5. Operation and maintenance

One of the points in favour of slow sand filtration as a water treatment process that appeals particularly to those responsible for public water supplies in developing countries and other areas where skilled staff may be difficult to recruit is its extreme simplicity of operation. Provided that a plant has been well designed and constructed there is little that can go wrong as long as the simple routine of operation is carried out.

The operation of the filter is determined by the filtration rate, which is controlled at the effluent outlet. Inflow, which may be delivered by a pump, by gravity supply from a constant level reservoir, or by flow from a raw water storage-pond regulated by an automatic control valve in an adjoining chamber, is adjusted so that the head of water in the supernatant reservoir remains constant at all times. Excessive raw water delivery will cause overflow through the scum outlets, while a reduction in the rate of inflow will cause the level in the supernatant water reservoir to drop; either condition should alert the operator to a defect in the mechanism controlling the supply of raw water. In the case of very small filters or those constructed to low-cost specifications and gravity fed from a reservoir, stream catchment, or similar source, a simple manually operated valve may be the only inlet control. This will need periodic checking if a balance is to be kept between the dangers of wasting raw water (through overflow) and diminishing output (through a dropping head over the filter-bed).

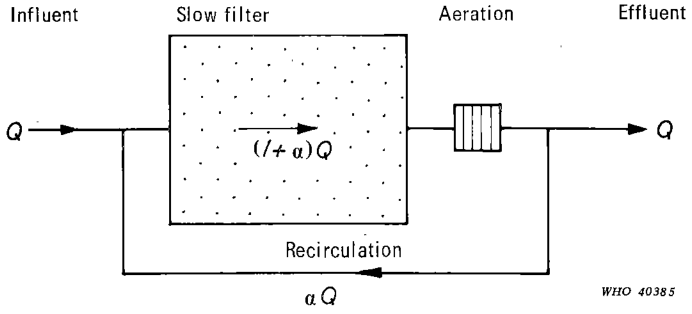
The filtration rate is controlled by a single regulating valve on the effluent delivery. At the beginning of the filter run this will be partially closed, the additional resistance thereby provided being equal to that which will later build up within the filter-bed. Day by day as the run continues this valve must be checked and opened fractionally to compensate for the choking of the filter and to maintain a constant filtration rate. In the early part of the filter run the daily build-up will be almost imperceptible, calling for very little valve adjustment, but toward the end the resistance will increase more rapidly, necessitating a more positive opening of the valve and signalling the impending need for filter cleaning.

To enable the operator to regulate the valve precisely, it is necessary to have some form of measuring device on the effluent outlet. The most satisfactory is a venturi meter immediately upstream of the valve, and in most installations of reasonable size it is considered essential. The meter dial is placed next to the valve control gear so that the operator can check the reading while making flow adjustments, and it is usual also to incorporate an automatic recording chart so that the manager or supervisor can assure himself that the velocity rate has been continuously controlled. In very small installations, a gauge showing the height of flow over the weir or telescopic outlet may be used as a substitute for the flow meter. This is very much cheaper than venturi equipment but less accurate and less easy to read.

Excessive algal growth may cause trouble in the operation of open filters. Pretreatment by microstrainers is one method of removing the algae contained in the raw water, but it will not necessarily prevent the growth of different species within the supernatant reservoir. Various methods of reducing their numbers have been adopted. The most effective (but expensive) way of excluding the sunlight that is essential for their growth is to cover the filters. When turbid river water is pretreated to provide a raw water source for the filter it is sometimes possible, by bypassing the pretreatment stage, to increase the turbidity in the supernatant water reservoir during periods of particular activity, thereby cutting down the penetration of the sunlight and inhibiting algal growth. This can be justified only when the interference due to the algae is greater than the choking effect of the turbidity.

To deal with occasional outbreaks of vigorous algal blooms, treatment of the raw water by chlorination (0.2–1.0 mg/l) or the application of copper sulfate (0.15 mg/l) is sometimes resorted to, but it is definitely not to be recommended as a general practice because it may interfere with the bacterial activity of the filter-bed, with a consequent drop in effluent quality. Chemical treatment should be carried out under strict supervision to ensure that mixing is adequate and to avoid overdosing. In small filters some improvement may be effected by the removal of algae by hand, particularly from the filter box walls above the sand-bed, but the expedient of breaking

FIG. 23. RECIRCULATION OF EFFLUENT



WHO 40385

up the *schmutzdecke* with rakes is a bad one since it can easily lead to a sharp fall in effluent quality.

If the dissolved oxygen content of the raw water drops below the potential oxygen demand, anaerobic conditions may develop within the bed. To some extent a reasonable growth of algae in the supernatant reservoir oxygenates the supernatant water as discussed in an earlier chapter. Where the composition of the raw water or the climate does not favour the growth of algae, or where chemical dosing or some other device has been used to remove or exclude them, it may be necessary to use other expedients to increase the dissolved oxygen content, such as aeration of the incoming raw water. A simpler method, which may be adopted when the condition is only temporary, is to recirculate part of the effluent as shown in Fig. 23. Its working may best be explained by an example.

Let us assume that raw water is being supplied to a filter at the rate of Q m^3/h and that it has a dissolved oxygen content of 6 mg/l with a potential oxygen consumption of 8 mg/l. Without recirculation the effluent would have an oxygen content of zero and an oxygen demand of 2 mg/l. Cascading over the weir after filtration may increase its oxygen content to, say, 9 mg/l, but the gain comes too late to prevent anaerobic conditions from developing within the filter-bed itself.

When a proportion (αQ) of the effluent (after aeration) is recirculated and mixed with the incoming raw water, the oxygen demand of the latter can be satisfied completely, leaving an effluent oxygen content C_e, which may be calculated as follows:

$$(Q \times 6) + (\alpha Q \times 9) - (Q \times 8) = (1+\alpha)\, Q \times C_e$$

$$C_e = \frac{9\,\alpha - 2}{\alpha + 1}\,.$$

To ensure that anaerobic conditions do not develop in any part of the filter-bed, the oxygen content of the effluent should not be allowed to drop below 3 mg/l. Substitution of this value in the equation gives $\alpha = \frac{5}{6}$, so that the filtration rate must be nearly doubled. This would materially increase the head loss, and might prove impossible towards the end of the filter run, although the rate of clogging would not increase since the recirculation of filtered effluent would not add to the total amount of impurities being removed by the filter.

The operator will be expected to keep the filter structure and its surroundings in clean condition and to remove floating scum, leaves, and other debris through the outlets provided. Apart from this he has one other main duty—to take samples of raw and filtered water at stated intervals for analysis.

The frequency with which samples are taken will depend (in practical terms) on the availability of facilities for analysis. In a large waterworks with its own laboratory, sampling will almost certainly be carried out daily, since the effluent analysis constitutes the only certain check that the filter is operating satisfactorily, and the raw water analysis provides what is possibly the only indication of a change in quality that might adversely affect the efficiency of treatment. At the other extreme is the small remote plant with two or three filters, able to afford only unskilled attendance and with no easy access to a laboratory. Even under such circumstances, an attempt should be made to conduct sampling on a regular basis. It may, for example, be carried out by the visiting supervisor or the local medical authorities. Water quality may also be measured with a fair degree of accuracy using field testing equipment based on membrane techniques; no formal laboratory is required nor a high level of skill. A compromise measure is to supplement infrequent bacteriological examinations with comparatively simple tests for free ammonia. Since ammonia should not be detectable in the effluent when aerobic conditions prevail in the filter, its presence is a good indicator of malfunctioning.

Initial commissioning of a filter

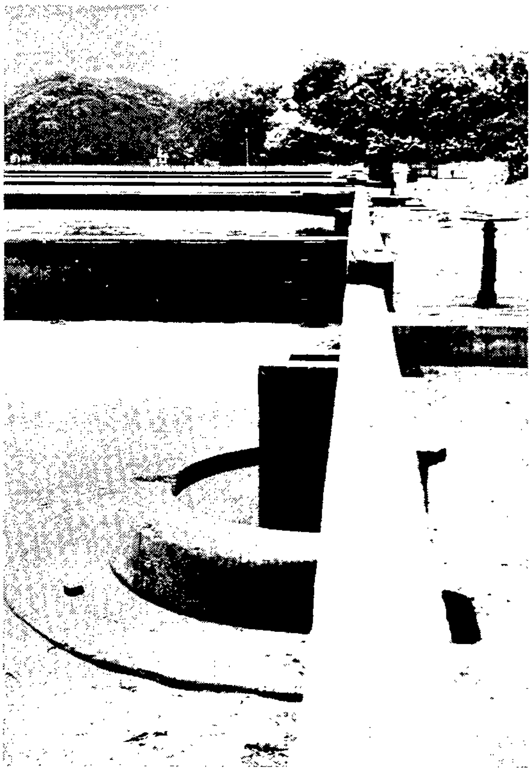
When first constructed, the bed of clean sand within which purification will eventually take place cannot, strictly speaking, yet be called a filter; certainly not a biological filter since the vital living organisms on which treatment depends are not yet present. The sand medium is, as we have seen, merely a framework upon which these organisms can establish themselves.

Building up the biological content of a new filter is a slow process calling for careful supervision. When another, actively operating filter exists nearby, some acceleration of the original "ripening" stage may be effected by "seeding" the new filter with some of the active material removed in cleaning, but otherwise there is no short cut to the following procedure.

First, with all outlet valves closed, the filter must be charged with filtered water, introduced from the bottom to drive out the air bubbles from the interstices of the sand, thus ensuring that the whole surface of every sand grain is in contact with the water. Water then continues to be introduced from below until the sand-bed is covered by a sufficient depth to prevent its being scoured or disturbed by turbulence from the admission of raw water. The raw water inlet may be sited immediately above the supernatant drain trough; if it is not, a concrete slab or some other protective device must be placed on the surface of the sand bed at the point where inlet turbulence is at its maximum (Fig. 24).

Top filling now commences, slowly at first, but at an increasing rate as the water cushion on the sand deepens, until the future normal working level in the supernatant water reservoir is reached. The outlet valve (H in Fig. 20) is then opened, and the effluent is run to waste at a rate

FIG. 24. CONCRETE APRONS TO PREVENT SCOUR AT INLET TO SLOW SAND FILTER
MADRAS WATERWORKS, INDIA



Madras Municipal Corporation/Swamy News Photo Service

(controlled by the filter regulating valve) of approximately one quarter of the normal filtration rate.

The filter must now be run, continuously and without interruption, discharging to waste (or to another filter) for at least several weeks in tropical climates and longer where temperatures are low. The time also depends on the nature of the raw water; the cleaner it is the longer the ripening process will take. The rate of flow is gradually increased during this period until it reaches the designed filtration rate. As ripening proceeds, there will be a slight increase in the head loss in the bed as the organisms build up, and the formation of a *schmutzdecke* will gradually become visible. These are signs that ripening is proceeding satisfactorily, but only after comparative chemical and bacteriological analyses of raw water and effluent have demonstrated that the filter is in full working condition may the waste valve be closed and the effluent directed to the public supply. From this point onwards the filter should operate under normal working conditions. If for any reason (say a temporary shutdown of the public supply while a new water main is being connected) delivery is interrupted for a period too long to be accommodated by filling the clear water reservoir to capacity, filtration should be continued and the effluent diverted to waste, since any shutdown for an extended period must be followed by further ripening if the quality of the effluent is to be maintained.

Filter cleaning

When, during a filtration run, the bed resistance has increased to such an extent that the regulating valve is fully open, it is time to clean the filter-bed, since any further increase in resistance is bound to reduce the filtration rate. Resistance accelerates rapidly as the time for cleaning approaches. In many filtration plants, indicators are installed showing the inlet and outlet heads, from which the head loss can be regularly checked; this gives a direct picture of the progress of choking and the imminence of the end of the run. Without any measurement of head loss the only true indicator of build up of resistance is the degree of opening of the regulating valve, though the experienced operator may be able to recognize preliminary visual warnings in the condition of the filter-bed surface. Certain other warning signs may be given by a slight deterioration in effluent quality—another good reason for regular analysis wherever practicable.

To clean a filter-bed, the raw water inlet valve is first closed, allowing the filter to continue to discharge to the clear water well as long as possible (usually overnight). As the head in the supernatant reservoir drops, the rate of filtration rapidly decreases, and although the water above the bed would continue to fall until level with the weir outlet, it would take a very long time to do so. Consequently, after a few hours (e.g., next morning), the effluent delivery to the clear water well is closed, and the supernatant water outlet is run to waste through the drain valve provided.

Unless there is sufficient capacity in the clear water reservoir to maintain the supply during the cleaning period or unless an additional filter is available to take over the duties of the one being cleaned, the remaining filters must be operated at an increased filtration rate, which will inevitably result in more rapid clogging. Clearly, one of the advantages of installing a number of small filters rather than a few of greater area is that less spare capacity has to be provided to prevent the overloading of the remaining filters during the cleaning of any one of them.

When the supernatant water has been drained off (leaving the water level at the surface of the bed) it is necessary to lower the water within the bed still further, until it is some 10 cm or more below the surface. This is done by opening the waste valve (D in Fig. 18) on the effluent outlet pipe. As soon as the *schmutzdecke* is dry enough to handle, cleaning should start. If the filter-bed is left too long at this stage it is likely to attract scavenging birds that will not only pollute the filter surface but disturb the sand to a greater depth than will be removed by scraping.

The cleaning of the bed may be carried out by hand or with mechanical equipment. Mechanical cleaning is a large subject and is dealt with in a separate section below. Hand cleaning is done by labourers using square-bladed shovels. Working as rapidly as possible, they should strip off the *schmutzdecke* and the surface sand adhering to it, stack it into ridges or heaps, and then remove the waste material by barrow, handcart, basket, conveyor-belt or other device (Fig. 25). When the filter-beds are very large, wide-tracked dumpers may be used, and the skimming may be accomplished by a similar tractor having an attached scraping blade, but only specially designed vehicles should be permitted on the bed surface otherwise the upper layers of the medium will be disturbed to the detriment of their bacterial population. For the same reason, barrows or handcarts should always be run on protective planks.

FIG. 25. MANUAL CLEANING OF A SLOW FILTER

Municipal waterworks, Amsterdam

When the *schmutzdecke* consists largely of filamentous algae forming an interwoven mat, cleaning is a simple matter. The labourers will quickly acquire the knack of curling back this mat in reasonably large sections at a time, provided that the operation is timed so that the material is neither waterlogged nor so dried out that it is brittle. If the predominant species of the *schmutzdecke* is diatomous or some other non-filamentous type, cleaning will be less easy, and closer supervision will be necessary to control the depth of scraping. After removal of the scrapings the bed should be smoothed to a level surface. The quicker the filter-bed is cleaned the less will be the disturbance of the bacteria and the shorter the period of re-ripening. Provided they have not been completely dried out, the microorganisms immediately below the surface will quickly recover from having been drained and will adjust themselves to their position relative to the new bed level. In this event a day or two will be sufficient for re-ripening.

The procedures to be followed during the re-ripening period will follow the pattern set when the filter was originally put into service, although they will be much accelerated. Before the filter box is refilled, the exposed walls of the supernatant water reservoir should be well swabbed down to discourage the growth of adherent slimes and algae, and the height of the supernatant water drain and of the outlet weir must be adjusted to suit the new bed level. The water level in the bed is then raised by charging from below with treated water from the clear water well or from one of the other filters. As soon as the level has risen sufficiently above the bed surface to provide a cushion, the raw water inlet is gradually turned on. The effluent is run to waste until analysis shows that it satisfies the normal quality standards. The regulating valve on the effluent line will be substantially closed to compensate for the reduced resistance of the cleaned bed, and the filter will then be ready to start a new run.

During cleaning operations precautions should be taken to minimize the chances of pollution of the filter-bed surface by the labourers themselves. Such measures as the provision of boots that can be disinfected in a tray of bleaching solution may be wise, hygienic personal behaviour should be rigidly imposed, and no labourer with symptoms that might be attributable to waterborne or parasitic disease should be permitted to come into direct or indirect contact with the filter medium.

Resanding

After several years' operation and, say, twenty or thirty scrapings the depth of filtering material will have dropped to its minimum designed level (usually about 0.5–0.8 m above the supporting gravel, according to the grain size of the medium). In the original construction a marker, such as a concrete block or a step in the filter box wall, is sometimes set in the structure to serve as an indication that this level has been reached and that resanding has become due.

During the long operation of the filter some of the raw water impurities and some products of biochemical degradation will have been carried into the sand-bed to a depth of some 0.3–0.5 m, according to the grain size of the sand. To prevent cumulative fouling and increased resistance, this depth of sand should be removed before resanding takes place, but it is neither necessary nor desirable that it should be discarded. Instead it is moved to one side, the new sand is added, and the old sand replaced on top of the new, thus retaining much of the active material to enable the resanded filter to become operational with the minimum re-ripening.

This process, known as "throwing over", is carried out in strips. Excavation is carried out on each strip in turn, making sure that it is not dug so deeply as to disturb the supporting gravel layers below. The removed material from the first strip is stacked to one side in a long ridge, the excavated trench is filled with new sand, and the adjacent strip is excavated, throwing the removed material from the second trench to cover the new sand in the first. The operation is illustrated in Fig. 26 and 27. When the whole of the bed has been resanded, the material in the ridge from the first trench is used to cover the new sand in the last strip.

In areas where sand is expensive or difficult to obtain, the surface scrapings from regular cleanings may be washed, stored, and used for resanding at some future date. These scrapings must be

FIG. 26. RESANDING OF A SLOW FILTER

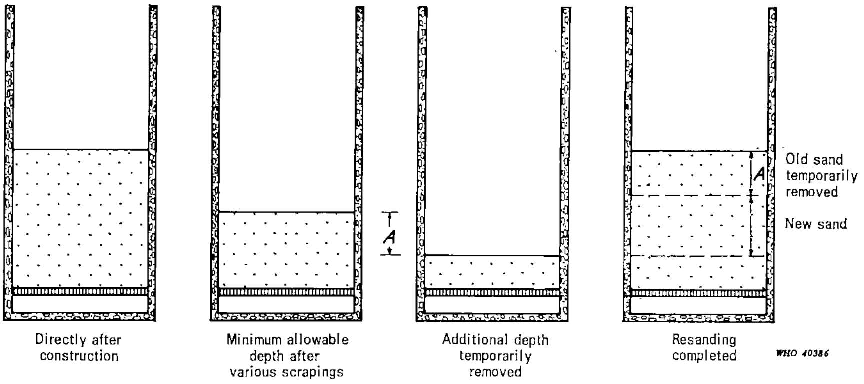
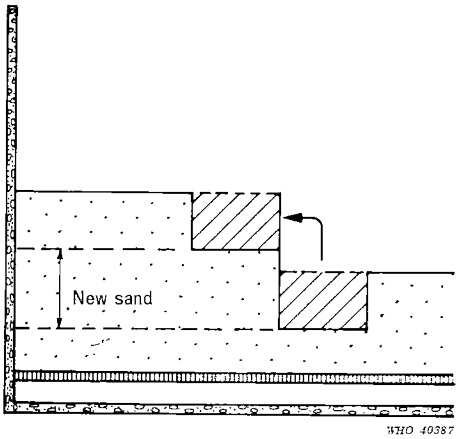


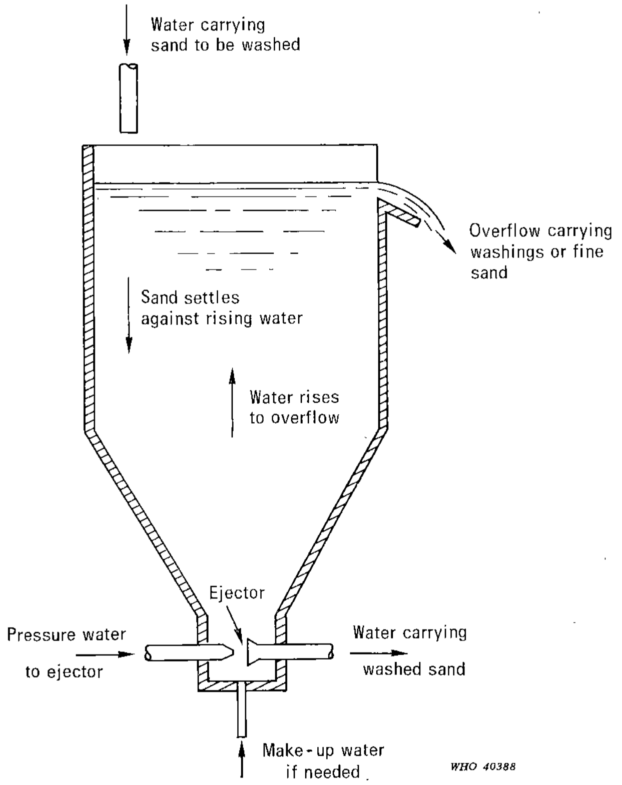
FIG. 27. "THROWING OVER" OF RESIDUAL SAND



washed as soon as they are taken from the filter, otherwise, being full of organic matter, the material will continue to consume oxygen, quickly become anaerobic, and putrefy, yielding taste- and odour-producing substances that are virtually impossible to remove during any later washing process.

A simple method of washing sand is shown schematically in Fig. 28, and a practical example is given in Fig. 29 and 30, which shows the sand-washing machine at the Madras waterworks, India. In this machine, the dirty sand from the filter-bed is fed into a drum. Filtered water is injected under pressure into the bottom of the drum, carrying the impurities upwards past a set of steel stirrers to the top, from where they are conveyed to a wooden Pelton wheel, which drives the stirrers. The clean sand and water are discharged to the filter-bed, while the dirty water flows into a sludge pit.

FIG. 28. SAND WASHING MACHINE, EJECTOR TYPE



From: Fair, G.M. & Geyer, J.C. (1954) *Water supply and waste-water disposal,* New York, John Wiley.

FIG. 29. GENERAL VIEW OF SAND WASHING PLANT AT MADRAS WATERWORKS, INDIA

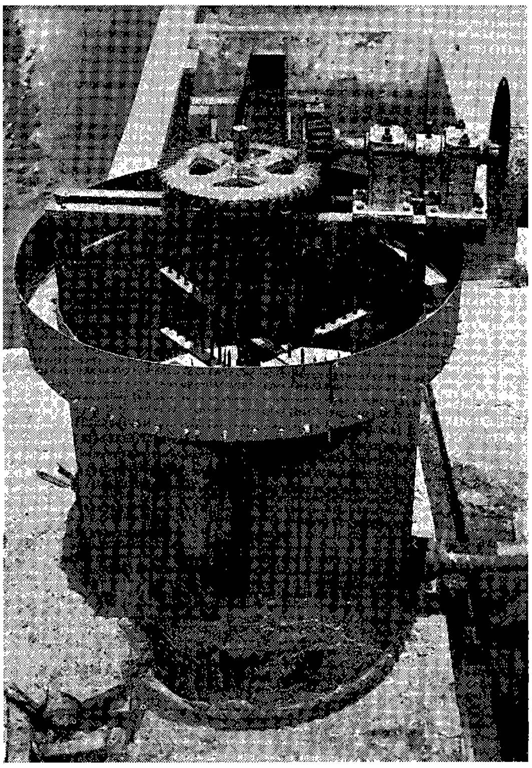
Madras Municipal Corporation/Swamy News Photo Service

A completely clean sand is difficult to attain, both when fresh from excavation and when subsequently prepared for reuse. Washing rarely removes the strongly adherent organic coating entirely from the grains, and, after exposure to air, this coating becomes soluble and acts as a nutrient for bacterial growths. Under favourable temperature conditions microorganisms will multiply, so that when the sand is reused during warm weather it may contain large numbers of bacteria, by no means all of which are of a nature to contribute to the water purification qualities of the filter-bed. It is often better, therefore, if washed sand is to be used, to carry out resanding operations in the winter, even if working conditions are then less favourable.

It must also be remembered that filter sand, when washed, loses its finer particles, so that the effective diameter is increased. This is likely to result in deeper penetration of impurities into the bed during subsequent filter runs.

A procedure once extensively adopted but little practised today is to wash the sand immediately after each scraping and return it to the filter-bed surface. The method has obvious advantages in the saving of transport and labour and in the fact that the depth of the bed remains constant, so permitting the use of shallower beds (since no additional depth need be allowed for the periodic removal of scrapings). Although this results in considerable savings in construction costs, the method has one serious disadvantage that caused it to be discontinued early in the present century—only the top 0.05–0.10 m of the filter-bed is ever washed in a complete cycle, and the sand below this layer remains in place indefinitely until, in due course, clogging becomes persistent.

FIG. 30. SAND WASHING DRUM AT MADRAS WATERWORKS

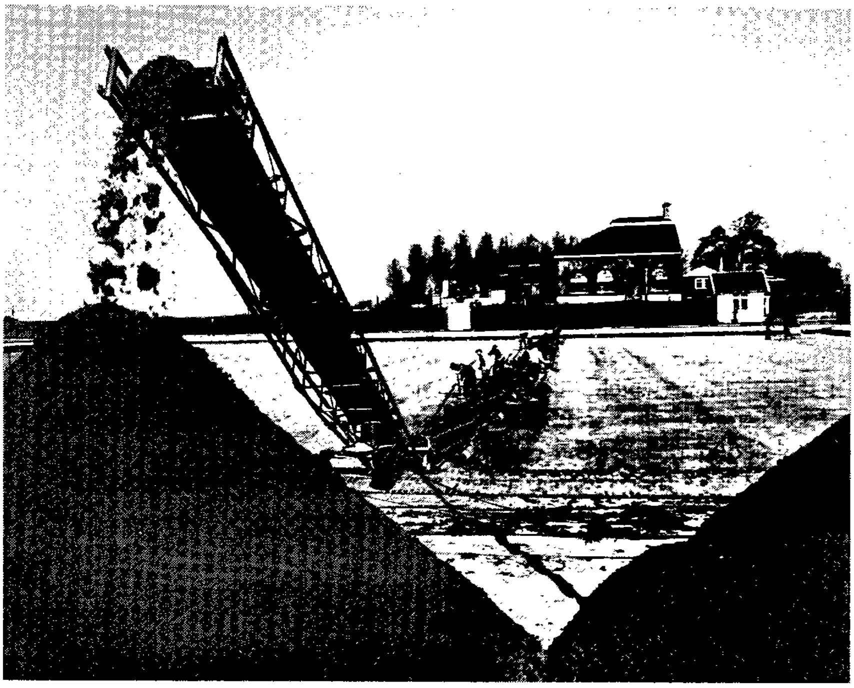


Madras Municipal Corporation/Swamy News Photo Service

Mechanical cleaning of filters

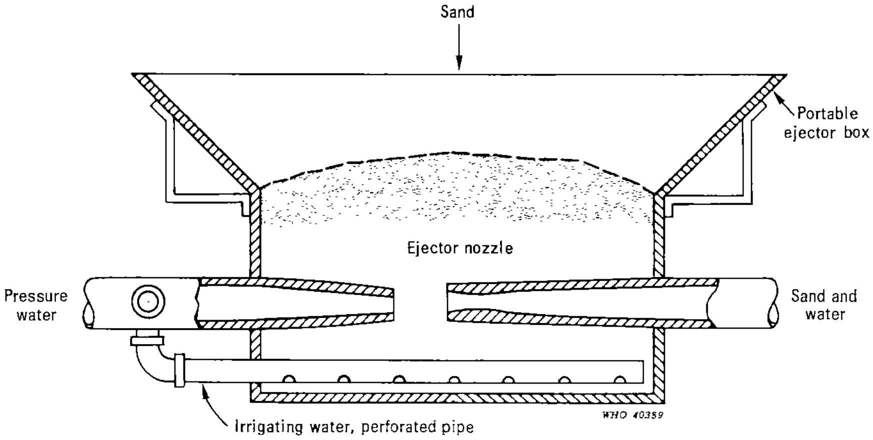
The manual method of filter-bed cleaning requires only unskilled workmen using hand tools; it demands no special materials, equipment, or skills, and relatively little skilled supervision. It may therefore have considerable attractions in areas of high unemployment, but it is certainly unpopular in countries where labour costs are high and unskilled workers difficult to obtain. This position has gradually developed in the industrialized countries and has been balanced by an equally gradual introduction of mechanical aids such as portable conveyor-belts (Fig. 31) and hydraulic sand ejectors (Fig. 32) that enable the waste material to be

FIG. 31. TRANSPORTATION OF SAND WITH A CHAIN OF PORTABLE CONVEYOR-BELTS



Municipal Waterworks, Amsterdam/Govert H. Vetten

FIG. 32. HYDRAULIC SAND EJECTOR



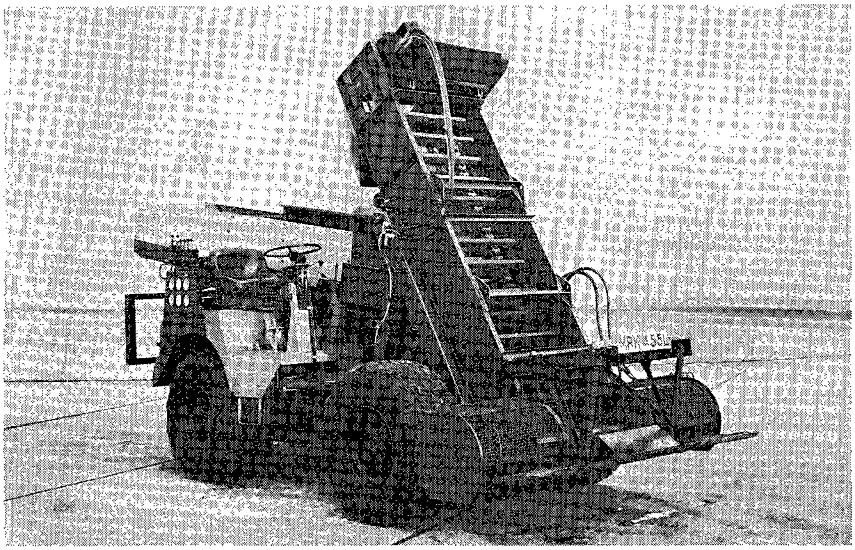
From: Fair, G.M. & Geyer, J.C. (1954) *Water supply and waste-water disposal*, New York, John Wiley.

lifted from the bed and conveyed to the central washing or disposal site with the minimum of handling. Over the past few decades the process of mechanization has accelerated, and there now exist, in many cities, systems whereby the whole of the cleaning of slow sand filters is carried out mechanically or hydraulically, using the bare minimum of operating staff.

The first fully mechanized system for this purpose was developed by the Metropolitan Water Board in London,[1] where very large filter-beds—up to 4000 m^2 in area—make hand cleaning a laborious and time consuming operation. The new system was devised to be used on existing beds, and so the need for special filter box construction had to be avoided. Each phase of cleaning is mechanized separately, using modified light agricultural tracked vehicles moving over the filter-bed itself. To prevent compaction of the medium (which would result in higher filter resistance immediately after cleaning) the soil pressure has been kept below 33 kN/m^2 by suitable adaptation of the vehicles.[2]

The key to the system is the use of skimming machines (Fig. 33) that scrape off the required amount of sand to a preset depth of 1–3 cm. From

FIG. 33. TRACTOR-MOUNTED SKIMMER



Metropolitan Water Board, London

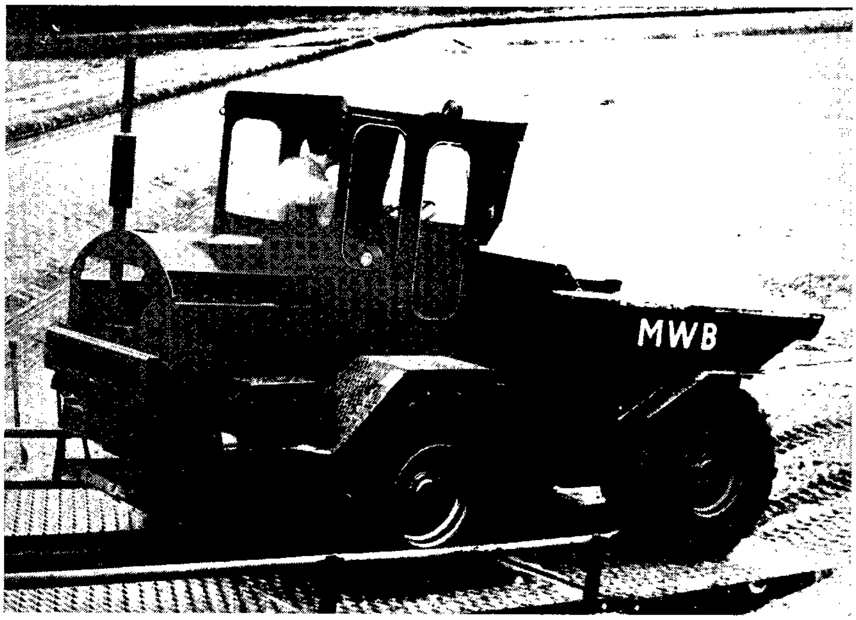
---

[1] Lewin, J. (1961) *J. Instn Wat. Engrs*, **15**, 15.

[2] In this publication pressures are given in newtons per square metre, in conformity with the recommendations of the International Organization for Standardization. 1 $N/m^2 = 1.019 \times 10^{-5}$ kgf/cm^2; 1 $kgf/cm^2 = 98.1$ kN/m^2.

the skimming blades the sand is carried to the rear by screw conveyor and belt loader, being discharged into a following tractor with dumper body (Fig. 34). Special rake attachments trailed behind the tractors leave the surface of the filter-bed in a level and finished condition. Trenching machines, also tracked, are used when a greater depth of excavation is needed, as in resanding (Fig. 35).

FIG. 34. FOUR-WHEEL-DRIVE DUMPER, 300 KG CAPACITY



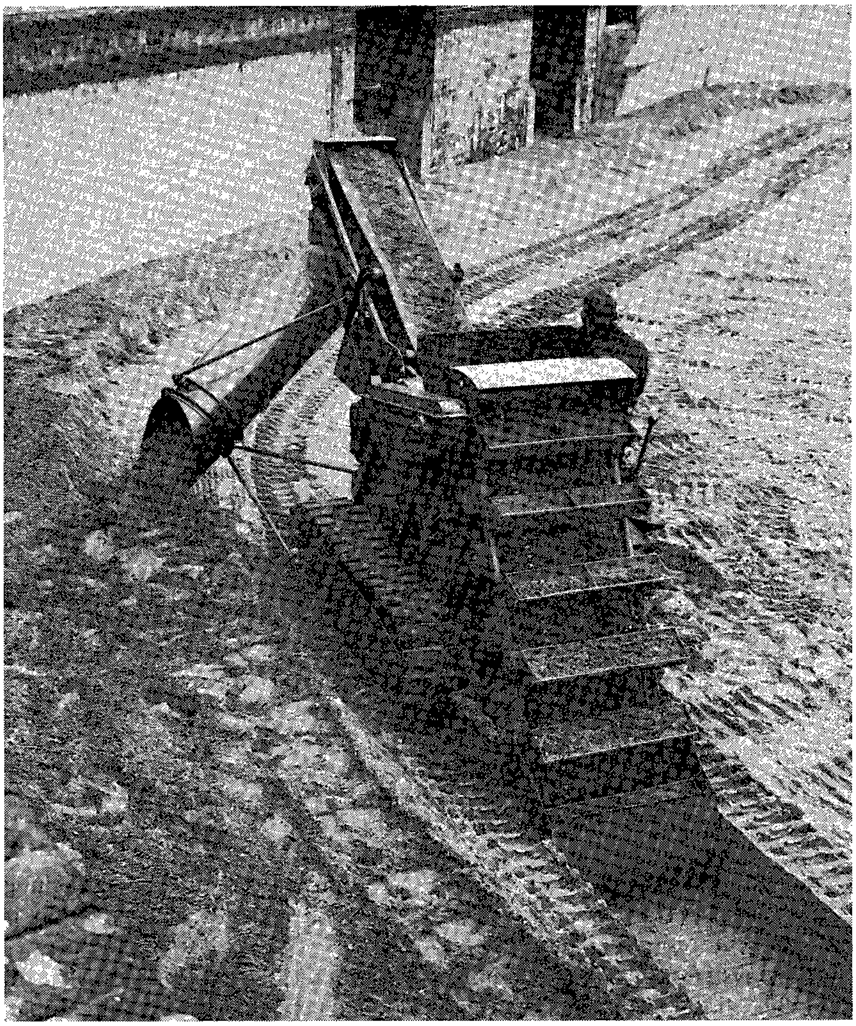
Metropolitan Water Board, London

The ramps shown in the photograph allow access to and from the filter-bed, enabling the dumper to operate direct between the skimmer and the sand bay and thus eliminating the intermediate stage in which the sand is dumped on the filter-bed and removed by crane.

This system permits the number of labourers required to be halved, although those employed must posses a higher degree of skill. When allowance is made for amortization of the capital outlay on equipment, the saving in operational cost is not impressive, while the presence of motorized vehicles on the filter medium always carries a hazard of pollution from oil drippings. However, there has been a great saving of time in filter-bed cleaning, and hence in the period during which each bed is out of action, and this may be taken as the principal justification for mechanization.

In addition to treating the public supply, the Berlin waterworks has adapted the slow sand filtration principle to the treatment of raw water used for groundwater recharge. The spreading basins (see Chapter 6) are

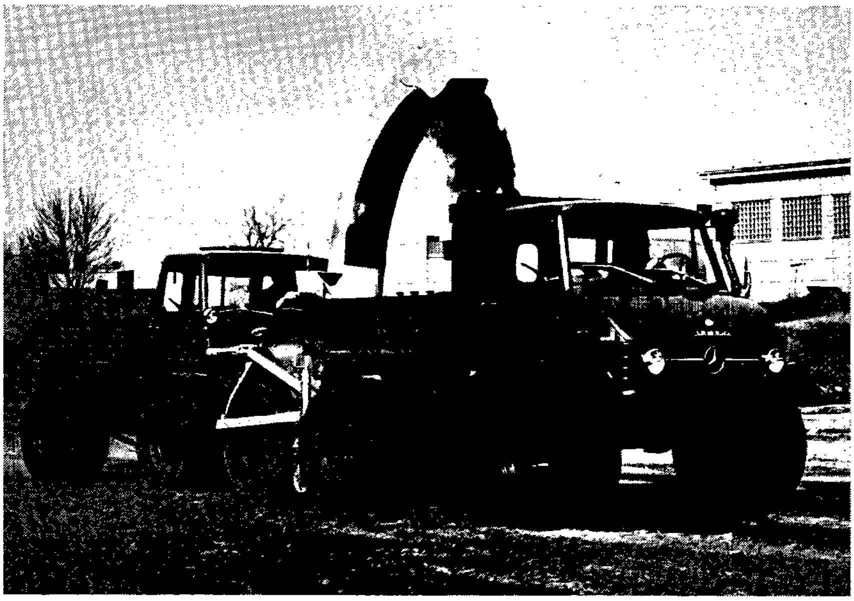
FIG. 35. TRENCHING MACHINE FOR RESANDING OPERATIONS



Metropolitan Water Board, London

lined with a 0.4 m depth of coarse sand (grain size 0.5–2.0 mm) through which the downward percolating water passes at 0.04 m/h. Despite the coarseness of the sand and the low rate of filtration, the nature of the raw water is such that clogging is rapid and each basin lining requires cleaning once every 3 weeks. This is effected by scraping off a layer 1.5 cm thick with somewhat similar mechanical equipment to that used in London —skimmers on tracks (soil pressure less than 30 kN/m^2) moving at 7–12 m/min—but the skimmers used in Berlin have blades 1.2 m wide

FIG. 36. MECHANICAL CLEANING AT THE BERLIN WATERWORKS

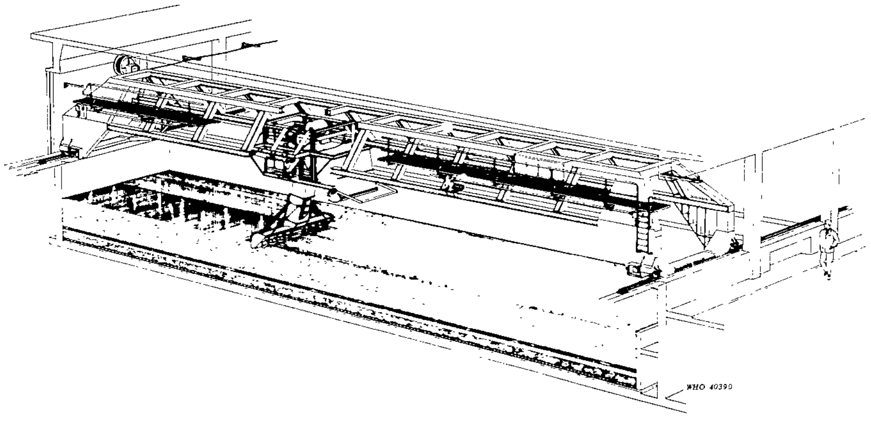


Berlin Waterworks/ Günther Metzner

separately supported on six pneumatic tyres, capable of preserving a constant depth of skim of up to 5 cm, however wavy the surface (Fig. 36). Instead of small tracked dumpers, large wheeled trucks are used, one per skimmer, fitted with oversized low-pressure tyres, and suitable for other duties when bed cleaning is not in progress.

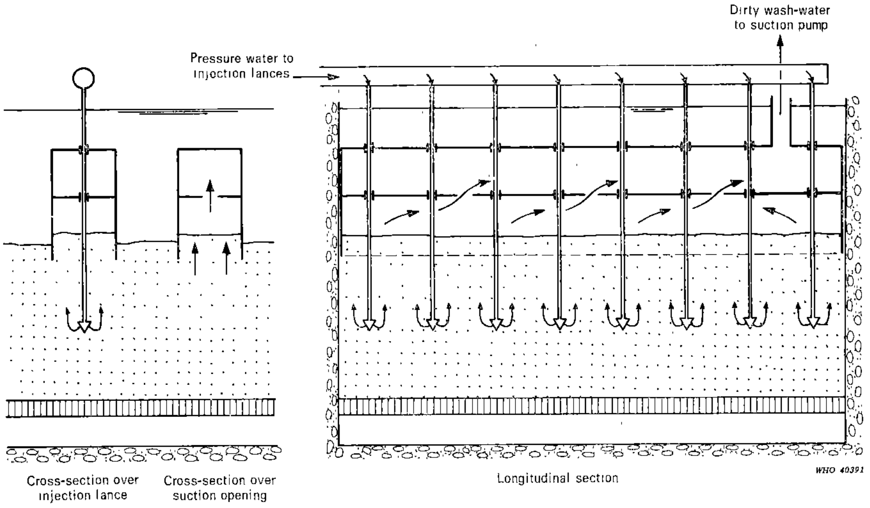
Mechanization has been carried a stage further at one of the water treatment plants at Amsterdam (Fig. 37). The filters, each 25 m × 40 m,

FIG. 37. SKIMMING MACHINE AT AMSTERDAM WATERWORKS



are constructed within a building on both sides of a central corridor. Each filter is spanned across its width by a travelling bridge from which the scraper mechanism is suspended. The filter sand is fine ($d_{10} = 0.12$ mm; $d_{60} = 0.2$ mm), resulting in a very shallow depth of penetration by impurities, hence a skim 1 cm or less in thickness is sufficient, and the sand surface is left completely flat after the passage of the scraper. The blade is 2.5 m wide, has a forward speed of 9 m/min and a backward speed of 18 m/min. A screw conveyor carries the sand to a bucket elevator, which transports the material to a bunker (also suspended from the bridge). The bunker has a capacity of 1 m^3, sufficient for the scrapings of two strips to a depth of 0.8 cm. When the bunker is full it is emptied into a steel tank in the corridor, which is transported by fork lift truck to a disposal site outside the building. Labour requirements are very small, and two men can clean a filter of 1000 m^2 in less than 1½ hours.

FIG. 38. MACHINE FOR THE HYDRAULIC CLEANING OF FILTER-BEDS (SIVADE SYSTEM)



The hydraulic cleaning of filter-beds is the result of a different approach to the same problem. Its first known application was in 1933, when Sivade installed a plant for the Compagnie Générale des Eaux, Paris.[1] Similar systems have been installed in London[2] (1958), Antwerp (1967), Istanbul, and various other cities.

Backwashing has always been the recognized method of cleaning rapid filters, but two particular problems made it difficult to adapt the same

---

[1] Laval, M. (1952) *J. Instn Wat. Engrs,* **6** ,155.

[2] Lewin, J. (1961) *J. Instn Wat. Engrs,* **15**, 15; Burman, N.P. & Lewin, J. (1961) *J. Instn Wat. Engrs,***15**, 355.

FIG. 39. HYDRAULIC SAND-WASHING MACHINE AT ANTWERP WATERWORKS, BELGIUM

Antwerp Waterworks/Frans Claes

The machine is shown with the box lowered beneath the surface of the supernatant water.

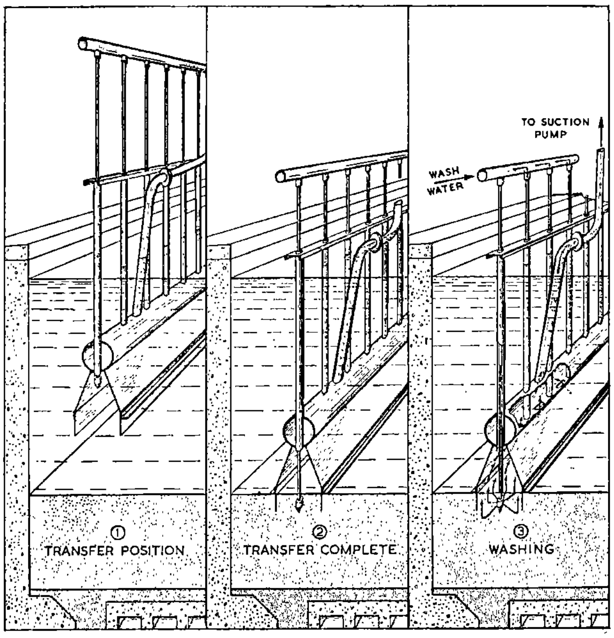
principle to the cleaning of slow filters—the large quantities of water required to clean the much greater filter areas involved and the necessity of avoiding excessive disturbance of the lower active layers of the bed.

The Sivade system surmounted these difficulties by subdividing the beds into comparatively small sections and washing each in turn and by introducing the wash water from above to a predetermined depth below the surface and allowing it to force its way upwards from this point.

The equipment (Fig. 38) consists of a long, narrow, two-storied, bottomless box 0.3 m wide and having a length equal to the width of the filter. The box is carried by a gantry spanning the bed (Fig. 39). The cleaning operation starts by lowering the box until its lower edge penetrates the bed surface by about 5 cm, thus isolating that strip of the filter-bed (Fig. 40). Injection lances 0.3 m apart are lowered through the box in guide tubes and penetrate the sand-bed to a level well below the normal depth of penetration of raw water impurities (i.e., 15–30 cm below the surface). The lances are connected at their upper ends, through flexible tubes, to a header pipe containing filtered water at a pressure of 10–30 m head. At their lower ends they are fitted with points having radially disposed orifices through which the wash water is transmitted into the bed. These orifices are small, so that the water emerges in high-pressure jets and, owing to the high resistance, is equally distributed along the length of the strip being treated.

When backwashing slow filters, a high degree of scouring is not required, and a small expansion of the bed medium suffices, hence relatively low washwater velocities are called for (of the order of 10–30 m/h, depending upon the grain size of the sand). The width even of the largest filters will rarely exceed 50 m, so that the area enclosed by the caisson box is relatively small (say 15 m^2 or less) and the quantity of washwater needed is correspondingly small.

FIG. 40. SAND WASHING *IN SITU:* MODE OF OPERATION



From: Burman, N.P. & Lewin, J. (1961) *J. Instn Wat. Engrs,* **15,** 355-367.

The water from the points of the lances rises to the surface, loosening and carrying the impurities from the upper sand layer, and passes through the lower chamber of the caisson boxes into the upper chamber, from which it is removed by a suction pump and delivered into a drain running alongside the filter. Careful adjustment of the box apertures through which the washings pass and careful balancing of the pressure and suction pumps ensure uniform washing conditions over the whole strip being treated. Backwashing lasts about one minute, after which the lances are withdrawn, the boxes are lifted, and the gantry is moved along the bed a distance equal to the width of the box, which is then relowered and the process repeated. Electrical controls enable the whole process to be carried out automatically. Occasionally heavy algal growths render the *schmutzdecke* too tough for complete removal by backwashing, in which case mechanical rakes are fastened to the side of the gantry to loosen up and remove the filamentous mat from each strip before backwashing.

Of all the cleaning methods available, hydraulic cleaning offers the greatest saving in time and labour. It is not even necessary to drain off the supernatant water, so the time normally taken in this process and in subsequent recharging is saved. One man can clean the largest filter in 9 hours. Since the impurities are washed clear of the sand within the bed itself virtually none of the medium is removed during the process. Hence there is no reduction in sand depth and a smaller initial bed thickness will suffice. An undisturbed depth of 40–60 cm (according to the grain size of the medium) should be allowed below the level of the lances. Thus, if the lances are set to penetrate 20 cm into the filter-bed, the total bed thickness will be only 60–80 cm.

However, apart from the high cost of the equipment involved, the system does have some disadvantages. It is not applicable to existing filters, because the walls have to be strong enough to accept the gantry rails and the filter-beds must be long and narrow if the apparatus is to be economically designed. A much more serious disadvantage is that the system suffers from operational defects that have not as yet been solved.

Firstly, a separation of grains occurs during backwashing, and the finer grains are brought to the surface, thus accelerating filter clogging and shortening the filter runs. Theoretically this disadvantage could be obviated by a better grading of the medium, but in the quantities used the cost would be prohibitive.

Secondly, since the filter is not emptied during cleaning, the environment in the supernatant water reservoir never becomes unfavourable to algal growth. Only some of the algae are removed, and the remainder are left in an active state of division to cause clogging and a further reduction in the length of filter runs.

Thirdly, some of the impurities are actually carried to a greater depth in the filter-bed by the wash water, owing to its unavoidably uneven distribution even when the points of application are as little as 0.3 m apart. The deeper the penetration of the lances the greater this effect is. This problem is the most serious drawback of the method and can result in deterioration of effluent quality. The only real cure would be a period of re-ripening, but this would nullify the main advantage—the speed with which a bed can be returned to service after hydraulic cleaning. Normally, therefore, chlorination of the effluent is relied on to counter any potential dangers from this source, and the "second line of defence" concept, which calls for the addition of chlorine as an *added* precaution, is therefore lost.

Another effect of the uneven distribution of the wash water may be seen by looking at the cleaned filter-bed surface. The position occupied by each lance is now marked by a small crater, within and below which organic impurities accumulate. The oxygen demand in the immediate vicinity of each crater often becomes so high that local anaerobic conditions result and become evident as black spots (caused by iron sulfides).

Choice of cleaning methods

The initial investment required for manual cleaning equipment is negligible, but as mechanization is introduced capital costs rise, becoming fairly high when it is carried out on the scale adopted at the London and Berlin waterworks and reaching a very high figure when travelling bridges are installed to support mechanical scrapers or hydraulic systems. Economic justification for the capital costs involved must obviously depend on the degree to which labour and other costs are reduced. Relevant factors include the reduction in time during which filters are out of service and the improvement in working conditions, which may ease the problem of staff recruitment.

Taking as an example a slow sand filter 2000 m^2 in area, the following table compares the length of time and numbers of men required to clean it and return it to service, using various methods described. The overnight lowering of the water level in preparation for the removal of the filter from service has not been taken into account. Savings due to mechanization will be somewhat less with smaller filters, rather more with filters of greater area.

COMPARISON OF CLEANING METHODS
Slow sand filter with an area of 2000 m^2

	Manual method	Tractor scrapers		Gantry scraper	Hydraulic method
		London	Berlin	Amsterdam	
Number of hours required for					
Draining	2	2	2	2	0
Cleaning	9	4	5	3	6
Refilling	5	5	5	5	0
Re-ripening	24	24	24	4	4
Total time out of service (hours)	40	35	36	14	10
Total number of men employed	8	4	2	2	1
Total number of man-hours involved	75	20	15	10	10

It will be noted that a saving of time on the re-ripening period is possible in methods using a travelling bridge (last two columns) because the sand is not contaminated by human contact when men do not actually enter the filter box. As the hydraulic method does not involve draining or refilling a further saving in time is possible.

Manual cleaning requires 75 man-hours of labour, while automatic methods, on average, require only 15. If the filter is cleaned five times a year, the saving in labour through the use of mechanical methods is 300 man-hours per annum. On a plant consisting of 10 similar filters (having a treatment capacity of about 50 million m^3/year, and assuming the cost of employing a labourer to be about US $ 2.33 per hour, the saving in money by mechanization would amount to about $ 7 000 per year, corresponding to an initial capital outlay of $ 70 000 (interest at 6%; amortization period 15 years). This would be ample for mechanization on the lines adopted in London and Berlin, but would be far from enough for the installation of systems using travelling bridges like those in Amsterdam and Paris.

These figures illustrate the way in which comparative calculations can be made, but they are not intended as an accurate picture of the current costs actually prevailing in the countries concerned. It should also be remembered that comparisons between manual and mechanized costs are valid only when the labourers are fully occupied on other useful work when not engaged on filter cleaning. For example the eight labourers required to clean the 10 filters described above would each be employed for some 40 hours per week—a total of about 16 000 man-hours per year for the whole team. Cleaning the 10 filters five times each would require less than 4 000 man-hours per year—about one quarter of their time. Unless there is other genuinely productive work on which these men can be employed during the intervals between cleanings, the true cost comparison (equal to $280 000 capital outlay) must be even more favourable to mechanization.

Management

The primary objectives of the manager of a water treatment plant will be to maintain a high quality standard of the delivered water at all times, to ensure that the supply is continuous for 24 hours a day and 365 days a year, and to achieve these aims in an economical way.

In general it may be said that some individual (whether or not he is described as a manager, whether he is in charge of one or many waterworks, and whether or not he has other functions unconnected with water supply) must be responsible for the supervision, safety, method of working, and economic running of every treatment plant, however small. Above all someone, somewhere, must think ahead—must recruit and retain an adequate labour force; must prepare for filter cleaning, resanding, and other activities in their due season; must foresee emergencies; must recommend improvements, extensions, or alterations as necessary and in good time to the appropriate financing authority; and must be sufficiently acquainted with the routine running of the plant to be able to ensure that it is being carried out efficiently.

It has been shown that a filter can exhibit individual characteristics that depend on a large number of external circumstances—variations in raw water quality, climatic changes, the biology of its algal population, the care taken during its initial construction, and so on. It is not a machine, the properties of which can be precisely calculated, but an ecosystem of living organisms the behaviour of which may be forecast only tentatively.

As a basis for making such forecasts, and hence for obtaining the best possible results under varying circumstances, the manager must first of all rely on the history of the individual filter concerned, and secondly on the experience gained with similar plants operating under comparable circumstances. Since it never can be said that the operational conditions of any two separated filters are and always have been precisely similar, the records of each assume an even greater importance as a guide to their future behaviour and capabilities and to the design criteria for new constructions, extensions, and improvements at the same (or comparable) treatment works.

The degree and form of records kept will obviously depend to a great extent on the literacy and ability of the operator. Imbeaux[1] set out what he considered to be essential data necessary to provide a complete history of each filter, and this (after nearly 40 years) still provides an excellent guide to water supply managers. The following are the basic records that he recommended to be kept for every filter:

(1) The date of each cleaning (commencement of process).

(2) The date and hour of return to full service (end of the re-ripening period).

(3) Raw and filtered water levels (measured each day at the same hour) and daily loss of head.

(4) The filtration rate, and hourly variations, if any.

(5) The quality of the raw water in physical terms (turbidity, colour) and bacteriological terms (total bacterial count, *E. coli*), determined by samples taken each day at the same hour.

(6) The same quality factors of the filtered water.

(7) Any incidents occurring, e.g., plankton development, rising *schmutzdecke*, and unusual weather conditions.

Many modern works are able to provide better data than these, particularly when the automatic recording of head loss, filtration rate, etc. provide a continuous picture. On the other hand, for many of the smaller or more remote treatment plants, daily bacteriological analyses will be impossible. However, even in these plants the manager should insist on records being kept to the extent of the local operator's ability, if only as a guide to the supervisor when making his periodic visits.

In a wisely managed water supply undertaking, critical periods will be anticipated. For instance, it should never be necessary for two filters to be taken out of service for cleaning simultaneously. Such an event would

---

[1] Imbeaux, E. (1935) *Qualités de l'eau et moyens de correction* [Quality of water and means of correction], Paris, Dunod, pp. 436-495.

put unnecessary strain on the remaining filters, and would fail to make the most economic use of the labour force, whose efficient employment depends on their activities being regularly spaced throughout the year. The situation can be prevented by cleaning some of the filter-beds before it is strictly necessary, and this is especially important immediately before difficult seasons—e.g., when heavy algal blooms are expected, as judged by the records of previous years.

Among the manager's responsibilities is the time distribution of plant operation. The greater efficiency of a filter when working 24 hours a day for 7 days a week has already been discussed, but there are still a number of smaller plants where one or two 8-hour shifts comprise the working day. Many factors enter the economic argument. A filter working round the clock need only be one third the area of one working 8 hours a day (and hence only one third of the cost). On the other hand the clear-water reservoir must be big enough to make up the difference between the lower treatment rate and the demand at peak periods of the day. The number of men required for three-shift working is more likely to depend on the pumping arrangements than on the filter, which can continue during the night hours without attention or with only occasional cursory inspection. Sometimes a filter is designed for future loading on a 24-hour basis but is operated for 8 hours during the initial period of low consumption. Whether it is better to do this or to run it continuously at one third of its designed filtration rate is a matter for local judgement. The decision might well depend on such minor considerations as reduced electricity tariffs for pumping at night or the need for employing for other purposes the staff who would normally keep an eye on the semi-automatic pumping plant.

Filters should be adequately protected against trespass and against intrusion by animals. A supernatant reservoir 1.5 m deep is sufficient to drown adventurous children. Not only should the full site be adequately fenced but the filters themselves should be suitably protected. If night working is expected, lighting and guard rails may be required to protect the staff.

In tropical areas the supernatant water reservoir may be found to contain fish that have either been brought in through the intake or carried in in egg form by birds. If such fish are top feeders like *Tilapia*, no harm ensues—they may in fact be beneficial in keeping down algae and the larvae of gnats or mosquitos.

However, carp and other bottom feeders must be removed as soon as their presence is noticed, either by netting or by temporarily lowering the supernatant water level, otherwise they will disturb the *schmutzdecke* and upper sand layer, through which raw water may then pass without adequate treatment.