Slow Sand Filtration for Community Water Supply in Developing Countries — Bulletin No. 9

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A Selected and Annotated Bibliography

9

Bulletin Series

ABSTRACT

This bibliography lists selected publications written on the subject of slow sand filtration for community water supply in developing countries. The major part of the publications is written in the English language and mainly deals with the technical aspects of the process. The publications are annotated and provided with keywords. An author- and keyword index as well as a list of institutions and organizations that can give further information on the subject are added to this bibliography.
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Slow Sand Filtration for Community Water Supply in Developing Countries

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BULLETIN NO. 9
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A special word of thanks goes to Mr. H.J.G. Hartong for the extensive work done on the literature survey and for the selection and annotation of the references presented in this booklet.

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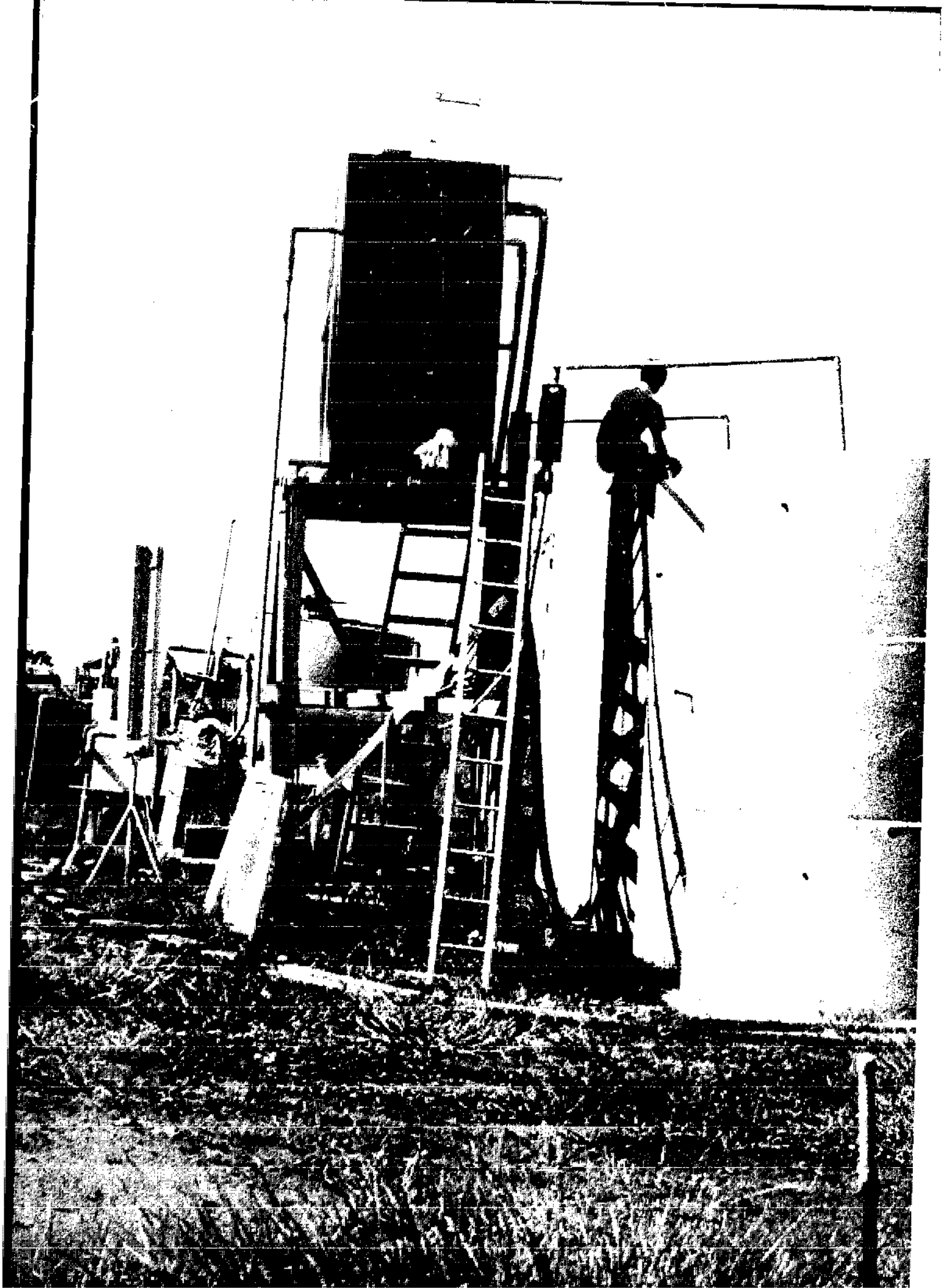

PREFACE

Although published nearly 150 years after the first application of slow sand filtration for public water supply, this bibliography is certainly not an anachronism. On the contrary, there is an ever growing awareness that today this tried and true water treatment system still may give excellent results at competing costs and that it is an alternative worth considering when selecting water purification methods for new schemes.

Both industrialized and developing countries cherish this interest. In the former ones the excellent polishing function of slow sand filtration as a last step in an often complicated treatment process is widely recognized, while the system may also be used as a safety barrier in case of calamities. The application of relatively high filtration rates and new methods of mechanical cleaning have made the process also interesting from an economic point of view.

In developing countries, where in general surface water is not so heavily polluted, slow sand filtration is often applied as a single treatment process; only where necessary preceeded by a simple pre-treatment for turbidity removal. Optimal use can be made of locally available materials such as bricks, mud blocks and mass concrete, while also filtersand of good specifications is readily available in most countries. Operation and maintenance are relatively easy and can be done by semi-skilled operators Operational costs are minimal, the more so as no chemicals are required. Slow sand filtration may be regarded as an appropriate water treatment process and its wider application may considerably contribute to an improved provision of safe drinking water in developing countries.

This bibliography lists references on slow sand filtration for rural water supply in developing countries and I trust that it will assist those concerned with the planning, design and implementation of water supply programmes in finding and using the information they need.

Prof. L. Huisman

INTRODUCTION

This selected and annotated bibliography has been prepared in the context of the international research and demonstration project on 'Slow Sand Filtration', undertaken by a number of institutions in developing countries in close collaboration with the International Reference Centre for Community Water Supply.
The project aims at promoting slow sand filtration for biological treatment of drinking water in rural and urban fringe areas of developing countries. As a first step, therefore, reliable information on the design, construction, operation and maintenance of slow sand filters under local conditions is being generated by means of a programme which comprises applied research, field investigations and literature studies.
The technical criteria developed will be further tested in the field on a number of full scale village demonstration plants. At the same time attention will be paid to cultural and socio-economic factors that could hamper the optimal performance of these plants.
Essential for the project is the demonstration character. An adequate dissemination of the outcome of the project activities both inside and outside the participating countries is striven after.
Appropriate publications, the organization of local, national and regional seminars and training courses are mechanisms that will be used for the transfer of specific knowledge and experiences.

This bibliography is a result of a literature survey carried out from September - December 1976.
Many periodicals, bibliographies and classified catalogues of documentation centres were scrutinized during this survey. As it was felt however, that especially relevant information from the field was hard to obtain in that way, an additional mail survey was set up. To that end, a tentative list of references was sent to several institutions and individual experts for critical review. Thanks to an encouraging response, a more extensive list of 300 references could eventually be compiled.
This bibliography comprises a selection of these references. In view of the objective of the slow sand filtration project, the main criterium for selection has been the practical value of the publication with regard to the application of slow sand filtration in rural areas of developing countries.
As much as possible, publications have been selected that are easily accessible. Most of them are written in the English language and have been published recently. As for this latter aspect, no special selection was necessary thanks to the encouraging fact that approximately 50 percent of the references found during the literature survey was published in the seventies of this century.

The references listed here mainly deal with the technological aspects of the process. As non-technical aspects of community water supply such as training, management, public health and socio-economic impact are not exclusively related to the system of slow sand filtration, no special publications on these topics are included in this bibliography.

However, if a publication dealing with filtration techniques also covers some non-technical topics, it is mentioned in the abstract. In case the reference covers more technical items than slow sand filtration, the abstract does not deal with these points.

The bibliography is provided with an authors-index and an index of keywords. For a good understanding of the keywords used, the index also gives the related terms.
The bibliography ends with a list of institutions that can provide information and literature on the application of slow sand filtration for rural areas of developing countries.

ANNOTATED REFERENCES

1. AGARWAL, I.C. and AGRAWAL, G.D.
Operating slow sand filters with alum-coagulated water.
Proceedings of a Symposium on Environmental Pollution. N.E.E.R.I.
Nagpur, India, 1973, pp. 209 - 217

algae/c:india/filtration rate/pilot plant/pre-treatment/raw water quality

This paper presents the results of investigations on operation of slow sand filters with alum-coagulated water on field units, both prototype and pilot-scale. The reduction in length of filterrun due to operation with alum-coagulated water did not seem to be appreciable. The clarification obtained as well as the bacteriological quality of filtered water as indicated by coliform count was comparable to that of normal slow sand filters. The results of analyses of the top layer formed, of primarily organic and algal content, are also reported. The results of this study confirm that slow sand filters can be operated with alum-coagulated water without rapid headloss built up and hence without appreciable reduction in the filterrun.

2. AGARWAL, I.C. and AGRAWAL, G.D. and MISHRA, Y.D.
Over loading of slow sand filters.
Symposium on water treatment distribution and management.
Nagpur, India, February 21 - 23, 1972, 7pp.

c:india/filtration rate/performance

Study at the water works of Kanpur, India, to explore the possibility of running slow sand filters at higher than conventional rates. From the operational data that resulted from experiments with two filters, it can be concluded that an increase in the filtration rate from 65 to 80 gdp/sft (3,16-3,90 m/d) did not result in a corresponding decrease in filterrun.

3. AGARWAL, I.C. and AGRAWAL, G.D.
Intermediate rate water filtration for hot and developing countries.
Proceedings 2nd International Conference on 'Environmental health engineering in hot climates and developing countries: water, waste and health in hot countries.'
Loughborough University of Technology, September 21 - 24, 1975, pp. 67 - 91

algae/cost/c:india/design/filtration rate/performance/pilot plant/pre-treatment/raw water quality

This study aimed at evaluating the performance of slow sand filters receiving alum-coagulated influents at conventional and higher rates of filtration. A detailed economic analysis was done to arrive at an optimal rate of filtration. Tests have been done with experimental filter units and pilot scale filters on the effects of four filtration rates, ranging from 133 to 1000 $l/m^2/hr$, on effluent quality, length of filterrun and economics, also in comparison to rapid sand filters. In the opinion of the authors, this intermediate rate water filtration has many advantages and is highly suitable for hot and developing countries. Intermediate rate filters retain the advantage of slow sand filters, namely simplicity in construction, operation and maintenance, efficiency and cheapness, while they substantially eliminate or reduce the disadvantages of slow sand filters.

4. AGARWAL, I.C. and AGRAWAL, G.D. and MISHRA, Y.D.
Cost analysis of slow sand and rapid sand filters.
Kanpur, India (n.d.)

cost/c:india/filtration rate/pilot plant/pre-treatment

When no chemical coagulation is used, slow sand filtration is much cheaper than rapid sand filtration (67%). Even when chemical coagulation is used as pre-treatment, filtration may favour the use of slow sand filters (saving 8%). Changing the filtration rate of slow sand filters, a minimum can be found but which is not the rate that may be adopted for design (optimum rate: 600 $l/m^2/hr$). The cost of treatment of water using slow sand filtration at a rate of 612 $l/m^2/hr$ is 51,8% less than the cost of treatment using rapid sand filtration at a rate of 8820 $l/m^2/hr$. In both cases the pre-treatment is the same.

5. AMERICAN WATER WORKS ASSOCIATION
Water works practice.
A manual issued by the American Water Works Association, 1925

c:u.s.a./filtration mechanisms/filtration rate/operation and maintenance/performance/pre-treatment/raw water quality/shading

The slow sand filtration part of this manual mainly deals with a brief description of some operation methods that have proved to be advantageous. The main aspect discussed is the operational cycle of: filling and commissioning the filter, period of forming headloss end of filterrun and preparing for cleaning, scraping, raking, re-sanding and cleaning the lower part of the sand filter. After describing the theory of filter action and filter efficiency, a description is given of double filtration in several cities in Europe and America.

6. BELSARE, S.V.
In defense of slow sand filters.
Journal of the Indian Water Works Association.
vol. VIII, 1976, no. 3, pp. 231 - 235

algae/c:india/design/filtration mechanisms/general description

Slow sand filters on their own are very effective in producing water with a high bacteriological purity, because of the various processes taking place in the filter media, as described in the article. As rapid sand filters are not so effective from a bacterial point of view, disinfection may have to be used so as to obtain complete bacteriological purity of the water. In rural areas reliable disinfection is not possible, due to lack of skilled supervision and of simple chemical tests. The author, therefore, advocates slow sand filters (especially for application in rural areas) as they have the extra advantage of simple construction and operation. After describing the filtration mechanisms: transport mechanisms (straining, sedimentation, inertial or centrifugal forces, diffusion, mass attraction, electrostatic or electro-kinetic attraction), attachment mechanisms (electro-static attraction, mass attraction, adherance) and the biological filtration mechanisms, the author discusses some construction details and comes to his conclusions mentioned above.

7. BENARDE, M.A. and JOHNSON, B.
Schistosome cercariae removal by sand filtration.
Journal of the American Water Works Association, 1971, pp. 449 - 453

filter material/filtration mechanisms/filtration rate/performance/pilot plant/raw water quality

Most reports published in the past on the use of sand to remove cercariae, have been negative. However, having no certainty on the subject the authors tried it again - this time using a twist. Rather than using a vertical filter column, the authors turned the column on its side and when doing so, they obtained the results that deserve additional evaluation. Reported are sand size, flow rates and depth of sand necessary for cercariae removal by a horizontal sand filter.

8. BHOLE, A.G.
Design of Water Treatment Plants, part III.
Journal of the Indian Water Works Association.
vol. VII, 1975, no. 4, p. 249

c:india/design/extra treatment/filter material/operation and maintenance

The publication deals with the design of a slow sand filter, a chlorine house and chlorinator, and an underground reservoir for storage of clear water. The design criteria of the slow sand filter unit includes the following: the size and number of filter units, the supernatant water reservoir, the filterbed, the filterbottom and underdrainage system, filterbox and filter control system.

9. BOUCHER, P.L.
Micro-straining.
Journal of the Institute of Water Engineers, 1951, 5, pp. 561 - 595

algae/cost/c:u.k./filtration rate/performance/pre-treatment

An account is given of the design and use of micro-strainers. A typical unit is described and illustrated and details are given of the straining fabric. When discussing the problem of determining the size of strainer and rate of operation required to treat water at a given rate of flow, the author stresses the importance of the conception of filtrability of fluids. Filtration of raw water through micro-strainers before filtration through sand, generally increases the rate of flow through the filters and the length of filterrun. Operational difficulties, methods of reducing these difficulties and operational experiences and results from some English water and sewage works are described. Subjects dealth with included cost of operation, the amount of head allowed on slow sand filters after micro-straining, life of the straining fabric and the advantage of pre-chlorination.

10. BROOK, A.J.
The bottom-living algal flora of slow sand filter beds of water works.
Hydrobiologia, 1954, 6, pp. 333 - 351

algae/c:u.k./filtration mechanisms/operation and maintenance

In 1947 a study was done on the unattached bottom-living algal flora of the slow sand filters of the Newcastle and Gateshead Waterworks at Whittle Dene, Northumberland. Marked differences in the floral composition were apparent in filters that had been in operation for different periods of time, many species disappearing from the older beds. Consideration of the factors probably involved suggested that the differences were largely due to the feeding activities of the aquatic fauna. This was confirmed by examination of larval food. These observations are considered in relation to those of other workers on the establishment of algae in fresh waters and on algal periodicity. A list is given of the algae found in the filters and the apparatus used for collecting samples is illustrated.

11. BROOK, A.J.
The attached algal flora of slow sand filter beds of water works.
Hydrobiologia, 1955, pp. 103 - 117

algae/c:u.k./filtration mechanisms/operation and maintenance

Results are given of an investigation carried out on the attached algal flora, as etimated by the growth on glass slides, of the slow sand filter beds of the water works at Whittle Dene, Northumberland. The flora mainly consists of filamentous and attached diatoms and Chaetophoraceae, which are listed at the end of the article, and shows marked seasonal differences,in composition and abundance. The factors affecting seasonal differences, colonization and succession are discussed. The occurrence of the principally attached algae is given in a table. Differences in the attached flora of filters that have been in operation for different periods of time, are considered in relation to the aquatic fauna.

12. BURMAN, N.P.
Routine water bacteriology and its influence on engineering practices.
Journal of the Institution of Water Engineers, 1963, 17, pp. 551 - 563

filtration mechanisms/operation and maintenance/performance

In a review of routine water bacteriology and its effects on engineering practice, the author discusses standard methods of bacteriological examination and recent improvement in methods. The effects of the various water treatment processes on the survival of bacteria are described with special reference to sand filtration and filterbed cleaning, chemical treatment and storage in reservoirs.

13. BURMAN, N.P.
Bacteriological control of slow sand filtration.
Effluent and Water Treatment Journal, December 1962, pp. 674 - 677

algae/c:u.k./filtration mechanisms/operation and maintenance/performance
/pre-treatment

The author discusses and explains some phenomena causing a change in the bacteriological efficiency of some slow sand filters in the United Kingdom. Several influences on the bacterial reduction of slow sand filters are described, such as: cleaning of the filterbed, i.e: removal of the zoogleal layer; pollution by birds; development of the zoogleal layer; coppering; re-sanding and re-washing during the summer months; the way of colony counting.

11. BURMAN, N.P. and LEWIN, J.
Micro-biological and operational investigation of relative effects of skimming and in situ sand washing on two experimental slow sand filters.
Journal of the Institution of Water Engineers, 1961, p. 355

design/filtration mechanisms/operation and maintenance/performance/pilot plant

The authors describe the operation of an experimental in situ sand washing plant. Hydraulic investigations concerned with the design of the plant and with the long-term effects on filtration, particularly in relation to the bacteriological quality of the filtrate are described. Some fundamental observations are made on bacterial changes occurring in the supernatant water and the sand during filtration.

15. CENTRAL PUBLIC HEALTH AND ENVIRONMENTAL ENGINEERING ORGANIZATION
Ministry of Works and Housing.
Manual on Water Supply and Treatment.
New Delhi, India, 1976

design/filter material/filtration rate/operation and maintenance/performance/raw water quality

The part of this manual dealing with slow sand filtration gives concise information on aspects, such as: design, operation, raw water quality, flow control, performance and maintenance.

16. COX, C.R.
Operation and control of water treatment processes.
World Health Organization, Geneva, 1969.
Monograph Series no. 49, 392pp.

algae/design/filter material/filtration rate/operation and maintenance/pre-treatment/raw water quality

This authoritative text on all aspects of the treatment of domestic water supplies brings together a body of information on water treatment and control. Its main purpose is to serve the needs of plant superintendents, operators and laboratory personnel. Sufficient theory is presented to provide a basic understanding of the processes described, with emphasis on practical operating problems. The approach used has been not to present standards of design, but rather to reveal how to get the most out of a plant already built. The chapter on filtration includes a short description of the slow sand filtration process dealing with some operational and design details, depending on the raw water turbidity or algal content, plain sedimentation or whether chemical pre-treatment is thought necessary.

17. DHABADGAONKAR, S.
Mini-filter for protected water supply to rural communities in Rajasthan.
Journal of the Indian Water Works Association.
vol. VII, 1975, no. 3, pp. 177 - 182

c:india/design/extra treatment/filter material/filtration rate/low cost and simple methods/operation and maintenance

The article begins with the description of community water supply problems in Rajasthan, India. The water treatment consists of raw water storage, mini-filtration, chlorination and treated water storage. Details are presented of the mini-filter, a packaged slow sand filter unit. The filter consists of a precast vessel, 60 cm internal diameter and 2,7 m height, covered on top. Depth of filtersand 100 cm, effective size 0,3 mm with a uniformity coefficient of 2,0. The suitability of this filter for potable water supplies up to 1000 litres per day is discussed.

18. EDWARDS, D.M. and MONKE, E.J.
Electro-kinetic studies of slow sand filtration processes.
Journal of the American Water Works Association, 1967, pp. 1310 - 1319

filtration mechanisms/performance/pilot plant/raw water quality

The operation of a colloidal clay-silica sand system was studied by introducing a bentonite clay suspension into a 20-in. silica sand column. The purpose of this study was to investigate the effect of pH, period of operation and depth of column on the electro-kinetic properties of the clay colloids and the total colloidal clay-silica sand system. It soon became quite apparent that another ingredient to the system, the accumulation of bacteria and their metabolic products, principally in the surface layer of the column, could not be disregarded. The zêta-potential of the column changed because the column was altered by the clay colloids and bacteria which accumulated in the surface layer. An important finding was that bacteria, at least of the type accumulating on soil surfaces, may exhibit a positive electrical charge. The positively charged bacteria, clay micelle orientation and diffusion into areas of low shear rate were the most probable mechanisms for the retention of clay colloids by the silica sand column. The growth of bacteria and the corresponding positive electro-kinetic charges in the inlet section of the filter could help to explain the actual behaviour of the Schmutzdecke development on field-installed slow sand filters.

19. FOLPMERS, T.
On the disappearance of B. coli and faecal Streptococci (Enterococci) as the result of slow sand filtration.
Antonie van Leeuwenhoek, 1941, pp. 104 - 110

c:netherlands/extra treatment/performance/pre-treatment

At the Rotterdam Water Works the raw water, after settling for 10 to 12 hours, goes first through a Paterson filter plant and then through a slow sand filter with a bed of 1,5 m deep. The water is either chlorinated after filtration or, in winter, treated with activated carbon before filtration. Determinations were made microscopically and on special media of Bact. coli and faecal streptococci. Faecal streptococci were found in the effluent from the slow sand filter at temperatures below 1^0C, but they began to disappear at higher temperatures. The disappearance of these organisms was not due to the filter action but to their destruction by amoebae and other protozoa. During cold weather, the protozoa get encapsulated and no longer consume bacteria. Feacal streptococci in the effluents from the filters were less numerous than B. coli. It can be assumed that water free of bacteria are more likely to be present in the effluent in winter; in this season the water should be chlorinated.

20. FRANK, W.H.
Récherches récentes sur la récharge des eaux souterraines par des filtres à sable opérant lentement et application pratique des résultats. Extrait de la publication de l'A.I.H.S. XII, no. 2, 1967, pp. 56 - 64,
Recent investigations on the artificial groundwater recharge by means of slow sand filters and practical application of the results.
Reprint of an A.I.H.S. publication; also published in the series: Issues of the Dortmunder Stadtwerke AG, nr. 62 (french).

algae/c:germany/filtration mechanisms/filtration rate/performance/pre-treatment/raw water quality

A well-illustrated description of the artificial recharge process in Dortmund, that consists of infiltration by means of slow sand filtration. For improvement of the recharging methods, a second biologically active zone (pre-filtration) must be constructed with an intensive aeration of the water between them. The pre-filters filled with gravel act as space filters and require a complete cleaning of the whole filter material only every 4 to 5 years. The results of this addition to the pre-filters were: to raise the O_2/CO_2 ratio; to lengthen the filterrun; to raise the filtration rate; to create a greater security against suddenly occuring impurities. The chemical, bacteriological and biological performance of the slow sand filter is described and illustrated extensively with special attention to oxygen content, pH value, phosphate content, bacteria count, number of germs, decomposition of detergents and mobility of manganese.

21. FRANK, W.H.
Research problems connected with artificial groundwater recharge in the Ruhr valley.
International conference on water for peace. Washington, 1976, 15pp.
also published in the series: Issues of the Dortmunder Stadtwerke AG, nr. 65
(see no. 20)

22. FRANK, W.H.
Fundamental variations in the water quality percolation in infiltration basins.
Vol. I, artificial groundwater recharge, paper 7.
Proceedings of a conference held at the University of Reading, England, September 21 - 24, 1970, 30pp.
also published in the series: Issues of the Dortmunder Stadtwerke AG, nr. 106
(see no. 20)

23. FRANK. W.H.
Artificial recharge in the Federal Republic of Germany.
International Water Supply Association, 9th Congress, September 11 - 14, 1972, New York, 2pp.
Special subject no. 11
also published in the series: Issues of the Dortmunder Stadtwerke AG, no. 124

c:germany/general description

A short description of the artificial recharge process practiced in Germany: before the raw water percolates into the underground, slow sand filtration takes place and functions both as infiltration area and as purification stage. After describing several points concerning the extension of the artificial recharge, the author discusses several topical problems related to the slow sand filtration aspects of this water treatment method.

24. FRANKEL, R.J.
Series of filtration using local filter media.
Paper presented at the annual conference of the American Water Works Association, Chigaco, 1972.
also published in: Journal of the American Water Works Association, February 1974, vol. 66, no. 2, pp. 124 - 127

cost/c:south east asia/extra treatment/filter material/filtration rate/low cost and simple methods/operation and maintenance/performance/pilot plant/pre-treatment/raw water quality

An inexpensive simple filtration system, making use of local materials, was sought for potable water supplies in developing countries of Asia. The most successful filtering material for a roughing filter was found to be shredded coconut husks and for a secondary polishing filter, burnt rice husks. The bacteriological efficiency of the combined roughing and polishing filters was generally on the order of 99%, as was investigated by carrying out laboratory experiments. With a minimal dose of chlorine, they produced clear and potable water with considerable savings in operation and maintenance costs, such as: materials, labour, and level of training for the operator.

25. FRANKEL, R.J.
Evaluation of low cost water filters in rural communities of the lower Mekong basin.
Asian Institute of Technology.
Bangkok, Thailand, 1974

c:south east asia/filter material/filtration rate/low cost and simple methods/operation and maintenance/performance/pilot plant/pre-treatment/ raw water quality

This report describes the results of a programme for testing the application of a new concept for the filtration of village water taken from surface streams, canals or ponds in South East Asia including installation and operation of full-scale pilot units in each of the 4 lower Mekong basin countries, together with supplemental laboratory testing and research. The method applied is a two-stage process, in which the water first passes through shredded coconut fibre, then through burnt rice husks. The data reported are the results of a pilot plant testing programme.

26. GECAGA, J. and RUNJI, C.G.
Slow sand filtration project in Kenya.
University of Nairobi, Kenya; Department of Civil Engineering.
An interim report, 1976, 36pp.

algae/c:kenya/filter material/filtration rate/low cost and simple methods /performance/pilot plant/raw water quality/shading

This project is undertaken in collaboration with the WHO International Reference Centre for Community Water Supply, within the framework of the IRC Slow Sand Filtration Project. Pilot plant investigations have been made of the biological, chemical and bacteriological performance of an open, a covered and an upward flow filter. The measured data of the raw and filtered water quality are added. The filtration rate was kept constant at 0,1 m/hr; filter sand specifications: effective size 0,65 mm and uniformity coefficient 1,38. Readily available sand has

been used, because it was thought that carefully graded sand might be difficult to obtain or too costly in rural areas, as it was the ultimate objective of the project to develop methods especially suited for a rural community water supply. This report describes the first part of the research that is still going on, so conclusions have not yet been drawn.

27. GHOSH, G.
Slow sand filters (for water purification).
Indian Engr. 1944, 115, p. 133

filter material/performance/raw water quality

Chemical and bacteriological analyses of waters which have been passed through filters containing sand of various sizes have shown that the effective particle size of the filter medium for slow sand filtration should be between 0,25 and 0,35 mm.

28. GROMBACH, H.E.
Study of rural water treatment plants in the Sudan Gezira, part I,II,III.
Paper of a Workshop held in Dar es Salaam.
World Health Organization Regional Office for the Eastern Mediterranean, EM/ES/79, Sudan 42/R, 1965

cost/c:sudan/design/extra treatment/filter material/filtration rate/low cost and simple methods/operation and maintenance/performance/pre-treatment/raw water quality

On the request of the Sudan Government, the WHO Regional Office for the Eastern Mediterranean provided a short-term consultant for the study of rural community water supply using water from irrigation canals in the Managil extension of the Gezira Irrigation Scheme. The author finds that the standard filter plants of the Sudan Gezira Board can give sufficiently clear water, if they are operated and maintained properly. The state of the slow sand filters in the Gezira area was found to be bad, mainly due to insufficient attendance and maintenance of the filters. So as to improve this situation, detailed suggestions are worked out: 1. to improve attendance and operation of the plants by means of a better education, selection and supervision of attendance and by organizing maintenance teams doing an annual maintenance job on the filters; 2. for routine maintenance of the plants. These suggestions include very practical information on this subject; 3. for improving the construction of clear water tanks and adding chlorinators. To make water safe, additional chlorination is recommended; 4. for modifications to be applied in new plants.

29. GUINVARC'H, P. and BLANCHARD, P.
Comparaison entre la filtration lente et la filtration rapide.
La technique sanitaire et municipale, 1956, pp. 89 - 128.
A comparison between slow and rapid filtration (french)

algae/cost/c:france/extra treatment/filter material/filtration rate/ operation and maintenance/performance/pre-treatment/raw water quality

The authors define slow and rapid filtration and consider factors affecting the rate of filtration, types of filters that may be used and the need for disinfection of water after filtration. River waters are considered to be of two types, those of pH 7,5 - 8,5 which are usually colourless, have a high alkinality and contain little organic matter and those of pH 5,5 - 7,5 which may be coloured, contain organic material and inorganic material in a colloidal form. The filtrability of each type of water is discussed. The standards that treated water should meet are listed, treatment of river waters by sand filters has been studied and tables are given of the results of experiments to determine the effect on the following factors on the efficiency of the filters: the temperature of the raw water; the grain size of the sand; the depth of the filterbed; the filtration rate; the number of times the water is filtered. The authors mention, with reference to water works in France, rates of filtration and filter media used, preliminary treatment of the water before filtration and treatment afterwards. The efficiency of rapid and slow sand filters in the removal of bacteria, algae, taste, colour, etc., are compared and the results of comparative experiments given in tables. Problems encountered in preliminary treatment of water, treatment after filtration and in the operation of filters, the need for trained operators, and the costs of the two methods of filtration are discussed.

30. HAZEN, A.
The filtration of public water supplies.
John Wiley & Sons, New York, 1910, 321pp.

c:u.s.a./design/filter material/filtration mechanisms/filtration rate/ general description/low cost and simple methods/operation and maintenance/performance/pre-treatment/raw water quality/shading

Old but still valid, this illustrated handbook deals with many practical, non-advanced simple aspects of slow sand filtration, such as: construction, filter control, scraping and sand-washing. The main topics described are: filter construction, filter material, filtration rate and headloss, filter cleaning, filtration theory and efficiency, intermittent filtration, continuous filtration and the effect of turbidity and colour on the performance of the slow sand filters. Although some ideas on the slow sand filtration process may have changed, this book still serves its purpose very well.

31. HESPANHOL, J.
Investigaçao sôbre o comportamento e aplicabilidade de filtros lentos no Brasil.
Universidade de Sao Paulo, Faculdade de Higiene e Saúde Pública.
Sao Paulo, Brazil, 1969.
Investigation on the performance and application of slow sand filters in Brazil. (portugese)

algae/cost/c:brazil/design/filtration rate/general description/low cost and simple methods/operation and maintenance/performance/pre-treatment/raw water quality

There are in Brazil a great number of slow sand filter plants for public water treatment in small communities. The lack of knowledge of the operational conditions and maintenance of these systems and of the degree of purification of waters being treated, has brought some doubt to the sanitary authorities and design engineers about the feasibility and modern application of slow sand filtration. In order to study the behaviour of such filters, a research was carried out on the trends and stages of slow sand filtration development in several countries. At the same time, in Brazil, the systems in operation, under construction or in the design stage were considered during inspection visits to nearly 20% of the plants known. In spite of unsatisfactory characteristics that were found in the design and in the working system, even in cases of neglected maintenance and administration, it was considered that slow sand filtration, from a biological point of view, is a treatment quite feasible to meet the demand of a good quality of water in small Brazilian communities.
Nevertheless, the recommendation for a large scale use of slow sand filtration is conditioned to improvement of design, to an increase in the technical abilities of the operators, and last, to improvement of the administrative aptitude of the authorities concerning public water supply. As a conclusion, new types of planned research for a better comprehension of slow sand filtration processes, their use on turbid and polluted waters and decreases in installation costs, were introduced. Many drawings of plants are shown.

32. HOBBS, A.T.
Manual of the British Water Supply Practice, 1950.
SKEAT, W.O.
Manual of the British Water Supply Practice, 1961, the Institution of Water Engineers, Cambridge

algae/c:u.k./filtration mechanisms/filtration rate/general description/operation and maintenance/performance

This comprehensive work on water supply practice contains a general but brief description of the slow sand filtration process. Several aspects of slow sand filters are described, such as: the design of the

basin structure, hydraulic equipment and some recent developments in the design of Metropolitan Water Board filters; furthermore, some aspects of operation and maintenance, such as hydraulics and rate of filtering, manual cleaning, mechanization of filter cleaning and re-sanding and sandwashing.The filter performance and filter action are explained by discussing the biological purification process. This manual has been brought up to date in several new editions: first 1950, second 1954, third 1961, fourth 1969.

33. HOUGHTON, G.U.
Slow sand filtration and biological processes.
Paper presented at the Symposium on Water Treatment in the Seventies, January 1970.

algae/cost/c:u.k./filtration mechanisms/filtration rate/operation and maintenance/performance/pre-treatment/shading

The author describes several aspects of slow sand filtration, especially related to his own experience in Essex. After discussing the general features of the slow sand filtration process, he describes in detail: land requirements; prefiltration; filter cleaning; filtration rate; sludge disposal of a coagulation plant; removal of bacteria, viruses, organic matter, odour and taste; effects of algal growth; and relative costs of double-sand and coagulation methods. Regarding other biological processes for water treatment, the author concludes there is sufficient evidence to suggest that further research might be profitable. The main advantage of initial treatment by non-submerged filtration or biological sludge blankets would appear to lie in those cases where plants take their water directly from a river, without raw water storage.

34. HUISMAN, L. and WOOD, W.E.
Slow sand filtration.
World Health Organization (Geneva) 1974, Sw.F. 16, 122pp.

algae/design/filter material/filtration mechanisms/filtration rate/ general description/low cost and simple methods/operation and maintenance /performance

Slow sand filtration, the oldest method existing for water treatment, is still an outstanding method of purification; not only in rural areas, but also in many cities in industrialized countries. Under widely differing circumstances it has proved to be simple, reliable, inexpensive and efficient.
It has the advantage over other methods, that it makes better use of the local skills and materials available in developing countries and

it is far more effective than rapid filtration in removing bacterial contamination. The objective of this book is to counteract the tendancy among many water treatment engineers to regard the method as old-fashioned and to ignore it when planning new facilities. Descriptions are included on the design, construction and operation of modern slow sand filters, the theory of biological filtration and the various methods of cleaning filters, which range from simple manual techniques to advanced mechanical or hydraulic systems. Means by which slow sand filtration can be matched to any level or technological development are illustrated and the important application of slow sand filtration within the artificial recharge of groundwater sources, is described in detail. The results of practical experience in many countries under different conditions are reported, as well as the theoretical work carried out in many institutions on different aspects of the process.

35. HUISMAN, L.
Slow sand Filtration.
University of Technology, Delft, the Netherlands.
Lecture notes 1975

algae/cost/design/filter material/filtration mechanisms/filtration rate /general description/operation and maintenance/performance/pre-treatment /raw water quality/shading

A thorough, well-illustrated studybook of slow sand filtration. These lecture notes deal in a comprehensive way with many aspects of the slow sand filtration process, that is clearly explained by drawings and calculations. Before discussing the basic principles of slow sand filtration such as filtration mechanisms, algal actions and hydraulics, the general application of slow sand filtration is described as it was in the past as well as it is today. Several technological levels of filter cleaning can de distinguished, varying from manual cleaning to mechanical and hydraulic filter cleaning. The experiences in filter cleaning of the water works of London, Berlin, Antwerp and Amsterdam are also described. The way of designing and constructing slow sand filters, especially with regard to filterbox, sandbed, filterbottom and filtercontrol is elucidated with simple calculations and fundamental drawings. Finally, artificial recharge as a slow sand filtration process is worked out in detail. An extensive bibliography is added to these lecture notes.

36. HUISMAN, L.
Treatment methods for water supplies in rural areas of developing countries.
University of Technology, Delft, the Netherlands, 1975, 90pp.

design/general description/low cost and simple methods

A well-illustrated paper prepared by the author for the WHO International Reference Centre for Community Water Supply. It deals with drinking

water supply problems in rural areas of developing countries. Several technical aspects of drinking water supply are described, such as: water consumption, water sources, water treatment, transport and distribution and which techniques are to be adapted to local circumstances. Essential aspects of the slow sand filtration process are briefly discussed. In the annexes, simple designs of slow sand filter plants are given, for which use can be made of locally available materials.

37. IVES, K.J.
Filtration of water and waste water.
C.R.C. Critical Reviews on Environmental Control, August 1971, pp. 301 - 306

algae/cost/filter material/filtration mechanisms/filtration rate/general description/operation and maintenance/pre-treatment/raw water quality

A concise description of several topics on slow sand filtration. The authors reviews the literature published in the field of slow sand filtration by Van de Vloed (73), Ridley (62) and Huisman (78). He summarizes main opinions of slow sand filtration specialists on subjects such as: rate of filtration, sand specifications, biological filter action, raw water turbidity, chemical pre-treatment, (mechanical) filter cleaning, cost of operation and some new developments in slow sand filtration techniques: intermittent operation, use of a layer of activated carbon, artificial turbulence, mathematical modelling in slow sand filtration.

38. IVES, K.J.
Algae and water supplies, 4. Physical removal of algae.
Water and Water Engineers, 1957, 61, pp. 432 - 434

algae/filtration mechanisms/performance/pre-treatment/raw water quality

The author reviews work carried out on the filtration and microstraining techniques for removal of algae from water. In addition to minute and motile algae, certain diatoms such as Synedia and Nitzschia have also caused trouble: the danger exists that some preliminary treatment may break up colonies of algae to allow the single cells to penetrate the filter.
Algal growths have been found to precipitate calcium carbonate and magnesium hydroxide on slow sand filters, and during periods of high turbidity it was possible to reduce the pH-value of the water by coagulation with alum, and the deposited carbonate then raised the pH-value, thus reducing the quantity of lime required. This also has an adverse effect, as it causes a rapid rise in the headloss when free aluminium ions are present. The advantages and disadvantages of using

the slow, primary, rapid or magnetite [illegible]lter are given. The primary application of the micro-strainers i[illegible]upply has been, in conjunction with slow sand filtrati[illegible]ercome seasonal difficulties due to planktonic development. Exp[illegible]ces and places where micro-strainers are employed are descri[illegible]

39. IVES, K.J. and JAIN, P.K.
Slow sand filtration.
University College London.
Civil Engineering Research, 1971 - 1974

algae/filter material/filtration mechanisms/filtration rate/performance /pilot plant/raw water quality/shading

Study of the slow sand filtration process with two adjacent slow sand filters, each 11 m^2 in area. Investigated were profiles of turbidity removal and headloss through the depth, which are found to be not directly linked. Turbidity removal proceeds throughout the depth, but headloss is predominant in the top few centimeters, also when the filters are shaded to reduce photosynthetic growth. Changing the standard sand used by a 'builders sand' showed that the performance of the filters was relatively unaffected by the sand specification. The activity of aerobic oxidising bacteria in the depth of a filter is determined by measuring the oxidation of phenol, deliberately added to the inflow. The dose of phenol is initially small to allow acclimatisation of the bacteria. The kinetics of phenol removal are related to the time during the filterrun and to the filtration rate.

40. JACOBSON, S.
Introduction of pre-chlorination of slow sand filters.
Journal of the New England Water Works Association, 1949, 63, pp. 128 - 149

algae/c:u.s.a./performance/pre-treatment/raw water quality

Experiments were done at the Whitney water filtration plant, New Haven, Conn., to determine the possibility of increasing filter runs through slow sand filters by chlorinating the water before filtration. Two filters were scraped; one filter was then used to filter water continuously chlorinated, the other was operated under normal conditions. The amount of chlorine added was increased gradually from 2 ppm at the beginning of the experiment to 6 ppm at the end of the run. The loss of head of water through the second filter at first increased about twice as through the filter treating chlorinated water; when the dose of chlorine was increased the rate of loss of head was further reduced. From the observations it was concluded that preliminary chlorination did lengthen the run of slow sand filtration without appreciably

altering the quality of the effluent. The capacity of the filters was increased by chlorination by 100 and 233 percent. In comparing the effluents from filters treating chlorinated and unchlorinated water, no improvement in taste, odour or appearance was caused by chlorination but there was a definite improvement in bacteriological quality.

41. JAPAN WATER WORKS ASSOCIATION
Guidelines for water works technical management.
Japan Water Works Association, Tokyo, Japan, 1975, 409pp.

algae/c:japan/operation and maintenance/raw water quality

This book deals in a comprehensive way with the management and control of all kinds of water supply and water treatment facilities, including a chapter with very practical information on the operation and maintenance of a slow sand filter. Its characteristics are given, especially related to raw water turbidity and raw water algae and treatment of algae in filters. The operation and maintenance of the slow sand filters is described in detail, giving practical information on the maintenance of the filterbed. Details are given of sand collectors for taking samples for filter layer survey, of the sandscraping process including the organization of the scraping work and tools being used (as well as for the sand-replenishing as for the sand-washing work), and of reporting data of the filter condition.

42. JAPAN WATER WORKS ASSOCIATION
Design criteria for water works facilities.
Japan Water Works Association, Tokyo, Japan, 1969, 204pp.

c:japan/design/filter material/filtration rate

This book contains a lot of practical and consise design criteria for all kinds of water works facilities. It also includes a chapter on slow sand filtration. Very practical advices are given concerning: structure, filtration rate, surface area, number of filters, shape and basin arrangement, filtersand and gravel, underdrainage system, depth and freeboard, control well, back-filling provisions, influent structures, drain pipes.

43. KUNTSCHIK, O.R.
Optimization of surface water treatment by a special filtration technique.
Journal of the American Water Works Association, October 1976, pp. 546 - 551

cost/c:germany/pre-treatment/raw water quality

Conclusions drawn from operational experience with slow sand filters led to the installation of a horizontal flow gravel pre-filter for the removal of suspended solids from Ruhr-river water to unloaden the slow sand filters. This unit removes up to 80% of suspended solids when the volatile component of the solids is less than 20% and operates 4 - 6 years, as regeneration intervals of the gravel filter. Results of pilot filter tests and full scale investigations are shown. This method of pre-filtration brings about a remarkable saving in cost in comparison to slow sand filters directly loaded.

44. LLOYD, B.
The construction of a sand profile sampler: its use in the study of the Vorticella populations and general interstitial microfauna of slow sand filters.
Water Research, 1973, 7/7, pp. 963 - 973

algae/c:u.k./filtration rate/operation and maintenance/performance

A simple and inexpensive method is described by which the component groups of the interstitial fauna can be examined undisturbed by means of direct microscopy. The method has been developed specifically to locate and enumerate the functional interstitial micro-fauna of slow sand filters used in water purification and it is designed to demonstrate the spatial relations of the constituent populations as they develop in time in a flowing system. The sampler has been successfully applied to monitoring the development of Protozoa and Rotifera in pilot scale and full scale slow sand filters at the London Metropolitan Water Board's Walton and Ashford Common Treatment Works. Results are presented for the incidence of the general micro-fauna and for the development, vertical distribution and effect of flow rate on the Vorticella populations.

45. LYNCH, W.O. and BAKER, C.R. and HABERER, J.H.
Experiences with micro-straining at Ilion.
Journal of the American Water Works Association, 1965, pp. 1422 - 1430

algae/c:u.s.a./performance/pre-treatment/raw water quality

The use of a micro-strainer has enabled the operators to use any source of water available, whereas in the past some sources of water could not be used because of algal problems. It was remarked that the penetration of the dirt in the filterbed was greater with micro-straining; therefore the operators have experimented with an artificial Schmutzdecke of diatomaceous earth.

46. MANN, H.T. and WILLIAMSON, D.
Water treatment and sanitation: simple methods for rural areas.
Intermediate Technology Development Services, London, 1973, 60pp.

design/low cost and simple methods/operation and maintenance

The purpose of this handbook is to put together, in a simple and logical form, various aspects that must be considered when investigating the development of a water supply and sewage disposal scheme for a small community. This booklet is meant to be used by technicians, village leaders, administrators of schools and hospitals and others who wish to develop a water supply and sewage disposal scheme for their own use. Many of the methods of water and sewage treatment described in this handbook are based on the standard practices used in developed countries, adapted however to suit rural tropical conditions. The drawings show simple apparatus, among which a slow sand filter, an upward flow sand filter and a horizontal sand filter. Short descriptions are added to the drawings, representing filter action and operation of these filters.

47. MERCHANT, N.M.
Construction of an intermittent water filter for villages in Southern Iran.
Pahlavi University, Department of Community Medicine, Shiraz, Iran, 4pp. (n.d.)

c:iran/design/filter material/low cost and simple methods/performance/ raw water quality

There are over 55.000 villages in Iran, 27.000 of which have a population of less than 100 inhabitants. Water borne diseases are widely prevalent due to lack of sanitary facilities and widespread pollution. Provision of safe, clean drinking water remained a challenging problem. An intermittent water filter was constructed in a galvanized iron drum, fitted with a tap. The filterbed consisted of a layer of gravel at the bottom, supporting a layer of course sand on which was spread a layer of charcoal, kept in position with a layer of gravel. The filter media filled 2/3 to 3/4 of the drum capacity. Turbid water was successfully filtered through the layers, as the efficiency of the filter reached maturation on 2 to 4 months with the removal of 97% of the suspended matter and 98% removal of bacteria. When exhausted, the drum may be emptied and the filter media spread under the sun, washed and refilled for furher use.

48. METROPOLITAN WATER BOARD
Reports of the Director of Water Examination on the results of the bacteriological, chemical and biological examination of the London waters.
no. 38: 1958, no. 44: 1971, no. 45: 1974

algae/c:u.k./extra treatment/filter material/filter mechanisms/ filtration rate/operation and maintenance/performance/pre-treatment/raw water quality/shading

These reports describe the bacteriological, biological and chemical performance of slow sand filters, often related to operational factors like: details and results of studies on the changes in the bacteriological quality of water during slow sand filtration, including a comparison of in situ washing and manual skimming (report no. 38); virus removal, bacteriological and biological examination of shaded and unshaded filterbeds, presence of gulls on filterbeds, presence of fungi, bacilli and actinomycetes after resanding (report no. 44); virus removal, presence of aerobic sporing bacilli in slow sand filters, bacteriological aspects in relation to filtration rates and operational factors as sand grading, bedshading and ozonization (report no. 45).

49. MINISTRY OF PUBLIC HEALTH, THAILAND
Study of an existing water treatment plant of simple design and operation system for supplying drinking water to rural communities in the lower Mekong basin countries.
Rural Water Supply Division, Department of Health.
Bangkok, Thailand, Augustus 1976, 36pp.

cost/c:thailand/design/extra treatment/filter material/filtration rate/ low cost and simple methods/operation and maintenance/performance/ pre-treatment/raw water quality

The purpose of this investigation was to study problems associated with the design and operation of an already installed slow sand filter (at Kranuan). The data and information gathered include loading, operational difficulties, operation cost and income, process efficiency, population and society of the village served. The plant consists of a sedimentation pond, two simple slow sand filters, a clear well with chlorination and an elevated tank.

50. MITRA, D.D.
The role of vital layer (or Schmutzdecke) in slow sand bacteriological purification.
Indian med. Gaz., 1943, 78, p. 440

algae/c:india/operation and maintenance/performance

Experiments done at the Pulta water works, Calcutta, from June 1940 to December 1942 showed that in most cases raking the surface of slow snad filters was not allowed by deterioration in the bacteriological quality of the filtrate, even though the rate of filtration was increased. The water works have a capacity of 9.9 mgd.

51. NATARAJAN, R.
Operation and maintenance of water treatment plants, part II.
Journal of the Indian Water Works Association.
vol. VIII, 1976, no. 3, p. 195

c:india/operation and maintenance

The author discusses the problems connected with operation and maintenance of water treatment plants to get optimal performance and includes a short description of the maintenance job of a slow sand filter.

52. NATIONAL ENVIRONMENTAL ENGINEERING RESEARCH INSTITUTE
Slow Sand (biological) Filtration, Laboratory investigations.
National Environmental Engineering Research Institute, Nagpur, India.
Quarterly progress report January - April 1976, 50pp.

c:india/filtration rate/performance/pilot plant/raw water quality

Pilot plants experiments, within the IRC Slow Sand Filtration Project on the effect of the filtration rate on the performance of slow sand filters. Results are given from experiments with 3 pilot filters, operating at rates of 0,1 - 0,2 - 0,3 m/hr, receiving the same raw water. At all the filtration rates, the filters treating raw water of a turbidity of less than 10 FTU, produce a filtrate generally free of E-coli and with a trubidity less than 1 unit FTU. The filter operating at 0,1 m/hr produced a filtrate with the least dissolved oxygen content, while the filters operating at 0,2 and 0,3 m/hr gave shorter filterruns compared to the 0,1 m/hr standard filter. It is suggested to operate slow sand filters in tropical countries at a rate of 0,2 m/hr when receiving raw water with a low turbidity.

53. NATIONAL ENVIRONMENTAL ENGINEERING RESEARCH INSTITUTE
Slow Sand Filtration.
National Environmental Engineering Research Institute, Nagpur, India.
An interim report, August 1976, 74pp.

algae/c:india/design/filtration rate/performance/pilot plant/raw water quality/shading

Continuation of the laboratory studies (see no. 52) on the performance of slow sand filters. The effect of shading of slow sand filters has been examined with 3 pilot plant filters, respectively an open filter, a partially shaded one and a completely covered filter. Results and data are given of the measurement of 22 operational, biological and chemical parameters. Field studies have been made of the performance of slow sand filters at Umrer town. Finally data are given on existing slow sand filter installations serving small and medium size communities in India.

54. NATIONAL INSTITUTE FOR WATER RESEARCH
The use of slow sand filters for filtration of water on a small scale for domestic use.
National Institute for Water Research, South Africa, 1975, 2pp.

design/filtration rate/low cost and simple methods/operation and maintenance

Design and operation and maintenance of a very small slow sand filter for domestic purposes. The filter should yield a capacity of 100 l/m^2hr and an area of 1 m^2 will provide enough water for the requirements of ten persons.

55. PARAMASIVAM, R.
Treatment alternatives for waters of low turbidity.
Journal of the Indian Water Works Association, 1975, VII, no. 1, pp. 27 - 32

cost/c:india/operation and maintenance/pre-treatment/raw water quality

Upflow filtration, downflow sand and anthracite, sand filtration and slow sand filtration are examined as alternative treatments to conventional sedimentation plus filtration for a low turbidity water. An evaluation of factors like process advantages, cost comparison, manpower requirements and sludge production and disposal lead to the fact that in India one prefers slow sand filtration to other methods.

56. PATKI, P.V. et al.
Experimental study on slow sand and rapid sand filters.
Journal of the Indian Water Works Association, 1974, VI, no. 3, pp. 157 - 162

cost/c:india/performance/pilot plant/pre-treatment/raw water quality

An experiment was carried out to determine the maximum raw water turbidity, which can be fed to a slow sand filter and the effect of using pre-treated water and also to study the performance of semi-rapid filters. A comparison of the cost, efficiency and suitability of the two types of filter shows that, although the slow sand filter is costlier than the semi-rapid filter, it produces a better quality and product.

57. PATWARDHAN, S.V.
Low cost water treatment for developing countries.
Proceedings of 2nd International conference on 'Environmental health engineering in hot climates and developing countries: water, waste and health in hot countries'.
Loughborough University of Technology, England
September 21 - 24, 1975, pp. 41 - 65

cost/c:india/design/filter material/filtration rate/low cost and simple methods/performance/pilot plant/pre-treatment/raw water quality

The problems in India are likely to be representative for the problems in developing countries in hot climate regions. The author discusses some major problems of India and suggests in this paper some approaches for developing an appropriate intermediate technology in the field of water treatment for the developing countries with hot climate conditions. The surface water sources available in India can be grouped in four categories (A-D) and several approaches are given for each group, such as: fine sand low rate filters, stage filters, mimo filters, graded horizontal filters, several simple pre-treatment systems. The author concludes that the flexibility of design and the low rate philosophy will help to achieve better performance and considerable reduction in capital and maintenance cost.

58. PEARSALL, W.H. and GARDINER, A.C. and GREENSHIELDS, F.
Freshwater biology and water supply in Britain. Freswater Biological Association of the British Empire, Scientific Publication no. 11, 1946, 92pp.

algae/c:u.k./extra treatment/filtration mechanisms/performance/pre-treatment/raw water quality

The principles involved in the development of fresh-water life and the factors favouring its development are discussed in these papers. One part deals with the biology of slow sand filtration. An explanation is given of the biological action of the filter-film and of the chemical effect on the biological performances of slow sand filters using copper sulphate, chlorination, algicides or lime as pre-treatment.

59. RAJAGOPALAN, S and SHIFFMAN, M.A.
Guide to simple sanitary measures for the control of enteric diseases. World Health Organization, Geneva, 1974, 103pp.

design/extra treatment/low cost and simple methods

This guide provides a compendium of knowledge on simple measures that can be implemented with limited resources to control enteric diseases. It is meant for the use by professional personnel responsible for public health and sanitary services in developing countries. The chapter on water supply systems contains some interesting appropriate technology solutions for spring protection, bank infiltration, disinfection, infiltration galleries, etc.

60. REID, G.W.
A catalogue of water supply and waste disposal methods for individual units.
Bureau of Water and Environmental Resources Research, University of Oklahoma, 1975, Norman, Oklahoma 73069

design/low cost and simple methods

This manual consists of 183 figures taken from published literature, listed in a reference table. The purpose of this manual is only to provide a collection of methods of water supply and waste disposal for individual units, so there is no explanation nor a discussion is given. Concerning slow sand filtration, a few drawings are given of a slow sand filter, an upward flow sand filter, a horizontal sand filter and a modified slow sand filter.

61. RENADE, S.V. and AGRAWAL, G.D. and MISHRA, Y.D.
Full scale trials on converted dual-media filter at Kanpur.
Journal of the Indian Water Works Association, 1976, VIII, no. 4, pp. 257 - 261

cost/c:india/filtration rate/performance/pre-treatment/raw water quality

The results of tests on a dual-media filter are presented and the influence of filtration rate as the length of the filterruns is discussed. Conditions of high and low turbidity were examined. The cost of conversion to dual-media is compared to cost on construction for the increase in capacity.

62. RIDLEY, J.E.
Experience in the use of slow sand, double sand filtration and micro-straining.
Proceedings of the Society for Water Treatment and Examination, 1967, vol. 16, pp. 170 - 191

algae/c:u.k./pre-treatment

Comparison of algae problems between the Hanworth Road works using exclusively slow sand filtration, the Kempton Park works using rapid sand filtration followed by slow sand filtration and the Ashford Common works using rotary micro-strainers followed by slow sand filtration. In a filtration process in two steps many problems are caused by primary filtration deficiency and by proliferation of algae in the slow sand filters.

63. ROBECK, G.G. and CLARKE, N.A. and DOSTAL, K.A.
Effectiveness of water treatment processes in virus removal.
Journal of the American Water Works Association, 1962, 54, pp. 1275-1292

filtration rate/performance/raw water quality

Tabulated and graphical results are given of small scale pilot plant experiments on the removal of poliovirus I from water during passage through unsaturated or water-saturated sand at rates equal to those of groundwater movement and through a coagulation - filtration process at rapid rates. It was found that 2 feet of clean well-packed sand removed the virus from water flowing at rates less than 4 feet per day; the percentage removed decreased with increasing rate of flow until most of the organisms passed through at rapid filtration rates. Alum dosing gave improvement of the latter results up to 99% virus removal.

64. SCHALEKAMP, M.
The effectiveness of rapidly operated slow filters and a new cleaning process.
Annual conference of the American Water Works Association. Session of Mineapolis, June 11, 1975

algae/cost/c:switzerland/filtration mechanisms/filtration rate/performance

The results of tests in St. Gallen, Switzerland, indicate that rapidly driven slow sand filters with a rate of 21 m/d give way to a satisfactory purification, but not quite as good as normally driven slow filters at a rate of 7 m/d. Examined are the effects of this raise in filtration rate on the length of the filterrun and on the bacteriological, biological and chemical performance and action of the filters, illustrated with many graphs and data.

65. SCHMIDT, K.
Intermittent operation of slow sand filters for artificial recharge of groundwater.
Lecture of the 2nd International Conference for foreign participants, Gottwaldot, Czechoslovak Socialist Republic, June 29 - 30, 1972, 26pp.
Also published in the series: Issues of the Dortmunder Stadtwerke AG, nr. 118.
Original version in German, translated into English by the WHO International Reference Centre for Community Water Supply.

algae/cost/c:germany/design/filtration mechanisms/performance/pilot plant/pre-treatment/raw water quality

At the Ruhr Valley Waterworks slow sand filters constitute a one-stage purification step of surface water and serve at the same time as an infiltration surface for the artificial recharge of groundwater.

Pre-filters, filled with course filter material reduce the load of suspended matter on the slow sand filters and cause a two-stage biological filtration process. Aeration before the entrance into the main filters changes the O_2/CO_2ratio. To solve problems of lack of oxygen and excessive algal growth, the slow sand filters are operated intermittently. Several figures and data of the performance of these filters are given, also in comparison to submerged filters.

66. SEVILLA, A.S.
A study of filtration methods for providing inexpensive potable water to small communities in Asia.
Thesis no. 442, Asian Institute of Technology, Bangkok, Thailand, 1971

cost/e:south east asia/filter material/filtration rate/low cost and simple techniques/performance/pilot plant/pre-treatment/raw water quality

An attempt was made on laboratory scale to find a new method for treating surface water that would be technologically and economically applicable to small communities in Asia. The most promising solution found was the use of local materials in a series filtration system incorporating both a roughing or primary filter followed by a secondary or polishing filter of the slow sand filtration design. Since there were no basis for the design and filtration rates to be used for each media under study, the study was geared towards evaluating an optimum filtration rate and influent turbidity limit for the filter to function efficiently and for an extended period of time to minimise the frequency of cleaning. Materials easily available in Asian rural areas were compared as filter media in terms of turbidity removal, length of filter run and head loss developement. Investigated were: Pea gravel, burnt rice husk, raw rice husk, coconut husk fibre, charcoal and sand. Burnt rice husk appears to be a potential substitute for sand in slow sand filtrationwhile coconut husk fibres could be substituted for coarse sand in a roughing filter. By using the series filtration system, the financial and labour requirements and the level of training needed by the operator could be reduced.

67. SIBER, S.
Slow sand filtration for small communities and rural areas.
Middle East Technical University.
Environmental Engineering Department, no. 73-02
Anakara, Turkey, July 1973

filter material/performance/pilot plant/raw water quality

In this study an attempt is made to determine the turbidity removal efficiency of a model slow sand filter. The practical use of the results

obtained from the experimental study is investigated. In the experimental part of the study,emphasis is laid on the effect of sand depth changes and influent water turbidity changes upon filtrate quality.

68. SLADE, J.S. and POYNTER, S.F.B.
The removal of viruses by slow sand filtration.
Scientific Services, Thames Water Authority.
Distributed by the IRC in the context of the Slow Sand Filtration Project.

filtration rate/operation and maintenance/performance/pilot plant/raw water quality

The ability of slow sand filters to remove enteroviruses from contaminated reservoir water has been assessed using experimental filters and attanuated poliovirus type 1. The effects of flow rate, depth of sand, temperature, filter maturity and cleaning on this process have been examined. The filters were found to be highly effective in removing viruses at up to 2,5 times the normal flow rate of 4,8 m/d and at temperatures as low as $5^{0}C$. The removal of bateriophage T7 and naturally occurring bacteria by filtration have also been studied. When compared with poliovirus, bacteria were less and bacteriophages were more efficiently removed.

69. SWISS ASSOCIATION FOR TECHNICAL ASSISTANCE and Ministry of Agriculture Community Development Department, Cameroon, 1975

c:cameroon/design/low cost and simple methods

Design criteria and some drawings are given of simple slow sand filters used in Cameroon.

70. SYMONS, G.E.
Filtration.
Water and Sewage Works 1956, 183, pp. 108 - 111 and 151 - 157

design/filtration mechanisms/general description/operation and maintenance/performance

While discussing filtration processes in water treatment, the author defines and classifies the types of filters used, and reviews the basic principles and hydraulics of filtration and the activities taking place during the process. The design and operation of slow sand and rapid sand filters are discussed in detail.

71. THANH, N.C. and PESCOD, M.B.
Application of slow filtration for surface water treatment in tropical developing countries.
Environmental Engineering Division, Asian Institute of Technology, Bangkok, Thailand.
Final report no. 65, 1976, 75pp.

c:south east asia/filter material/filtration rate/low cost and simple methods/performance/pilot plant/pre-treatment/raw water quality

The aim of this study, undertaken in the context of the IRC - Slow Sand Filtration Project, was to provide an acceptable water (by using surface water for supply in Asian villages) as cheaply as possible using simple treatment systems. Investigated with pilot plant studies are the performance of 1. a slow sand/burnt rice husk filter in combination with a coconut fibre filter, as a series filter system; 2. a dual media filter, coconut fibre and burnt rice husk in the same filter box; 3. dual media filters, made of burnt rice husk or coconut fibre overlying sand. Assessed is the influence of raw water turbidity and filtration rates on the quality of treated water, expressed in turbidity and coliform removal, and the duration of filter runs based on the observation of head-loss development. Two long term filtration studies have been made at raw water turbidities of 50 and 100 JTU.

72. UNIVERSITY OF SCIENCE AND TECHNOLOGY, GHANA.
Slow sand filtration studies.
Environmental Quality Division, Department of Civil Engineering, University of Science and Technolohy, Kumasi, Ghana.
First progress report 1976, 41pp.

algae/c:ghana/design/filtration mechanisms/filtration rate/low cost and simple methods/performance/pilot plant/raw water quality

Within the framework of the IRC - Slow Sand Filtration Project, several studies have been done at the Owabi and Kumawu pilot plants. Investigated are, among other things: the raw water quality; the effect of the filtration rate on the ripening period and the length of filterrun and the filter performance; the identification of algae in the raw water, in the filtrate and in the scrapings from the top of the filter; the comparison of the slow sand filtration pilot plant with treatment processes at the existing plant. The design of a household slow sand filter is also shown. This report describes the first part of the research still in progress, so no conclusions have yet been drawn.

73. VLOED, A. van de
Comparison between slow sand and rapid sand filters.
7th report, 3rd Congress I.W.S.A. 1955, p. 537

algae/cost/filtration mechanisms/general description/performance/pre-treatment/raw water quality

The author states that there is a great number of conflicting data concerning slow sand filtration and he thinks that sand filtration is still regarded as an art rather than a science. The only way to avoid mistakes is a scientific method of treating the subject of slow sand filtration. In the first part, the author determines the problems to be solved and gives a scientifical explanation of the filtering process. Having thoroughly discussed the theory of the filtration process, an attempt has been made to use these theoretical data in practical filtration problems related to rapid sand filtration and slow sand filtration. When comparing rapid sand filters to slow speed sand filters, the following conclusions can be drawn: rapid sand filters will almost always be found useful when filtration of water is needed for public supplies; the slow sand filter should be used as a secondary filter to cope mainly with complex matter in solution; the choise of the purification systems depends highly on the raw water quality; the costs of a rapid sand filter construction are lower than those of a slow sand filter, whereas the operation costs of the former are higher than those of the latter. The author remarks that the comparison is a rather difficult one, because these filters are constructed to treat different water qualities. An international enquiry has been set up to find out whether forementioned scientific and theoretical results are applied in other countries; this enquiry is attached to the report.

74. VOLUNTEERS FOR INTERNATIONAL TECHNICAL ASSISTANCE and U.S. Agency for International Development.
Village Technology Handbook.
Schenectady, New York, 1970, 387pp.

design/low cost and simple methods/operation and maintenance

This handbook of village technology devotes about half of its pages to water resources, including simple technology for developing water sources, lifting and transport, storage and power development and water purification. A simple household sand filter is described, including data on its performance, operation and maintenance, to deliver 1 liter per minute of clear water, ready for boiling or chlorination. Illustrations and additional references are included. The aim is to enable villages in different parts of the world to learn from each other's experiences.

75. WAGNER, E.G. and LANOIX, J.N.
Water supply for rural areas and small communities.
World Health Organization, Geneva, 1959, 340pp.
Monograph Series no. 42

design/filter material/filtration rate/general description/operation and maintenance

The whole system of improved water supplies is examined; beginning with the assumptions about health benefits to be derived from it, and continuing through planning, examination of source water, technology available, treatment, distribution and use. The management of the system is also considered in terms of personnel and training, administration, finance, operation and maintenance. This handbook contains descriptions and clear illustrations of simple technologies of spring protection methods, dug wells, treatment facilities, etc. Slow sand filtration is very well described, in particular the construction of the filter.

76. WHITEHEAD, R.C.
Shustoke reservoir: biology and algal control.
Journal of the Institution of Water Engineers, 1948, 2, p. 577

algae/c:u.k./extra treatment/performance/pilot plant/pre-treatment/raw water quality

Prolific growth of attached algae on the filterbeds and of planktonic algae in the reservoir cause a reduction of the filtration rate of the Birmingham water works. Records have been made of the performance of an experimental filtration plant and of biological observations of the reservoir and the existing filters. Various methods of algae control have been tried, such as: dosing copper sulphate, pre-chlorination, bulkdosing in the reservoir.

77. WILLIAMS, F.H.P. and SOMPONG, S.
Some properties of rice hull ash.
Geotechnical Engineering, 1971, vol. 2, pp. 75 - 81

filter material

This report describes some tests that were carried out on the rice hull ash to obtain a better understanding of its properties, such as: composition, structure, specific gravity, compaction tests and static loading tests.

78. WORLD HEALTH ORGANIZATION
Biological or Slow Sand Filtration.
Community Water Supply Research and Development Programme.
Background paper, WHO/CWS/RD/70.1, 24pp.

algae/design/filter material/filtration mechanisms/filtration rate/general description/operation and maintenance

The paper fights against the idea that biological or slow sand filtration is an old-fashioned, out-dated method of water treatment which has been completely superseded by rapid gravity and various high-rate filtration techniques. On the contrary, biological filtration, under suitable circumstances, is not only the cheapest but also the most effective method of water treatment. This background paper is based on a report by prof. Huisman who visited installations in five countries in Europe and studied data from the U.S.A. and other parts of the world. It includes sections on the theory of biological filtration, the planning, design and construction of biological filters, flow control and pipework and the cleaning and operation of the filters.

79. WORLD HEALTH ORGANIZATION
The village tank as a source of drinking water.
Community water supply research and development programme; outline for coordinated research project.
WHO/CWS/RD/69.1, 1969, 17pp.

design/extra treatment/low cost and simple methods/operation and maintenance/raw water quality

Improvement of drinking water quality by means of a water treatment system taking the village tank or pond as its source of supply. It is believed that the most likely combination of water treatment units to serve the purpose of improvement will consist of an intake handpump and a slow sand filter. Several simple construction drawings of the intake and the slow sand filter are shown in this paper, in which also is discussed the filter construction, filter operation and disinfection.

ANNEXES

ANNEX I

INDEX OF AUTHORS

ANNEX II

INDEX OF KEYWORDS AND RELATED TERMS.

ANNEX III

LIST OF REFERENCE INSTITUTIONS.

C.E.T.E.S.B.
(State Company for Pollution Control and
the Protection of the Environment)
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