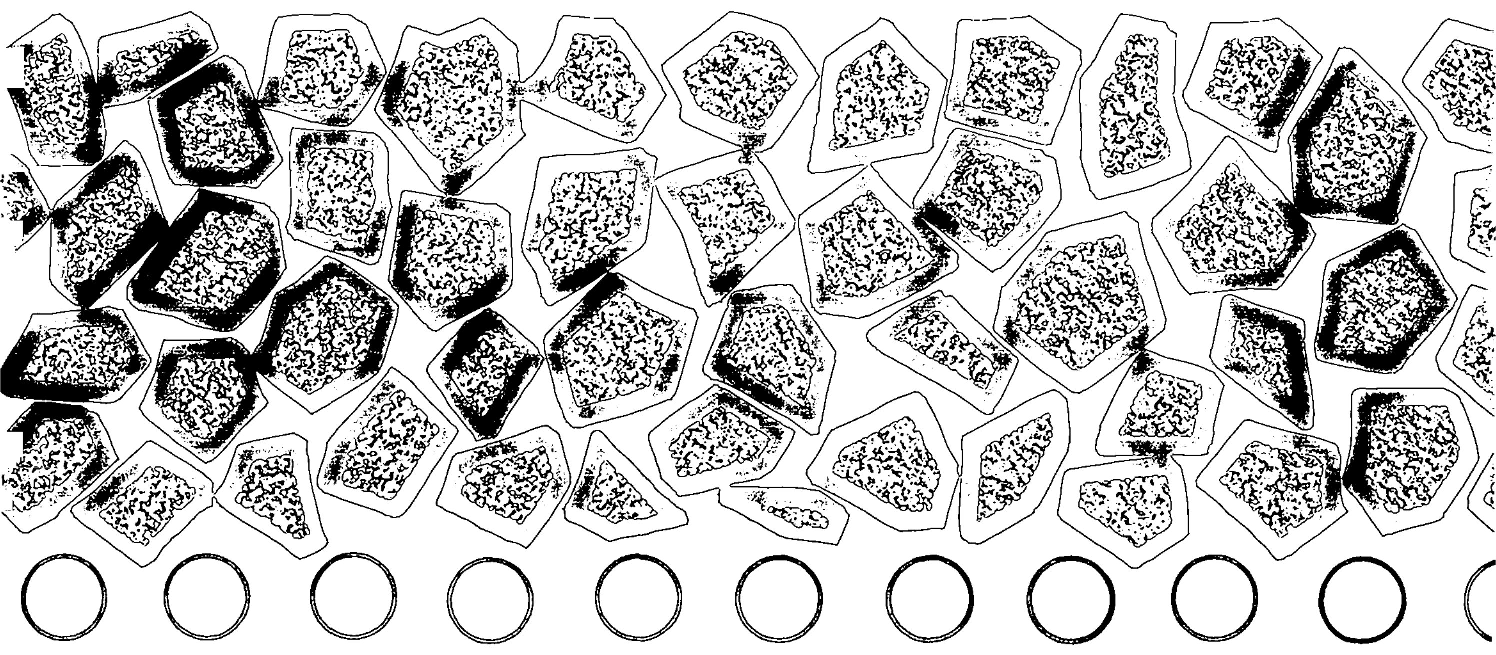
SLOW SAND FILTRATION

A low cost Treatment for Water Supplies in Developing Countries

Slow sand filtration is a form of surface water treatment technology which should be considered in any situation where low cost and ease of operation and maintenance are desirable features.

These criteria might equally well apply in developed and developing countries, but this booklet is primarily aimed at developing country applications because of the special circumstances and urgent needs in those countries.



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EXECUTIVE SUMMARY

Slow sand filtration was the first water treatment process introduced to improve the quality of surface water in Europe and North America and soon proved to provide protection against cholera and typhoid. It has remained a suitable treatment technology throughout the world and is recognised as particularly appropriate for application in developing countries by reason of the simplicity of design and construction and the ease of operation and maintenance. In areas where land is available, slow sand filtration is a low-cost water treatment process which can be operated and maintained by a trained member of the local community. No other available water treatment technology, excluding disinfection, can produce as safe a drinking water and provide as great a protection of public health. Pretreatment processes for highly turbid surface waters are available and allow wider application of slow sand filtration in tropical areas. Other minor disadvantages are generally outweighed by the advantages and some developing countries have already taken advantage of the technology in their water supply programmes. There is still a lack of awareness of the benefits to be gained from increasing application of slow sand filtration in many developing countries and the objective of this booklet is to draw attention to facts about this appropriate technology and encourage more countries to take advantage of its simplicity and low cost.

THE PUBLISHING ORGANISATIONS

The Water Research Centre (WRc) is the principal organisation in the UK for research and development into all aspects of water technology. It employs about 600 staff at three locations in modern, well-equipped laboratories. WRc is a WHO Collaborating Centre for Drinking Water and Water Pollution Control.

Further information about WRc can be obtained from Water Research Centre, Henley Road, Medmenham, PO Box 16 Marlow, Bucks, SL7 2HD, England.

The International Reference Centre for Community Water Supply and Sanitation (IRC) is an internationally operating, independent, non-profit making organisation dealing with information and technical support for water and sanitation improvement in Developing Countries. Support is provided by means of publications, training and education, evaluation and advice, development and demonstration.

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1. THE NEED

1.1 The Target

A simple, low-cost water treatment system is essential for widespread application in developing countries. Slow sand filtration (SSF) is a form of surface water treatment technology which should be considered in any situation where low cost and ease of operation and maintenance are desirable features. These criteria might equally well apply in developed and developing countries but this booklet is primarily aimed at developing country applications because of the special circumstances and urgent needs in those countries.

1.2 The Global Situation

World Health Organization (WHO) statistics on water supply provisions in developing countries clearly indicate that many millions of people in developing regions of the world were, in 1983, still denied a safe and adequate water supply:

THE GLOBAL SITUATION IN 1983

WHO Region	*Total Population*				*Population with Water Supply*			
	Urban		*Rural*		*Urban*		*Rural*	
	10^3	%	10^3	%	10^3	%	10^3	%
Africa	100 097	25	299 332	75	61 419	61	77 548	26
Americas	257 086	67	127 385	33	219 823	86	50 532	40
Eastern Mediterranean	254 111	24	823 749	76	167 255	66	357 094	43
South-East Asia	74 136	40	111 796	60	51 995	70	51 969	46
Western Pacific	112 423	41	162 005	59	96 684	86	44 518	27
TOTAL	797 853	34	1524 267	66	597 176	75	581 661	38

Source: World Health Organization (Ref. 1)

Although the International Drinking Water Supply and Sanitation Decade (IDWSSD), 1981-1990, has focussed attention on the desirable goal of 100% water supply coverage in the short-term, progress with national programmes still leaves much to be desired. With the huge backlog to be made up and the continuing high rate of population growth, the level of investment required to attain the objective will be beyond the reach of most developing countries unless low-cost approaches are generally accepted by executives, planners and designers.

Simpler forms of technology are also more manageable where skilled technical supervision is not available and this factor alone will sustain the long-term performance of simple water supply systems serving low-income communities in developing countries. More advanced water systems have often been observed to cease operating within a few years of construction, where they were neither operable nor affordable by the recipients and the central agency had made no provision for operation and maintenance support.

1.3 The Health Problem

Inadequate water supply and poor sanitation account for approximately 30,000 deaths daily, many of them infants, and several hundreds of millions of people are suffering from water-related illnesses at any one time. Such morbidity is not only a drain on productivity in developing countries but seriously affects the quality of life in general.

Many water-borne diseases are spread through the unavoidable ingestion of pathogenic micro-organisms and parasites in drinking untreated water from surface sources. Whenever safe spring or borehole water is not available within reasonable distance and at a suitable depth, contaminated surface waters are normally the only source of supply possible and their treatment is essential. Slow sand filtration is the simplest low-cost process for surface water treatment which can provide a safe and acceptable drinking water comparable with that produced by complex chemical coagulation/rapid sand filtration treatment plants. In Europe and North America, slow sand filters were the first treatment applied to public water supplies and were instrumental in preventing cholera and typhoid epidemics. Even today, as indicated in Chapter 6, they still make a significant contribution in providing the reliable water supply service which communities in developed countries take for granted. They must now be made to play a dominant role in protecting the health of communities in developing countries which are increasingly being forced to draw on surface waters for their potable supply.

1.4 The Unit Cost of Treatment

In countries where resources for development are grossly inadequate, the water supply sector must compete for its share of available funds with other deserving sectors. Most National Plans now include provisions for water supply but in few developing countries will allocations allow complete coverage of the population with safe and adequate water supply by 1990, the Decade goal. Under these circumstances, the unit cost of providing water to communities becomes extremely important. The lower the cost per person, the greater the number of people who will benefit from available resources and the sooner the total population will be provided with at least basic needs. Water supply executives, planners and designers who fail to take advantage of the low-cost benefit of slow sand filtration will be condemning significant numbers of people to continuing exposure to waterborne diseases and denying them the improved quality of life which a safe and adequate water supply would help to bring.

1.5 Operation and Maintenance

The reason why so many 'white elephant' water treatment plants lie derelict in developing countries is because the technology chosen was too sophisticated for the recipient communities to operate and maintain. In many cases, the cost of operating conventional chemical treatment plants was beyond the capacity of low-income communities to bear without government subsidy. Adoption of slow sand filtration, where technically feasible, will reduce operation and maintenance costs and allow plant operators to be provided by the local community. The water agency's technical support system will only be required for general supervision, solution of major problems and provision of spares. Community involvement in planning the supply will ensure that valuable local knowledge can be used in site selection and that local needs are considered. If members of the community are aware of what is being provided and why, and know what contributions are expected of them, their involvement will promote an attitude of identity with and interest in the water supply system which will contribute to its long-term success. In the past, Government support systems for water supply schemes outside major cities in developing countries have not been effective and unless a community can operate and maintain its own system, and can afford to do so, the chances are high that the benefits of the investment will be lost.

2. THE TREATMENT SYSTEM

2.1 Stages of Treatment

A water treatment system incorporating slow sand filtration can be designed to produce a safe drinking water from even a polluted turbid river water. In such a system, the slow sand filter is the most important treatment process but not necessarily the only one. Unless the raw water is relatively free of suspended and colloidal impurities, an exceptional situation in developing countries, a pre-treatment stage is necessary before the slow sand filter. Water from a slow sand filter will be relatively safe, certainly much improved over the raw surface water, and will be of better quality than water from this source treated by rapid sand filters. However, to guarantee pathogen-free water at all times, particularly during the initial ripening period after filter cleaning, disinfection is necessary. Clear water storage will usually be required before collection or distribution.

2.2 The Slow Sand Filter

The basic elements of a slow sand filter are shown diagrammatically in Fig. 1 but each plant will have site-specific variations of detail to minimize cost, taking advantage of local conditions. Essential features of the slow sand filtration process are:

A – A storage capacity above the sand bed to provide the necessary head to produce the design flow through the bed under the worst head loss conditions.

B – A bed of media which achieves the filtration and other effects, including biological purification, which a slow sand filter is known to provide in upgrading the quality of an influent water.

C – A system of underdrains to allow unobstructed passage of treated water and to support the filter medium so that a uniform rate of filtration is maintained over the whole area of the filter.

D – Filter regulation and control devices to maintain the water level over the bed during operation at the design filter rate and allow adjustment of water level during filter cleaning and re-introduction to operation after cleaning.

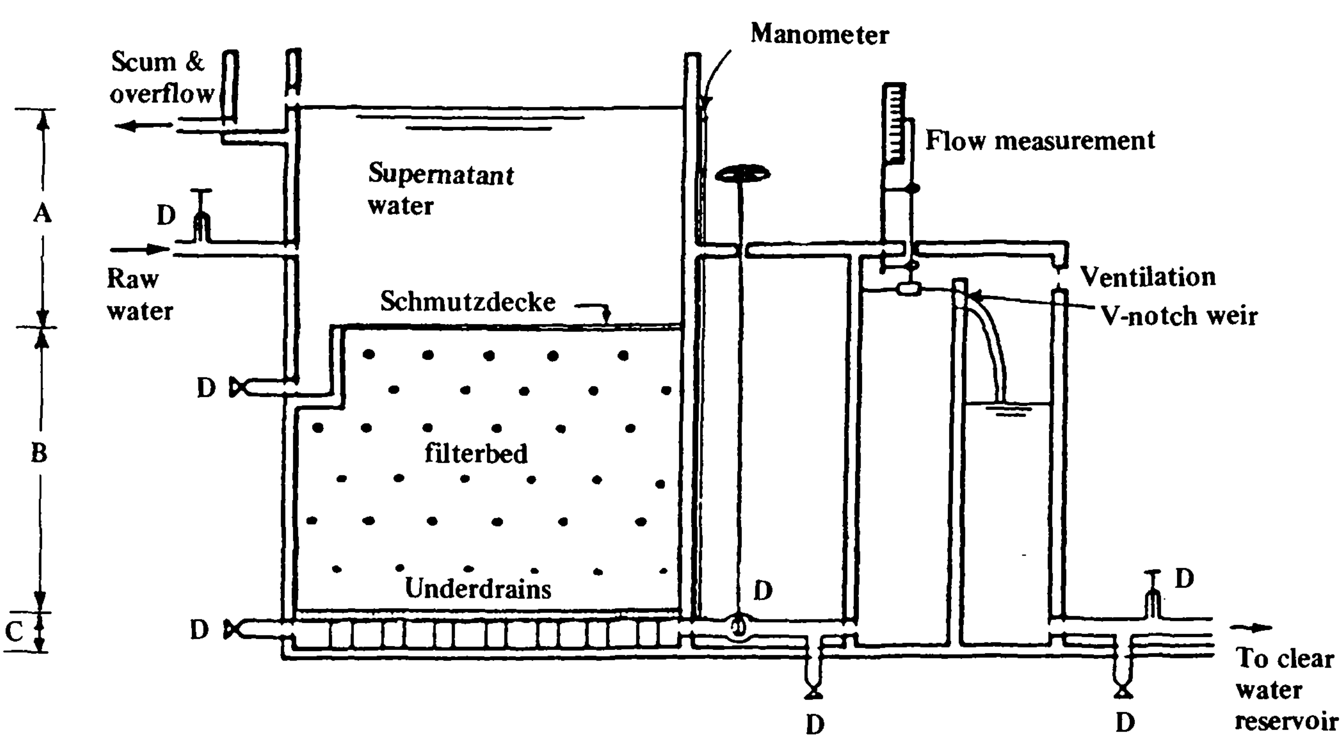


FIG. 1 – BASIC ELEMENTS OF A SLOW SAND FILTER

Typical design features of a slow sand filter are as follows:

CHARACTERISTICS OF A SLOW SAND FILTER

Feature	*Characteristic*	*Range*
A	Depth of water above sand	1-1.5 m
	Freeboard above water level	0.2-0.3 m
B	Depth of media	0.8-1.4 m
	Grading of sand – effective size	0.15-0.3 mm
	– uniformity coefficient	2-5
	Filtration rate	0.1-0.2 m/h
C	Size of gravel (0.3-0.5 m depth)	25-50 mm
	Depth of underdrainage system	0.3-0.5 m
	Spacing of laterals*	1-2 m
	Size of holes in laterals	2-4 mm
	Spacing of holes in laterals	0.1-0.3 m
D	Effluent weir level above sand	30-40 mm

*Brick underdrains often replace pipe networks in developing countries.

2.3 Physical and Biological Processes

After entry of water to the filter box and during several hours of storage above the sand surface, flocculation and sedimentation of large particles takes place. In passing through the sand bed, straining, filtration and adsorption processes are proceeding simultaneously, especially in the first 40-60 cm, and biological action occurs near the surface.

During storage above the sand bed the water will be exposed to sunlight during daytime and this will have a bactericidal effect. In addition, some micro- and macro-organisms will settle out with solids during this storage period. However, the major biological activity in a slow sand filter occurs in the surface layer, called the 'schmutzdecke', where bacteria, algae, protozoa, and rotifers are entrapped, proliferate and die. Organic components of the raw water are broken down by organisms in this layer and the end result is physical, chemical and bacteriological improvements in water quality.

2.4 Treated Water Quality

Slow sand filtration brings about the greatest improvement in water quality of any conventional water treatment process. Bacterial removal will be from 98 to 99.5% or more, *E. coli* will be reduced by a factor of 1000 and virus removal will be even greater. A slow sand filter is more efficient than any other process in removing parasites (helminths and protozoa). Nevertheless, the effluent from a slow sand filter might well contain a few *E. coli* and viruses, especially during the early phase of a filter run. Even so, accepting the variability in efficiency of chlorination in rural areas, slow sand filtration produces a safer effluent than conventional chemical treatment/rapid sand filtration processes and the high degree of upgrading from raw water quality is usually sufficient to provide significant community health benefits. Chlorination will always be desirable if continuous and effective application can be assured.

2.5 Pretreatment

A highly turbid raw water will clog a slow sand filter very quickly, giving rise to the need for very frequent cleaning. Since filter cleaning is not an automatic process, as in a rapid sand filter, and takes some time to complete, a cleaning frequency of less than once every two or three months would be onerous. In addition, removing the surface layer of sand during cleaning interrupts the biological action and adversely affects water quality for one or two days after start-up, making very short filter runs inadvisable. Pretreatment will be necessary when the raw water contains an average turbidity level in excess of about 25 NTU but should be considered for lower turbidity levels because it will reduce the frequency of filter cleaning and might well be cost-effective. A range of processes are available to bring about the necessary pretreatment before final polishing in the slow sand filter (Ref. 2), including the following:

Infiltration systems can sometimes be applied at the point of abstraction from the surface water source. Fig. 2 shows several alternatives, including infiltration galleries, river bed filtration and wells which will upgrade the raw water quality before transfer to slow sand filters.

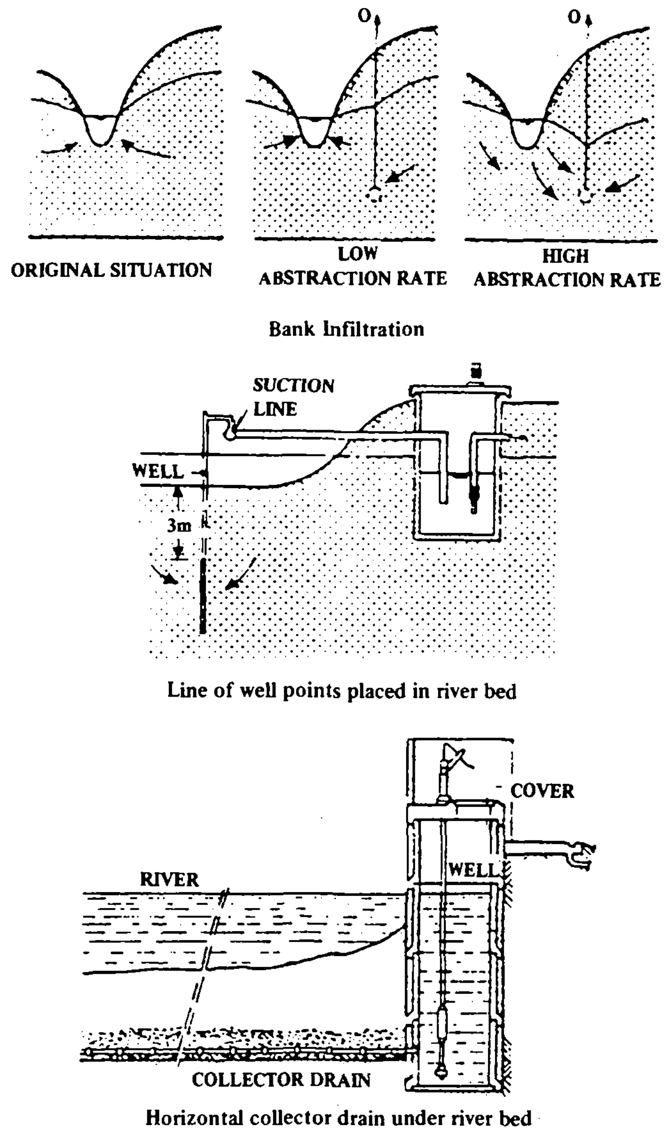
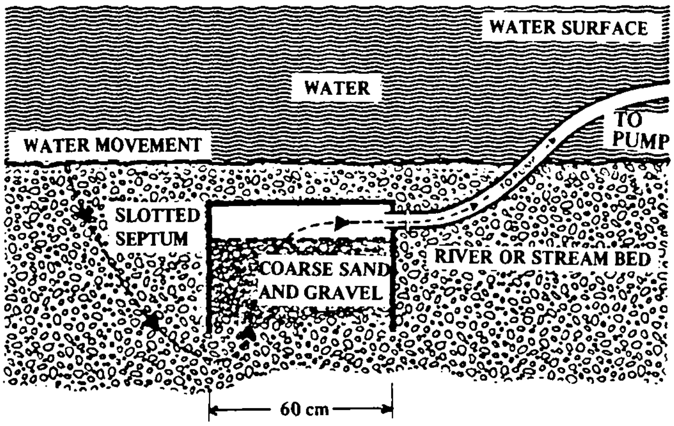


FIG. 2 – PRETREATMENT BY INFILTRATION

Another form of *in-situ* upgrading system available is the *SWS filter* (Ref. 3), one version of which is shown in Fig. 3. In this design the filter box is placed in the bed of a river and, when water is pumped from above the septum, a filter is formed naturally beneath and a significant improvement in clarity is achieved. The other type is used where the river bed material is not suitable; here, gravel from another site is placed around a well screen in a filter box which is then suspended in the water source. Both types can be cleaned manually and, up to now, have only been used for small-scale applications.

The largest application so far has been by the University of Surrey, UK, where three units were operated at starting flow rates of 1.1-1.5m^3/h per unit. However, these flow rates usually declined to less than half by the end of the filtration run due to progressive blockage of the filter. Filter runs of 5-10 days were reported. Units were operated with positive displacement pumps and backwashed from an overhead storage tank. Larger scale application of these units therefore may meet with important constraints in rural areas.



Cross-section of glass fibre SWS 'Camp' filtration unit in sand bed.

FIG. 3 – PRETREATMENT BY SWS FILTRATION

Sedimentation tanks and lagoons are other forms of pretreatment device which can be applied where settleable solids are contained in the raw water. However, in tropical regions most of the solids burden in rivers is not readily settleable and even long retention times in lagoons will not produce an effluent suitable for application to slow sand filters. Settling tanks will only be a partial answer to pretreatment in most locations but might well be beneficial as protection for other forms of prefiltration during flood periods, when turbidity levels can be very high. Bankside storage lagoons, where affordable, will be beneficial in bringing about some degree of turbidity removal and pathogen reduction.

Where the natural strata at the point of abstraction are not suitable for infiltration upgrading and sedimentation is not appropriate, or provides only partial pretreatment, other prefiltration systems can be applied. As mentioned, the SWS filter is a possibility for small supplies but, for larger-scale applications, roughing filtration in specially constructed units is also feasible and effective. Both vertical- and horizontal-flow prefilters can be used but *horizontal-flow prefiltration*, combining the processes of filtration and gravity settling, has received considerable attention in recent years (Ref. 4). One possible design is shown in Fig. 4 and this system is claimed to remove 60-70% of influent solids and coliform organisms from turbid waters (up to 150 NTU average turbidity and up to 2000 NTU peak levels for short periods) at filtration rates between 0.3 and 1.5 m^3/m^2h. This type of prefilter has a relatively low capital cost and requires manual cleaning only every few years. To adopt this type of filter, gravel or other inert material must be locally available but *vertical-flow filters* have been operated using alternative forms of media. Roughing prefiltration has been achieved using *coconut fibre* in place of gravel and sand has been replaced by *burnt rice husk* in slow filters following prefiltration (Ref. 5). Washing of coconut fibre is not worthwhile when the roughing filter becomes blocked and replacement with fresh material is recommended.

A recent development, not yet fully exploited, has been the application of *non-woven fabric filters* as pretreatment. These were first reported being used on the surface of very small slow sand filters to extend the length of filter run (Ref. 6) and they have recently been applied to the surface of the SWS filter box for rural water supply in the Gezira project of the Sudan. When fabric filters become clogged they are cleaned by manual washing and immediately replaced on the surface of the media they are meant to protect. Their application to large filters is yet to be tested and might create additional maintenance problems which could not be coped with in rural areas of developing countries.

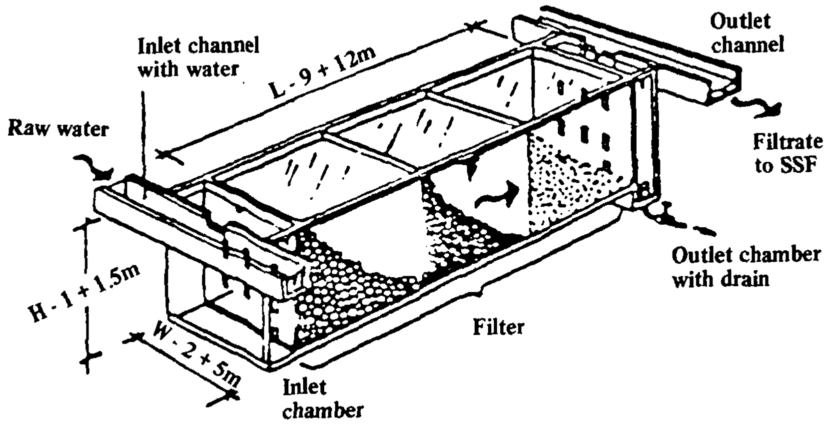
3. ADVANTAGES OF SSF

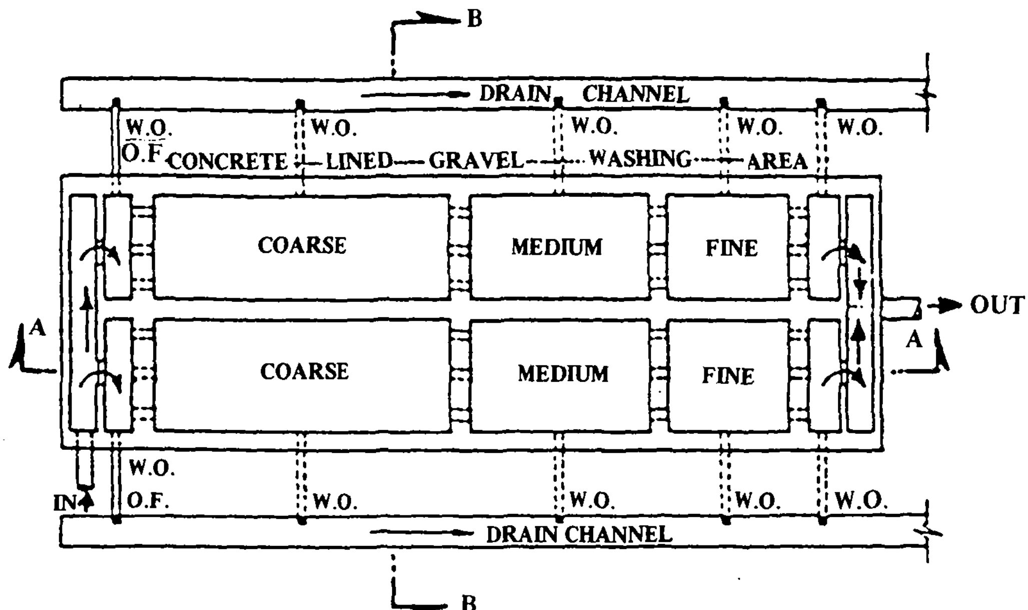
3.1 Simplicity

Unlike a rapid-gravity sand filter, the slow sand filter is not backwashed automatically and this simplifies system design. The different forms of filter illustrated in Fig. 5 create no difficult problems in design or construction. Equipment requirements are minimal and easily handled by local plant operators. Control and measurement devices can be very simple, as indicated in Fig. 1, and undemanding in use. All materials and equipment should be available in most developing countries and the need for imported items would not normally arise.

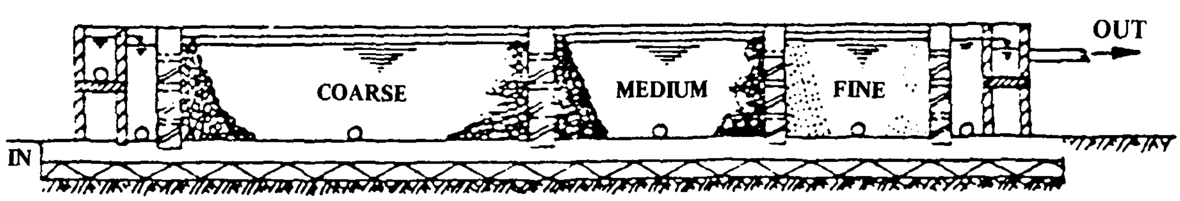
No other form of water treatment technology has the simplicity of prefiltration and slow sand filtration. However, careful design is essential if a system is to operate without problems, especially when pretreatment is necessary. Fortunately, there are many design guides available to advise inexperienced designers (for example, Refs. 2 and 7). Only a limited amount of professional supervision is necessary during construction and, possibly, the community to benefit could participate in this phase of a project.

In spite of the slow sand filter lacking technical sophistication and being easy to design, construct and operate, when properly applied it will operate reliably throughout its design life and make a significant contribution to improving community health. Its very simplicity assures its long-term success in rural areas of developing countries where more complex forms of water treatment have a poor record. For the same reasons, slow sand filtration is being revived for treatment of rural supplies in developed countries and can equally contribute to the solution of urban problems; many large cities, including Amsterdam, Denver and London, still use slow sand filters.

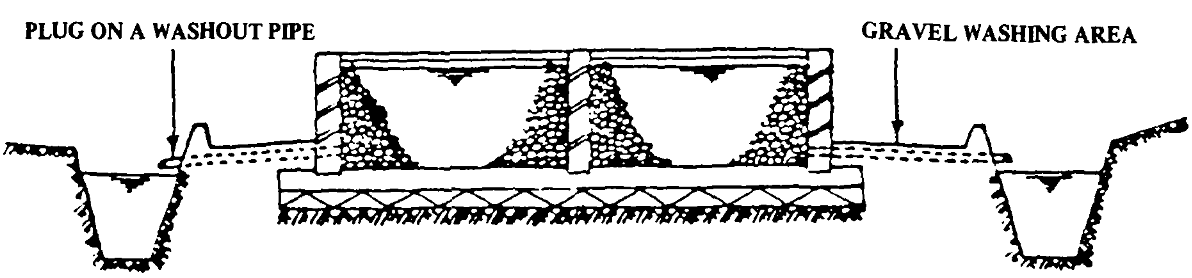




PLAN

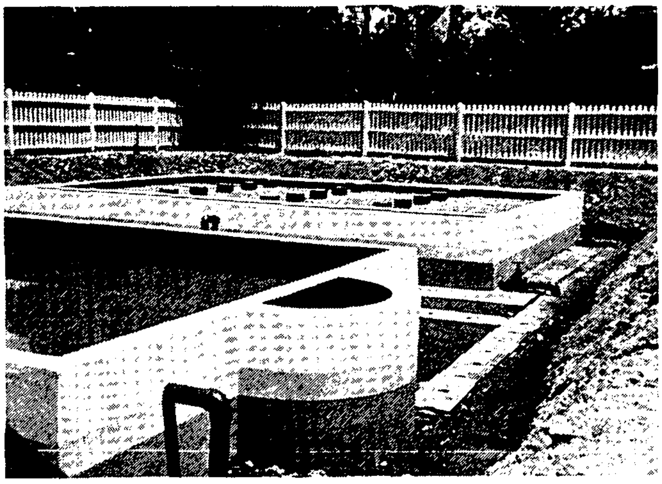


SECTION A - A



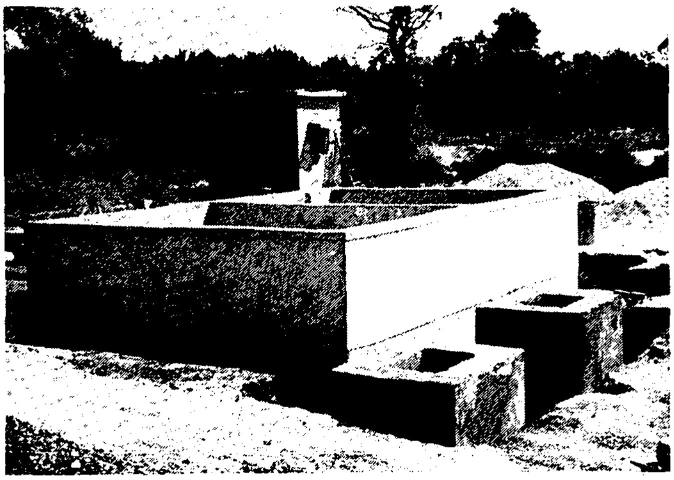
SECTION B - B

FIG. 4 - PRETREATMENT BY HORIZONTAL-FLOW FILTRATION



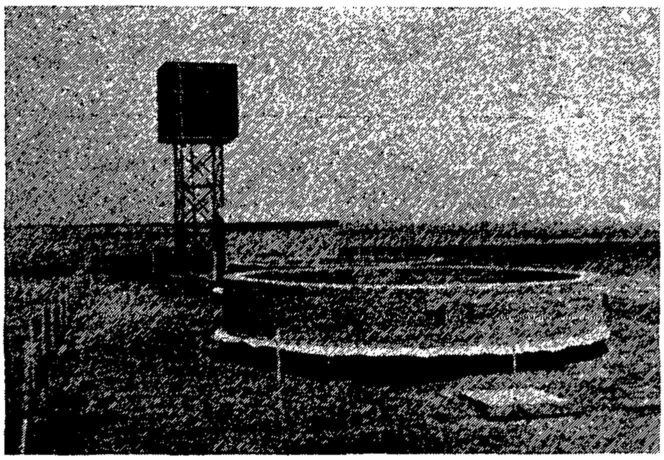
IRC

SSF and Horizontal Roughing Filter, Thailand



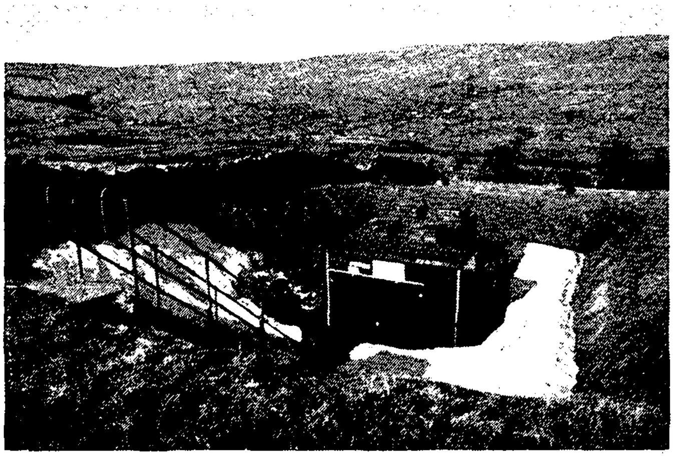
IRC

SSF plant under construction, India



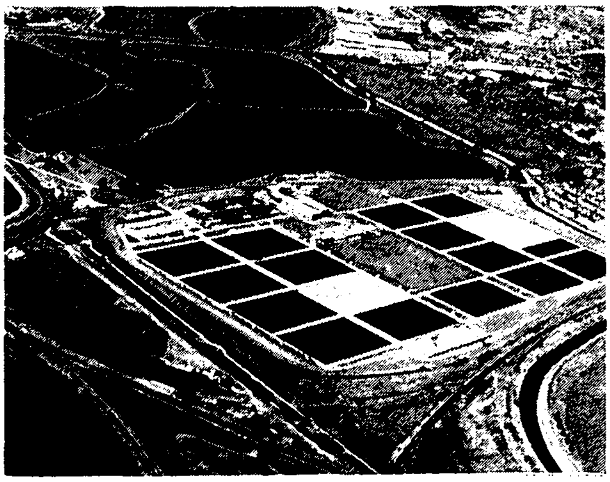
IRC

Circular brick masonry filter, Sudan



WRc

Small-scale prefabricated SSF unit, United Kingdom



Thames Water

London's drinking water treated by SSF, United Kingdom

FIG. 5 – APPLICATIONS OF SLOW SAND FILTERS

3.2 Village-level Operation and Maintenance (VLOM)

A series of filters is the least demanding train of water treatment processes for village-level operation and maintenance. The absence of chemical preparation and dosing and lack of unit desludging requirements make operation a very simple process. Local operators can, with a minimum of training, learn to carry out the simple routine procedures for successful operation and maintenance. The robustness of the limited amount of equipment in the system reduces the risk of mechanical breakdown and minimizes maintenance requirements. Continuous attendance by an operator is not essential since the unit is a gravity-flow filtration system.

Filter cleaning by removing the 2-3 cm surface layer of sand (and ultimately resanding of the filter with fresh or washed sand once a minimum bed-depth has been reached) is a simple manual process in which the villagers can participate. This will only be necessary every 2-3 months if the influent to the slow sand filter does not have an average turbidity in excess of 20 NTU. Cleaning of prefilter units will also tend to be a simple operation, although with some units (such as the SWS filter) the frequency of cleaning might be greater than for the slow sand filter where raw water turbidity is high.

3.3 High Effluent Quality

Without the need for chemical treatment, the combination of prefiltration and slow sand filtration will provide a quality of effluent which can be matched only by several stages of the most sophisticated water treatment processes. No other simple series of processes can upgrade turbid surface waters with anything like the efficiency of the SSF system. Treated water will generally have a turbidity of the order of 1 NTU and look crystal clear. For much of the time it will be free of pathogens, as indicated by the absence of faecal coliform organisms, and only occasionally, if the raw water is heavily polluted, will it contain a few *E. coli* bacteria.

Other raw water quality parameters which might also be improved in passage through a slow sand filter are colour, total iron and organic matter. Water alkalinity, hardness and most other chemical components are not changed by slow sand filtration.

3.4 Low Cost

Accepting the effectiveness and reliability of water treatment in the slow sand filtration system, low construction and operating costs are of paramount importance in national programmes for extending safe and adequate water supplies to underserved sections of the population. In view of the use of local materials and simple equipment in construction the need for imported items is obviated. Taking advantage of local skills in design and construction and involvement of the community during construction and in operation and maintenance further reduces capital and recurrent costs. Avoiding the use of chemicals in treatment will practically eliminate materials purchasing, leaving only local labour costs for operation and maintenance. Pumping from the source to the point of distribution, if necessary, will be required whatever the form of treatment technology but energy requirements in slow sand filter treatment are negligible.

Cost figures for slow sand filtration vary from country to country and comparisons are not of great value. In addition, published cost data are often in different forms and units, making their comparison almost impossible. A recent review (Ref. 8) of the costs of slow sand filter installations in the UK suggested present worth* figures for the base year 1982 of between £55,000 and £100,000/1000 m^3d. (US$ 77,000 - 140,000/1000 m^3d). In this case, the portion of present worth associated with operation and maintenance reflects the high cost of labour. The study also found little difference between the present worth figures for rapid-gravity filters and slow sand filters, although land costs were not included. Roughly equivalent total annual cost figures for slow sand filters in India have been published (Ref. 9) on the basis of a 15 years design period and 10% interest rate. In 1983 Indian rupees (US$ 1 = Rs 12.5), the average annual cost of slow sand filters, including land cost, worked out at Rs 430,000/1000 m^3d (US$ 34,400/1000 m^3d), no doubt due to the low cost of labour. Furthermore, it was suggested that slow sand filters were more economical than rapid-gravity filters for plant capacities up to 8000 m^3/d (representing the supply of 70 lpcd to a population of 120,000). The total cost of producing water from slow sand filters varied from 1300 Rs/1000 m^3 (US$ 100/1000 m^3) for small plants (capacity less than 270 m^3/d) to about 500 Rs/1000 m^3 (US$ 40/1000 m^3) for plant capacity 5000 m^3/d and was sensitive to the mode of operation of the filters. A 1984 paper on slow sand filtration in the US (Ref. 10) gave treatment cost predominantly falling below US$ 0.10/1000 gal (US$ 26.4/1000 m^3) but this almost certainly included only operating and maintenance costs.

If the community served by a water supply project is to pay the whole or part of the total cost, the adoption of slow sand filtration for surface water treatment will allow the production of water at an affordable cost. Economic tariffs will not normally be an intolerable burden on a low-income rural community and any necessary Government subsidy would be minimized with this type of treatment technology. The importance of the local community's participation in reducing water tariffs will be appreciated by them and this will foster commitment to the project.

3.5 Economy of Water

In arid areas, the saving of water through not having to desludge sedimentation tanks or backwash rapid-gravity sand filters might be an important advantage of slow sand filtration.

4. DISADVANTAGES AND HOW THEY CAN BE OVERCOME

4.1 Land Use

A slow sand filtration treatment plant will take up a greater area of land than a conventional rapid-gravity sand filtration plant. This might well eliminate the possibility of using the system to serve large communities near major cities, where land costs are high, but around provincial towns and in rural areas of developing countries land will usually be available at reasonable cost. Even near cities, the advantages of the SSF system might outweigh this apparent disadvantage in providing water supply to peripheral communities.

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*Present worth was defined as the amount of money required for the construction of the units (initial capital cost, excluding land cost) together with the sum that must be invested (at 10% interest) to cover annual costs (operation and maintenance) over 20 years and to account for the additional annual costs due to inflation (at 5% per year).

4.2 Labour Intensive

Slow sand filtration systems will require attention on a regular but not necessarily continuous basis. The numbers of operators normally required will be no more than in an automated rapid-gravity sand filtration plant and will be less than in a manually-operated rapid-gravity filter plant. More labour is required during filter cleaning but this is for short periods every 1-2 or more months and villagers could assist with this activity in rural plants. In larger plants with many filters, a permanent cleaning crew will be required. The fact that labour is still relatively cheap in developing countries will reduce the importance of this potential disadvantage.

4.3 High Turbidity Problem

Waters with average turbidity in excess of 25 NTU cannot be applied to slow sand filters because the length of the filter run would be unacceptably short. This problem limited the application of slow sand filters in developing countries until suitable pretreatment systems were developed. Nowadays, if the range of turbidity in the raw water is known, a combination of processes can be designed to prepare the raw water for final application to the slow sand filter. This will usually require only a single prefilter unless the raw filter turbidity exceeds 150 NTU for extended periods.

4.4 Intermittent Operation

To avoid destruction of the 'schmutzdecke', slow sand filters should be operated continuously and, except when being cleaned, the water level should never be drawn down below the surface of the sand. After a period of shut down, the effluent quality deteriorates significantly. In rural areas of developing countries the needs of the community might be served by a single operating shift with shut down for 16 hours a day. Additionally, the sense of responsibility of unsupervised operators in plants designed to operate 24 hours a day might not be high and shut downs will occur at random when an alternative attraction arises.

Proper training of operators, who will usually be members of the local community, will overcome the latter problem. At worst, all plants should operate for at least 16 hours per day and, rather than completely shutting down overnight, declining-rate operation could be practised. Under such conditions, the inlet valve is closed initially and the water level over the sand drops continuously through the night, with a resulting decrease in filtration rate but no deterioration in water quality. However, a larger filter area will be required to maintain the same output. Provision of elevated raw water storage might be a more economical solution than declining-rate filtration. Intermittent operation should be avoided at all cost.

4.5 Large Volume of Graded Sand

Slow sand filters will contain from 50-100 times more sand than rapid-gravity sand filters and the supply and cost of this medium will be a problem in areas where sand is not available locally. An alternative in rice-growing countries is burnt rice husk, which has been used successfully to replace sand in a slow filter (Ref. 5).

Some designers believe that a uniform grading of sand is essential for use in sand filters. Experience in India (Ref. 11) has shown that builder grade sands with effective size up to 0.3 mm and uniformity coefficient below 3, which can be obtained locally, give a satisfactory performance and reduce the cost of media.

4.6 Algal Growth

Under tropical conditions, there is the possibility that some types of algae will proliferate in slow sand filters. Experiments with filter covers in India (Ref. 11) confirmed that filter performance was not affected but algal growth was retarded. In most cases, covering of filters will not be necessary and only where algal growth cannot be effectively prevented and serious problems are experienced, for example after pretreatment, should this solution be contemplated. Likely algal problems include filter blocking and taste and odour nuisance (Ref. 2).

4.7 Need for Final Chlorination

Final chlorination is essential if the safety of slow sand filtered water is to be guaranteed at all times but this applies even more to conventionally treated rapid-gravity filtered water. Slow sand filtered water is known to be superior from a health point of view and, with the unreliability inherent in rural chlorination systems, will provide a safer supply than that produced by a conventional treatment plant without chlorination.

5. KEY FACTORS LEADING TO SUCCESS

5.1 Institutional Approaches

Of critical importance is the Government's attitude towards the water supply sector in developing countries. If there is a strong commitment to providing a basic level of service to everyone as soon as possible then slow sand filtration systems will have a prominent role in water supply programmes. Their advantages cannot be overlooked in addressing the problems of rural settlements and smaller urban communities.

Once Government is committed to the water supply programme, planners must recognize that a 'bottom up' approach is necessary, rather than the usual centralized hierarchical decision-making process which has dominated the sector. Communities must be consulted from the beginning and water agencies should utilize their regional representatives and local health and agricultural workers in the developmental stages of a project, rather than dictate the outcome from head office. Coordination among the various agencies involved and the communities is a key factor in dictating the success of a programme and this should be achieved through regular meetings, social surveys and inter-agency discussions.

If slow sand filtration is to play its rightful role in providing safe water to low-income communities in developing countries, engineers in water agencies must be prepared to accept new directions in technology. This will be more difficult in countries where SSF has not contributed significantly to water treatment in the past but even where slow sand filters have been used they are often thought to be an 'old-fashioned' form of water treatment. In fact, there is a resurgence of interest in this very appropriate technology throughout the world and there is every likelihood that it will be increasingly applied.

The simplicity of slow sand filtration will allow water agencies to place more reliance on the community, both in implementing projects and for operation and maintenance. This is advisable, to further reduce the cost of what is already a low-cost water treatment system. However, the agency's responsibilities must include training and public education as well as technical support when needed. In addition, the collection of charges will be necessary to ensure that the community contributes on a continuing basis and thereby has a vested interest in making the system work. It should be recognized that slow sand filter plant failures in the past have been caused by neglecting to carry out even the minimal maintenance necessary.

5.2 Community Involvement

Involvement of the community in all decisions on water supply is now considered essential to the success of any programme (Ref. 12). The people to benefit from a project must be able to express their needs and points of view at all stages of planning and implementation. Alternatives must be discussed publicly and their financial implications clearly explained. In view of their importance as providers and users of water, it is especially important for *women* to take part in these discussions.

Once the system design has been agreed, and this will often include slow sand filtration, the community must participate in the implementation phase. Integrating community labour and resources into the construction of projects is not easy but is worthwhile, not only for cost saving reasons but also to generate interest in the project and a continuing commitment to its success. Sometimes, a water supply programme can contribute to community development through the involvement of residents in the production of components for the scheme. The encouragement of such an 'informal sector' will not only provide employment within the community but will also provide cheap components for the current and future projects.

Operation and maintenance are now recognized as being a shared responsibility between the community and the water agency. To be able to achieve this, the agency must provide training to local members of the community, who will serve as plant operators, and organize a back-up technical service. Both the training and technical service requirements of slow sand filtration are less than for alternative surface water treatment systems thus making SSF plants more manageable by local communities.

5.3 Public Education and Operator Training

In any water supply programme, the public must be informed of the health benefits which can result. Very often the full benefits will only be achieved if sanitation is provided along with water supply and home hygiene is improved. Nevertheless, health and hygiene education is an essential component of and best introduced in conjunction with a water supply programme. Project evaluation a few years after implementation will provide a guide as to the continuing need for and support requirements of health education. Some training of local health and/or agricultural extension workers will often facilitate public education in rural areas.

The successful operation and maintenance of slow sand filtration systems will depend on the efficiency of training of local plant operators. Relatively simple training programmes will be required but the community should not be left to its own devices to learn how to manage the water supply system. Plant operators should be identified early in the planning period so that they can be deeply involved in decisions on the system. They should maintain close relationships with all levels of the community and have regular meetings to discuss problems. Operator training should include health education and instruction on communicating with the public. Water agency back-up in the form of technical support for local operators is an essential feature of rural water supply programmes (Ref. 13).

6. SLOW SAND FILTRATION AROUND THE WORLD

A survey has recently been carried out on 27 slow sand filtration plants out of 47 identified in the *United States*, some of which have served effectively for 80 years or more (Ref. 10). The majority of the 27 plants surveyed supply communities of fewer than 10,000 persons, 31% of the plants supply less than 1000 people, and the average plant capacity was 39,000 m^3/d. Perhaps the largest slow filter plant in the US is at Denver, Colorado, where six filter beds occupying 4.2 ha have produced up to 170,000 m^3/d since 1901 and continue to do so.

In the *United Kingdom*, the water industry maintains more than 200 slow sand filtration works, of which 10% treat volumes in excess of 30,000 m^3/d. Much of the metropolitan area of London receives Thames River water which has been through settlement lagoons, microstrainers and slow sand filters before being chlorinated. The Ashford Common Works in Middlesex, now rated at 410,000 m^3/d, is to be uprated to produce 690,000 m^3/d by increasing the filtration rate from 0.2 to 0.3 m/h. This will require more frequent cleaning, already a mechanized process, and 'real-time forecasting' will be incorporated into the advance planning of the operation. As a result of the significant level of failure of chlorination in rural locations, the Yorkshire Water Authority has recently installed an automatic slow sand filter at Stalling Busk to serve a small rural community.

An 'Integrated Research and Demonstration Project' on slow sand filtration has been coordinated by the International Reference Centre for Community Water Supply and Sanitation (IRC) in The Hague over the past decade. During the first phase, research institutions in *Ghana, India, Kenya, Sudan* and *Thailand* carried out applied research on engineering aspects of the process. Phase two concentrated on the implementation of village demonstration plants in most of these countries (Ref. 12), as well as in Colombia where some 20 new SSF plants have been built or are being planned. The project is still continuing and presently is aimed at cost reduction by development of suitable designs, training of caretakers and appropriate pre-treatment methods.

Africa has been slow to take advantage of slow sand filtration with the exception of the *United Republic of Cameroon*, where many SSF plants have been installed over the past 20 years through a cooperative programme with HELVETAS, the Swiss Association for Technical Assistance. *Tanzania* is now incorporating SSF technology in several village water supply schemes after running field tests on horizontal roughing filtration (HRF) and slow sand filtration from 1980 to 1984 (Ref. 15). In the *Seychelles*, two slow sand filtration works are in operation but the shortage of land generally restricts their application in the islands.

Many countries in *Asia* have long-term experience with slow sand filtration, particularly *India*, where the technology has been used since 1865 for the treatment of river and canal waters. Sedimentation in tanks providing 4-7 days' retention commonly precedes the slow sand filters. This type of treatment plant exists in every State and more than 60% of the plants serve populations between 2000 and 10,000 (Ref. 11). Many of these plants are now poorly maintained and their performance leaves much to be desired. In *Thailand*, slow sand filters have been used for rural water supply since 1967 and now at least 57 plants are in operation. However, a 1984 evaluation (Ref. 16) indicated that performance was not satisfactory in most plants due to the lack of knowledge of operators and supervisors, their poor wages, disinterest of the community and an unwillingness to pay for the service. It is clear that even an appropriate technology like slow sand filtration must only be applied after proper planning and full consultation with the community. Training and fair payment of operators are essential and the community's interest in receiving a safe water should be maintained through health education. The demonstration projects previously mentioned incorporate these characteristics.

In 1982, the Pan American Center for Sanitary Engineering and Environmental Sciences (CEPIS) in Lima, Peru produced designs for modular treatment plants (Ref. 17) to provide engineers throughout *Latin America* with 'package' solutions for a range of water treatment problems. Slow sand filtration dominated as the most appropriate choice of treatment for the majority of applications and alternative pretreatment designs included high-rate settling units (with sloping plates) and horizontal flow pre-filters. Five modular designs with capacities from 3.6 to 10.8 m^3/h were detailed for four levels of maximum raw water turbidity (<100JU, <250JU, <1250JU and <1500JU), provided the turbidity particles are larger than 1 μm.

In this short review of the applications of slow sand filtration it has not been possible to gather information on the extent of usage of this form of technology in all countries. Many countries which are known to use slow sand filters have not been mentioned but it is hoped that the few examples given will provide some indication of the ubiquitous distribution of SSF plants and their importance in approaching the challenge of rural water supply in developing countries.

7. ASSISTANCE AVAILABLE

As a result of the International Drinking Water Supply and Sanitation Decade, international, bilateral and non-governmental agencies are now active in the sector. A wide range of support for water supply programmes is available to developing countries. Financial assistance can be provided by International and Regional agencies, like the World Bank or the Asian or African Development Banks, and through bilateral aid between countries. In general, each agency applies different procedures and proposals must fall within the specific criteria applied. Nowadays, community benefit is of primary significance in assessing proposals and the local managerial and technical ability to operate and maintain systems throughout their design life are important. Properly planned slow sand filtration projects will be favourably considered, provided a written proposal of high quality is presented. More important in the context of this booklet is the range of technical assistance which different organizations are able to provide to water supply agencies wishing to introduce or extend systems including slow sand filtration.

Many United Nations agencies offer technical support for water supply, including the World Bank, WHO, UNICEF, UNEP and UNCHS (HABITAT), and some special units concentrating on water supply and sanitation have been created within the agencies or in association with national institutions. Among the more prominent units in respect of slow sand filtration are:

Unit for Global Promotion and Cooperation for Water Supply and Sanitation	– within the Division of Environmental Health, World Health Organization, 1211 Geneva 27, Switzerland
Technology Advisory Group (TAG)	– within the Water Supply and Urban Development Department, World Bank, 1818 H Street, NW, Washington, DC 20433, USA
International Reference Centre for Community Water Supply and Sanitation (IRC)	– a WHO Collaborating Centre, PO Box 93190, 2509 AD, The Hague, The Netherlands
International Reference Centre for Wastes Disposal (IRCWD)	– a WHO Collaborating Centre, Ueberlandstrasse 133, CH-8600 Dübendorf, Switzerland
Pan-american Center for Sanitary Engineering and Environmental Sciences (CEPIS)	– within Pan-american Health Organization, WHO, Casilla Postal 4337, Lima 100, Peru

Bilateral aid agencies exist in most industrialized countries and many have supported water supply projects in developing countries. The US Agency for International Development has sponsored a special Water and Sanitation for Health Project (WASH) to act as a coordination and information centre. In 1970, the Canadian Government created the International Development Research Centre (IDRC), which has supported research and development of rural water supply systems since 1976. Many developed countries have specialist water research and development institutions, such as the Water Research Centre (WRc) in the UK, which has advised developing countries on SSF technology. Another form of bilaterial assistance is provided by young technicians and engineers who serve on rural water supply schemes as Peace Corps, Voluntary Service Overseas (VSO) or Canadian Universities Service Overseas (CUSO) volunteers.

Arising out of the IRC collaborative project on 'Slow Sand Filtration for Community Water Supply in Developing Countries' several institutions in developing countries are now in a position to provide technical assistance for slow sand filtration projects. These include:

Instituto Nacional de Salud, Division of Basic Rural Sanitation, Apartado Aereo 80080, Bogota, Colombia

Universidad del Valle, Facultad de Ingenieria, Apartado Aereo 25360, Cali, Colombia

National Environmental Engineering Research Institute (NEERI), Nehru Marg, Nagpur 440020, India

National Water Commission, PO Box 65, Kingston, Jamaica

Ministry of Health, Public Health Department, PO Box 30016, Nairobi, Kenya

University of Khartoum, PO Box 321, Khartoum, Sudan

Asian Institute of Technology, PO Box 2754, Bangkok, Thailand

Provincial Waterworks Authority, 72, Jang Wattana Road, Bangkhen, Laksi, 10210 Bangkok, Thailand

An Environmental Sanitation Information Center (ENSIC) supported by IDRC has been established at the Asian Institute of Technology in Bangkok and regularly issues newsletters, abstracts and reviews. The Agriculture and Water Unit of the Intermediate Technology Development Group (ITDG), 9, King Street, London WC2G 8HW, UK disseminates information on low-cost water supply and provides advice and assistance on specific cases. In 1980, the Swiss Center for Appropriate Technology at ILE, University of Saint-Gall, Varnbuelstrasse 14, CH-9000 St. Gallen, Switzerland, with support from the Swiss Association for Technical Assistance (SATA), published a manual for rural water supply in developing countries based on their experience in the Republic of Cameroon.

A sizeable investment in developing country water supplies is made each year by Non-Governmental Organizations (NGO's) and the recent droughts in Africa have increased public support for such activities. Among those NGO's involved in water supply are: Actionaid, Catholic Fund for Overseas Development (CAFOD), Christian Aid, Euro Action-Acord, Oxfam, Save the Children Fund, Wateraid and World Vision. Oxfam has supported the development of a modular water treatment package including slow sand filtration and prefiltration (Ref. 18) for disaster situations.

A complete review of information on 98 external support agencies and non-governmental organizations is to be found in the Water Decade Directory (Ref. 19). The Catalogue of External Support in the Directory can also be obtained separately and contains details on each agency's and each organization's activities and statistics on their projects.

REFERENCES

1. World Health Organization. Estimate of Regional Figures for Water Supply Provision in 1983, *Private Communication*, Community Water Supply and Sanitation Unit, Division of Environmental Health, WHO, Geneva, 1985.

2. Huisman, L. and Wood, W.E. *Slow Sand Filtration*, World Health Organization, Geneva, 1974.

3. Cansdale, G. The SWS Sand Filter and Pump, *Waterlines*, 1, 1, 11-13, 1982.

4. Wegelin, M. Horizontal-flow Roughing Filtration: An Appropriate Pretreatment for Slow Sand Filters in Developing Countries, *IRCWD News*, 20, 1984.

5. Thanh, N.C. and Pescod, M.B. Application of Slow Sand Filtration for Surface Water Treatment in Tropical Developing Countries, *Final Report No. 65*, Asian Institute of Technology, Bangkok, Thailand, 1976.

6. Pardon, M., Wheeler, D. and Lloyd, B. Process Aids for Slow Sand Filtration, *Waterlines*, 2, 2, 24-28, 1983.

7. Dijk, J.V. van and Oomen, J.H.C.M. Slow Sand Filtration for Community Water Supply in Developing Countries – A Design and Construction Manual, 1, *IRC Technical Paper No. 11*, International Reference Centre for Community Water Supply, The Hague, 1978 (under revision).

8. Ellis, K.V. Slow Sand Filtration as a Technique for the Tertiary Treatment of Municipal Wastewaters, *M.Sc. Thesis*, Loughborough University of Technology, UK, 1984.

9. Paramasivam, R., Mhaisalkar, V.A. and Sundaresan, B.B. Slow Sand Filtration – An Appropriate and Cost Effective Technology for Small and Medium Water Supplies in Developing Countries, *Proceedings National Workshop on Slow Sand Filtration*, National Environmental Engineering Research Institute, Nagpur, India, 1983.

10. Slezak, L.A. and Sims, R.C. The Application and Effectiveness of Slow Sand Filtration in the United States, *Journal A.W.W.A.*, December, 38-43, 1984.

11. Sundaresan, B.B. and Paramasivam, R. (Ed.) Slow Sand Filtration Research and Demonstration Project – India, *Final Report*, National Environmental Engineering Research Institute, Nagpur, India, 1983.

12. International Reference Centre for Community Water Supply and Sanitation. Slow Sand Filtration – Community Education and Participation, *Seminar Report*, The Hague, 1983.

13. Visscher, J.T. and Veenstra, S. Slow-Sand Filtration: Manual for Caretakers, *IRC Training Services No. 1*, 1985.

14. International Reference Centre for Community Water Supply and Sanitation. Slow Sand Filtration for Community Water Supply in Developing Countries, Report of an International Appraisal Meeting, *IRC Bulletin Series 16*, The Hague, 1981.

15. Mbwette, T.S.A. Slow Sand Filters – The Tanzanian Experience, Asian Institute of Technology, Environmental Sanitation Information Center, *Newsletter*, 7,2,4, Bangkok, Thailand, 1985.

16. Provincial Waterworks Authority. *Report on Evaluation of the Existing Conditions of Slow Sand Filters in Thailand*, Bangkok, Thailand, 1984.

17. Pan American Center for Sanitary Engineering and Environmental Sciences. Modular Plants for Water Treatment. Vol. 1 and 2, *Technical Documents Series 8*, Pan American Sanitary Bureau, Regional Office of WHO, Lima, Peru, 1982.

18. Anon. Full Marks for Oxfam's Water Supply Package, *World Water*, July, 1982.

19. World Water. *U.N. Water Decade Directory*, Liverpool, 1984.