6. Slow sand filtration and artificial recharge

As the function of a safe water supply in the prevention of epidemic diseases such as typhoid and cholera came to be generally accepted during the last century, the demand for such supplies grew rapidly, and cities in all parts of the world started to install piped systems. At that time, having no knowledge of the role played by pathogenic bacteria and consequently no conception of the potentialities of chemical disinfection, water suppliers and consumers alike judged water by its physical attributes—absence of turbidity, taste, colour, and odour. It was found that two types of source could provide water that was of good quality according to these criteria; by a fortunate chance it was later shown that supplies obtained from these sources were also those most likely to be free of dangerous bacteria. They consisted of:

(1) groundwater abstractions, and

(2) water drawn from clear springs and lakes and subsequently treated by slow sand filtration.

It has been shown in earlier chapters that slow sand filtration embodies many of the natural processes of purification, and this is most evident in the downward percolation of rainwater through porous soil until it reaches and recharges the body of groundwater stored in an aquifer. To what extent this process was understood it is difficult to say, but for many centuries groundwater has been accepted as the purest source for domestic purposes, and it was undoubtedly for this reason that the first choice of early water undertakings was almost always groundwater, as soon as technology had provided a means of abstracting it economically in the quantities required.

With the growth of industry, population, and individual demand, water consumption in the cities rose rapidly and continuously, and by the beginning of the present century many of the groundwater sources were proving inadequate to meet the demand. The effect of industrial pollution on surface waters was already beginning to be felt in the neighbourhood of the cities looking for extra water, and as yet no methods of removing these pollutants had been devised. Experience with groundwater had been excellent, and so the obvious direction in which to attempt to improve supplies lay in augmenting the yield of the proven aquifers. This led, in 1897, to the first application of artificial recharge by Richert for the water supply of the city of Göteborg in Sweden. He was able to augment the amount of water entering the aquifer, giving a corresponding increase in the quantity abstracted with no deterioration in quality.

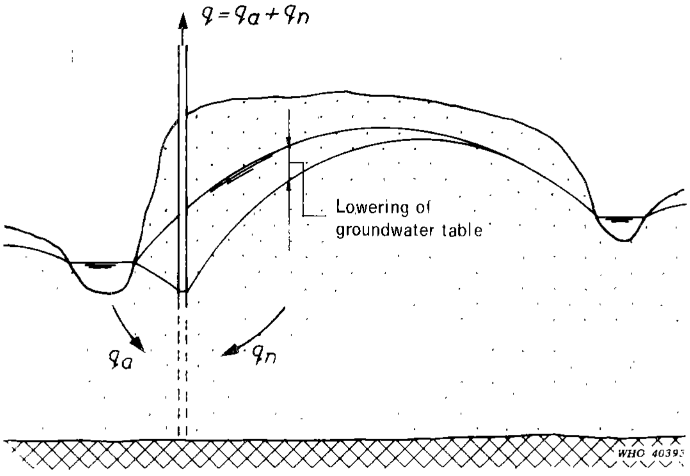
Methods of artificial replenishment

Since that time many successful projects for the augmentation of underground supplies have been carried out. In general these have fallen into two categories:[1]

(1) Artificial recharge, by spreading surface water over pervious soils in basins, ponds, or ditches, by flooding less pervious areas, or by injecting water directly into the aquifer through wells, shafts, or pits.

(2) Induced recharge, by abstracting groundwater from sites close to surface water bodies having pervious banks or beds, thus lowering the subsurface water table in the vicinity and stimulating an increased downward flow from the surface water into the ground.

FIG. 41. INDUCED RECHARGE WITH A LINE OF WELLS PARALLEL TO A STREAM



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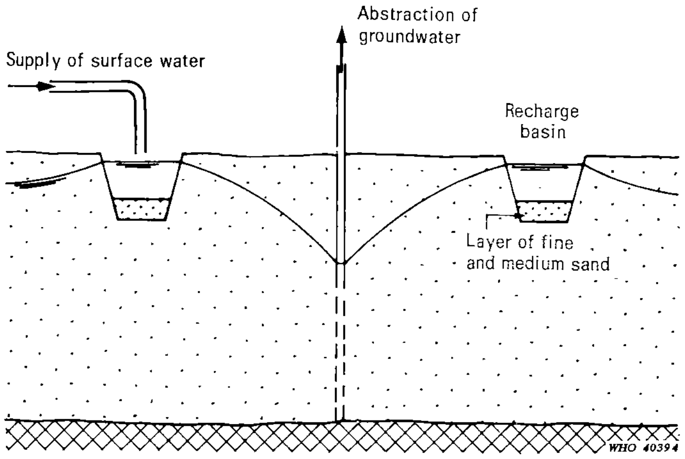
[1] Huisman, L. (1965) *Artificial replenishment.* In: *International Water Supply Association, Sixth Congress Stockholm, 1964*, London, International Water Supply Association, vol. 1, p. J1.

Induced recharge often occurs unintentionally wherever a stream crosses a catchment in which the groundwater table has been lowered by subsurface abstraction. For planned induced recharge, the collectors are deliberately set near to and parallel to the course of the stream (Fig. 41). To obtain the best results the distance between the watercourse and the collectors must be chosen with care. They must be sufficiently close together to ensure that groundwater tables are not lowered over a wide area to the prejudice of agricultural and other interests. At the same time the inflow and abstraction must be far enough apart to ensure that the recharging water travels a sufficient distance and remains within the ground a sufficient length of time for natural purification to take place. Spacing too closely could lead to short circuiting of this natural process.[1]

In artificial recharge, water from another source, often from a river or other body a considerable distance away, is conveyed to the point at which aquifer replenishment is required, where it is allowed to percolate downwards through the ground or is directly injected if the soil overlying the aquifer is impervious. If the pervious material of the aquifer continues upwards to the surface, the recharge water can be fed into spreading basins, which may consist of ditches parallel to the collectors when the transmissibility of the water-bearing strata is low (Fig. 42 and 43), or of ponds at greater distances from the collectors when the transmissibility is high (Fig. 44).

FIG. 42. ARTIFICIAL RECHARGE



Where the aquifers are "confined", i.e., where there is an impervious

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[1] Huisman, L. (1967) *Artificial recharge for public water supplies in urbanized regions*. In: *International Association of Scientific Hydrology, Symposium, Haifa, 1967*, Gentbrugge, International Association of Scientific Hydrology (IASH Publication No. 72), p. 200.

FIG. 43. ARTIFICIAL RECHARGE WITH DITCHES

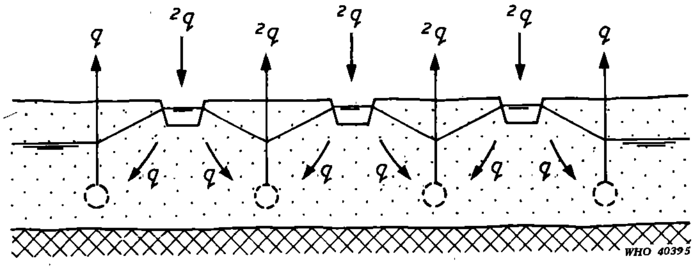
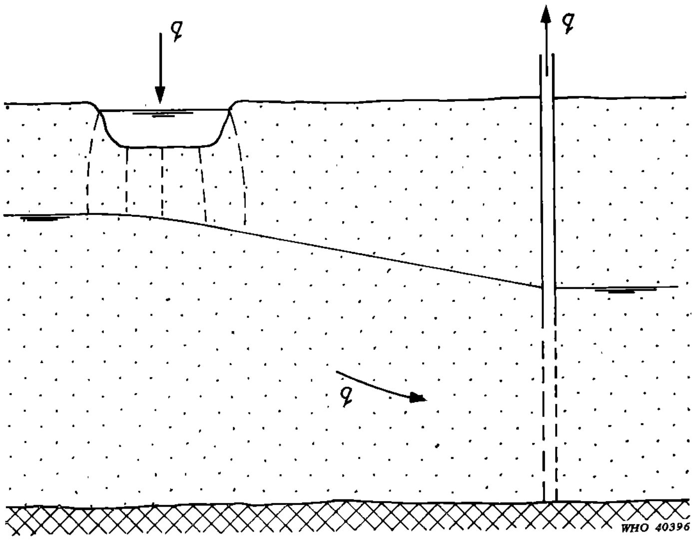


FIG. 44. ARTIFICIAL RECHARGE WITH PONDS



layer above the water-containing strata, the same method may be used only when the impervious material is sufficiently thin to permit full penetration by the spreading basins (Fig. 45), otherwise a well, shaft, or pit must be used to reach the aquifer (Fig. 46). In either case adequate separation of inflow and outflow must be maintained or the quality of the water will suffer.[1] Provided that the recharge system is carefully designed and that the quantities of replenishment water introduced are within the transmission capacity of the subsoil, the groundwater table outside the immediate area of withdrawal will be unaffected.

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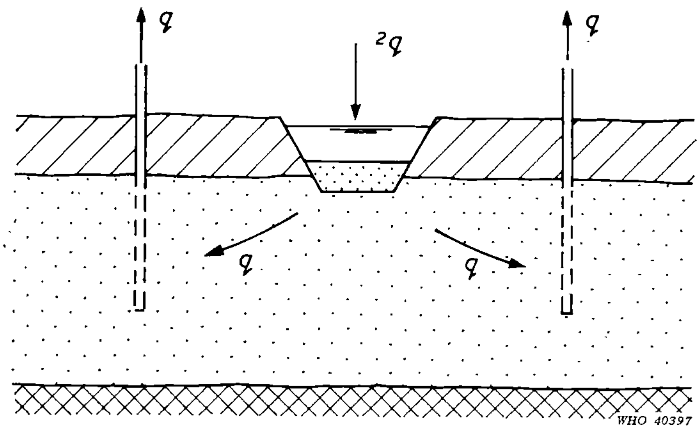
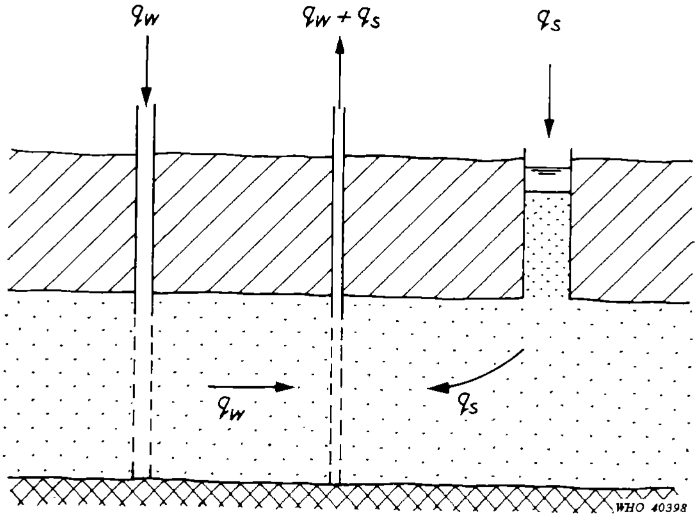
[1] Huisman, L. & van Haaren, F.W.J. (1967) *Treatment of water before infiltration and modification of its quality during its passage underground.* In: *International Water Supply Association, Seventh Congress, Barcelona, 1966,* London, International Water Supply Association, vol. I, p. G1.

FIG. 45. ARTIFICIAL RECHARGE WITH SPREADING BASINS



Induced recharge has always suffered from a declining capacity as the surface of the pervious ground in contact with the water source (e.g., the bed and banks of a stream or lake) becomes choked with suspended matter. Some natural scouring takes place when a stream is in spate, but this is often prevented by the introduction of measures of flow control (such as impounding dams or weirs) designed to improve the regularity of the replenishment. Now that persistent and nondegradable pollutants of

FIG. 46. ARTIFICIAL RECHARGE WITH WELLS AND SHAFTS

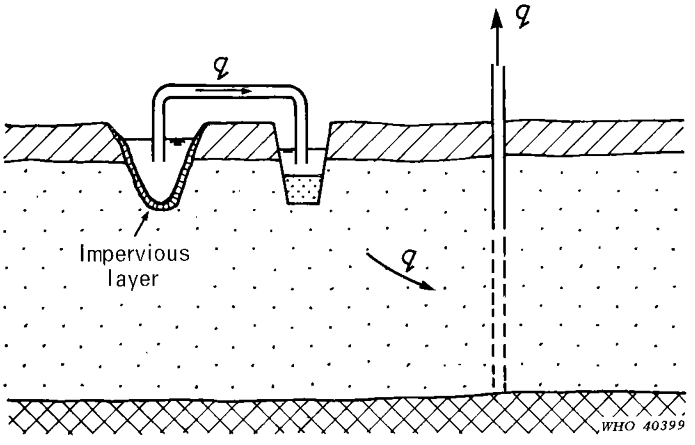


domestic and industrial origin are present in most rivers in the vicinity of cities (where induced recharge is most likely to be called for), this method of replenishment is becoming less widely practised because it is impossible to control the quality of the inflow to the aquifer and there is thus a possibility that the groundwater reserves will become polluted.

The water used for artificial recharge, on the other hand, can be treated before being fed into the aquifer. The treatment may take the form of aeration and the removal of oxygen-consuming organic compounds by conventional filtration (with or without the application of chemicals), so that fully aerobic conditions may be maintained throughout the recharge process, including the period during which the water is within the aquifer. Should the river-water being used as a source for replenishment be found to contain poisonous substances that cannot be removed by the pretreatment processes, it is possible to discontinue artificial recharge until the position is rectified, while continuing to use the groundwater present in the aquifer as a source of supply. Induced recharge, on the other hand, cannot be stopped as long as abstraction is taking place, and the only way to prevent pollutants from being drawn into the aquifer is to stop withdrawal altogether—a remedy often impossible to adopt without seriously interrupting the supply to the public.

Hence induced recharge is nowadays little practised in densely populated and industrial areas and is restricted to the vicinity of streams of consistently good quality that normally exist only in remote areas. Where induced recharge has to be abandoned because of deteriorating quality of the source water, it is sometimes possible to convert the process to artificial recharge through controlled injection points, as illustrated in Fig. 47.

FIG. 47. ARTIFICIAL RECHARGE REPLACING INDUCED RECHARGE



An additional factor to be considered is that the naturally occurring and the artificially introduced waters within an aquifer must be chemically compatible. The rather complex investigations involved in ensuring this condition are outside the scope of the present publication, but it should be noted that they may call for pretreatment of the recharge water, especially when it has been brought from a different source from that naturally supplying the aquifer.

Slow sand filtration in artificial recharge

The purpose of artificial recharge is to increase not only the volume of the replenishment water but its rate of transfer from surface to aquifer. In the natural process, the very slowness and limited quantities involved in this transfer mechanism serve as a protection against the development of clogging and other undesirable conditions in the water-bearing strata. The artificial intensification of this mechanism thus calls for a parallel supplement to the natural purification process. When the recharge water is to be injected into a confined aquifer through wells or shafts it must be given full pretreatment by conventional methods to achieve a quality equal to that expected in the abstracted water. When spreading basins or similar devices are used as replenishment points it is possible to combine treatment and recharge by incorporating slow sand filters into the basins themselves.

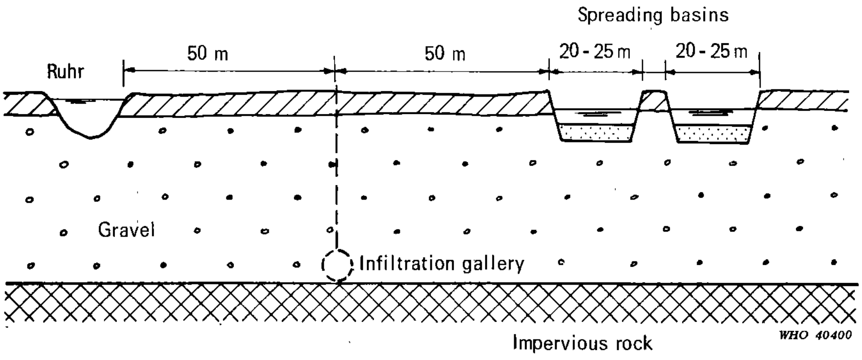
This is accomplished by covering the bottoms of the basins with a layer of sand 0.5–1.0 m thick, having a grain size distribution equal to, or slightly coarser than, the slow sand filters described in earlier chapters. The sand must be sufficiently coarse to prevent its grains from being carried into the material of the aquifer with which it is in contact and fine enough to prevent deep penetration of the impurities contained in the raw water. If the grading is correct the sand-bed will function in precisely the same way as the bed of a conventional slow sand filter, the impurities will collect and undergo treatment on and immediately below the bed surface, from which they can be removed in a similar way at the end of the filter run. As the filtration rates are normally considerably lower (0.01–0.1 m/h) than those in conventional filters, the treatment efficiency is high and filter runs are usually long. The effluent from the bed percolates downwards into the aquifer instead of into a filter drainage system, and since it then has to travel over a considerable horizontal distance (usually more than 50 m) its detention time may be measured in days, weeks, or even months instead of in hours.

Precautions must be taken against subsequent pollution while the treated water is flowing through the ground strata. With confined aquifers this presents little difficulty, since the overlying impervious strata will prevent downward percolation of contaminating substances, but in the case of unconfined aquifers a strict control of activities on the surface between the inflow and abstraction points may be necessary.

Artificial recharge in the Ruhr

A practical example of artificial recharge of a confined aquifer, using slow sand filters adapted as spreading basins, is provided in the Ruhr district of the Federal Republic of Germany (Fig. 48). At first a system of induced recharge was installed, based upon a series of galleries and lines of vertical wells constructed parallel to, and some 50 m away from, the River Ruhr, but owing to the construction of impounding reservoirs in its tributaries, the bed became progessively more clogged until infiltration became negligible.

FIG. 48. ARTIFICIAL RECHARGE IN THE RUHR DISTRICT



It was therefore decided to convert the system to one of artificial recharge, and two spreading basins with sand-bed bottoms were constructed at a distance of 50 m on the other side of the gallery. They were fed by river water and delivered their effluent into the gravel layer that lies below the confining impervious topsoil. At the beginning of the filtration run, the water level in the basins is some distance below the level of the river (which is itself kept reasonably constant by weirs). As the resistance in the beds builds up through clogging, the infiltration rate is kept at its designed value by increasing the depth of supernatant water in the basins until no more gravity flow from river to basins is possible. The influent pipe is then closed and the water level drops to below the surface of the sand-bed, which is cleaned in the same way as is a conventional slow sand filter. Reference has been made in the preceding chapter to the mechanical equipment used in this cleaning process. One of the twin basins is always kept operating while the other is being cleaned, so that recharge is continuous.

A few years ago, despite efforts to maintain the quality of water in the river, some contamination occurred and the quality deteriorated. In particular there was an increase in oxygen-consuming organic compounds,

FIG. 49. ARTIFICIAL RECHARGE WITH PREFILTRATION

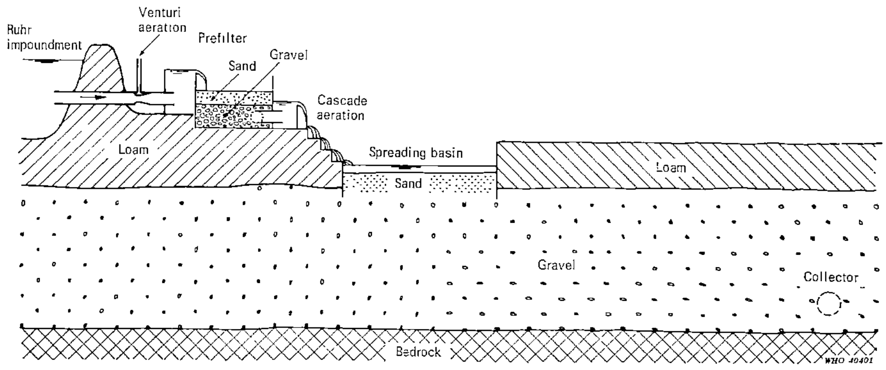
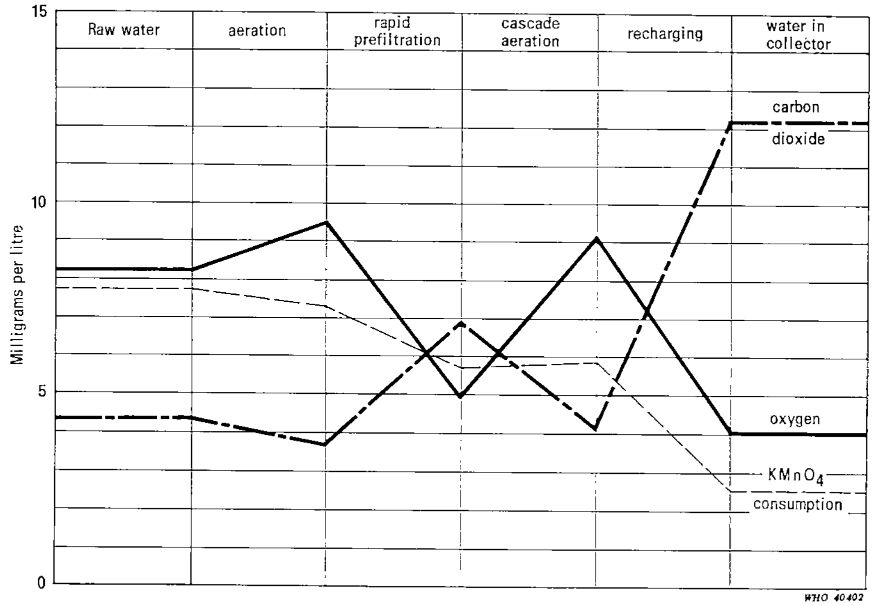


FIG. 50. CHANGES IN THE COMPOSITION OF THE WATER DURING EACH STAGE OF THE TREATMENT ILLUSTRATED IN FIG. 49



which threatened to lower the oxygen content of the effluent from the spreading basins and cause anaerobic conditions to develop in the aquifer, so dissolving iron and manganese from the subsoil. The effect of this sequence would have been to necessitate treatment of the abstracted water by aeration and refiltration, thus defeating the whole purpose of slow sand filtration in the artificial recharge process. Accordingly the simpler expedient of pretreatment (Fig. 49) was adopted. In this system the oxygen content of the raw water is increased by aeration and its oxygen demand decreased by filtration, which removes part of the oxygen-consuming impurities. The improvement in the quality of the water at various stages may be seen in Fig. 50.

Reduction of salt content

One of the problems associated with the pollution of streams and rivers with domestic or industrial wastes is the continuous rise in the content of inorganic salts. These salts are stable and unaffected by conventional water treatment processes, including filtration. Common salt (NaCl) is normally the most ubiquitous and, while in reasonable concentrations it cannot be rated as harmful to the consumer, it can nevertheless render a water supply unpalatable and unsuitable for many industrial purposes. It is, moreover, an indicator of the possible presence of other less innocuous inorganic compounds that may have originated from the same source of pollution.

In the years 1960–64, the River Rhine, which receives direct and indirect discharges from the numerous industrial plants along its banks, had a salt load averaging no less than 270 kg of chloride per second in an average river flow of 2 200 m^3/s—i.e., an average chloride (Cl^-) content of 123 mg/l. In the course of the year the river flow varies from a maximum in winter and spring to a minimum in summer and autumn, so that while the amount of chloride remains reasonably constant the concentration fluctuates considerably. Fig. 51 illustrates the variation in chloride concentration during normal years and during a particularly dry summer, such as may be expected to occur once in 10 years.[1] It will be seen that maximum concentrations of 230 and 320 mg/l occurred in the normal and the dry years respectively, and that the commonly accepted limit of 150 mg/l was exceeded during 4½ months of a normal year and 9½ months of a dry year. The level at which undesirable taste and corrosion effects manifest themselves (200 mg/l) was exceeded during 2 and 5 months in the normal and the dry year respectively. Today the chloride flow is in the

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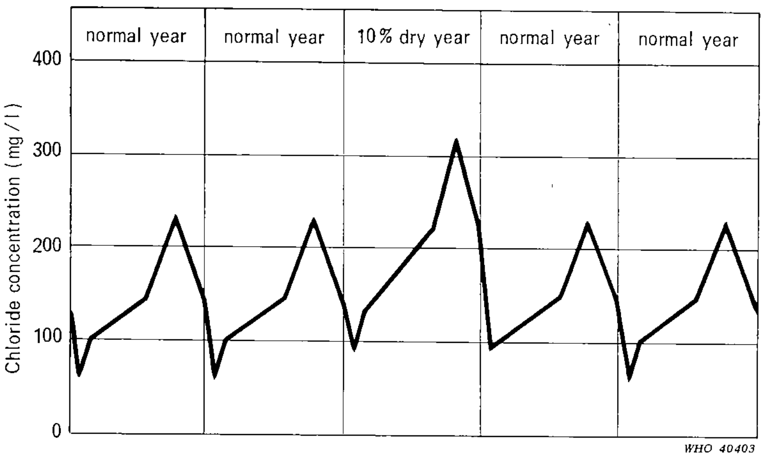
[1] Martijn, Th.G. (1967) *Water*, **51**, 76.

FIG. 51. VARIATION IN THE CHLORIDE CONTENT OF THE RIVER RHINE IN NORMAL AND DRY YEARS



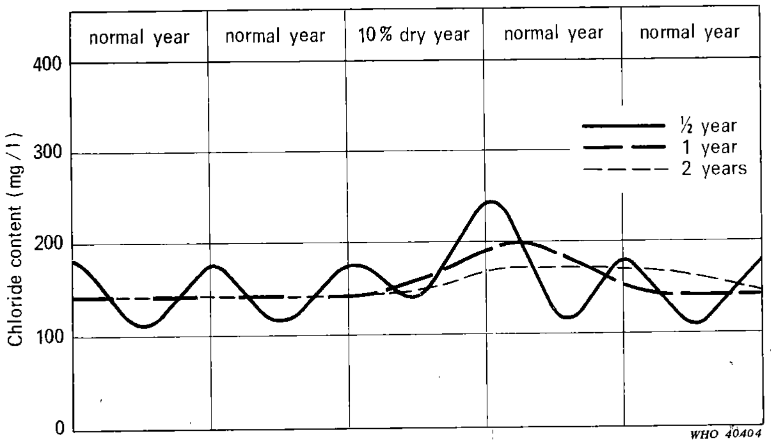
neighbourhood of 360 kg/s, and the other figures exhibit a corresponding deterioration.

In the Netherlands, water from the River Rhine has to be used for public supplies, but when the chloride content is above about 200 mg/l it is unsuitable for this purpose. To reduce the salt concentration by desalination methods would be prohibitive in cost, even if electrodialysis were used to make a limited reduction only. A more economical solution is the mixing of water extracted at different times of the year, thus smoothing out extreme variations in quality, but in view of the great quantities extracted annually to supply this populous region the only way in which this can be done is to perform the mixing and storage in the immense reserves that lie underground.

The method of accomplishing this is artificial recharge, with varying distances between the influent and abstraction points, so spaced that the length of time within the aquifer (which varies according to the distance travelled by the water below ground) can be planned in advance. Fig. 52 shows the resultant fluctuation in chloride content in the abstracted water over a succession of normal years, interrupted by a dry year. Comparison with Fig. 51 will show how the extremes of quality variation have been smoothed out, making the resulting water acceptable for use in public supplies. When the difference between maximum and minimum detention times has values of $\frac{1}{2}$, 1, and 2 years, the highest chloride contents become 248 mg/l, 200 mg/l, and 173 mg/l respectively—a very considerable improvement on the quality of the river-water during the same periods.

Increasing the detention time from a few days (as in the Ruhr recharge illustrated in Fig. 48) to months or years is not necessarily expensive when abstraction points and pumping equipment already exist. The natural recharge of the groundwater reserves is the amount of rainfall percolating to the aquifer (i.e., the total precipitation less evaporation losses), which in the Netherlands normally amounts to about 0.3 m/year, so that the normal yield of the underground catchment is limited to about 0.3 million cubic metres per year for each square kilometre of surface area.

FIG. 52. VARIATION IN THE CHLORIDE CONTENT OF WATER FROM THE RIVER RHINE AFTER RECHARGE, WITH PLANNED VARIATION OF UNDERGROUND DETENTION TIME



The curves show the effect of differences between maximum and minimum detention times of ½ year, 1 year, and 2 years.

With, for example, an aquifer thickness of 50 m and a porosity of 30%, the amount of groundwater stored in the pores of the water-bearing strata is 15 million m^3 per square kilometre of surface area. Thus the use of artificial recharge with an average retention period of 6 months makes available a capacity of 30 million m^3/year/km^2—no less than 100 times the yield originating from rainfall over the same area

For densely populated, heavily industrialized areas where surface waters are polluted and alternative sources nonexistent or prohibitive in cost, artificial recharge on the lines described may prove the best solution to the problem of maintaining an ample water supply of acceptable quality, provided that the geology of the area is favourable to underground storage. The principle is also capable of extension to other types of water-short areas where appropriate aquifer conditions exist.