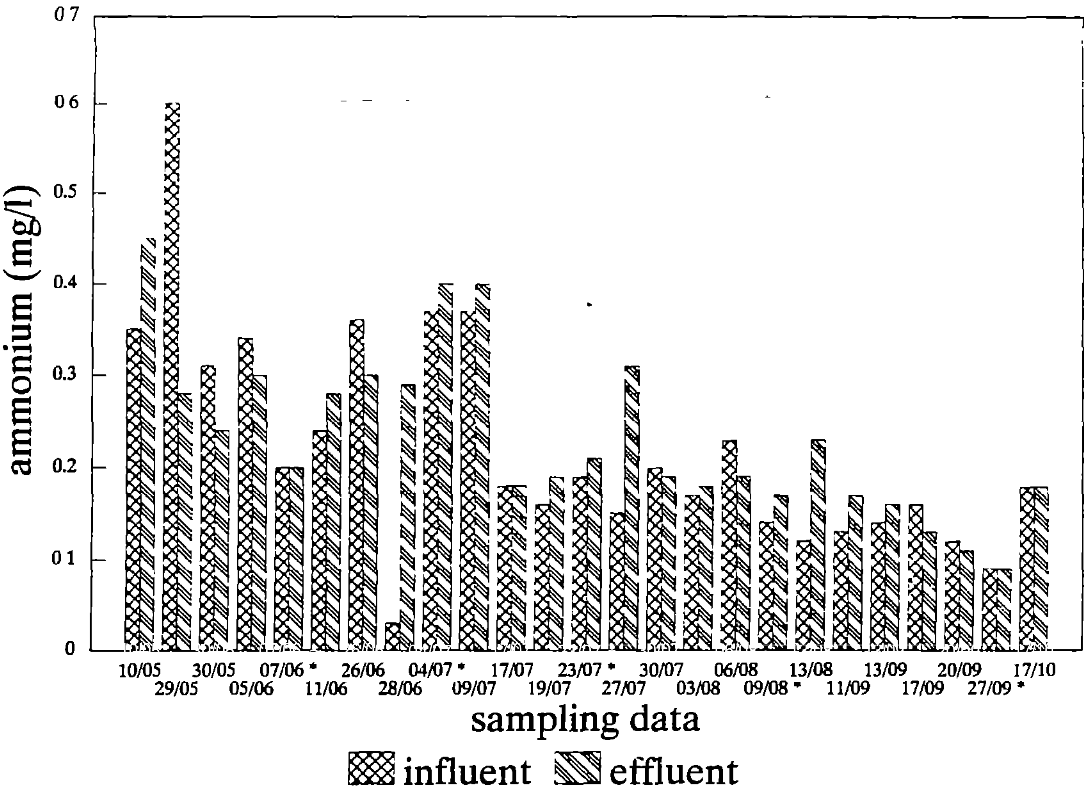


Fig.V.6.1 Slow-sand-filter, ammonium concentration
(May - Oct '90)

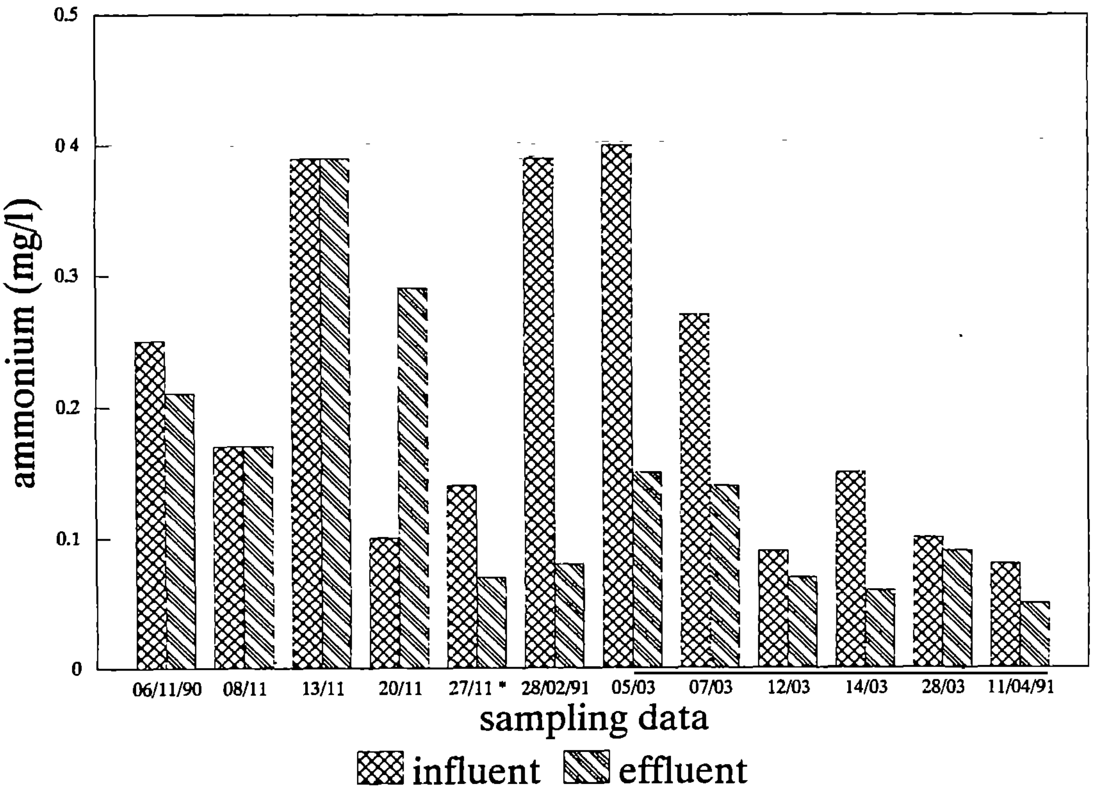


Fig.V.6.2 Slow-sand-filter, ammonium concentration
(Nov '90 - Apr '91)

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11. **Groot, C.P.M. de en Breemen, A.N. van**: Ontspanningsflotatie en de bereiding van drinkwater

12. **Blanken, J.G. den en Hoogh, M.P.A.J. de**: Modelvorming voor verwijdering van indicatororganismen in het actief-slibproces.

13. **Mishra, K.K. and Breemen, A.N. van**: Gravel-bed flocculation.

14. **Vlis, E. van der**: De filtratietheorie. (maart 1988)

15. **Koreman, E.A. en Breemen, A.N. van**: Toepassing van het vriesdooiproces bij de ontwatering van coagulatieslib.

16. **Ganzevles, P.P.G., Kop, J.H. en Ywema, R.**: Materiaalkeuze afvalwaterleidingen. (juni 1988)

17. **Nieuwenhuyze, R.F. van, Stokman, G.N.M., Kuijper, R., Gerritsen, J.J. en Donze, M.**· Detectie van proceswater met behulp van thermische remote-sensing.

18. **Blanken, J.G. den en Hoogh, M.P.A.J. de**: Modelvorming voor een goede procesregeling van de desinfectie met chloor c.q. ozon aan de hand van instelbare en/of direct meetbare variabelen. (augustus 1988)

19. **Noppeney, R.M.**: De invloed van stagnante zones op dispersie.

20. **Noppeney, R.M.**· Gevoeligheidsonderzoek Alarmmodel Rijn; De invloedslengte van samenvloeiingen bij dispersie. (november 1988)

21. **Noppeney, R.M.**: De verspreiding van olie op rivieren benaderd met het Taylor-model.

22. **Noppeney, R.M.**. De invloed van near-field processen op een far-field dispersie beschrijving.

23. **Ellen, T. van** : De invloed van afvoerfluctuaties op de verspreiding van een verontreinigingsgolf (juni 1989)

24. **Blanken, J.G. den**: Afscheidssymposium prof.ir. A.C.J. Koot.

25. **Hooykaas, L.J., Donze, M. en Klapwijk, Sj.P.** : Fosfaatbalans van de polder Reeuwijk en de Reeuwijkse plassen. (januari 1989)

26. **Verwoerdt, P. en Mazijk, A. van:** De één-dimensionale dispersievergelijking van Taylor bij een opdeling van de rivier in vakken. (maart 1989)

27. **Mazijk, A. van**: Gevoeligheidsonderzoek Alarmmodel Rijn, eindrapportage. (mei 1989)

28. **Blanken, J.G. den en Hoogh, M.P.A.J. de**: Desinfectie van behandeld afvalwater met chloor: vergelijking van eenpunts- en tweepuntsdosering;
deel 1: Tekst, bijlage A, B en C.
deel 2: Bijlage D, E, F en G.
(mei 1989)

29A. **Verstappen, G.G.C.**: Gedrag van organische micro-verontreinigingen in rivieren. (juli 1989)

29B. **Mooren, J.J.M. en Heide, J. van der**: Leaching of heavy metals from thermally decontaminated soils. (maart 1989)

30. **Nieuwstad, Th.J., Wortel, N.C., Bout, F.N. van den en Alting, B.J.**: Een vergelijking tussen ladingsgewijze en continue zuivering van afvalwater. (juni 1989)

31. **Kramer, J.P., Wouters, J.W. en Kop, J.H.**: Dynasand Filtratie. (juli 1989)

32. **Nieuwstad, Th.J.**: Treatment of municipal wastewater in a pilot-scale airlift-loop reactor. (december 1989)

33. **Ankum, P.**: Polders; achtergronden, ontwerp en toekomstige ontwikkelingen.

34. **Brandsma, T.**: Evaporation in Hydrology and Meteorology. (juli 1990)

35. **Mooren, J.J.M.**: Het uitlooggedrag van kunstmatig samengestelde en verontreinigde grond (2 delen)

36. **Singh, S.N., Boekelman, R.H., Rientjes, T.H.M. en Dam, J.C. van:** Behaviour of groundwater of the polder Groot-Mijdrecht.

37. **Boekelman, R.H. en Rientjes, T.H.M.**: Workshop hydrological models.

38. **Stavrides, N., Rientjes, T.H.M. en Dam, J.C. van:** Network optimization, a simple approach applying GIS and MLR.

39. **Duindam, P., Morales, C. and Heide, J. van der:** Investigacion sobre los desechos solidos de la ciudad de Masaya, Nicaragua.

40. **Heide, J. van der:** Evaluacion hidraulica de plantas potabilizadoras de filtracion rapida en Nicaragua.

41. **Heide, J. van der:** Metodologia de potabilizacion de agua superficial en Nicaragua.

42. **Veldkamp, R.G.**: Randvoorzieningen van rioolstelsels kritisch beschouwd

43. **Kruithof, J.C., Schippers, J.C. and Dijk, J.C. van:** Abastecimiento de Agua Potable de Agua Superficial en los años Noventa.

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