Multi-stage surface water treatment for community water supply in Colombia

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Using a multi-barrier treatment for drinking-water greatly increases the potential of slow sand filters. Gerardo Galvis, Jan teun Visscher, and Barry Lloyd describe how this treatment process contributes to a remarkable overall improvement in water quality.

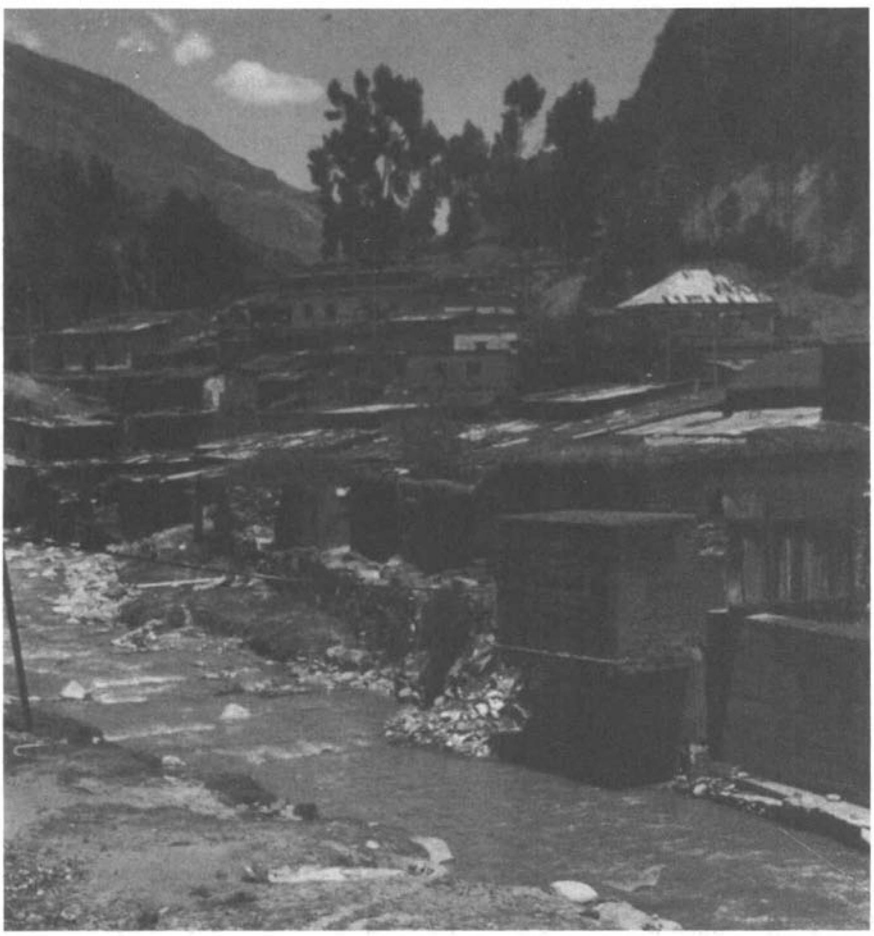
SLOW SAND FILTRATION is regaining its reputation, both in industrialized and developing countries, as a reliable and highly efficient treatment technology. The filtration process is able to remove most turbidity, and virtually all harmful entero- (affecting the intestine) bacteria and enteroviruses and all protozoan cysts. Slow sand filtration is not, however, a panacea for all water quality problems in all circumstances. Slow sand filters are inadequate when the levels of harmful substances in the raw water are extremely high, and when the raw water contains substances which reduce or inhibit the purification processes in the slow sand filters.

Typical efficiencies

Table 1 presents the typical treatment efficiencies that slow sand filters can achieve. The reported efficiencies have normally been achieved in filter units operated at normal hydraulic loading rates ranging from 0.04 to 0.2m/h at temperatures above 5°C, and in sandbed depths of greater than 0.5m.

The efficiency rates in Table 1 cannot always be achieved though, because much depends on the substances in the water. For example, when turbidity is largely made up of colloidal material and very small particles below 0.5m, as is the case in some clay-bearing water catchments, removal efficiencies may range from 0 to 40 per cent for raw water turbidities below 10NTU. Enhanced biological activity within the sandbed definitely contributes to the improved removal of turbidity.[1] As the surface waters of developing countries are becoming increasingly polluted, improved treatment technologies and more stringent standards should be established. Unfortunately this is unlikely to happen in the near future, because the governments have little money and there is a lack of appropriate monitoring systems. Nevertheless, it is important to aim for low turbidity levels, even if this is not specifically indicated in national standards.

Even if high removal efficiencies can be obtained, slow sand filtration alone cannot always produce drinking-water of a high standard. Raw water sources in many locations in industrialized countries are so deteriorated that a combination of treatment processes is required to meet these standards. This is also the case in developing countries, although these standards are normally more relaxed.



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The efficiency rates of the treatment systems will depend on the substances in the water: this river in Peru is overhung with latrines.

Reduced efficiency

Normal efficiencies are sometimes hampered by other circumstances. These may interfere with the filtration and purification processes, leaving too little time available between consecutive scrapings of the filter to allow adequate maturation. Important inhibiting conditions are low temperatures, high turbidities and algal blooms.

Low temperature The efficiency of slow sand filtration may be reduced when the unit is operating under low temperatures. *E. coli* removal will be reduced from 99 per cent at 20°C to 50 per cent at 2°C.[2]

Turbidity Raw water turbidity should not be above 10NTU for

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prolonged periods of time, although occasionally higher peaks of up to 50NTU can be accommodated by the filter units for one or two days without major increases in head loss. Even these short peaks may bury the large number of bacterial predators present in the sand bed and thus reduce their capacity to remove harmful bacteria.[4]

Algal blooms Algae may grow in the rivers, lakes, or storage reservoirs from which water is brought to slow sand filters. Most of the algae are retained by the slow sand filters, but under certain conditions occasional algal blooms may develop. These massive growths may create severe problems such as the premature blocking of the filters, the production of taste and odour in the water, and an increase in the concentration of soluble and biodegradable organics in the water. The pH of the water may rise considerably, causing magnesium hydroxide and calcium hydroxide to be precipitated onto the sand grains, thereby either blocking the filter or increasing the effective size of the sand and reducing the efficiency of the filtration process.

Controlling the algae is difficult, but two possible methods are reducing the nutrient contents in the raw water, or creating a storage system of deep reservoirs in which algae can be controlled by the exclusion of light.

Colombian projects

In 1984 the raw water quality of the streams in the region Valle de Cauca in Colombia were studied as part of a research and development project of slow sand filtration.

Two main types of rivers can be distinguished, highland rivers and lowland rivers. The highland rivers receive water from relatively small catchment areas, many of which are facing erosion problems. As a result the water quality shows short but high peaks of turbidity when it rains. The lowland rivers receive both water from the highland rivers and untreated sewage from small and large settlements, and thus have a higher level of contamination but a slower response to rainfall. It was clear that slow sand filters alone could not cope with the prevailing turbidity levels and faecal coliform counts in both highland and lowland rivers (see Figures 1 and 2).

Pilot experiments were established, each with different pre-treatment techniques to improve the water quality before it was passed on to the slow sand filters. The results were very promising, and the pre-treatment systems did remove a considerable part of the suspended solids, reduced faecal

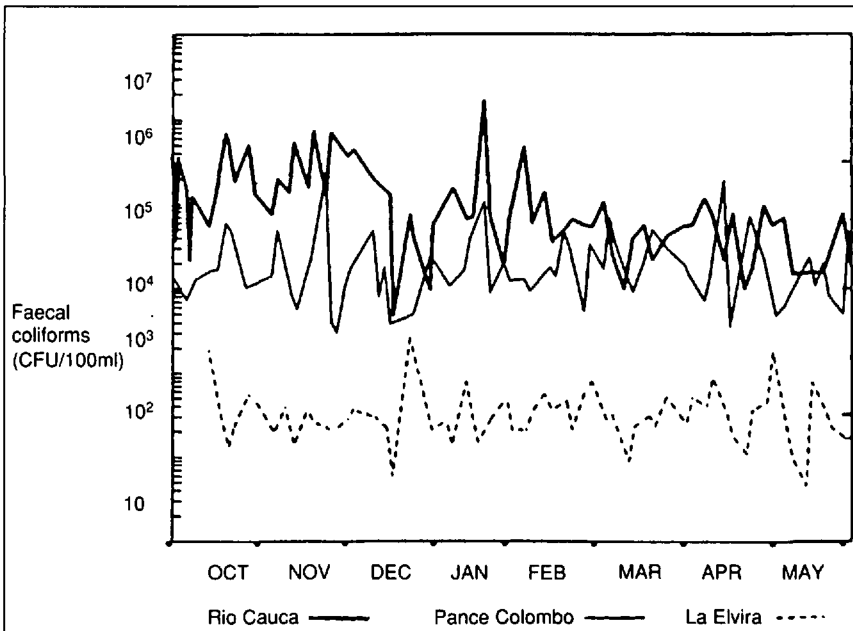


Figure 1. Faecal coliform counts per 100ml in three rivers of the Andean Cauca River Valley (sampling period October 1990-May 1991).

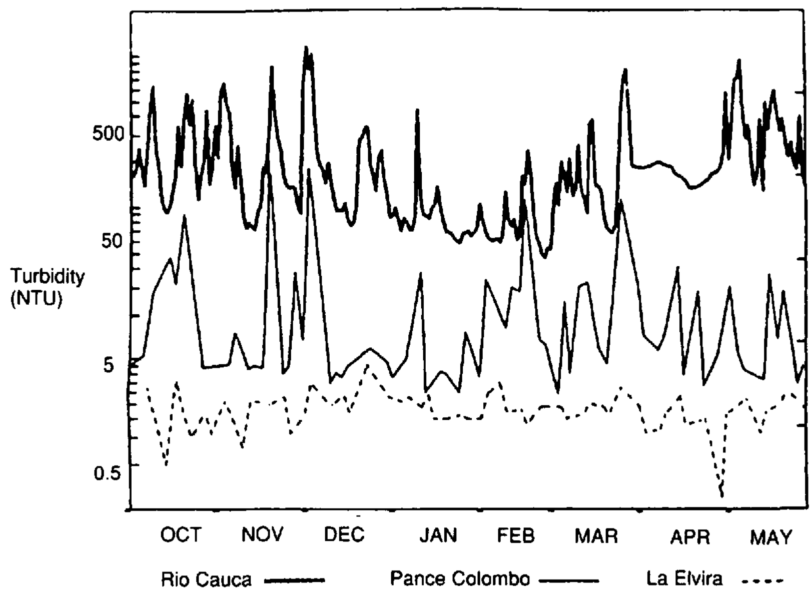
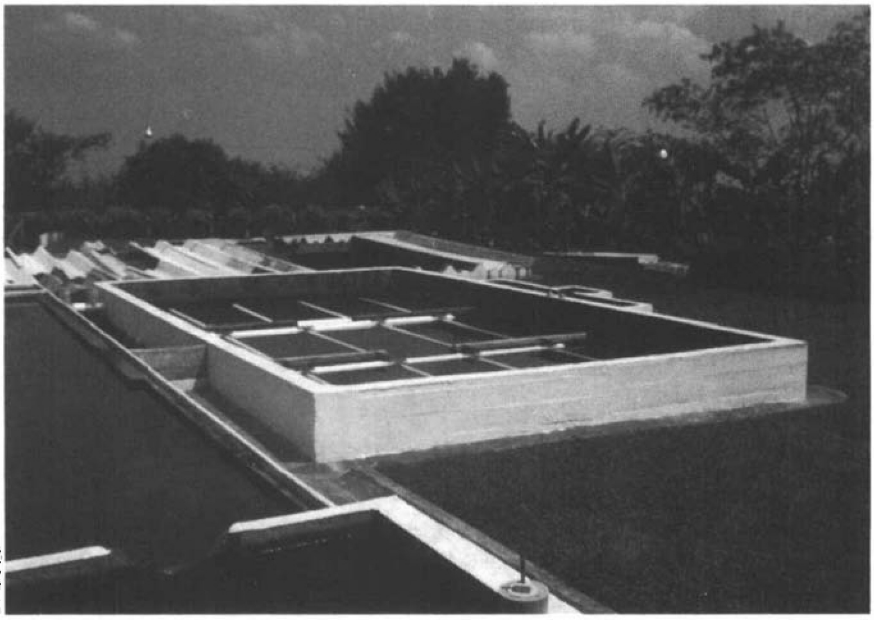


Figure 2. Turbidity levels (NTU) in three rivers of the Andean Cauca Valley. Pance and La Elvira are on the hilly sides of the valley (sampling period October 1990-May 1991).

Table 1: Typical treatment efficiencies of slow sand filters[1,2,3]

Parameter	*Typical reduction*
Entero-bacteria	90-99% or higher. Coliform removal efficency is, however, reduced by low temperatures, increased hydraulic rates, the use of coarse filter sand, shallow sandbeds, decreased contaminant concentration, and the periodic removal of the biological filter skin.
Cercariae of schistosoma	Virtually complete removal.
Protozoan cysts	99-99.9% removal, even after filter scraping.
Turbidity	Generally reduced to less than 1NTU.
Colour	30-90%, 30%; being the average.
Organic matter	COD 30-70%; TOC 15-30%; 50 to 90% of organic matter such as humic acids, detergents, phenols, and some pesticides and herbicides are removed.
Iron, Manganese	Largely removed.
Heavy metals	30-90% or even higher.



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The upflow (gravel) filter at the El Retiro treatment plant in Cali.

coliform counts, and even true colour levels.[5]

Selecting and protecting the best available source is far more economical and effective than allowing the watershed area to deteriorate and then having to rely on advanced treatment.[6] Watershed management in developing countries is as yet not covered by adequate legislation, and there are not enough trained staff to oversee it. It is essential that more collaboration between communities and waste agencies is encouraged. Other 'social' controls may also be necessary, for example regulating tree cutting and the use of pesticides in remove areas, which may also mean compensating farmers in the watershed for lost income, especially in regions which have just embarked on a cash economy.

The subsequent construction of full-scale plants confirmed the performance of the pre-treatment systems and the slow sand filters. The systems thus constructed follow the multi-barrier concept, in which reliance is placed on more than one stage of treatment to produce safe water for the consumers. Together these stages progressively remove the contaminants from raw water and consistently produce a safe and wholesome drinking-water. Ideally, water low in sanitary risk should then be disinfected with chlorine or an alternative, normally the last line of defense and considered a safety barrier.[4] For disinfection to be an effective safety barrier, the preceding barriers must remove virtually all harmful micro-organisms and possible interfering substances, so that terminal low-dose disinfection will be an efficient safeguard.

Table 2 presents information on seven water treatment systems in the region Valle del Cauca in Colombia.

Performance

Each system comprises four different treatment steps:

1. A conditioning stage, sometimes consisting of plain sedimentation, but in the newer systems more likely a dynamic filter unit. This unit contains a thin layer of fine gravel on top of a shallow bed of coarse gravel. The water entering the unit passes over the gravel bed and part of it is drained through the bed to the next treatment unit, while the rest is returned to the river. The system will clog when peak turbidities are being received, the flow through the bed will then be reduced, and thus low quantities of suspended solids will reach the next treatment unit in the system. In most of the highland rivers in the Valle del Cauca region these peaks are of short duration, and cleaning and recommencing operation of the dynamic filters is only a matter of a few minutes. These systems are still under development, which explains the different flow rates which are being applied.
2. Roughing filters, which are mostly of the single- or multi-stage upflow type, although two horizontal flow roughing filters are also included. These units are operating at flow velocities ranging from 0.6 to 1.0m/h.
3. Inlet-controlled slow sand filter plants.
4. Drop-feed chlorination, which is applied as a final safety barrier.

The performance of the different systems for four important parameters: faecal coliform, suspended solids, turbidity, and true colour were measured. Four of these plants, Colombo, Cañas Gordas, Retiro, and Javariana, are in an area with average temperatures of 24 +— 10°C, while the other three are in slightly lower temperature zones of

Table 2: Operational parameters of seven water treatment facilities

		Pretreatments				*Slow sand filters*	
Treatment	*Flow (l/s) (mean)*	*Type*	*Length (m)*	*Size range (mm)*	*Velocity (m/h)*	*Filter units*	*Filtration rate*
Ceylan	9.4	URFS	2.0	3-25	0.7	2	0.14
La Marina	6.8	URFS	1.8	6-20	0.6	2	0.16
Cañas Gordas	7.6	DF	0.6	7-25	9.0	3	0.16
		URFS	2.0	3-25	0.6		
El Retiro	8.8	URF	1.0	3-25	0.7	2	0.15
Colombo	0.7	DF	0.6	13-25	1.1	2	0.11
		URF	1.2	4-25	0.6		
Cider	0.7	HRF	7.0	5-16	0.8	2	0.15
Javeriana	1.5	DF	0.6	5-25	0.8	2	0.08
		HRF	4.0	3-16	1.0		

URFS = Upflow roughing filter in series
DF = Dynamic filter
URF = Upflow roughing filter
HRF = Horizontal flow roughing filter

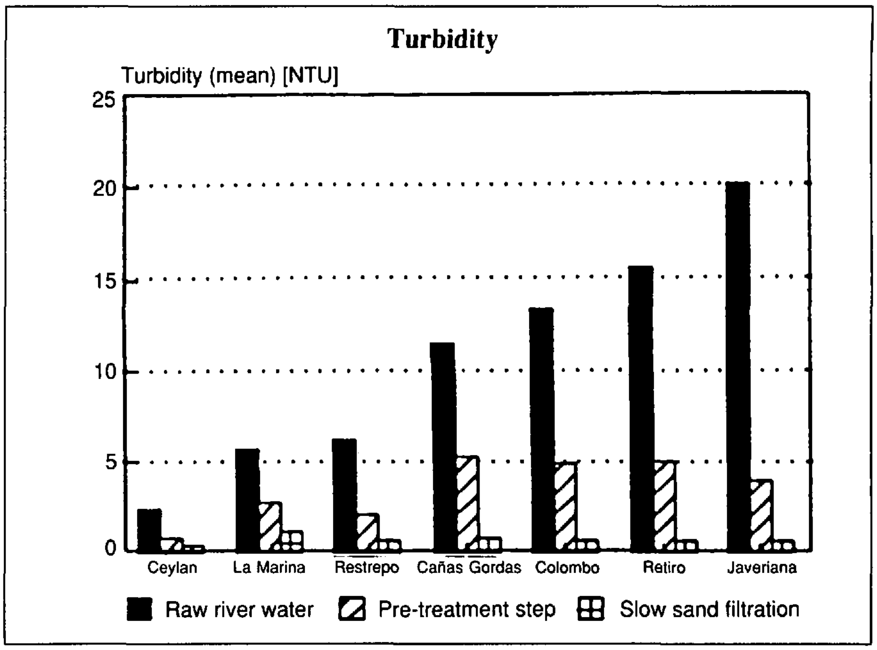
18 +— 10°C. Even if the last barrier of low-dose disinfection fails, the water produced in the Colombian systems will still represent a low sanitary risk for the consumers of the treated water, with average faecal coliform counts below 1 per 100ml after slow sand filtration.

Figure 3 shows how the different treatment systems adapted to the type of raw water and the concentration of impurities in it. The systems show higher removal efficiencies for more contaminated water. In Ceylan the average removal of faecal coliform bacteria is 2.6 log units, and in Colombo, which receives more contaminated water, this is 4.4 log units. This aspect is being studied further in the ongoing research in Colombia, where pilot schemes are now reaching consistent reduction levels of 5.5 log units. The pre-treatment systems are as robust as the slow sand filters and are much less vulnerable than the chemical pre-treatment systems. Moreover, the treatment efficiency obtained in the pre-treatment units and the slow sand filters ensures that only a very low chlorine dose is required for final disinfection.

Table 3 presents some data on filter run periods of the slow sand filters which are ranging on average from 2.5 to 7 months, with filter rates of some 0.15m/h. The only exception is the plant in La Marina, which is having filter runs of only one month. This plant was one of the first schemes constructed, and did not benefit from the design improvements established in later schemes. More important is the amount of algae in the plant, which may be the main reason for the shorter runs.

The slow sand filter technology has worked very well as part of a multi-barrier water treatment system. Under the conditions in Valle del Cauca, the combination of slow sand filtration and roughing filtration is proving to be very effective. The levels of turbidity, faecal coliform, and particularly of true colour were much better than was expected. The filtrate from the plants only requires a very low chlorine dose as an ultimate safety barrier.

Through improved water source protection and pre-treatment systems which are now being developed, slow sand filtration can be applied in a much wider number of settings than earlier thought possible. These findings are very relevant for developing countries as well as industrialized countries, as it will provide an alternative to chemical pre-treatment processes.



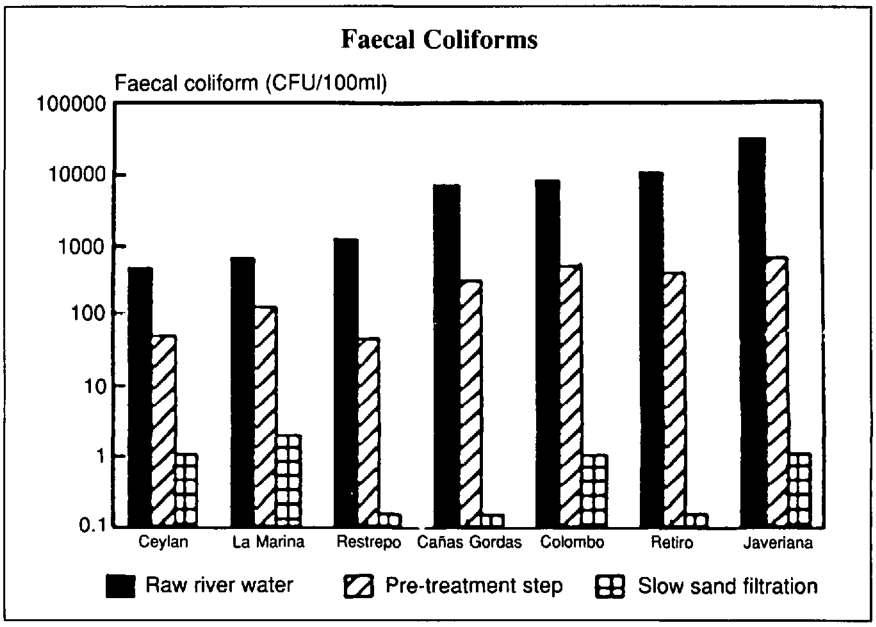


Figure 3. The different methods of treatment adapted to the levels of turbidity and faecal coliforms in the water.

Table 3: Filtration rate and run lengths of the full scale demonstration projects (October 1990-September 1991)

Demonstraction projects	*Head losses (m)*	*Filter run length (days)* Mean	Min.	Max.
Ceylan	0.66	206	206	206
La Marina	0.71	34	15	57
Cañas Gordas	0.65	84	61	115
El Retiro	0.85	85	64	107
Colombo	0.28	82	45	105
Cider	0.60	178	177	187
Javeriana	0.60	203	141	265

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