Multi-Stage Filtration

Thematic Overview Paper 15
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What this TOP is about

Multi-Stage Filtration (MSF) is an integrated solution for improving community water supply in rural communities and small to medium sized towns. Although it has been implemented in some areas and piloted in others, MSF as a technological package remains unknown in many countries. MSF was developed in the 1990s by researchers in Colombia where it is now being applied on a larger scale and some efforts were made to support wider dissemination and further development particularly in Latin America. The Millennium Development Goals (MDGs) require improved interventions in the water and sanitation sector. This challenge includes the need to improve water quality in many countries. MSF is one of the more interesting options, and perhaps the only solution for many community water supply systems. The challenge includes the need to improve existing systems, particularly the many slow sand filtration (SSF) systems around the world that do not perform well because of lack of pre-treatment. These systems need to be converted into MSF systems for better performance.

This Thematic Overview Paper (TOP) provides the basis for sector professionals to become aware of MSF technology and to learn more about it. It supports the WATSAN community with background information about the technology and design criteria, and with case studies, contacts and references to facilitate implementation worldwide. It examines why MSF is a viable technological option and explains its advantages and disadvantages. The TOP provides information, analysis and explanation of the major challenges and trends in MSF, and links to further sources of information and MSF specialists.

Contents

This Technical Overview Paper (TOP) on multi-stage filtration is divided into nine sections. Readers can follow the whole document, or dip into topics of interest.

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3.	The process and its limitations	explains processes and limitations
4.	Costs and management	discusses cost issues
5.	Experience and research	illustrates research experiences
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Acronyms and scientific measures

The following acronyms are used in this TOP:

BOC	Biodegradable organic carbon
CGF	Coarse gravel filtration
CFU	Colony Forming Units
DyGF	Dynamic gravel filters
MSF	Multi-stage filtration
NGO	Non-governmental organisation
NOM	Natural organic matter
NTU	Nefelometric Turbidity Units
O&M	Operation and maintenance
PCU	Platinum Cobalt Units
RSF	Rapid sand filtration
SSF	Slow sand filtration

1. Introduction

In many developing countries, sanitary risks associated with surface water are becoming greater due to poor protection of water sources and inadequate wastewater and solid waste management (PAHO, 1997). For example, in Colombia only 206 (<20%) of municipalities have wastewater treatment facilities and there is little reliable data about their performance. Surface water may also show unpredictable and erratic changes in quality due to run-off during rainy periods. This is a critical problem for waterworks operators, for example, in some Andean and Caribbean countries where 80% of water supply systems depend on surface water (Foster et al, 1987; Colombian Development Department, 1998). Surface water may carry considerable sanitary risk and require treatment to remove or reduce disease causing organisms. This risk is lower for well protected sources in the mountains than for lowland rivers in populated areas.

Slow sand filtration (SSF) is the oldest water treatment technique used in water supply systems and has been successfully implemented in northern Europe and North America for treating surface water with relatively low levels of contamination (Rachwal et al, 1988; Sims and Slezak, 1991). Experience with SSF has not been successful In Latin American countries such as Brazil (Hespanhol, 1969; Di Bernardo, et al., 1999), Peru (Canepa, 1982; Pardón, 1989) and Colombia, where high turbidity levels in the rivers caused premature clogging of the filters, resulting in the need for frequent cleaning and the ultimate abandonment of many systems.

This failure contributed to increased worldwide interest in Rapid Sand Filtration (RSF) of chemically coagulated water. RSF has evolved quickly during past decades and Latin American engineers have made important contributions to upgrading the processes and simplifying the equipment, making operation and maintenance (O&M) less complex, and reducing investment and operational costs (Arboleda, 1993; Di Bernardo, 1993). However, O&M remains demanding and the purchase, transport, storage, and correct dosage with chemical compounds is complex and costly. This technology is better suited to larger treatment plants since the administrative and technical challenges limit its wider application in community water supply for small and medium sized rural communities and municipalities. Even modern compact automated RF plants are subject to the same O&M problems

The technical complexity and affordability of smaller water treatment systems is a worldwide concern. For example, the 1996 Amendment of the Safe Drinking Water Act in the USA recognises the complexity of systems providing water supply to populations below 10,000 people. The USA Environmental Protection Agency says that RSF should be used only in systems with access to a full-time skilled operator and that SSF may be most suitable for small and medium size systems when used with source water of a suitable quality (EPA, 1998). This corresponds with the findings of an SSF research and demonstration project implemented in different countries by IRC and partners. The project favoured SSF because O&M is easy, it does not require chemicals, and it is very effective. This project was particularly successful in India where it supported the construction of SSF systems in four states. In Andhra Pradesh alone more than 2000 SSF systems are now in place. However, many of these systems do not perform well because of intermittent operation and problems with high turbidity (Visscher, 2006).

SSF has two important limitations. Firstly, poor water quality may exceed treatment capacity if high turbidity levels lead to premature clogging of filters, or if colour levels exceed removal capacity. (Colour in water is a marker for organic compounds which can react with chlorination processes to produce harmful and carcinogenic substances. Excessive coloration of water can also make it unacceptable to communities.) Secondly, the biological nature of SSF treatment requires a continuous flow of the water to ensure a continuous supply of oxygen and nutrients. Treatment is negatively affected by low temperature, low nutrient concentration or low levels of dissolved oxygen.

To reduce problems associated with these limitations, research was initiated into the development of pre-treatment systems to improve water quality before it reaches the SSF. The search for low cost systems with simple O&M led to the development of Multi-Stage Filtration (MSF), a combination of SSF and gravel filters. Development of MSF started in Latin America in the 1980s with promising results (Pardón, 1989; Galvis et al, 1989). In 1986, an experimental system with bench scale pilot units was built by the Cinara institute of Valle University (CINARA) in Cali, Colombia, as part of an SSF research and development (R&D) project, supported by IRC, to establish the potential of coarse gravel filtration to overcome SSF limitations. These bench scale pilots were about ten times bigger than laboratory scale units.

Promising results led to the development of a large research project, coordinated by CINARA and IRC and supported by the government of the Netherlands and institutions in Colombia. Comparative research was carried out in Puerto Mallarino, Cali, on different combinations of gravel filtration and SSF, using water from a highly polluted low land river. At the same time, research was carried out on full scale MSF systems that were being constructed in Valle region. Positive results attracted financial support from other international organisations which helped to further strengthen research, and led to intensive contact with researchers in other parts of the world, which helped to further develop the technology. Accounts can be found in the references at the end of this TOP including Bellamy, 1985, Lloyd and Helmer, 1991, Okun, 1991, Heldrich and Craun, 1991, Logsdon, 1991, Pardon, 1989, Smet and Visscher, 1989, Di Bernardo, 1994, Collins and Graham, 1994, and Galvis et al, 1989, 1992, 1996, 1999.

CINARA and IRC also launched TRANSCOL, an important national programme to transfer MSF technology to eight regions in Colombia through 'learning projects'. This contributed to wider dissemination of MSF, but at the same time established that it is not sufficient to look only at the technical challenges. For water supply systems to perform adequately, requires attention to 'framework conditions' such as training, back-up, legislation etc. that support the technology. The interaction between communities and their water supply is complex and water supply problems cannot be solved simply through a hardware approach. Success also requires a “software”; i.e. a way of thinking that takes into account the social, organisational and ecological dimensions of MSF systems (Visscher, 2006). Positive results in Colombia led to dissemination of MSF in a wide range of other countries including Mexico, Ecuador, Bolivia, Peru, Brazil, Nicaragua, the United States and some African countries.

2. The technology

Multi-stage filtration (MSF) is a combination of coarse gravel filtration (CGF) and slow sand filtration (SSF). This combination allows the treatment of water with levels of contamination well above that which can be treated by SSF alone. MSF retains the advantages of SSF as a robust and reliable treatment that can be maintained by operators with low levels of formal education. It is much better suited than chemical water treatment to rural communities and small and medium-sized towns in developing countries and in more remote areas in industrialised countries. Other treatment processes such as sedimentation, sand traps and screens can precede MSF systems. Wherever possible, terminal disinfection should be included as a safety barrier after MSF.

Figure 1 shows a layout of an MSF system with three components, dynamic gravel filters (DyGF), coarse gravel filters (CGF) and SSF. The illustration also shows a terminal disinfection safety barrier following MSF. This technology can be used either with one stage of coarse material filtration (CMF), for example DyGF, or – as in the illustration – two stages of CMF, i.e. DyGF and CGF, preceding SSF. MSF does not compromise the advantages of an SSF system in terms of ease of operation and maintenance and the end result is good water quality. It is an option that is applicable to many rural communities and small and medium-sized towns, where treatment with chemical products has very little potential.

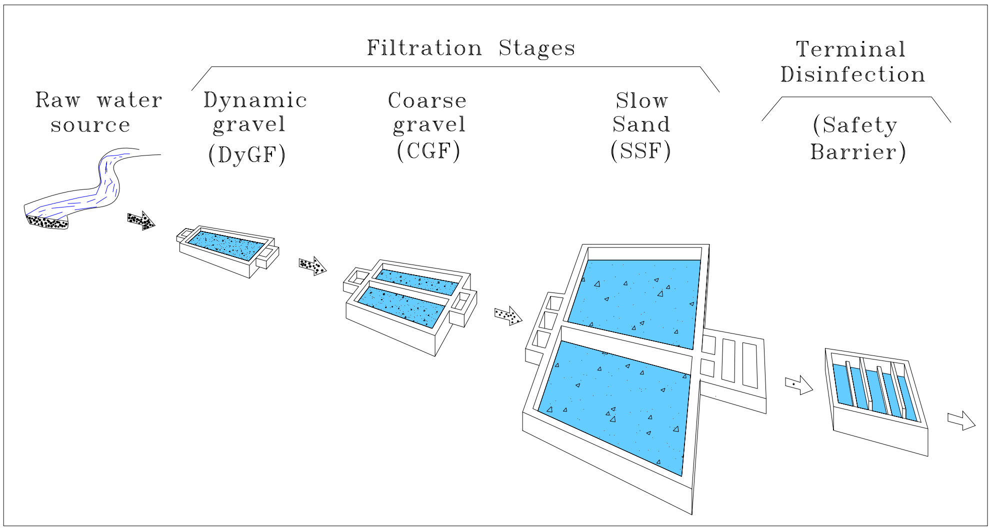
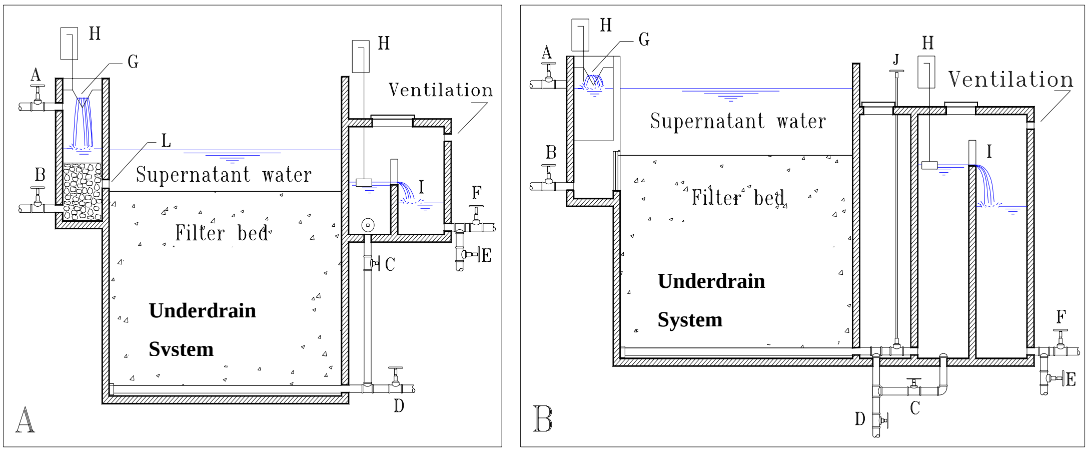


Figure 1. General layout of a multi-stage filtration water treatment plant (Galvis, G., 2000)

There are several options for MSF technology based on possible combinations in different treatment stages. Combinations need to be properly specified to meet water quality guidelines and treatment objectives. However, it should be emphasised that selecting and protecting the best available water source is far more economical and effective than allowing catchment areas to deteriorate and then relying on complex and costly water treatment options.

2.1 Slow sand filtration technology

An SSF unit consists of a structure that contains a filter bed, a supernatant water layer, drainage systems and flow control (Fig. 2). SSF water treatment is the result of a combination of physiochemical and biological mechanisms that interact in a complex way. Inorganic and organic matter enters the SSF units with the raw or pre-treated water, which passes through the filter bed under gravity and under the pressure of the supernatant water above. Photosynthesis gives rise to another fraction of organic matter, which adds to impurities in the water. However, soluble matter is removed from the water in the sand bed by bacteria and other micro-organisms. The filter bed acts as an organic and aerobic cleansing unit, as zooplankton grazing occurs and the entire biomass respires continuously, using oxygen from the water.



A: Inlet valve to regulate filtration rate
B: Valve to drain the supernatant layer of water
C: Valve for backfilling unit with filtered water
D: Valve to drain the filter bed
E: Valve to waste filtered water
F: Valve to contact tank or water storage
G: Inlet weir
H: Calibrated flow indicator
I: Outlet weir
J: Outlet control valve

Figure 2. Basic components of SSF units with inlet (A) and outlet (B) flow control

The flow in SSF units must be controlled to maintain the proper filtration rate to ensure that the biological process receives oxygen and nutrients. The flow rate can be controlled at the inlet or at the outlet of the filter. This usual method in SSF was to keep the supernatant water level at the maximum desired level above the filter bed often using a float valve. The driving force that takes the water through the filter is the difference between the level of the supernatant water and the level of the water overflow in the outlet box which is situated at the maximum height of the sand level. This is the available head to drive the water. Initially, when the sandbed is clean, the water would be able to flow through it at too high a filtration rate. To prevent this, the outlet valve (J) is almost closed which creates resistance (head loss) which ensures the proper filtration rate. As the filter skin (Schmutzdecke) gradually becomes blocked by impurities, resistance in the filter skin increases, creating additional head loss. To avoid a consequent loss of effective flow of water through the bed, the outlet valve is gradually opened to maintain the flow of water though the filter media at the desired filtration rate.

In inlet-controlled filters, the method now used in Latin America, the water flow to the filters is kept constant. The gradual increase in head loss in the filter skin is compensated by an increase in the height of the supernatant water, thereby increasing the pressure of water and rate of flow through the filter. Comparative research has shown similar performance in terms of effluent water quality, head loss in the filter bed, and length of filter runs for inlet and outlet-controlled SSF units run in parallel, with filtration velocities in the range of 0.13 – 0.5 m/h.

In both inlet and outlet controlled systems, the treatment process starts in the layer of supernatant water where because heavier particles can sediment and biological activity also takes place. The supernatant water also provides some buffer capacity.

Because of the importance of the continuity of the biological process, an SSF system should include at least two units, allowing a continuous water supply when one filter is off line, by increasing the filtration rate in the other unit(s).

The drainage system consists of a principal drain with lateral branches, usually built from perforated pipes, brickwork or tiles and covered with a layer of graded gravel and a layer of coarse sand. The use of corrugated pipes has been introduced by CINARA in Colombia and led to a reduction in the height of the drainage system. This system needs to:

- Support the filter material and prevent it from being drained away
- Ensure uniform abstraction of the water over the filter unit
- Allow for filter backfilling and the ability to drive out air pockets

The layer of supernatant water provides the static head necessary for the passage of water through the sand bed. In a clean bed, the initial head loss is usually below 0.1 m, which gradually increases until the maximum level is reached. The maximum height of the supernatant water in recently constructed systems has been reported in the range of 0.6-1.2 m.

The filter bed consists of relatively fine sand characterised by an effective grain size diameter d10 of 1.5 to 3.0 mm and a uniformity coefficient, uc = d60/d10 below 5. It is necessary to use fine sand to ensure that materials are being removed from the water at the top of the sand bed and subsequently can be removed by surface scraping. The minimum depth of the sand bed should be 0.4–0.5 m and the sand should be clean and free of clay, earth and organic material, which often makes it necessary to wash the sand before using it.

Operation and maintenance Because of the biological nature of the process, SSF units must operate continuously. The rate of filtration can be slowed, but intermittent operation should be avoided, since oxygen depletion and lack of nutrients compromise biological activity. After several weeks or months of running, the SSF unit will gradually become clogged as a result of the accumulation of inorganic and organic material, including the biomass that is formed on top of the filter bed. The major increase in head loss occurs in this top layer. By scraping off some 1 to 3 cm of this layer, hydraulic conductivity is restored to the same level of efficiency as at the beginning of the filter run. The sand that is scraped off should be washed and stored. After several scrapings, when the filter bed reaches its minimum depth (0.4 – 0.5 m), the washed and stored sand from the different scrapings with whatever new sand is necessary should be placed in the filter underneath the existing sand layer. This process is called resanding, and is usually achieved by digging out sand from half the width (temporarily storing it on top of the other half of the bed), then putting washed sand stored form earlier scrapings together with some new sand in the dug out space. Next, the temporarily stored sand is placed on top of the fresh sand. Finally, the process is repeated for the other half of the bed and the total surface is levelled.

2.2 Design guidelines

Differences are found in SSF systems around the world. In part, these reflect progress in understanding the technology, which has particularly resulted in a considerable reduction in the height of the filter. One can find old filters of over 3 m, whereas recently constructed systems in Colombia have a height of less than 2 m.

Table 1 shows design criteria by different authors. Differences between these criteria particularly concern the filtration rate and the diameter of the sand. The use of coarser sand has a limitation in that impurities will penetrate deeper into the bed, which will require the scraping of thicker layer and may cause a reduction in treatment efficiency. The filtration rate is strongly influenced by the quality of the water and the level of pre-treatment. In Europe, SSF systems are still used in a number of countries, treating very clean water with high filtration rates up to 0.7 m/h. For the application of SSF in community water supply in developing countries, the criteria suggested by Galvis et al (1998) seem to be most appropriate. It has been conclusively shown that higher filtration rates can be applied. This facilitates cleaning because it allows other units to be temporarily operated at a higher filtration rate when one unit is taken out of service for cleaning.

The “design period” in this table is the period for which the system is designed to meet the needs of the population, under conditions of an assumed population growth. A short design period has the advantage of reducing the risk of building filters that are unnecessarily large, because predictions are inaccurate.

Table 1. Comparison of design criteria for Slow Sand Filtration by several authors

Design Criteria	**Ten States Standards USA (1987)**	**Huisman and Wood (1974)**	**Visscher, et al. (1987)**	**Galvis, et al (1998)**
Design period (years)	Not stated	Not stated	10 -15	8-12
Period of operation (h/d)	24	24	24	24
Filtration rate (m/h)	0.08 - 0.24	0.1 - 0.4	0.1 - 0.2	0.1 - 0.3
Sand bed: Initial height (m)	0.8	1.2	0.9	0.8
Minimum height (m)	Not stated	0.7	0.5	0.5
Effective size (mm)	0.30 - 0.45	0.15 - 0.35	0.15 - 0.30	0.15 - 0.30
Uniformity coefficient: Acceptable	Not stated	< 3	<5	<4
Preferred	≤ 2.5	< 2	<3	<3
Support bed height including drainage (m)	0.4 - 0.6	Not stated	0.3 - 0.5	0.25
Supernatant water maximum height (m)	0.9	1 - 1.5	1	0.75
Freeboard (m)	Not stated	0.2 - 0.3	0.1	0.1
Maximum surface area (m^2)	Not stated	Not stated	< 200	< 100

2.3 Pre-treatment options

Various pre-treatment alternatives can be used to improve raw water quality before it reaches the SSF units. Coarse Gravel Filters (CGF), which use gravel as the filter medium, are described in the following sections and schematically illustrated in Figure 3.

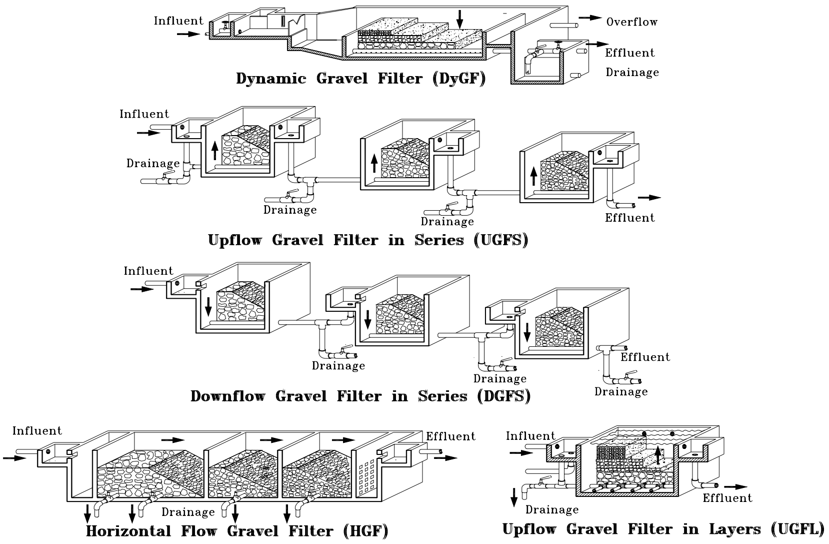


Figure 3.Schematic views of coarse gravel filtration alternatives (Based on Galvis and Visscher, 1987)

CGF alternatives have been classified according to the main application purpose and the flow direction. This includes dynamic gravel filters and respectively upflow, downflow and horizontal flow gravel filters. Coarse gravel filters have normally been specified to produce an effluent with turbidity < 10-20 NTU, or suspended solids < 5 mg/l to support and facilitate the treatment process at the SSF units and increase the operational run time of the units.

In this TOP, we present two systems currently used in MSF systems in Colombia. For more details and options readers are referred to IRC Technical Papers 34 (Multi-Stage Filtration: An innovative water treatment technology - http://www.irc.nl/page/1894) 40 (Small Community Water Supplies - http://www.irc.nl/page/1917) and 46 (Facilitating Community Water Supply - http://www.irc.nl/page/29210).

2.3.1 Dynamic gravel filters (DyGF)

A DyGF consists of two or more parallel units packed with 3 layers of gravel of different sizes ranging from coarse at the bottom to fine at the surface (Figure 4). The water (Qf) percolates through the gravel bed from top to bottom, reaching the drainage system, from where it flows to the next treatment unit. Due to the relatively coarse gravel used, head loss over the filter bed is very small (around 0.01 m). On the surface, opposite the inlet zone, there is an overflow weir with its crest at some 0.03 to 0.05 m above the gravel bed (Guzman, 1997). The filter operates initially under constant rate conditions. The head loss gradually increases to compensate for increasing resistance in the gravel bed so that water flows into the system more quickly than it can flow through the filter. When the supernatant water reaches the level of the overflow weir, the filter then needs to be cleaned. The DyGF concept was developed by CINARA in Colombia in an IRC supported project. DyGF contributes to an improvement in water quality and protects subsequent units against excessive loads of suspended solids. Suspended solid have been reported to be reduced by 23% to 77% for DyGF units processing natural raw water with suspended solids in the range of 7.7 – 928 mg/l, and operating at filtration velocities in the range of 9 to 1 m/h. If protection against peak loads is the main purpose, higher filtration rates can be applied, as shown in Table 2. (Galvis and Fernandez, 1991).

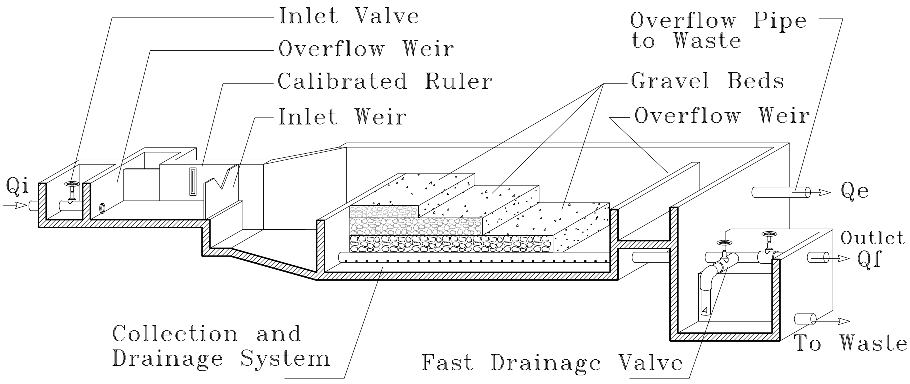


Figure 4. Layout of a dynamic gravel filter (DyGF)

Table 2. Guidelines dynamic gravel filter design (Galvis and Fernandez, 1991; Wegelin, 1996)

Parameter	**Main treatment objective**	
	Improve water quality	**Reduce impact of suspended solids peaks**
Filtration speed (m/h)	0.5-2.0	>5
Filter bed layer: Upper (thickness in m and size in mm)	0.20, and 3-5	0.20-0.30, and 1.5-3
Middle (thickness in m and size in mm)	0.20, and 5-15	0.10, and 3-5
Lower (thickness in m and size in mm)	0.20, and 15-25	0.10, and 5-15
Surface operating speed (m/s)	Nil or 0.1-0.3	Nil or <0.05
Surface washing speed (m/h)	0.2-0.4	0.2-0.3

Normally, the filter height is around 0.6 to 0.8 m. The filter box is built of masonry or reinforced concrete. The outlet structure must ensure that overflow water as well as wash water is collected during surface cleaning of the unit.

2.3.2 Upflow gravel filtration (UGF)

In an UGF the water passes through the gravel bed from the bottom to the top. During this passage impurities are retained in the filter. Upflow filtration has the advantage that the heavier particles are removed first at the bottom of the filter. When the time comes to clean the filters, these can be removed by opening the fast drainage valve, allowing gravity to drain and clean the filter. Two type of UGF exist. In the Upflow Gravel Filter in Layers (UGFL), gravel is placed in layers of different grain sizes, ranging from coarse at the bottom to fine at the surface (Figure 5 and Table 3). The other type, called Upflow Gravel Filter in Series (UGFS), is used for more contaminated water. This system comprises two or three units with different gravel sizes, each unit being filled mainly with one gravel size, starting with coarse grains in the first and moving to fine in the last unit.

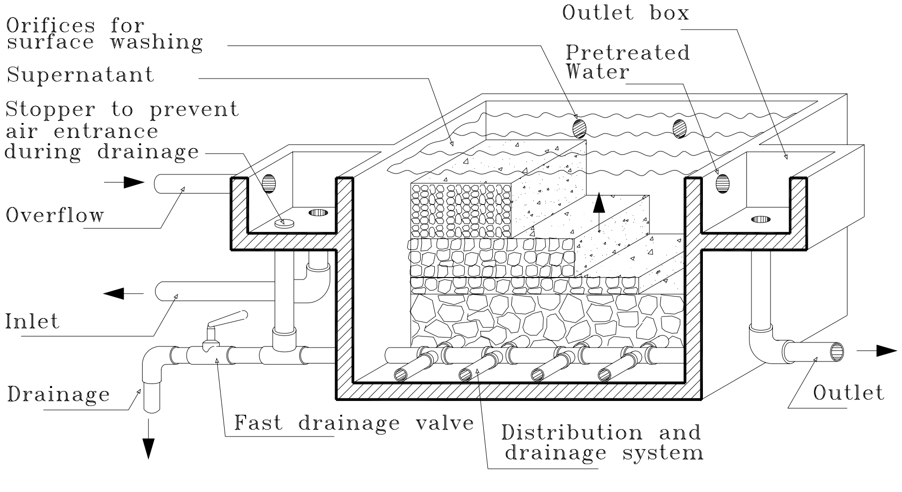


Figure 5. Layout of upflow gravel filter in layers (UGFL)

Table 3. Design criteria for upflow gravel filtration (Based on Galvis et al, 1989; Wolters et al, 1989; Galvis et al, 1993)

Parameter	**UGFL**	**UGFS1,2,3***
Filtration rate (mh-1)	0.3-1.0	0.3-1.0
Main gravel size fractions per compartment:	One compartment	Three compartments
Length (m) and (gravel size in mm)	0.20-0.30 (25-19)	0.60-1.0 (25-19)
	0.20-0.30 (19-13)	0.60-1.0 (19-13)
	0.20-0.30 (13-6)	0.60-1.0 (13-6)
Underdrain supporting gravel layer	0.15-0.30 (25-35)	0.15-0.30 (25-35)
Height of supernatant water (m)	0.20	0.20
Static head available for hydraulic cleaning (m)	>2.5	>2.5
Initial fast drainage speed for cleaning (m/h)	>10	>10
Filter bed area per unit (m2)	<20	<20

* 1, 2, or 3 compartments in series

The height of an UGF is usually less than 2 m. An increase in filter bed depth enlarges the silt storage capacity and the removal efficiency, but may make hydraulic cleaning more difficult.

2.4 Building materials

The use of local materials should be considered. Sometimes suitable materials, especially sand and gravel, are difficult to obtain in or close to the community and must be brought in from elsewhere. This must be taken into account when planning this kind of system.

The quality and characteristics of construction materials used within MSF can vary from one place to another according to climate conditions, and the way they have been handled and cleaned. Construction quality depends upon skills, monitoring, building controls and community supervision. Good building requires not only good design, but also transparent budget management and supervision.

The following building processes and techniques have been identified in Colombia and other Latin American countries as effective for use with MSF:

Concrete: the exact mixture of sand, gravel, cement and water depends on the required strength required, as established by local standards or local building regulations.

Reinforced concrete: a cement and sand mortar reinforced with steel rods or chicken wire. The concrete is reinforced with a network of vertical and horizontal rods with a small diameter (4-5mm), placed about 50 to 120 mm apart. As steel will be used, information should be sought about the quality of steel available in the project area.

Reinforced concrete is suitable for both straight and curved structural elements like circular filters, because the degree of deformation is small. It must be cured carefully, especially in hot or dry climates, to ensure satisfactory adherence.

Masonry: Bricks and mortar can be used to consolidate walls in filtration units, but must be of high quality to obtain a watertight structure. In underground circular filters with diameters of 5–10m, the walls must be 0.2–0.3m thick and should be checked for leaks.

Key issues when using masonry include:

- Vertical joins between the masonry units bricks should not be directly on top of each other;
- Bricks should not be broken into pieces smaller than half their standard size;
- Well-fired bricks must be used; those fired at high temperatures made close to the fire are preferred as they are stronger;
- Bricks must have an absorption level of less than 25%;
- Mortar should be made with 1 part cement to 2-3 parts sand.

A combination of masonry and reinforced concrete can also be used. For this, a 5-10 cm wall of bricks is built as the outer mould, in which a 2-3 cm layer of reinforced concrete is laid. This structure combines the binding powers of reinforced concrete with the greater resistance to impact and easy shaping of masonry.

Filtering material: The filtering material is preferably made up of sand and gravel extracted close to the MSF site. Filtering material should guarantee the following factors:

- grain size and distribution;
- sediment content and
- solubility.

The sand should have an effective diameter of 0.15-0.35 mm and a uniformity coefficient less than 5. The sand must be washed very well; silt content should be below 2%. Hydrochloric acid solubility must not exceed 5% in 24 hours.

Coarse gravel units should meet the design specifications as regards grain size and the depth of filter beds. The specified size range should be guaranteed by the builder. Selecting each size can be done on site with strainers and sieves.

2.5 The design process

Project location is a key issue as it affects investment and operational costs. The treatment system should be close to the local population to facilitate the operator’s work, and to ensure adequate supervision. The location should ensure optimal hydraulic performance preferably by gravity supply from source to delivery as this makes it easier to maintain the required flow through the system.

The design period, projected population growth and per capita water demand all have considerable impact on the size of the system, and thus on investment and running costs. There is little economy of scale in the construction of MSF systems. It is not much more costly to build a future extension than to build a larger system in the first place. A relatively short design period can therefore be chosen of say 8–12 years, which has the advantage that incorrect estimates of population growth and consumption patterns have a lower impact. For example, an estimated population growth of 2% implies that over an eight year period the design population becomes 1.17 times the current population: over a 15 year period it is 1.34 times the current population. If growth turns out to be lower than expected, the excess capacity built into a longer design period represents a large wasted investment. It is extremely important to involve the community in discussions about capacity, particularly if existing consumption levels are very high and community expectations exceed the capacity of the water source or available financial resources.

It is important that the designer understands that the following principles apply to MSF:
- Multi-stage treatment implies that there is more than one treatment stage to remove water pollutants and produce water that is consistently fit for drinking;
- Integrated treatment takes into account the potential and limitations of each treatment barrier in removing different types of pollutants
- Terminal disinfection is the final barrier that safeguards the bacteriological quality of the water.

In order for terminal disinfection to be effective, the previous barriers need to remove virtually all pathogenic micro-organisms and substances that can interfere with the disinfection process.

The overall water treatment system also needs to provide water that complies with WHO guidelines (2006) (http://www.who.int/water_sanitation_health/dwq/gdwq0506.pdf).

Treatment should be appropriate to the risk associated with each particular water source, noting that these risks can be reduced by proper management of the water catchment area, and by improving socio-economic conditions in the community. It is essential to take into account hardware and software (i.e. in the way that people think and act), and organisational and environmental dimensions. This is particularly important because of the biological nature of MSF. A ‘soft system’ approach which addresses people’s levels of skill, their attitudes and practices, is needed to ensure long term sustainability (Visscher 2006). A design with straightforward operation and maintenance needs has a better chance of functioning properly, but even in a simple design, back-up support and continuous training will often be required. In the CINARA projects special attention was paid to the aesthetics of structures, to ensure that they were in line with the natural environment. This had a positive impact on the community and raised their interest levels. In a number of communities in Colombia, visits to the facility are made by the community and by school children annually or more frequently. This type of rapport between the community and the MSF project helps to maintain community interest in good quality water supply.

3. The process and its limitations

3.1 Processes

MSF is predominantly an ecological process. Designers, constructors, operators, managers and users should know the advantages and limitations of MSF, and understand the relationship between the water system and the environment, particularly the condition of the water source, if the system is to operate efficiently and effectively (Visscher, 2006). They need to understand the relationship between nutrient concentrations in the raw water, microbiological populations of algae, bacteria, and protozoa, and environmental conditions such as temperature, pH, dissolved oxygen and sun radiation. All these factors affect the performance of the filters, the ripening process (see below) and treatment efficiency.

The main physical mechanisms contributing to particle removal are (Yao et al, 1971; Amirtharajah, 1988):

- surface straining,
- interception,
- transport, and
- attachment and detachment.

The brief description of these processes given here is taken from an extensive description on multistage filtration plants (Galvis 1999).

Particles that are too large to pass through the pores of the filter media are removed by **straining or sieving**. This mainly takes place on the surface of the filter bed, where the head loss is concentrated, and is independent of the filtration rate. According to Amirtharajah (1988), the size of pore openings range between 0.07 and 0.1 dc (grain diameter). With sand grains of 0.20 mm, this means that all particles with dp (particle diameter) >20 μm will be completely removed. Gradually smaller particles are also removed as a filter skin develops and pore sizes reduce. Haarhoff and Cleasby (1991) consider this development at least partly responsible for the initial improvement in performance at the beginning of each filter run, usually referred to as the ripening period.

The biological process seems to be an important element as well, as it may intercept bacteria, as well as other contaminants. Lloyd (1974; 1996) found a considerable difference in bacterial removal efficiency between pilot SSF units that had been inoculated with the peritrich protozoa Vorticella convallaria, a ciliary suspension feeder, and uninoculated control units. This improvement was greater when the population of protozoa was larger, and when the elapsed time between the samples was longer, clearly showing the ripening process.

To remove smaller particles that enter the pores of the filter requires transport mechanisms to take them to the surface of the sand (Figure 6) and attachment forces that cause the particles to adhere to the sand grains. As particles accumulate inside the bed, fluid velocities within the pores will increase as some may be blocked or partly blocked, resulting in stronger drag forces on the deposited particles. Eventually, if these forces are great enough, the deposited particles will become detached and transported deeper into the filter or into the effluent. Detachment may also occur due to avalanche effects that originate in the dome-shaped deposits on top of the grains (Ives and Clough, 1985, quoted by Ginn et al, 1992). The transport mechanisms are described as diffusion, sedimentation, interception, inertia, and hydrodynamic action. The first three are predominant in water filtration (Yao et al, 1971; Amirtharajah, 1988). The mechanism of inertia is important for air filtration but is negligible for water filtration. The mechanism of hydrodynamic action is due to the particle rotating and moving across streamlines and is primarily related to the particle's shape and its interaction with the water. A quantitative treatment of this mechanism has not been completed (Amirtharajah, 1988).

Diffusion results from random Brownian motion through bombardment of the particle by molecules of water. This mechanism can only be significant for dp<1μm (Yao et al, 1971).

Sedimentation or the gravity effect, and the associated settling speed of the particle, separates suspended particles from flow streamlines and allows them to reach the sand grain (collector). This mechanism can only be significant for dp>1μm (Yao et al, 1971), and plays an important role in filtration because of the large surface area on the grains available for deposition. Particle density and temperature are important factors in sedimentation. The combination of diffusion and sedimentation results in removal of particles as small as 1 μm, much smaller than the size of the pores in the sand bed.

Interception occurs when particle motion along a streamline is close enough (<0.5 dp, the diameter of the particle) to the collector for contact to occur. Although interception has been considered a distinct transport mechanism, some researchers have incorporated it as a boundary condition for attachment resulting from diffusion and sedimentation (Amirtharajah, 1988).

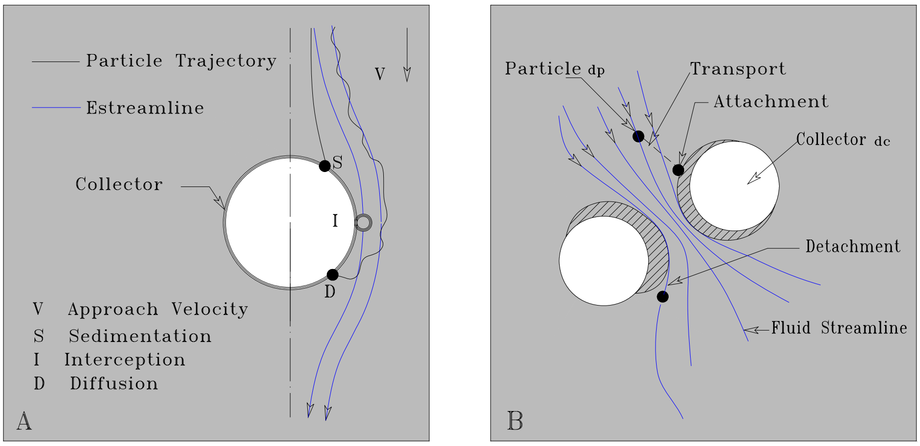


Figure 6. Basic transport mechanisms in water filtration (A: Yao et al, 1971; B: Amirtharajah, 1988)

When particles are very close to the collectors, surface forces cause their attachment to the collectors. Attachment may involve electrostatic attraction, London-van der Waals forces, or surface chemical interactions. However, based on the experience with RF, it is not clear how particles finally adhere and can be effectively removed in SSF without the use of chemical coagulants. A majority of the particles, as well as the sand grains, are negatively charged around the neutral pH range, and this would limit the role of Van der Waals forces, which require particles to be practically in contact with the grain surfaces or the surface of previously deposited material (Haarhoff and Cleasby, 1991).

Jorden (1963, quoted by Haarhoff and Cleasby, 1991) considered the possibility of polyvalent cations acting as a bridge between particles and the surface area of the filter. In line with this hypothesis, it has been found that virus adsorption on sand is enhanced with increasing ion strength and with higher concentration of higher valence cations in solution. Due to the importance of the biological activity in SSF, Haarhoff and Cleasby (1991) consider it plausible that adsorption involves attachment of particles assisted by biological actions such as the exocellular polymers (ECPs) produced by microorganisms. These ECPs are capable of flocculating kaolin suspensions (Pavoni et al, 1972) and organisms in activated sludge (Metcalf and Eddy, 1979; Galvis, 1981). Bellamy et al (1985, 1985a) noted that microorganisms growing on the surface of filter material can produce ECPs. They suggested that this also happens in SSF and that these polymers facilitate destabilisation of clay and bacteria to enhance the attachment of these particles to the biomass available in the upper layers of the sand bed, thus helping to remove them from the water.

Working with continuous flow bench scale experimental filtering cells, Lloyd (1974; 1996) found that the spirotrich protozoa Tachisoma pellionella grew rapidly in the flow cells, but did not remove more bacteria than the sand in the uninoculated cells. Since this correlated with his microscopic observations that these organism grazing bacteria are already attached to the sand surfaces, Lloyd concluded that they can probably fulfil a vital role in maintaining the ability of the sand surface area to remain active for further adsorption.

3.2 Limitations

3.2.1 Levels of contamination that exceed treatment capacity

Suspended solids or turbidity High levels of turbidity or turbidity of a colloidal nature may cause difficulties for MSF treatment. However these are definitely less than for SSF treatment, where it may result in premature blocking of the SSF units (resulting in filter runs of less than a month) and reduce treatment efficiency by covering part of the biologically active micro organisms. Different authors provide different upper limits for the turbidity level that SSF units can resist (Galvis, 1999). The suggested acceptable limits range from below 5 NTU to below 50 NTU. Most authors accept higher values in the range of 50-120 NTU, provided these are of short duration, i.e. a few hours to 1-2 days, although they recognise these higher limits are undesirable.

Iron and manganese Bacteria that contribute to the oxidation of iron and manganese are present in the filter bed. A low concentration of iron improves the removal capacity of the MSF for organic components. High concentrations however (above 1 mg/l may contribute significantly to SSF unit clogging.

Algae Algae grow in rivers, lakes, storage reservoirs and in the supernatant water of the SSF and gravel filters. The presence of algae in moderate quantities is usually beneficial for MSF. Most algae are retained by SSF, but under certain conditions significant algae growth (algal blooms) may develop. This massive growth can cause filters to clog very quickly. The decay of algae may produce high concentrations of soluble and biodegradable organic material in the water, which, in turn, creates smell and taste problems, and may contribute to microbial growth in the distribution system.

Organic colour and organic carbon One limitation of SSF is its low efficiency in the removal of organic colour and organic carbon. Very different removal efficiencies are reported in literature, which seem to depend primarily on the composition of the organic compounds. Field research in Colombia showed that SSF units removed between 5% and 40% of COD (mean value 16%) with no significant difference between upland and lowland rivers.

True colour Much of the colour in water comes from materials in suspension. True colour is the colour that remains when this suspended material is removed by centrifugation. The platinum-cobalt (Pt-Co) standard method is used to measure true colour through visual comparison with a series of standard solutions containing known amounts of potassium chloroplatinate and cobalt (II) chloride. A low colour level is desirable from an aesthetic perspective, but also because of the potential formation of harmful by-products that result from a reaction between chemicals in the purifying process and organic material that is responsible for the colour level.

Heavy microbiological contamination In some communities the only available water source may be so heavily contaminated with harmful microorganisms that MSF will not be able to produce a good quality supply. The strategy has to be to explore the possibility for an alternative source or the adoption of much more sophisticated treatment which will be costly and difficult to sustain. The long-term solution should be aimed towards improving the water source though catchment protection and waste water treatment.

3.2.2 Conditions that inhibit or reduce the efficiency of the treatment process

Various circumstances can interfere with the treatment process and reduce the efficiency of MSF units.

Low temperature Low temperature increases the viscosity of water and reduces biochemical activity in the sand bed, affecting treatment efficiency. E. coli removal may be reduced from 99% to 50% when the temperature falls from 20°C to 2°C. The strategy in countries with cold winters has been to cover filters or build them underground to prevent freezing and to reduce the impact of low temperatures. This has considerable financial implications. Reducing filtration rate is another way to reduce the impact of low temperature on the treatment process.

Nutrients Micro organisms active in the sand bed require nutrients such as carbon, nitrogen, phosphorus and sulphur for their metabolism and growth. Humic and fulvic acids, a source of natural colours, are rich in carbon but low in the other elements. This may result in a low level of biological activity which may be part of the explanation for the low removal of natural colour in SSF, when treating water sources that are well protected.

Dissolved oxygen Dissolved oxygen levels in the water can be depleted if there is a high amount of biodegradable material, particularly when the dissolved oxygen level in the water source is low, and this may result in undesirable anaerobic conditions in the filter skin. This anaerobic condition in the filter must be avoided because it may create serious water quality problems such as bad smell and taste, allow re-suspension of heavy metals with aesthetic implications, and may interfere with the final disinfection stage.

4. Costs and management

4.1 Initial capital investment costs

In general the investment cost in a water treatment plant is based on a number of key aspects that include:

- Plant capacity
- Type of plant (type of technology)
- Equipment cost (local and imported)
- Design criteria and cost
- Land prices
- Material cost (local and imported)
- Labour cost
- Geographic location
- Transport
- Climatic conditions
- Level of competence and profit margins of building firms

A review of MSF systems built in different regions of Colombia showed that materials (reinforced concrete, gravel, sand), land, soil excavation, building (including facilities for sand storage) and water disinfection, together represent approximately 80% of the direct investment cost, discounting including costs for administration costs, profits and contingencies (Galvis et al, 1989; Cinara-Mindesarrollo, 1996 and 1998). The remaining 20% is distributed between the cost of valves, fencing, lighting, accessories and pipes. These costs can be expressed as a cost model:

$$C = aQ^b$$

In which C is cost of building; Q is plant capacity; and a, b are coefficients. The value of coefficient “a” corresponds to the unit capacity of the plant. The coefficient b, usually smaller than 1, indicates economies of scale. If the value of b is close to 1, economy of scale is low, and cost efficiency cannot be obtained by increasing of the size of the system.

In the IRC supported project, participating staff in India developed this model for SSF and compared the results with the use of conventional systems in India (Sundaresan and Paramasivan, 1982). Their conclusion was that SSF was more economical in terms of investment cost for water treatments plants with a capacity to produce less than 50 l/s. When operation and maintenance costs are also taken into account, the break-even point is increased to 286 l/s.

In 1988, CINARA, with support from IRC, developed cost models for SSF systems based on experience with full-scale demonstration projects in the hillside areas of the Valle del Cauca (Galvis et al., 1989). The study included models for estimating building quantities and the cost of building SSF systems with production capacities between 2 and 30 l/s, using filtration rates of 0.15 m/h. The study also assessed economy of scale and the effect of filter box height on the start-up cost. It also provisionally included the cost of coarse gravel filtration (CGF), estimated to make up 75% of SSF costs. This estimate was based on the very first full-scale experiments with CGF technology in Colombia. It was found that the start-up cost for systems that included SSF and CGF were more favourable than for conventional systems for plant capacities up to 70 l/s (Galvis et al, 1989). CINARA later worked out more detailed assessments based on the comparison of the estimated cost of different MSF systems that were designed using the criteria indicated in Table 4.

Table 4. Design criteria for filtration stages of MSF plants used as basis for the models

Design criteria	MSF component				
	DyGF	**UGFL**	**UGFS (2)**	**UGFS (3)**	**SSF**
Filtration rate (m/h)	2	0.6	0.6	0.6	0.15
Filter bed depth (m)	0.60	1.2	1.2 (1)	1.2 (1)	1.05 (2)
Filter height (m)	0.80	1.4	1.4 (1)	1.4 (1)	1.90
Supernatant water height	0.05	0.1	0.1 (1)	0.1 (1)	0.75
Free board (m)	0.15	0.1	0.1	0.1	0.10
Maximum surface area (m2)	10	25	25	25	100
Number of units in parallel	2-6	2-6	2-6	2-6	4-12
Number of units in series	1	1	2	3	1

(1) For each filter unit; (2) Including support media layer of 0.20 to 0.25m, with commercially available corrugated PVC manifold drainage pipes

Designs were made for different plant capacities. The costs were established by multiplying the construction volumes with the unit prices prevailing in that period in the Valle region in Colombia. These costs of different MSF systems were compared with conventional RSF systems (Figure 7). The results show that depending on the type of MSF system, they have lower construction cost for plant capacities below 21 l/s for MSF that combines DyGF with SSF and 8 l/s for the most robust MSF combination with DyGF, 3 stages of UGF and SSF. Taking O&M cost into account increases the MSF competitive advantage over RSF.

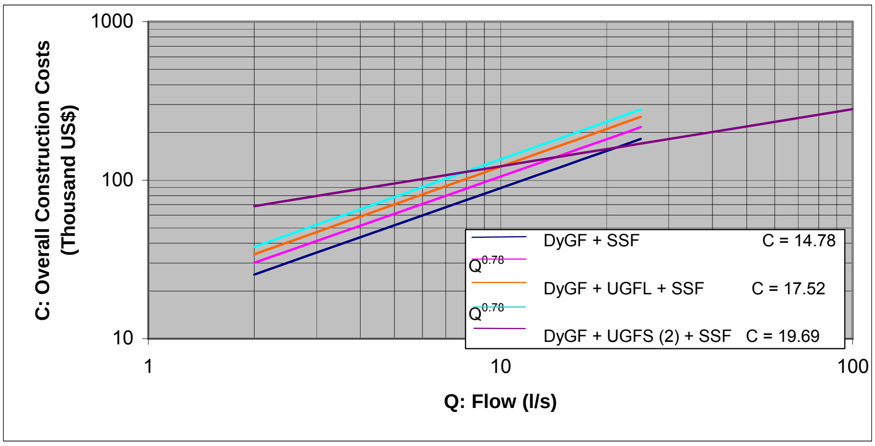


Figure 7. Overall construction costs of MSF alternatives and conventional RF plants; Cauca region, Colombia (Galvis, 1999)

The following observations can be made concerning the building and cost models:

- The proposed method for obtaining these models has been found useful for finding preliminary cost value estimates.
- The models have been developed for treatment capacities in the range of 2 to 25 l/s.
- Cost models are only applicable for the region where unit costs have been established. However, models can be adjusted for a particular situation or region, by evaluating work with the technology in the region concerned. The level of reliability of the cost estimate depends to a great extent on the quality of information concerning the unit cost.
- For MSF technology, the cost increases with the risk level associated with the water source. A higher risk requires a larger number of filtration steps and so greater building operations and costs.
- Under similar operating conditions (plant capacity, building materials, unit and labour cost and raw water quality), the MSF option that includes UGFL is the most economical, followed by the options including UGFS (2) and UGFS (3). When these MSF alternatives operate with different filtering rates, cost models become a practical tool for facilitating economical analysis.

4.2 Operation, maintenance and administration costs

Most water treatment cost studies are confined to investment costs, and usually relate only to RSF. Much less is known about operation, maintenance, and administration costs, especially of MSF. Factors with an important effect on operation, maintenance and administration costs in a water treatment system include:

- Labour costs
- Costs of consumables (local and imported)
- Maintenance requirements
- Energy costs
- Water quality regulations
- Number of users

Based on practical experience with full-scale MSF plants operating under gravity flow conditions in the Valle region in Colombia, the running costs of this technology are mainly labour costs. Experience with MSF developed over a ten year period indicates that staff costs make up approximately 85% of operating costs. The other 15% covers items such as electricity, wash water, and gardening. This estimate, obtained during training activities and through information collected from caretakers and community organisations, includes administration time which varied significantly between communities (Cinara, 1998). It is expected that the gradual development of more formal small enterprises for small water and sanitation systems in Colombia will contribute to improving time management and to reducing the time necessary to administer systems, which includes the time spent on conflict resolution inside or outside the community organisations.

As indicated, cost figures may vary considerably because they depend on local conditions. Table 5 gives an overview based on the most recent data from Colombia reported by Alzate (2000) for systems up to 10 l/s.The table clearly shows that O&M cost are considerably lower for MSF.

It is important to realise that pipelines and the distribution network represent the largest cost component in water supply systems with the cost of the treatment plant perhaps representing only 25% to 40% of the total cost. It is also important that the cost of pumping water is not included in the annual O&M cost as the data come from MSF systems that operate under gravity flow. However pumping costs may be assumed to be similar for all alternatives that are being compared in one area.

Table 5. Cost comparison of RSF and MSF treatment in Colombia

	Construction cost per l/s	Annual O&M cost per l/s
MSF (2 – 10 l/s)	US$ 16700 – 27800	US$ 470 – 1375
RSF (2 – 10 l/s)	US$ 16700 – 46400	US$ 1375 – 3740
Costs are based on systems in four regions in Colombia at 1999 price level (Alzate 2000). Costs are only indicative as they may vary based on local conditions. Higher cost relate to smaller systems. In Colombia 1l/s (86.4 m3/day) represents the water supply for 450 to 600 people.		

5. Experience and research

In Latin America and the Caribbean, SSF has been used to treat water in larger cities such as Buenos Aires and Kingston. The majority of the cities in these regions, however, use RSF technology. In most cases, the introduction of SSF to the region was carried out without adjusting it to local conditions, and as a result, its impact has been very limited. Most SSF plants were built in countries such as Brazil (Hespanhol, 1969) and Peru (Canepa, 1982; Pardón, 1989; Lloyd and Helmer, 1991) and had major difficulties in design, operation and maintenance. Similar situations have been encountered in Africa, in countries such as Cameroon, Kenya and Zambia, and also in Asia; in India, Pakistan and Thailand. In the state of Andhra Pradesh in India, for instance, there are over 2000 SSF systems but most of them have design and operation deficiencies (Visscher, 2006).

Despite these difficulties, renewed interest in SSF became apparent at the end of the 1970s. The most extensive project was the IRC Research and Demonstration SSF project implemented between 1975 and 1985 in India, Thailand, Kenya, Sudan, Jamaica and Colombia. Others also carried out research activities supported by organisations in England and Switzerland, contributing to understanding the technology's potential and limitations and to its wider promotion.

During the 1990s, interest in SSF was growing in a number of countries, particularly India, Colombia, Peru, the United States but also including some African countries and Pakistan. By that time it had become clear that pre-treatment was needed prior to SSF and this led to the development of MSF by CINARA in Colombia, as described in the Introduction, of this TOP. Subsequently CINARA also promoted the application of MSF through learning projects in Bolivia, Ecuador, Mexico, and, most recently (2005), Honduras.

Other research that also contributed to insights into SSF and GF including:

- Wegelin (1986), Lebcir (1992) and Boller (1993) focusing on modelling the exploration of the removal of solids with clay suspensions;
- Di Bernardo in Brazil and Lloyd (1974, 1996) in Peru and in England,with emphasis on the biological processes;
- Graham (1996) in England on the application of filter fabrics; and
- Collins (1996) who helped to reintroduce SSF into the USA. Collins co-organised (with Graham among others) two international research conferences and two regional workshops on slow sand filtration.

Most of the studies have been implemented in small filters often using acryl pipes with a diameter of 15 to 20 cm, although the research in Cali, Colombia, used pilot filters with a diameter of 1.5 m. The limitation of the small pilot units may be that their hydraulic behaviour does not reflect what happens in full scale units, nor do they give an adequate impression of the true O&M requirements.

The majority of research on SSF and MSF concentrates on removing suspended solids or turbidity, and to a lesser extent on coliform removal. Less consideration is given to other substances such as iron, manganese or natural organic matter, which can be relevant to MSF and SSF behaviour, the community's acceptance of the treated water and the performance of terminal disinfection.

The limited level of research using full scale systems in parallel with laboratory research has limited the development of MSF treatment plants. According to Collins (1999) "on-site studies greatly reduce confounding influences induced by raw water quality variations and will make treatment technology comparisons more meaningful and equitable". Lack of such research, particularly in developing countries, is hampering further development of MSF and related technologies.

Research in Colombia confirms that laboratory research, pilot scale testing and performance analysis of full scale plants very much reinforce each other and lead to more meaningful results. Studies include long term project monitoring by local caretakers with low formal education levels, under the supervision of community organisations with some technical and managerial support. Other aspects, such as building cost considerations and O&M have been included in some research studies to make it easier to estimate capital and running costs, which should contribute to the selection of more sustainable solutions under local conditions. A return visit to several MSF systems built under the technology transfer programme in Colombia in the early 1990s revealed that MSF systems were still performing. However, only in communities where the 'framework conditions' had been established, in terms of training and back-up support for operators, was performance adequate. Other MSF systems needed to be improved (Visscher, 2006).

5.1 Preliminary studies with MSF Pilot Units

An experimental system with technical scale pilot units was built in Cali in 1986 to establish the potential of coarse gravel filtration to overcome the water quality limitations of slow sand filtration using a highly polluted river in a tropical Andean environment. Though experimental, the systems were big enough to provide water for a small community. The system built at Puerto Mallarino was fed by gravity with water from the Cauca River, taken from the inlet structure of the main treatment plant of the city. The research system comprised five MSF parallel lines; each made up of different CGF alternatives and SSF units working. The CGF stage included downflow gravel filtration in series (DGFS), and upflow gravel filtration in layers (UGFL) and in series (UGFS). The filtration rates were set at 0.7 m/h and 0.15 m/h at the CGF and SSF stages respectively. Figure 8 illustrates the layout of the technical pilot plant in the Puerto Mallarino research station.

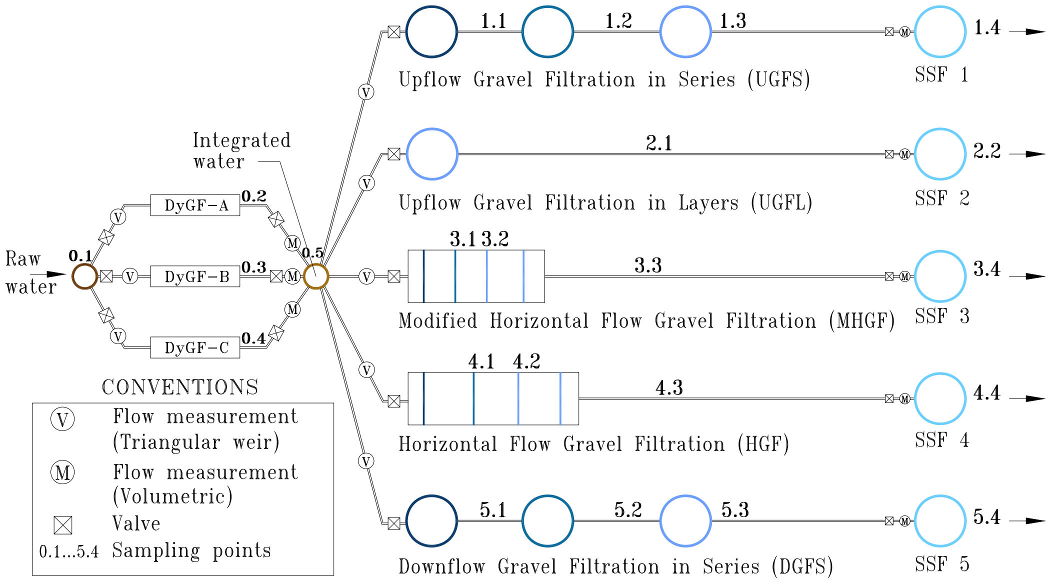


Figure 8. Schematic flow diagram of the multi-stage filtration (MSF) pilot system

Research was carried out for more than 10 years in Puerto Mallarino (pictured), during which time water quality was monitored regularly. The data indicate that turbidity levels for 90% of the samples were below 80 NTU for raw water but that there were peak values of more than 3600 NTU. The river is highly polluted and its coliform counts amount to on average 63,000 Colony Forming Units (CFU) with maximum levels of over 500,000 CFU (Galvis et al, 1989). Initial results were positive particularly for turbidity removal, but at 50 to 200 CFU, coliform counts were still rather high after MSF.

MSF pilot plant units at the Puerto Mallarino research station

A number of adjustments were made to the systems which helped to improve results considerably. Based on these results Galvis (1999) concludes that the different MSF alternatives that were tested at CGF rates up to 0.6 mh-1 and SSF rates up to 0.15 mh-1, all produced effluents with low microbial risk (mean ≤ 3 and maximum ≤ 25 CFU/100 ml). These results open the possibility of safe water even from highly polluted sources, using terminal disinfection as a safety barrier after MSF processing.

In this period, the performance of several full scale MSF systems in Valle region was also monitored by CINARA (Table 6). The data show that these MSF systems were able to deal with water qualities with average turbidity levels between 3 and 24 NTU, and peak loads between 15 and 300 NTU. Faecal coliform removal is impressive, confirming the potential of MSF to reduce the risk of transmission of water borne diseases. Colour is also successfully removed, reducing average colour levels from between 5 and 30 PCU (with peak values up to 200 PCU), to average levels that ranged between 3 and 4 PCU with peaks up to 30 PCU.

Table 6. Performance of different MSF systems in Valle region (1990 – 1998)

Name	**l/s 1**	**Turbidity (NTU) 2**		**Faecal Coliform Counts / 100ml 2**	
		In	**Out**	**In**	**Out**
El Retiro	15.1	14 (180)	0.6 (2.7)	5847 (69,500)	0.5 (8)
Cañasgordas	8.9	12.1 (75)	0.8 (4.1)	7000 (223,000)	1.5 (23)
La Rivera	3.8	5.9 (51)	0.6 (4.3)	3600 (23,100)	0.5 (28)
Javeriana	1.8	24.2 (300)	0.9 (12)	14,935 (204,000)	0.8 (25)
Shaloom	1	3.8 (22)	0.8 (2.9)	2895 (14,200)	4.3 (46)
Colombo	0.6	14.6 (122)	0.6 (6)	51,900 (677,000)	0.9 (82)
La Marina	7	6 (112)	1.1 (6.2)	803 (35,700)	1.8 (28)
Ceylan	9.4	2.8 (15)	0.4 (5.8)	330 (1920)	0.9 (12)
Restrepo	0.8	7.5 (55)	0.6 (2.8)	831 (15100)	0.7 (23)

1. Plant capacity in l/s (1 l/s provides 350 people with 250 litres per day)
2. Figures are given as mean value, with the maximum value in brackets

In parallel with these research activities, a national programme to transfer MSF technology was developed and applied in eight regions of Colombia. In this period 16 demonstration projects were developed, which was the basis for strengthening capacity at the institutional and professional levels allowing further dissemination of MSF technology. There are currently over 125 full scale MSF plants operating in different regions of Colombia.

More recent research increasingly aims at optimising overall performance and the processes and mechanisms involved in the removal of specific components. Such an example is the work done by Collins and Graham, Di Bernardo and Cinara with natural and synthetic non woven fabrics to protect sand media in SSF. So far results have shown an increase in the length of filter runs and a potential to apply higher filtration rates without

adversely affecting the water quality (the photograph below shows a full-scale plant with synthetic blankets on top of SSF). This application may allow MSF systems to deliver more water for more people without a large investment. However, in general, more research and data are needed to produce optimisation guidelines for MSF and SSF plants.
Collins has conducted research in cooperation with numerous water utilities in the USA by characterising natural organic matter and looking at its removal in different water treatment processes, including SSF, as this matter may change into potentially harmful substances when the water is chlorinated. He has also carried out research about the role of Schmutzdecke (the filter skin) and temperature in microbial removal in SSF Further information at http://www.unh.edu/civil-engineering/research/erg/faculty/Collins/

Some other investigations look at the use of chlorine to remove iron and manganese and into arsenic and iron removal at household level. Some interesting results can be consulted at http://www.unesco-ihe.org/mui/projects/default.htm?http://www.unesco-ihe.org/mui/projects/arsenic.htm

MSF plant with synthetic blankets. Research project by CINARA in Cali, Colombia

6. MSF development and perspectives for achieving the MDGs

Access to safe water and adequate sanitation are essential for improving public health, reducing poverty and enabling economic development, particularly in countries where a large part of the population is affected by water related diseases. Water borne diseases together rank among the three main causes of mortality and morbidity in the world (Craun et al, 1994).

In the 1990s, the number of children killed by diarrhoea, around 2.2 million deaths per year (WHO, 2000) – caused by lack of safe water and sanitation – was more than the number of victims of all recorded armed conflicts since the Second World War. Moreover, half of the world's hospital beds are occupied by patients ill with water related diseases. Expensive health services are being used to treat diseases that are easy to prevent. A lack of drinking water mainly affects poor inhabitants of rural communities, whose livelihoods depend upon water and land resources. Inadequate sanitation solutions and demography growth in cities exacerbate this situation and hit the poorest in urban areas.

Improving household connections to central water supply networks, providing public water sources, such as standpipes pumps, and wells, maximising rainwater collection and protecting water sources are some of the water supply activities and initiatives that must be taken to achieve sustainable improvements in safe water supply. It is crucial to understand the cost effects of administration, operation and maintenance, which must be appropriate for local conditions.

Consideration of local conditions also include the misuse and poor protection of catchment areas, along with pollution of rivers by solid waste, domestic wastewater, pesticides and chemicals from agricultural, industrial and mining activities. These considerations are especially important in countries where water systems rely on surface water sources. In some Latin America countries this may be the case for up to 80% of systems.

MSF technology has significant advantages as it does not use chemicals, equipment or imported materials. It can be easily administrated, maintained and operated by local community organisations. Projects in operation for more than 10 years have shown that the impact of introducing MSF plants in piped systems has a minimal effect on tariffs. Case studies show that the amount never exceeds 4% of total family income. MSF technology therefore has potential to contribute to Millennium Development Goal 10, to 'halve, by 2015, the proportion of people without sustainable access to safe water'.

Based on the data from Colombia indicative figures can be given for systems that provide some 150 lpd. The construction cost of such MSF systems range from US$ 27 – $ 46 per person, representing some 25% to 40% of the overall cost of the water supply systems. This implies a considerable investment but according to Hutton and Haller (2004 cited by

Visscher 2006), the economic benefits of this investment far outweigh these cost and leads to accelerated growth.

Operation and maintenance cost of MSF systems (excluding back-up support) may range from US$ 0.7 to $ 2.2 per year (US$ cent 1.3 to 4.1 per person per week) which even for a person living on less than one US$ per day seems affordable. While such data cannot be generalised for other locations, it may be expected that the order of magnitude will be similar (Visscher 2006).

7. Case studies

7.1 Information exchange between communities helps to restore an MSF plant in La Tulia, Valle del Cauca department, Colombia

The community of La Tulia, in the municipality of Bolivar, Valle del Cauca, is served by an MSF treatment plant which had operation and maintenance deficiencies. Untreated water was being supplied to users. The rural water supply programme (PAAR) promoted information exchange between communities to tackle this situation.

Community administration staff from the La Tulia water supply system visited and shared experience with communities in El Retiro and La Sirena, near the city of Cali, both of which have MSF treatment plants that have been operating for 18 years. The aim of the exchange was to widen their knowledge about operation and maintenance of treatment plants for drinking water using MSF and to identify how the system can be reformed and put into effective operation.

These activities were very valuable as they enabled administration staff from La Tulia to optimise their treatment plant by carrying out the following work:

- washing filter sand,
- plastering,
- installing covers in the treated water chambers,
- fitting accessories for water entry to the SSF,
- making adjustments and
- controlling operation and maintenance work.

The La Tulia community administration has reopened the MSF plant and has made great progress in providing a higher quality service. Administrative processes, such as accounting, customer service and meter reading have also improved.

For more information, contact: Silena Vargas, Social Worker, Instituto Cinara - Universidad del Valle. Email: sivargas@univalle.edu.co

7.2 Gravel pre-filtering plus oxidation to remove iron and manganese

In research conducted by the Instituto Cinara at the Universidad del Valle, sponsored by Colciencias, technologies for removing iron and manganese from underground and surface water have been evaluated at pilot scale. Upflow gravel filters in layers and in series, over one and two stages have been studied. Oxidation was improved through aeration and by chlorination before the GF units. The operational characteristics of the technology are shown in Table 7, including the source type and their efficiency at removing iron, manganese and faecal coliforms. The treatment alternatives evaluated are compared in Table 8.

Table 7. Operational characteristics of the technologies evaluated

Technology	Source	Filtration rate (m/h)	System components	Filtering bed	
				Granulometry	Total Height (m)
Oxidation UGFS 2	Surface	3	Constant head hypochlorinator and two upflow gravel filters in series	From 1 ½ to ¼	1.0
Oxidation UGFS 3	Underground	3	Dosing pump and three upflow gravel filters in series	From 1 to 1/16	1.0
Aeration UGFL	Underground	0.48 – 0.55	Aeration trays and one upflow gravel filter layer	From 1½ to 1/8	1.2

Table 8. Technology comparison

Technology	% Removal		Effluent Quality (mg/L)		Technology Discussion
	Iron	Man	Iron	Man	
Oxidation UGFS 2	58	*	0.56	*	Lower removal efficiency with respect to the other technologies evaluated. As the iron concentration is ≥ 0.3 mg/L, the system needs a more concentrated chlorine solution, which in addition to increasing operation technology costs, can cause other problems like water smell and taste leading to rejection by users. Some effects of increasing the chlorine dose are the formation of disinfection sub-products as a result of the reaction between organic material and chlorine.
Oxidation UGFS 3	84	90	0.007	0.005	Greater removal efficiency in the system. Less risk of sub-products forming. Greater filtering speed. Lower investment costs. The area required is 5 times smaller than UGFL or conventional filters in series (Vf between 0.3 and 0.6 m/h).
Aeration – UGFL	73	89	0.56	0.05	Greater removal efficiency. Less risk of sub-product formation. Investment costs are 6 times greater than the UGFS 3 oxidation technology, because of lower filtration rate.

* Manganese was not detected in the surface source

** The source did not have microbiological pollutants such as E. Coli

7.3 Overcoming turbidity variations by combining an infiltration gallery with slow sand filters in Mizque, Bolivia

The municipality of Mizque, with a population of 3,040 inhabitants in 600 homes, is located in the department of Cochabamba, Bolivia, and obtains its water from the River Uyuchama, which has high turbidity peaks lasting longer than 24 hours. To overcome these problems and to guarantee safe drinking water for the population PROSABAR (a programme of the Ministry of Housing and Basic Services) built a treatment system with an infiltration gallery and a slow sand filtration system. The microbiological risk at the source varies from medium to high. Between the dry and rainy periods, there are sharp variations in turbidity. High peaks of extreme turbidity values of 1350 NTU usually last 2 to 3 days, but can continue for up to a week.

The infiltration gallery can capture a flow of 8 l/s. It has been built across the river in a 50 m wide and 5 m deep trench. The length of the filtering media is 2.26 m with gravel layers of 1/2” -3/4”, 3/4”- 2” and 2” - 4”, covered by a layer of geotextile material. Captured water flows into a vault made of concrete through 35 mm slots. There is an inspection chamber at one end and a collection chamber at the other, with pipes that channel water into the slow sand filters.

The SSFs are made up of three filtering units. The filtration area per unit is 33 m2 and the filtration rates for these units are 0.30 m/h. It was shown that combining these treatment steps, the filtration gallery considerably improves water quality making it fit for SSF treatment. The system gave removal values for turbidity and faecal coliforms of 99%, for untreated water with turbidity at 400 NTU and faecal coliforms of 1230 CFU/100 ml. The effluent turbidity varied between 0.4 to 2 NTU, with the turbidity peak duration of 2 days.

For more information, contact Alvaro Camacho, email: alcamachog@unete.com, or Luis Darío Sánchez, Engineer, Instituto Cinara, Universidad del Valle, email: luisanc@univalle.edu.co

7.4 Multi-stage filtration (MSF) to prevent biofilm growth in a distribution network

The complex interaction between organic material at the source and the development of biofilm in distribution networks can cause progressive deterioration of water quality in the distribution network.

This process was demonstrated in a community located in the rural zone of Cali municipality in Colombia, where it resulted in the declaration of an emergency situation followed by a revision of the whole system.

On evaluating the physiochemical and microbiological quality at the source, average values of 4,000 CFU/100 ml for faecal coliforms were found and 75,000 CFU/100 ml for total coliforms. These were not adequately removed during treatment with chemical coagulation due to design and operation problems at the treatment plant, which allowed pollutants to penetrate the distribution network and favoured the formation of biofilm, a slimly layer of micro organism on the surface area in the pipes. This posed a considerable microbiological risk to users.

Samples were taken at several locations in distribution network showing average values of 2183 CFU/100 ml for mesophiles, 7 CFU/100 ml for faecal coliforms and 39 CFU/100 ml for total coliforms. Considering these conditions, research was carried out with the aim of taking corrective measures to reduce the health risks to users. These measures included technological changes in the treatment plant, providing a multi-stage filtration system in combination with chemical coagulation (with iron chloride or aluminium sulphate). The MSF system provided for pre-filtering with an upflow gravel filter and slow sand filters with activated carbon.

The treatment plant was designed for a flow of 6 l/s. It is made up of two dynamic filters operating in parallel, a rapid mix structure for dosing the coagulant, 2 contact flocculators or clarifiers using upflow gravel filtering in layers, 2 upflow gravel filters in layers, and 4 slow sand filters. The plant began to operate in 2003. A layout of the plant can be seen in Figure 9.

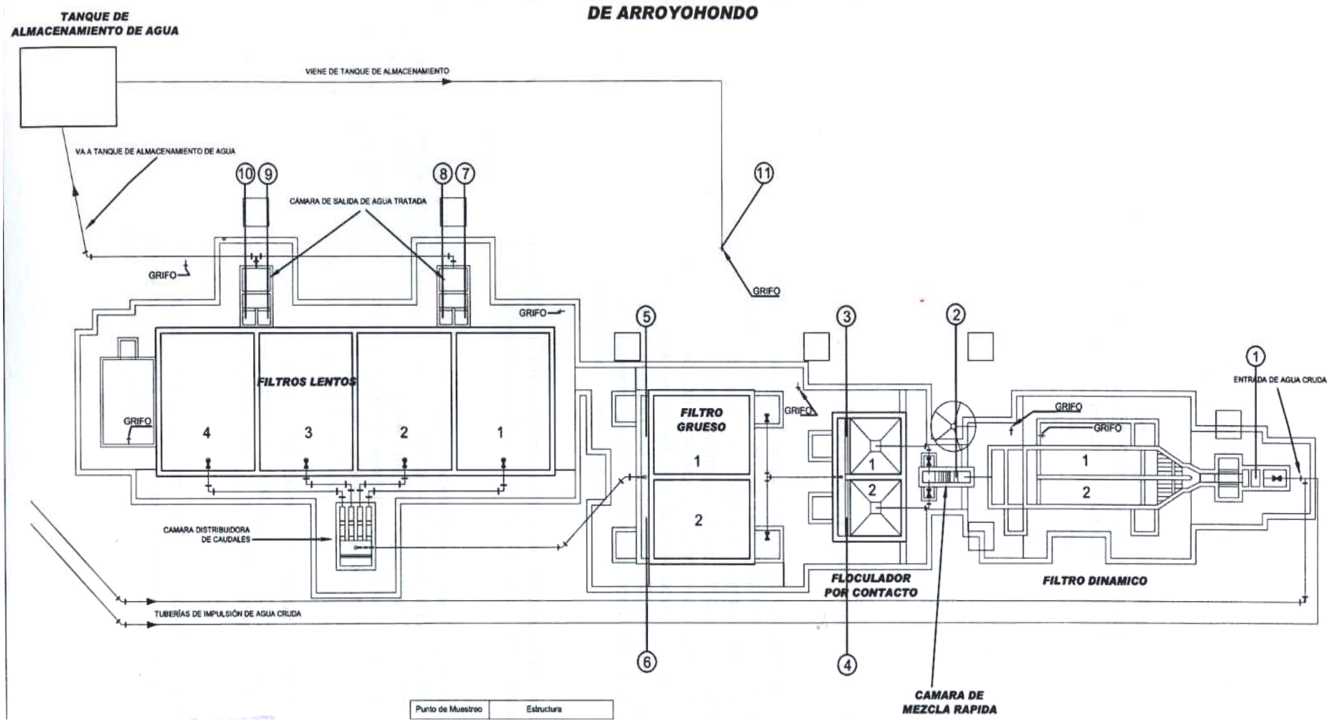


Figure 9. Treatment plant general layout

An evaluation at the treatment plant tested for turbidity, true colour, faecal and total coliforms and mesophile bacteria. This showed that the system can be operated with chemical coagulation when (25% of the time) affluent turbidity is greater than 25 NTU and without coagulant when (75% of the time) affluent turbidity is less than 25 NTU. As regards chemical risk, the source has organic material problems due to the discharge of domestic waste waters upstream of the entry point. Results of between 9 and 36 PCU were found when true colour analyses were run.

The results indicate that at the end of the process, the slow sand filtering units produce water with turbidity between 0.1 and 0.65 NTU and true colour between 2 and 7 PCU. Measurement of microbiological contamination found total coliforms between 0 and 39 CFU/100 ml and faecal coliforms between 0 and 7 CFU/100 ml before disinfection. The MSF plant has a removal efficiency of 95% of turbidity, 73.3% of true colour, 99.72% of mesophiles, 99.97% of faecal coliforms and 99.75% for total coliforms.

For more information, contact: Instituto Cinara, Universidad del Valle, Water Supply Research Group, 2004. Luis Darío Sánchez MSc luisanc@univalle.edu.co; Lina María Burbano naribano@univalle.edu.co; Arlex Sánchez asanchez@univalle.edu.co

7.5 Performance of a rural multi-stage filtration plant after two years in Rwanda

Two years after its handover, the Nyabwishongwezi Water Treatment Plant (WTP) and associated operational details were monitored in a short-term study. This multi-stage filtration system run by the local water association (REGIE) in Nyabwishongwezi, Rwanda, was monitored for turbidity, suspended solid and faecal coliform removal. Results indicated that although the quality of the product water did not comply with WHO guidelines, it was aesthetically much more acceptable than the source water (River Umuvumba). Despite operational difficulties, REGIE continues to run the system and to serve local rural communities. The relative success of the Nyabwishongwezi Regie contrasts dramatically with the experiences of the nearby communities served by the Ntoma WTP that reportedly only worked for two days. The review of the Nyabwishongwezi plant identified several problems have been identified and discussed with the REGIE.

This case was taken from IWA Water Policy 6 (2004) 559-570.
http://www.iwaponline.com/wp/00606/wp006060559.htm
C. C. Dorea, B. A. Clarke and S. Bertrand

Contact: CEHE –Centre for Environmental Health Engineering, Department of Civil Engineering, University of Surrey, UK http://www.surrey.ac.uk/CEHE/

7.6 Performance of multi-stage filtration using different filter media in Kenya

This study was aimed at introducing multi-stage filtration as an alternative water treatment technology, using a combination of SSF and horizontal flow roughing filter (HRF) as a pre-treatment system. A pilot plant study was undertaken and MSF performance was evaluated against the existing conventional system, for its efficiency in removing selected physical and chemical pollutants from drinking water, along with the biological water quality improvement using MSF without chemical use. The MSF system's overall effectiveness was also evaluated, including its use of locally available material, i.e. gravel, improved agricultural waste (charcoal maize cobs) and broken burnt bricks for pre-treatment filtera. The benchmark was the Kenya Bureau of Standards (KEBS) values for each selected parameter. Results showed that with proper design specifications, MSF systems perform better than conventional systems under similar raw water quality and environmental conditions. Locally available materials can also be effectively used as pre-treatment media, allowing a filter run greater than 82 days, and can therefore serve as alternatives where natural gravel is not readily available. MSF greatly improved the bacteriological quality of the water, recording removal efficiencies of over 99% and 98% for E. coli and total coliforms respectively. Despite the observed performance, MSF should be complemented with chlorination as a final buffer against water-borne diseases. However, the dose will be greatly reduced in comparison with the conventional system.

For more information, contact: GMM Ochieng[1], FAO Otieno[1]*, TPM Ogada[2], SM Shitote[2] and DM Menzwa[2]. E-mail: otienofao@tut.ac.za

[1] Faculty of Engineering, Tshwane University of Technology, Private Bag X680, Pretoria 0001, South Africa

[2] Faculty of Technology, Moi University, PO Box 3900, Eldoret 30100, Kenya

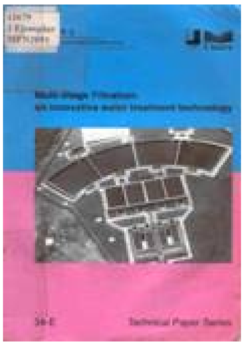
http://www.wrc.org.za/downloads/watersa/2004/July-04/10.pdf

8. TOP Resources

8.1 Publications

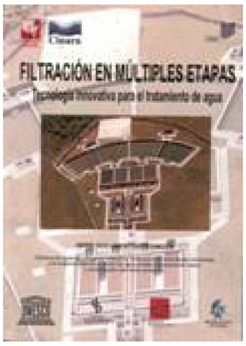
Uso de fibras naturales y sintéticas en filtración lenta en Colombia: Una experiencia en ambientes tropicales (2001) (Natural and Synthetic Fibre Use in Slow Filtration in Colombia: An Experiment in a Tropical Environment)

The document summarises the results of research carried out on the use of natural and synthetic blankets to protect filtering beds in slow sand filters. The aim was to identify their potential as protection in the slow sand filter stage in MSF systems in a tropical environment. From the great variety of natural fibres existing in the country, two, 'ecomusgo' and felt, were selected for evaluation at pilot scale. The study concluded that these natural blankets caused filament microorganisms that can cause sanitary risk, and this was a limitation for their wide scale application in drinking water filters.



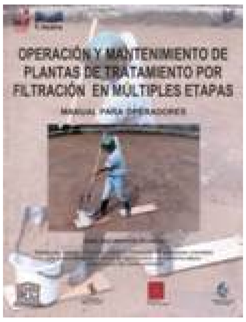
Multi-Stage Filtration: An Innovative Water Treatment Technology (1996). CINARA/IRC, ISBN 90-6687-028-1

This introduces Multi-Stage Filtration as a sustainable technology that suits local conditions and administrative capacity in a number of communities. The authors discuss the need for adequate linkage between agencies and communities to ensure water treatment system sustainability. Data are given on costs and other considerations for technology selection. There is detailed information about different gravel filter systems as well as how various MSF systems can be selected to treat water sources with different sanitary risk levels. Based on the Research and Development of Pre-treatment Technology for Water Supply Systems project, carried out from 1989 to 1997, it is available in Spanish and English.



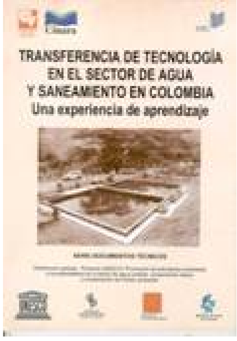
Filtración en Múltiples Etapas Tecnología Innovativa para el Tratamiento de Agua Multi-Stage Filtration (1998) Univalle-CINARA, ISBN 958-8030-20-9

The project was aimed at identifying and proposing viable and reliable alternatives for water treatment compatible with the existing supply systems in rural areas as well as small and medium-sized towns. The project's focus was on developing multi-stage filtration, as a combination of gravel filters and slow sand filtering, and was coordinated by the Instituto Cinara at the Universidad del Valle, Colombia and IRC, the Netherlands.



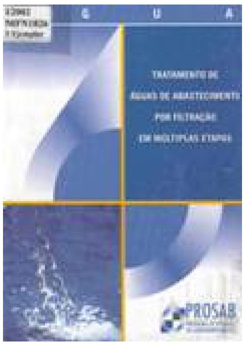
Operación y Mantenimiento de Plantas de Tratamiento por Filtración en Múltiples Etapas: Manual para Operadores (1998)
(Treatment Plant Operation and Maintenance for Multi-Stage Filtration: Operator's Manual).
Univalle-CINARA, ISBN 958-8030-19-6

The manual explains the general features of water supply systems and MSF treatment plants and the role of the operator(s), shows the different filters in the treatment (Coarse Gravel Filters, Upflow Gravel Filters and Slow Filters) and gives general information about operation and maintenance, problems often found in the filters and how to solve them.



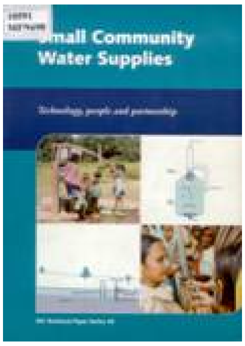
Transferencia de Tecnología en el Sector de Agua y Saneamiento en Colombia: una Experiencia de Aprendizaje (1998)
(Technology Transfer in the Water and Sanitation Sector in Colombia: A Learning Experience)
Univalle-CINARA, ISBN 90-6687-026-s

This document was written as part of the Integrated and Organised Technology Transfer for Water Supply Systems project, TRANSCOL, which took place in Colombia from 1989 to 1996. The programme objective was to introduce drinking water production technology in eight regions of the country, using Multi-Stage Filtration. The publication describes the programme and its results, introduces the most important issues for investment sustainability, discusses theory and practice relating to technology transfer, and to a learning project focus.



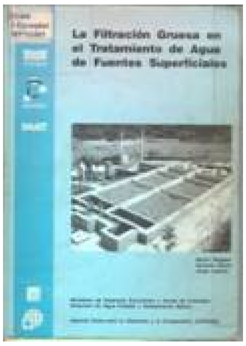
Tratamento de Águas de Abastecimiento por Filtracação em Múltiplas Etapas (1999)
(Water Supply Treatment by Multi-Stage Filtration)
Prosab, ISBN 858-6552-69-0

This book is the fruit of the results of the research network set up by the sanitation research programme PROSAB, on the issues of "efficiency, limitations and applicability of unconventional water treatment systems (slow filtration, direct upflow and downflow filtration)". The book presents MSF as a re-emerging technology that already has versatile technology status, and implementation costs compatible with national realities. It states that MSF is easily adaptable to water quality changes, and has fairly unspecialised operation and maintenance. MSF performs excellently in bacteria removal and has a greater potential benefit for public health than do conventional physiochemical processes. The PROSAB network was coordinated by Prof. Luis Di Bernardo from the São Carlos Engineering Faculty at the Universidade de São Paulo, Brazil. For more information, consult the PROSAB website: http://www.sanepar.pr.gov.br/prosab



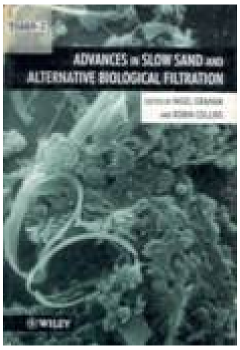
Small Community Water Supplies: Technology, People and Partnership (2002)
IRC, ISBN 90-6687-035-4

A completely revised edition of the 1981 textbook which links water supply science and technology with the specific needs of small communities in developing countries. The book is meant for engineers, other staff involved in water supply programmes and projects and for students, and it provides a general introduction to a wide range of technologies. Topics include planning and management, community water services in Central and Eastern European countries, water quality and quantity, integrated water resources management, artificial recharge, rainwater harvesting, spring water tapping, pumping, groundwater withdrawal, surface water intake and small dams, water treatment, water transmission, water distribution, technologies for fluoride and for arsenic removal, and water supply in disasters and emergencies.



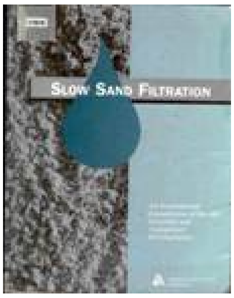
La Filtración Gruesa en el Tratamiento de Agua de Fuentes Superficiales (1998)
(Coarse Filtration in Surface Water Treatment)
SKAT, ISBN 3-90808001-72-2

The book details options for water treatment in situations with infrastructure or industrial development limitations. The first part focuses on general water treatment issues and gives the reader a vision of the different challenges they face from the moment a water treatment technology is selected. In the second part, the reader is provided with a comprehensive overview of the pre-treatment process, applied to solid material separation, and to a detailed description of this technology’s application.



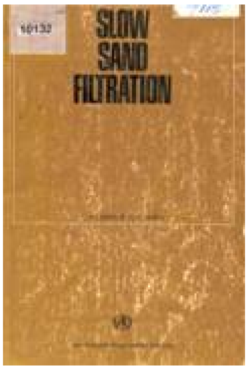
Advances in Slow Sand and Alternative Biological Filtration (1996) John Wiley & Sons Canada Ltd. ISBN 0-471-96740-8)

This book is compiled from contributions to the Third International Slow Sand/Alternative Biofiltration Conference, held in London and Amsterdam in April 1996. It highlights the latest research developments in slow sand and alternative biological filtration processes for drinking water treatment, including advances in the understanding of the fundamental mechanisms of these processes. Progress in operation and upgrading techniques for the processes are described, with case studies from around the world. The principal themes of the book are: removal of natural organic matter (NOM), biodegradable organic carbon (BOC) and ozonation by-products; biofilter media characteristics; influence of process design variables and modifications; modelling process performance; pre-treatment applications; operational experience and cleaning; and upgrading treatment processes.



Slow Sand Filtration: an International Compilation of Recent Scientific and Operational Developments (1994)
American Water Works Association, ISBN 0-89867-754-8

This handbook provides readers with a comprehensive overview of the application of slow sand filtration to modern drinking water technology. It covers a variety of issues not addressed in previous works, including regulatory concerns, the consultant's role in formulating a proper design for operators, assimilating operating experience into practice, explaining removal mechanisms, looking at the spectrum of cleaning techniques, and the emerging area of pre-treatment, which extends the application of slow sand to a wider range of water conditions.



Slow Sand Filtration (1974)
WHO, ISBN 92-4-1540370

A classic work which discusses SSF as a means of biological filtration. It claims that SSF is not only the cheapest and simplest, but also the most efficient method of water treatment. Its advantages have been proved in practice over a long period, and it is still the chosen method of water purification in certain highly industrialised cities, as well as in rural areas and small communities.

Filtración Lenta en Arena Tratamiento de Agua para Comunidades: Planeación, Diseño, Construcción, Operación y Mantenimiento (1993)
(Slow Sand Filtration Water Treatment for Communities: Planning, Design, Building, Operation and Maintenance)
IRC, CINARA, ISBN 90-6687-022-2

The book includes established information on slow sand filtration, as well as the regulations defined by demonstration projects in developing countries. It explains the main principles of water supply to communities, as well as community participation, before a detailed discussion of slow sand filtration. The system's overall design is described and capital and running costs are described. Data are illustrated with a case study on planning and design of a slow filter system for a hypothetical community. Detailed information is given on structural design, supported by design examples. It should be noted that these examples are based on specific local conditions and are not necessarily applicable under other circumstances. Building regulations are outlined that could significantly improve building quality in many cases. Finally, the book sketches detailed procedures for operation and maintenance and highlights the importance of thorough training.

Proyecto Integrado de Investigación y Demostración en Filtración Lenta en Arena, Informe Final (1989)
(Integrated Slow Sand Filtration Research and Demonstration Project – Final Report). Univalle, CINARA, IRC.

This document contains information about the demonstration project based on technology promotion in the hillside area of the River Cauca valley, Colombia. Objectives include: training and developing human resources; and identifying and evaluating the feasibility of pre-treatment alternatives with water that has a high solid content. It looks at ways of improving plant design to facilitate operation and maintenance; developing educational material for operators; identifying and evaluating simplified equipment to study plant behaviour; and studying building costs for conventional plants compared with slow sand filtration plants. The book reflects on the project's implications and perspectives at regional, national and international levels.

Filtración Lenta en Arena y Pretratamiento: Tecnología para Potabilización de Agua
Slow Sand Filtration and Pre-treatment: Technology for Water Purification

This document describes, in general terms, the characteristics of the integrated slow sand filtration project coordinated by IRC and includes key information about SSF technology, such as treatment principles, basic design criteria, different system component characteristics, building options and materials, and cost issues. Also considered are issues inherent in coarse media pre-treatment, some of which have overcome the limitations of SSF technology in filtering untreated water with relatively high turbidity values.

Recent Progress in Slow Sand and Alternative Biofiltration Processes (2006)

This document provides a state-of-the-art assessment on a variety of biofiltration systems from studies conducted around the world. The authors collectively represent a perspective from 23 countries and include academics, biofiltration system users, designers, and manufacturers.

It provides an up-to-date perspective on the physical, chemical, biological, and operational factors affecting the performance of slow sand filtration (SSF), riverbank filtration (RBF), soil-aquifer treatment (SAT), and biological activated carbon (BAC) processes. The main themes are: comparable overviews of biofiltration systems; slow sand filtration process behavior, treatment performance and process developments; and alternative biofiltration process behaviors, treatment performances, and process developments.

8.2 Websites

In alphabetical order:

American Society of Civil Engineers
http://www.asce.org/
ASCE's core purpose is to advance the art, science and profession of engineering to enhance the welfare of humanity. Specific information regarding water quality improvement by slow sand filtration can be obtained through the search tool using slow sand filtration as a keyword.

Abstracts and articles are available. The website includes experiences and application of slow sand filters for wastewater treatment, as well as training opportunities.

Bio Sand Filters Organization
http://www.biosandfilter.org/biosandfilter/index.php/item/229
The site includes a review of the differences between rapid sand filtration and slow sand filtration, since the processes involved and applications are inherently different. The differences between continually-operated and intermittently-operated sand filters (both commonly used in humanitarian programmes) are also explained.
The Bio Sand Filters Organization has drawn together detailed information on the processes at work in slow sand filtration, including an in-depth look at flow rates and the physical/mechanical and biological processes involved. The different kinds of filter media that can be used are explained. Technical information about slow sand filtration and articles are downloadable.

CEPIS - Pan American Centre for Sanitary Engineering and Environmental Sciences
http://www.cepis.ops-oms.org
The Pan American Centre for Sanitary Engineering and Environmental Sciences, CEPIS, is the specialist environmental technology centre of the Pan American Health Organization (PAHO), the World Health Organization (WHO) Regional Office for the Americas. CEPIS is part of PAHO's Health and Environment Division and develops its activities with the support of PAHO/WHO Country Representative Offices.

The CEPIS/PAHO mission is to cooperate with the countries of the Americas in controlling risk factors related to deficiencies or absence of basic environmental sanitation that, directly or indirectly, affect the health of its populations.

The site can be searched and PDF files, presentations and articles related to multi-stage filtration and slow sand filtration may be downloaded. Resources are mainly available in Spanish.

Email: cepis@cepis.ops-oms.org
Contact: Galvis@cepis.ops-oms.org

Centre for Environmental Health Engineering (CEHE) at Surrey University
http://www.surrey.ac.uk/CEHE/

The Centre for Environmental Health Engineering (CEHE) is a research centre with international expertise and projects covering the entire water cycle. These encompass water resources surveillance, modelling and management, water treatment, supply and regulation, wastewater treatment, disposal and safe reuse, pollution control and waste management. CEHE is a designated World Health Organization (WHO) Collaborating Centre for the protection of water quality and human health.

One of the main research themes of the centre is water treatment. Professor Barry Lloyd has collaborated in developing multi-stage filtration technology in the past as an adviser to Cinara, and a supervisor for MSc and PhD students.

CINARA - Instituto Cinara at the Universidad del Valle
http://cinara.univalle.edu.co
Cinara, the research and development institute for water supply, basic sanitation and integrated water resource management, is a non-profit NGO with offices at the Universidad del Valle in Cali, Colombia. Cinara has been developing multi-stage filtration technology since 1980, using an inter-institutional and interdisciplinary approach that takes community participation and gender issues into account in order to improve water quality for human consumption and other applications. Cinara's facilities (including a pilot plant that treats surface water, a documentation unit, accommodation for tailor made courses, an auditorium, internet access, and physiochemical and microbiological labs) allow the institute to carry out research, training and technology transfer for water quality improvement. Around ten full scale MSF projects are running near Cali. These "learning and teaching projects" treat different surface water qualities and are operated by community organisations. Cinara has documented its experience with MSF through books, handbooks, videos, CDs, short courses, conferences, papers and formal courses offered at the under and postgraduate levels.

Imperial College
http://www3.imperial.ac.uk/portal/page?_pageid=102,1&_dad=portallive&_schema=PORTALLIVE
The Civil and Environmental Engineering Division has carried out high-level research on multi-stage filtration. MSF research, researchers, publications, short courses and postgraduate programs can be found at: http://www.cv.ic.ac.uk/discover/

IRC International Water and Sanitation Centre
http://www.irc.nl/
The IRC is a knowledge-based organisation that is responsive to the water and sanitation needs of developing countries and countries in transition. IRC has supported and advised different research and development programmes on slow sand filtration in Asia, Africa and

South America. MSF technology has evolved from the combination between slow and gravel filtration technology.

During the 1990s, IRC and Cinara carried out technology transfer projects focused on multi-stage filtration in eight regions in Colombia. The same institutions, supported by others at the national and international level, studied gravel filtration as a pre-treatment for raw surface water, at pilot plant and full scale levels.

Articles, publications and news are downloadable. There are several publications and reports on MSF technology. Search keywords: multi-stage filtration and slow sand filtration.

Water, Engineering and Development Centre (WEDC) at Loughborough University
http://wedc.lboro.ac.uk
One of the world's leading institutions concerned with education, training, research, and consultancy relating to the planning, provision, and management of infrastructure for development.

PDF articles and publications are available. There are several thesis reports and experiences of MSF technology application in Africa and Pakistan, which can be found using the search keywords, multi-stage filtration and slow sand filtration. Check out the publications catalogue.

US Environmental Protection Agency
http://www.epa.gov/safewater/regs/swtrsms.pdf
The 1996 SDWA Amendments contain provisions related to water and sanitation systems serving <10,000 people, recognising their differences in costs, technology, management capacity, and risk characteristics. One of the project areas created after the 1996 SDWA Amendments included the production of a list of water treatment technologies that these systems can use to comply with US regulations. In this list, EPA suggests than RF should be used only in those systems with full-time access to a skilled operator and considers that SSF may be the most suitable filtration technology for small and medium size systems when used with source water of the appropriate quality (EPA, 1998). Search keywords: slow sand filtration.

8.3 Training courses

Postgraduate Programme in Sanitation and Environmental Engineering, Universidad del Valle, Colombia
Since September 1993, the Universidad del Valle has offered a postgraduate diploma programme in sanitation and environmental engineering. The course lasts approximately one year. To earn a Masters, a research project must be carried out over an additional period of 6 to 8 months.

The programme objective is to give the participants an integrated education and develop their advanced skills to allow them to perform an important social function in environmental management, through their depth of knowledge, research in specific fields of sanitary and environmental engineering, and participation in making decisions of local, national or regional significance, according to their field of action.

For more information:
Universidad del Valle, Sede Meléndez, Edificio 341, 1er Piso
A.A. 25157 Cali, Colombia
South America Telefax: (57 – 2) 3302002
Email: pisa-uv@mafalda.univalle.edu.co

Hydraulic and Sanitation Engineering Postgraduate Programme, São Carlos Engineering Faculty, Universidade de São Paulo, Brazil
The postgraduate programme in hydraulic engineering and sanitation at the São Carlos Engineering Faculty was the first to teach the area of water resources. The aim is to encourage humanity’s interest in the environment, principally aquatic, so that plans can be made for environmental action. For more information, consult: http://www.shs.eesc.sc.usp.br/ensino/posgraduacao/default.htm

Masters Programme in Urban Infrastructure and Water Supply, UNESCO–IHE Institute, the Netherlands
The urban infrastructure programme aims to train and educate professionals in the fields of water supply, sanitation, and integrated engineering in urban infrastructure, as well as water service providers. The programme is principally aimed at civil and sanitation engineers who work in water supply, municipal or private companies that deal with supply and wastewater removal, municipal councils, government ministries and consultants. It includes short low-cost water supply technology courses and modules on appropriate technology for developing countries. For more information, consult: www.ihe.nl

CINARA - Institute for Research and Development in Drinking Water Supply, Basic Sanitation, and Integrated Water Resource Management
Workshop on Multi-Stage Filtration Treatment System Design and Planning
This course is suitable for staff from municipal or community service supply enterprises, sanitation or civil engineering professionals, and consultants. It deals with issues related to planning, design, operation, maintenance, analysis and selection of multi-stage filtration treatment alternatives. It examines issues such as multiple treatment barriers to lower the sanitary risk in water purification, and water supply system sustainability, especially in rural and urban periphery areas in developing countries.

The course lasts 15 days, 20 places are available, and it includes an element of fieldwork.
Contact: Luis Darío Sánchez MSc. – luisanc@univalle.edu.co

8.4 Tools

Software: Drinking Water System Technology Selection (2000)
Colombian Environment, Housing and Land Development Ministry – Instituto Cinara, Universidad del Valle

The drinking water system technology selection model facilitates technology selection for rural communities, small and medium sized municipalities and urban periphery settlements with a population range of 500–30,000 inhabitants. The model takes sociocultural, institutional, technological and financial issues into account (Galvis, 2000).

SelTec Software has the following objectives:

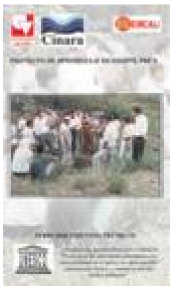
- To select sustainable technological alternatives for drinking water, when there is no technology at the site
- To evaluate the sustainability of an existing plant in the locality
- To estimate start-up, administration, operation and maintenance costs, for each of the technological options considered in the selection model (Vargas, 2000).

This software was developed as part of the ‘Technology Selection and Cost Analysis in Drinking Water Purification Systems’ project, carried out by Cinara for the Water and Sanitation Department of the Environment, Housing and Land Development Ministry, which is responsible for sector planning in Colombia.

For more information, contact:
Alberto Galvis MSc, Cinara – Universidad del Valle. algalvis@univalle.edu.co
http://www.minambiente.gov.co

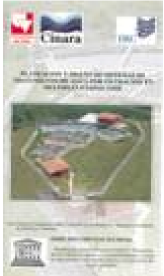
CD ROM: Filtración en Múltiples Etapas, FiME
Multi-Stage Filtration (MSF) (1998)
Univalle, CINARA
A multimedia educational support developed as a contribution to the MSF technology transfer and socialisation process. It uses easy to understand language, and combines video, recorded voices, lectures and animation to explain how the technology works, and support the documentation and decision making process for professional and technical staff in the water and sanitation sector. It is a valuable tool for workshops at MSc and Bachelor level and for communities to learn about topics such as improving water quality for human consumption.

For more information, contact:
Luis Darío Sánchez MSc, Cinara – Universidad del Valle. luisanc@univalle.edu.co



Video: Proyecto de Aprendizaje en Equipo, PAEs
Team Learning Projects (TLPs) (1998)
Univalle, CINARA

From its 15 years of experience in research and development projects in the water, sanitation and water resource conservation sector, Cinara has developed a methodology which it has called team learning projects (TLPs). TLP methodology contributes to the sustainability of the investments in water supply made by government and by communities. TLPs are inspired by the concept of sustainable human development, where professionals from different disciplines and different institutions join communities in their struggle, and find out that 'self-discovery' is one of the best ways to learn. The methodology seeks active and creative participation of community members and leaders, and for their involvement in all phases of the project cycle.



Videos: Multi-Stage Filtration (1998)
Univalle, CINARA

- Diseño y Planeación de Sistemas de Tratamiento de Agua por Filtración en Múltiples Etapas, FiME
  Multi-Stage Filtration Treatment System Design and Planning
- Operación y Mantenimiento de Plantas de Tratamiento de Agua por Filtración en Múltiples Etapas, FiME MSF Water Treatment Plant Operation and Maintenance

Available in Spanish

MSF is an environmentally friendly and affordable technology for drinking water treatment, which can operated and maintained by communities with low educational levels and limited management capacity.

Team work between communities, leaders, governmental institutions and NGOs, with coordination from Cinara and IRC, has implemented research processes and MSF technology development and transfer through pilot studies at the Puerto Mallarino research station and in full scale plants in different regions of Colombia.

These two videos have been used as a tool to support community capacity strengthening processes, along with seminars and workshops offered by Cinara – Universidad del Valle to facilitate and support the technology transfer process in Colombia and Latin America.

8.5 Who is Who – Contacts

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8.6 Events

Past Events

Agua 96
International Seminar on Water Quality Improvement
Cali-Colombia
Articles were presented on pre-treatment options, SSF and MSF.
Contact: Luz Edith Guiral
Email: luzguira@univalle.edu.co

3rd World Water Congress
Drinking Water Treatment (Selected Proceedings of the 3rd World Water Congress of the International Water Association)
Held in Melbourne, Australia, 7-12 April 2002

World Filtration Congress 8
European Federation of Chemical Engineering Event No 607
The Brighton Centre, Brighton, UK
3-7 April 2000
Website: http://www.iwaponline.com/ws/00205/05/default.htm

Small Water and Wastewater Systems
Fremantle (Perth), Australia
11- 13 February 2004
The conference was focused on design, operation, maintenance and management of small treatment units. Innovation in the field, case studies on safe and reliable systems, nutrient removal, water reuse and methods for unattended operation were discussed at the conference. Water supply and the treatment of wastewater for single houses or housing complexes were also discussed.

Organisers: the International Water Association and the Australian Water Association
Contact: Dr Kuruvilla Mathew
Email: K.Mathew@murdoch.edu.au
Website: http://www.etc.murdoch.edu.au/pages/conf/water04.html

9th International Water Technology Conference
Sharm El-Sheikh, Sinai, Egypt
17- 20 March 2005
The objective of the conference was to bring together experts, researchers, and decision-makers in order to discuss all water-related issues, from water resources management to water treatment, sewage treatment and water desalination.

Organisers: Mansoura University, Egyptian Water Resources and Irrigation Ministry, the American Society of Civil Engineers (Egypt Section) and the Egyptian Water Technology Association (EWTA)
Contact: Magdy Abou Rayan
Email: mrayan@globalnet.com.eg
Website: http://www.iwtc.tk

3rd IWA Leading-Edge Conference on Water and Wastewater Treatment Technologies
Date: 6 - 8 June 2005
Place: Sapporo, Japan
Language: English
Organized by: International Water Association - IWA
Contact: Noirin Casey
Telephone: (+ 44 0 207) 654 5518
Fax: (+ 44 0 207) 7654 5555
Email: let2004@iwahq.org.uk
Website: http://www.iwahq.org.uk/template.cfm?name=sg17
http://www.let2004.com/templates/Conferences/LET/let.aspx?ObjectId=104

The annual Leading-Edge Conference on Water and Wastewater Treatment Technologies is focused specifically on progress and developments in water and wastewater technologies. To keep the programme targeted and discussions meaningful, the conference consists of only two parallel sessions: one for drinking water and one for wastewater. Several workshops will be held on the afternoon of the final day.

The Drinking Water subjects are: membrane systems for drinking water; desalination technologies; natural organic matter removal; advances in disinfection; new adsorbents and adsorption processes and innovative treatment technologies.

WHO/NHMRC/IWA Managing Safe Drinking Water
Quality in Small Communities
Alice Springs, Australia
18 – 22 July 2005
Contact: Philip Callan
Email: Philip.callan@nhmrc.gov.au

Technology 2005
2nd Joint Specialty Conference for Sustainable Management of Water Quality Systems for the 21st Century
San Francisco, California, USA - Palace Hotel
28–31 August 2005

Sponsored by: Water Environment Federation (WEF); European Water Association (EWA); Japan Sewage Works Association (JSWA); and the California Water Environment Association (CWEA)

At this conference, leading engineers and scientists from all over the world exchanged the latest findings and successful case studies highlighting new technologies, novel applications of established technologies, and innovative solutions to historical operational challenges and to emerging issues.

The conference focus included:
- Technologies for use in rural and developing locations;
- Emerging technologies and research studies;
- Plant design, hydraulics, and construction;
- Rehabilitation and upgrading of facilities;
- Pathogen issues and disinfection technologies;
- Wastewater treatment, including aerobic and anaerobic systems.

Water Environment Federation
601 Wythe Street, Alexandria, VA, 22314-1994 USA
Tel: 1-800-666-0206 (U.S. and Canada)
Tel: 1-703-684-2452 (Outside the U.S. and Canada)
Fax: 1-703-684-2492
Website: http://www.wef.org/conferences/Wastewater_Technology2005.jhtml

Agua 2005
31 October – 4 November /05
International Seminar - Integrated Approach in the Improvement of Water Quality
Organised by: Universidad del Valle – Instituto Cinara, PAHO, CEPIS
Contact: Luis Dario Sanchez MSc/Dr Janet Sanabria
Email: luisanc@univalle.edu.co , agua2005@univalle.edu.co
Website: http://cinara.univalle.edu.co

Water Quality Technology Conference and Exposition (WQTC)
Quebec City, Quebec, Canada
6 – 10 November 2005

Summary
This event attracts 1,500 of the industry's leading water quality experts each year to exchange the latest research and technical information. The technical programme will be developed from topics covering all aspects of water quality and technology, and will include such subjects as monitoring and detection techniques, treatment processes, coagulation and filtration, organic and inorganic contaminants, distribution system water quality, and emerging issues, to name just a few.

Organisers: American Water Works Association
Contact: David Talley
Email: dtalley@awwa.org
Website: http://www.awwa.org/conferences/wqtc/

Small Water and Wastewater Treatment Plants
Mérida, Mexico
26 – 1 March 2006.
Contact: Simon González
Email: gonmar@servidor.unam.mx

Slow Sand/Biofiltration
Mulheim, Germany
3 – 5 May 2006
Contact: Nigel Graham
Email: n.graham@imperial.ac.uk

Future Events

Water Supply Technology
Yokohama, Japan
22 – 24 November 2006
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Email: tachi@jwrc-net.or.jp

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About IRC

IRC facilitates the sharing, promotion and use of knowledge so that governments, professionals and organisations can better support poor men, women and children in developing countries to obtain water and sanitation services they will use and maintain. It does this by improving the information and knowledge base of the sector and by strengthening sector resource centres in the South.

As a gateway to quality information, the IRC maintains a Documentation Unit and a web site with a weekly news service, and produces publications in English, French, Spanish and Portuguese both in print and electronically. It also offers training and experience-based learning activities, advisory and evaluation services, applied research and learning projects in Asia, Africa and Latin America; and conducts advocacy activities for the sector as a whole. Topics include community management, gender and equity, institutional development, integrated water resources management, school sanitation, and hygiene promotion.

IRC staff work as facilitators in helping people make their own decisions; are equal partners with sector professionals from the South; stimulate dialogue among all parties to create trust and promote change; and create a learning environment to develop better alternatives.

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About CINARA

CINARA (Instituto de Investigación y Desarrollo en Abastecimiento de Agua, Saneamiento Ambiental y Conservación del Recurso Hídrico) is an institute of Valle University involved in research, development and transfer of technologies and methodologies in the water and sanitation sector. Its focus is rural areas, small and medium-sized municipalities and low-income urban areas facing important problems in the provision of good quality, efficient and environmentally friendly water supply and sanitation services.

The staff of CINARA includes professionals with technical, socio-economic and administrative backgrounds, who can draw on external advisors in specialized areas and work as an interdisciplinary team, complementing each other's knowledge and experience. This team fulfils a function of process facilitator and initiator, working closely with sector institutions and communities to improve the sanitary conditions and the protection and conservation of the water resources, being a crucial element to improve the quality of life of the communities.

CINARA interacts and receives support from a network of national and international partner organizations based in countries such as the Netherlands, Great Britain, Switzerland and Brazil, which has enabled it to expand its support to a large number of regions in Colombia and other countries including Bolivia, Ecuador, Honduras, Guatemala and Pakistan, maintaining the premise that development is centred in people, making communities the protectors and initiators of their own development.

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