THE ROLE OF GROUNDWATER RECHARGE IN WASTEWATER REUSE:

THE DAN REGION PROJECT - ISRAEL

by

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Abstract

Groundwater recharge with tertiary effluent via spreading basins is practiced in the Dan Region project for indirect reuse of municipal wastewater from the Tel Aviv Metropolitan Area. A comprehensive monitoring program accompanies the full-scale recharge operation. The chloride ion is a reliable tracer of the recharged effluent in the aquifer. The effluent quality is substantially improved by passage through both the unsaturated zone and the calcareous sandstone aquifer, particularly with respect to: organic matter, phosphorus, chemical stability, sodium adsorption ratio and several trace elements. In addition to effluent treatment, groundwater recharge provides seasonal and multi-annual storage, has economic as well as psychologic merits, and enhances the reliability of the reclamation system.

INTRODUCTORY REMARKS TO PAPER PRESENTED AT SYMPOSIUM ON "WASTEWATER RESUSE FOR GROUNDWATER RECHARGE", SEPTEMBER 6-7, 1979, Pomona, California

by

Emanuel Idelovitch

Mr. Chairman, Ladies and Gentlemen,

I am very glad to be here and very grateful to the organizers of this Symposium for the opportunity to talk about our groundwater recharge program with municipal effluent in Israel.

After listening to the talks given yesterday and after the conversations I had during coffee and lunch breaks with Dr. Bouwer, Dr. Asano and others, I realized more than ever before that the concept of groundwater recharge that we have adopted in the Dan Region Project in Israel is quite different from your concepts here in California. It seems that the only recharge operation that, in many respects, is similar to our Dan Region Project is Arizona's Flushing Meadows.

Indeed, there appear to be two different concepts with respect to the incorporation of groundwater recharge into wastewater reuse programs; they can be briefly described as follows:

1. <u>Wastewater Reuse for Groundwater Recharge</u> (the prevailing concept in California)

Recharge to a groundwater aquifer is the ultimate use of the reclaimed effluent. All the treatment is carried out prior to recharge and it is usually a very high degree of treatment - practically to drinking water quality. The recharge system and the location of the production wells are such that the recharged effluent cannot be segregated from the rest of the aquifer. The effluent "loses its identity" and its movement in the aquifer can hardly be traced. The production wells located in the vicinity of the recharge zone pump an admixture of small amounts of recharged effluent and large amounts of native groundwater, which is supplied to unrestricted uses including drinking. The long-term health hazards possibly involved in drinking such water are unknown but will always be mentioned as a problem, no matter what the final product quality is.

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The Dan Region Sewage Reclamation Project provides for advanced treatment of municipal wastewater from the Tel Aviv Metropolitan Area and indirect reuse of the effluent by groundwater recharge. Stage One of the Project (Figure 1) which has been in operation since 1975, serves at present the southern suburbs of the city of Tel Aviv-Jaffa and the neighbouring municipalities of Holon, Bat-Yam and Rishon-Le-Zion, with a total connected population estimated at about 400,000 (in August 1979).

The wastewater entering the plant undergoes biological treatment in two parallel series of recirculated oxidation ponds. The secondary effluent from the oxidation ponds undergoes tertiary chemical treatment in two steps: high lime - magnesium treatment in a reactor-clarifier and detention of the high pH effluent in polishing ponds, mainly for free ammonia stripping and natural recarbonation (Figure 2).

The tertiary effluent has been recharged to the regional groundwater aquifer since January 1977 by intermittent spreading over sand basins; the recharge site is located some 1.5 km east of the treatment plant site (Figure 1). The recharged water, after mixing with natural groundwater and prolonged detention in the aquifer, will be pumped by means of recovery wells, chlorinated and conveyed to the national water supply network (Figure 3).

In the final stage of the Project, when the recovery wells will pump mostly recharged effluent, the reclaimed water will be supplied to non-potable uses, especially unrestricted irrigation of agricultural crops, by means of a dual system conveying separately potable and non-potable water. At present most of the existing recovery wells pump native groundwater to the potable supply network. In the near future, the recovery wells will pump an admixture of recharged water and native groundwater. Activated carbon treatment of this water for removal of residual dissolved organics is now being investigated at pilot scale to provide an interim solution that will enable the wells to continue pumping to the potable network until the dual supply system is in operation.[1]

Groundwater recharge with surface water, by basin spreading and by well injection, mainly for storage purposes, is a routine practice in Israel as part of the national water supply system management. "Incidental" groundwater recharge with sewage effluents has occurred for many years by percolation from septic tanks, oxidation ponds, disposal lagoons and wastewater-irrigated fields. Nevertheless, the "intentional" recharge of municipal effluent to a potable groundwater aquifer, which is a relatively new concept,

2. Groundwater Recharge for Wastewater Reuse (the concept of the Dan Region Project in Israel)

"Controlled" passage of the effluent through the soil-aquifer system is incorporated into the wastewater reuse scheme for its numerous benefits.

By recharging the effluent to the groundwater aquifer in an area free of public supply wells and by surrounding the recharge site with adequately-spaced recovery wells, a sub-basin is created which can be segregated from the rest of the aquifer. Only partial treatment is carried out prior to recharge (pre-treatment) since the soil-aquifer system provides for additional treatment by a rather unique combination of physical, chemical and biological processes.

The bulk of the recharged effluent is extracted by the recovery wells and supplied to uses compatible with its quality - generally non-potable uses, primarily unrestricted irrigation of agricultural crops.

If the quality of the reclaimed water is not adequate for a specific purpose, additional treatment (post-treatment) can be provided at the recovery wells.

Accurate monitoring of the effluent in the aquifer is a prerequisite for the proper operation of such a recharge system; thus, reliable tracers of the effluent in the groundwater are needed. The effluent does not lose its identify; it rather gets a new, improved one.

Health hazards associated with reclaimed water are less of a problem, since the water is not used for drinking unless it is found safe and it is recognized as such by the health authorities.

was adopted in the Dan Region Project only after much controversy and a one-year delay in the granting of the first annual recharge permit (for 1977).[2]

The data accumulated within the framework of the comprehensive monitoring program carried out in conjunction with the recharge operation have made an important contribution to the better understanding, both by professionals and by laymen, of the effect of effluent recharge on the potable groundwater aquifer. Consequently, the recharge permit for 1978 was granted with much less difficulty, and that for 1979 without difficulty at all.

Description of Recharge Site

The recharge site is located in an area of rolling sand dunes, about 4 km east of the Mediterranean Sea, lying above the central part of the coastal aquifer (pleistocene). This aquifer is composed mainly of calcareous sandstone ("kurkar") and is divided into sub-aquifers by silt and clay layers.

The climate of the area is typically Mediterranean. Summers are warm (average temperature range usually 20-30°C), and dry (daily evaporation 5-6 mm); winters are mild (average temperature range usually 10-20°C) and with rainy spells (daily evaporation 2-3 mm). The long term average annual precipitation is 535 mm.

Recharge Facilities. The recharge facilities consist of four basins, referred to as 101, 102, 103 and 104 (Figure 1), with a total area of about 29 ha (73 acres). The upper soil layer of the recharge basins consists of uniform fine sand (less than 0.3 mm). Basin 102, which has been used as a test basin, is divided into five sub-basins to enable higher hydraulic loading per unit area and to permit greater operational flexibility, which is needed for research purposes. All the sub-basins are provided with staff gauges for measuring water levels. Installations for the sampling of percolating effluent, which were specially designed for this purpose, were constructed in two sub-basins of basin 102. Basin 101 is also being divided into sub-basins (the construction is expected to be completed by the end of 1979).

Recovery Facilities. A ring of recovery wells, spaced 300-400 m from one another, has been planned to surround the recharge area, in order to ensure pumping of the recharged water to uses compatible with its quality and to minimize the influence of the recharge operation on private wells (Figure 3). Of this ring, seven wells located west of the recharge area have been drilled, equipped and operated, and seven other wells located south and southeast of the recharge area have been drilled and will be equipped during 1979/80. The western wells are located at distances varying between 400 and 1,200 m from the recharge site. The southern wells are located 900 to 1,700 m from the recharge site (Figure 1).

Monitoring Program. A monitoring network of 15 observation wells has been established in the vicinity of the recharge basins

(Figure 1). Observation well samples are taken after at least a half-hour of pumping with compressed air, which is sufficient to exchange the water in the well several times.

Three types of groundwater quality analyses were established "indicative", "basic", and "comprehensive". The functions of these analyses are described below.

"Indicative"- to ascertain whether the recharged effluent has reached a certain well. This analysis includes: chlorides, electrical conductivity, $KMnO_4$ consumption and detergents.

"Basic" - to examine groundwater quality (after effluent has reached the well) with respect to basic wastewater parameters, in order to determine the effect of the recharged effluent on groundwater quality and the purification capacity of the soil-aquifer system.

"Comprehensive" - to thoroughly determine groundwater quality with respect to water quality standards for irrigation and domestic uses.

The frequency of the "indicative" analysis is one to four months for the observation wells, depending on their distance from the recharge basin, and six months for the production wells. The "basic" analysis is carried out every month in observation wells pumping effluent. The frequency of the "comprehensive" analysis is six months for selected observation wells and twelve months for selected production wells.

Recharge Operation

The recharged operation carried out in the Dan Region Project in the period 1977-1979 is briefly described below with respect to volumes recharged, recharge regime, infiltration rates and groundwater hydrology.[2,3]

Volumes of Effluent Recharged. More than 20 million cu.m of effluent were recharged to the groundwater aquifer during the initial 2½ years of operation - between January 1977 and June 1979. The distribution of the recharge by basins was as follows:

Basin 101 - 8.6 million cu.m
Basin 102 - 6.7 million cu.m
Basin 103 - 4.2 million cu.m
Basin 104 - 1.2 million cu.m

Total 20.7 million cu.m

Recharge Regime. The recharge basins were flooded intermittently so as to maintain high infiltration rates and to enhance effluent purification during percolation. Basin 102, which has been used for research purposes, was operated according to a recharge cycle of one day flooding and two to three days drying. The recharge cycle in the other basins generally varied from one or two days flooding - one day drying, to three days flooding - four days drying, depending on the hydraulic capacity of the various basins and the number of basins in operation.

Infiltration Rates. Infiltration rates, which were monitored in basin 102, were influenced by effluent quality, climatic conditions and the time elapsed since basin bottom cleaning. An average long term infiltration rate of 2-2.5 m/day was maintained under a recharge regime of one day flooding and two to three days drying.[3] Assuming that about one month per year is required for thorough drying and cleaning, the annual hydraulic load per square meter of recharge basin is approximately 200-250 cu.m.

Groundwater Hydrology. A radial groundwater mound has formed beneath the recharge area. After 2½ years of recharge, groundwater levels have risen about 6 m below the center of the recharge area and 2.5 m about 600 m distant.[3] The thickness of the unsaturated zone below recharge basin 102 was about 25 m at the end of June 1979.

Quality of Recharge Effluent

The recharge effluent is obtained by chemical treatment of the secondary effluent from the oxidation ponds, which consists of the high lime - magnesium process, and detention of the lime effluent in polishing ponds mainly for free ammonia stripping and natural recarbonation. Consequently, the recharge effluent generally had a low alkalinity and a relatively low content of suspended solids, organic matter, nitrogen and phosphorus.

However, it had a relatively high pH and Langelier Saturation Index, because the natural recarbonation which takes place in the polishing ponds is not complete and artificial recarbonation (by addition of CO_2) is not carried out. In order to improve the chemical stability of the effluent prior to recharge, the tertiary effluent has been mixed since May 1978 with about 10-20% water from a recovery well (No. 7) which contains a large proportion of effluent seeped from the treatment ponds. In the near future, two additional recovery wells (Nos. 6 and 8), which have also been affected by effluent seeped from the treatment ponds and cannot pump to the potable supply network, will be operated in the same mode.

The effluent quality is usually higher in summer than in winter, because of the greater efficiency of the lime clarification process as well as of the ammonia stripping process.[4,5]

The quality of the recharge effluent with respect to basic wastewater parameters is shown in Table 1 and in Figure 4. Ammonia and total nitrogen are lower in summer than in winter, because of the better ammonia removal at higher temperature. Suspended solids and phosphorus are somewhat higher in winter because of the poorer performance of the clarification process which is more sensitive to deviations of pH and magnesium dosage from optimum values [6]. The high dependence of the clarification process on external magnesium addition is particularly evident from the data obtained prior to the beginning of $MgCl_2$ addition to the lime reactor-clarifier.

Despite the high quality of the recharge effluent, its salinity - expressed as total dissolved solids or electrical conductivity - is much higher than that of the background water in the aquifer underlying the recharge area. With respect to major ions, a comparison of the two types of water represented by the Schoeller diagram (Figure 5), shows that chloride and sodium concentrations are much higher in the recharge water (6-7 me/l) than in the groundwater (0.5 me/l), whereas calcium, magnesium and bicarbonate concentrations are approximately the same (sometimes even slightly lower in the recharge effluent), because of the softening effect of the high lime process.

Spread of Recharged Effluent in the Aquifer

The chloride ion serves as a reliable tracer of the recharged effluent in the aquifer, for two main reasons:

- it is virtually unaffected by any soil chemical, physical or biological process;
- there is a substantial difference (one order of magnitude) between chloride concentrations in the recharge effluent (180-240 mg/l) and in the native groundwater (20-25 mg/l).

The pattern of chloride concentration rise, which reflects the effluent percentage in the well water, is shown in Figure 6 for two observation wells: well 61, located 60 m from basin 102 (where recharge started in June 1977) and well 54, located 300 m from basin 101 (where recharge started in January 1977).

The time elapsed between the initial arrival of effluent and the complete displacement of the native groundwater by recharged effluent is defined as the "transition period". The effluent percentage in a well at a given time and the length of the transition period are primarily a function of the distance of the well from the nearest recharge basin. For observation wells located close to a recharge basin, such as 61, the transition period was short - about 3 months; for observation wells located further from the recharge basin, such as 54, the transition period was much longer - more than 2 years (and is still incomplete). As the recovery wells are located at greater distances from the recharge basins, their transition periods will be even longer (several years).

After about 2½ years of recharge (January 1977 - June 1979), the recharged effluent had spread some 600 m from the center of the recharge area but it had not yet reached any recovery well (the nearest of which is 150 m further west). The recharged effluent is stored at present in the aquifer, where it displaces native groundwater towards the recovery wells.

Effluent Quality Changes During Passage Through the Unsaturated Zone and the Aquifer

Effluent percolating through the unsaturated zone and flowing in the aquifer is affected by numerous physical, chemical and biological processes. The overall effect of these processes on effluent quality has been evaluated by comparing the quality of the water sampled from the observation wells with the quality of the recharge effluent. During the transition period, when the well water contains only a certain percentage of recharged effluent, it is necessary to take into account the mixing of effluent with native groundwater. In such cases, the measured concentration of a particular constituent in the well water was compared with the concentration expected in the well water (according to the effluent percentage calculated from chloride concentrations) if it were not affected by passage through the soil-aquifer system.

It has not been possible to evaluate the water quality changes which occur only as a result of the percolation of the effluent through the entire unsaturated zone (20-30 m), because it is practically impossible to sample the percolating effluent from large depths (before it reaches the groundwater). However, the water quality changes occurring in the upper soil mantle (to a depth of 2 m) have been evaluated from analyses of the percolating effluent sampled by means of the installation specially constructed for this purpose. The difference between the quality of the percolating effluent at 2 m depth and the quality of the water in an observation well pumping 100% effluent can be attributed jointly to percolation through the remainder of the unsaturated zone and to flow through the aquifer.

The findings on water quality changes during groundwater recharge are presented in this paper with respect to: general organics (expressed as $KMnO_4$ consumption); phosphorus; nitrogen; pH and alkalinity; sodium, calcium and sodium adsorption ratio; trace elements (boron and selenium).

The effect on water quality of percolation through the upper 2 m of soil was evaluated from two series of experiments carried out during the periods when the percolating water sampling installation was in operation (July-December 1977 and September 1978 - February 1979).

The overall water quality changes during percolation through the entire unsaturated zone and flow through the aquifer were evaluated on the basis of data from observation wells 61 and 63, which have been pumping 100% recharged effluent since February and June 1978, respectively. The recharge effluent quality in the period January-May 1977 (when recharge was carried out in basin 101) was not taken into account in this evaluation, since that effluent did not reach observation wells 61 and 63. These wells were affected only by recharge in basin 102, which started in June 1977.

General Organics. Organic compounds are presumably the main substances of concern in connection with wastewater reuse because of their great variety and the difficulties involved in their identification and measurement, on the one hand, and the lack of knowledge with regard to their health effects, on the other hand.

After biological and chemical treatment as carried out in the Dan Region Project (which does not include activated carbon adsorption), the concentration of general organics expressed as COD, TOC, DOC or $KMnO_4$ consumption is still relatively high, although BOD concentration is low (Table 1). The role of the soil-aquifer system in further reducing the concentration of organics is, thus, particularly important in order to obtain high-quality reclaimed water.

The removal of residual suspended solids (mostly organic) and of residual BOD was virtually complete in the soil-aquifer system.[1]

A moderate reduction in the total organic content of the effluent - expressed as $KMnO_4$ consumption - occurred during percolation through the upper 2 m (Figure 7). The average $KMnO_4$ reduction was 26% in 1977 and 22% in 1978-79. The main processes causing this reduction are presumably filtration of particulate organics and aerobic bacterial degradation of some dissolved organics in the well-aerated upper soil mantle.

A considerable reduction in the organic content of the effluent - expressed as $KMnO_4$ consumption - occurred during percolation through the entire unsaturated zone and flow through the aquifer (Figure 8).

The pattern of variation in the $KMnO_4$ consumption of the groundwater in observation wells affected by the recharged effluent consisted of two distinct periods:

(1) In the transition period, during which the effluent reached the well in increasing proportions, the $KMnO_4$ consumption gradually increased, but only to levels which were less than those expected from the effluent percentage in the well. The removal efficiency of the soil-aquifer system was calculated from effluent percentage, based on the chloride concentration in the well water, and periodic average concentrations in the effluent according to estimated travel time to the well. During this period, the organics removal efficiency - expressed as percentage reduction of $KMnO_4$ consumption - was between 60 and 80%. At the end of the transition period, the $KMnO_4$ consumption reached a peak of 4-5 mg/l.

(2) During the period when the well was pumping 100% recharged effluent, the concentration of organic matter expressed as $KMnO_4$ consumption started decreasing and reached a value which remained relatively stable thereafter (about 2 mg/l).

> The organic matter removal efficiency of the soil-aquifer system (expressed as percentage reduction of $KMnO_4$ consumption), thus, increased to nearly 85%.

Similar variation patterns were noticed for all other parameters measuring organics, such as DOC, COD, and detergents.

The pattern of change in the organic content of the groundwater affected by the recharged effluent (rise to a peak then descent to a stable value) indicates that the dominant process in the removal of organics is microbial degradation and not adsorption. The first period appears to correspond to the time needed for a new microbial population to develop, after adapting to the organic compounds found in the effluent. A similar behavior pattern was reported by Roberts et al[7] for specific organic substances such as naphtalene, after artificial injection of effluent into groundwater by wells.

This finding is of great importance in connection with the long-range behavior of the soil-aquifer as a treatment system, since it indicates that, if the quality of the recharged effluent will essentially remain the same and the recharge operation will be properly managed to ensure that the bacterial population developed will continue to survive, a considerable reduction of the organic content of the effluent can be maintained for an indefinite period of time; in such a case, the soil-aquifer system will never be "exhausted" with respect to organics removal.

Another conclusion resulting from this finding is that, whereever feasible, groundwater recharge should be used for organics removal prior to using carbon adsorption. If the reclaimed water is to be used for potable purposes, activated carbon treatment of the water pumped from the aquifer would presumably be more efficient and more economic, since the "costly" carbon adsorption sites will be used only by the residual refractory organics that could not be removed by bacterial degradation in the soil.

Phosphorus. Despite the considerable reduction of phosphorus concentration by tertiary chemical treatment, concentrations in the recharge effluent were still significant, especially in winter (about 1 mg/l). During percolation through the upper 2 m soil (dune sand) phosphorus removal was exceedingly variable. Furthermore, the phosphorus removal capacity of the upper mantle of dune sand appears to have reached exhaustion after 1½ years recharge in the test basin. By January 1979, the phosphorus concentration in the percolating effluent at 2 m depth was essentially the same as in the recharge effluent.

However, phosphorus concentrations in the observation wells pumping 100% recharged effluent did not rise above background levels (Figure 9), thus indicating excellent phosphorus removal, presumably by adsorption on deep clay and silt layers as well as by calcium phosphate precipitation. Results from another research carried out in the Dan Region Project in connection with the effluent seeped from the oxidation ponds showed that even when phosphorus concentrations in the percolating water were higher (10-12 mg/l), concentrations in groundwater containing a large percentage of effluent remained in the range 0.01-0.05 mg/l.[8]

The excellent removal of phosphorus by the soil-aquifer system seems to indicate that in groundwater recharge projects the removal of phosphorus in the biological or chemical treatment step prior to recharge should not be of as great concern as it sometimes tends to be.

Nitrogen. The changes occurring during groundwater recharge in the concentration of nitrogenous compounds in sewage effluents has been extensively studied.[9] In the Dan Region Project, the total nitrogen concentration in the native groundwater (wells 61 and 63 prior to recharge) was about 2 mg/l and consisted primarily of nitrates. The total nitrogen concentration in the recharge effluent was 7-11 mg/l and consisted mainly of ammonia and organic nitrogen.

In the upper 2 m of soil, partial oxidation of ammonia to nitrates took place, as well as some removal of total nitrogen.[2] Nitrogen concentrations in wells 61 and 63 alternately rose and fell (the peak reached was 8 mg/l), but always consisted primarily of nitrates. These data indicate that, while nitrification was complete and reliable, denitrification was partial and fluctuating.[3] This finding was expected, considering that the relatively short flooding cycles employed in the Dan Region Project favor the development of aerobic microbial populations in the soil-aquifer system. The nitrification and denitrification processes occurring during groundwater recharge could not be quantified at this stage because of the seasonal variations in the nitrogen content of the recharged effluent, on the one hand, and the difficulty in determining the exact travel time to observation wells 61 and 63 (due to frequent changes in the operation of the various recharge basins), on the other hand.

Alkalinity and pH. Since the recarbonation of the high pH effluent which occurs in the polishing ponds naturally (by absorption of CO_2 from the atmosphere) is not complete, the recharged effluent had, in the first recharge year (1977), a high pH (usually in the range 9.5 - 10.5) and an alkalinity consisting mainly of carbonates, but occasionally also including residual hydroxides. In order to ensure the completion of the first-stage recarbonation in the polishing ponds, to prevent scale formation on the pumps and pipes conveying the water to the recharge basins, small amounts of neutral groundwater have been pumped, since mid-1978, to the last polishing pond from a neighbouring recovery well, which has been affected by seepage from the oxidation ponds. Consequently and also as a result of a lower operating pH in the lime treatment plant, the recharged effluent in the second half of 1978 and beginning of 1979 had a lower pH (in the range 9-9.5) and an alkalinity consisting of carbonates and bicarbonates.

After 2 m percolation, a slight decrease in total alkalinity was observed, as a result of some $CaCO_3$ precipitation; however, the major effect of the percolation through the upper soil mantle was the conversion of all residual hydroxides to carbonates (completion of first-stage recarbonation) and the conversion of most carbonates to bicarbonates (second-stage recarbonation). As a result of these transformations (Table 2), the pH of the recharged effluent dropped considerably during 2 m percolation, on the average from 10 to 8.8 in the first period of experiments (1977) and from 9.3 to 8.3 in the second (1978-79); the Langelier Index decreased on the average from +1.5 to +0.14 in the first experimental period and from +1.14 to 0 in the second (Figure 10).

Since the amounts of available CO_2 in the air pores of the upper soil zone are insignificant, it appears that the release of CO_2 (or other acids) by the soil bacterial population is responsible for the intense recarbonation occurring in the upper soil zone. The theoretical CO_2 consumption was calculated, considering that one molecule was required for conversion of hydroxides to carbonates and another one for formation of bicarbonates from carbonates:

$$[CO_2] = [OH^- + HCO_3^-] \frac{44}{100}$$

where OH^- and HCO_3^- are hydroxide and bicarbonate alkalinities, respectively, expressed in mg/l as $CaCO_3$.

The results (Table 2) showed that the average CO_2 consumption during the recarbonation process in the upper 2 m was 20 mg/l in the first experimental period and 14 mg/l in the second. This recarbonation process in the upper soil mantle is a considerable benefit of the groundwater recharge system in the Dan Region Project as it eliminates the need for artificial addition of CO_2, which is expensive especially if the gas cannot be obtained as a by-product of sludge incineration.

Sodium Adsorption Ratio (SAR). The recharge effluent is somewhat softer than the native groundwater as a result of the high-lime softening process, but has a much higher sodium concentration (average 150 mg/l as compared to 10 mg/l). Consequently, the SAR of the recharge effluent,which indicates the proportion between monovalent cations (basically Na) and divalent cations (Ca and Mg), was much higher (6 to 7) than that of the native groundwater (about 0.5). The effluent passage through the soil-aquifer system caused a considerable reduction of the sodium concentration, and in parallel, an increase in hardness, due to cation exchange between Ca and Mg, on the one hand, and Na on the other hand. The deviations of the concentrations of these three cations measured in a certain well from those expected according to the effluent percentage in the well, which were calculated from data available for observation wells 61 and 63, confirmed that the responsible mechanism is indeed cation exchange.[2]

The SAR of the water in wells 61 and 63 was much lower than that of the recharge effluent during a relatively long period of time, because of the lag in the rising of sodium to the concentrations found in the effluent and the corresponding increase in Ca and Mg concentrations (Figure 11). After a certain period of time, the sodium concentration and hardness (and consequently also the SAR) in the groundwater reached values similar to those in the recharged effluent, thus indicating completion of the cation exchange process in this section of the aquifer. Although the SAR reduction is temporary, it is of great importance since the reclaimed water is to be used mainly for irrigation of agricultural crops.

Boron. Boron concentration is of particular importance in connection with the reuse of the effluent for unrestricted irrigation of agricultural crops. Removal of boron compounds by adsorption on magnesium hydroxide during high lime-magnesium treatment is the main mechanism which reduces the boron concentration in the recharge effluent to acceptable limits of 0.3-0.5 mg/l.[4,5]

The boron concentration in the native groundwater is only 0.02-0.03 mg/l i.e. one order of magnitude lower than in the recharge effluent.

Only about 10% of the effluent boron content was removed by percolation through the upper 2 m of the unsaturated zone during the second experimental period (after more than one year of recharge). The dune sand soil apparently has a rather limited boron adsorption capacity. (Boron data from the first experimental period are not available).

Boron was initially well removed during percolation through the entire unsaturated zone and flow through the aquifer, as indicated by boron concentrations measured in observation wells 61 and 63, which were much lower than those in the recharge effluent. However, after several months, boron concentrations (especially in well 63) gradually increased until they reached concentrations similar to those in the effluent (Figure 12).

The pattern of boron concentration in the groundwater affected by the recharged effluent indicates a process of adsorption, which presumably occurs on clay layers as well as on magnesium hydroxide usually present in the silt and sand fraction of arid-zone soils[10] The rise of boron concentrations in wells 61 and 63 to levels similar to those in the recharge effluent seems to indicate that the boron adsorption capacity was gradually exhausted in this section of the aquifer. Incidentally, this apparent exhaustion point occurred when boron concentrations in the recharge effluent were particularly low (0.3 mg/l).

Data on boron concentrations in the recharge water and in the groundwater that will be obtained in the future will provide further information on the boron adsorption capacity of the soil-aquifer system. The reduction of boron concentration, even though temporary, is of great importance in connection with the use of the reclaimed water for agriculture.

Trace Elements. Available data on long-term behaviour of land treatment systems with respect to trace elements is limited. The contribution of the data accumulated in the Dan Region Recharge Project on this subject is also limited, mainly because the concentrations of most trace elements in the recharge effluent (which has undergone high-lime treatment) are similar to those in the native groundwater. In addition, results obtained for some heavy metals, notably for iron and zinc, are erratic presumably due to the effects of galvanized well casing, compressed air pumping, etc.

Exceptions to the above are selenium, copper and fluoride (as well as boron which was previously discussed). The concentrations of these elements in the recharge effluent were higher than in the native groundwater, but they were reduced by passage through the unsaturated zone and the aquifer to levels similar to those found in the native groundwater. The main mechanisms responsible for trace element removal are presumably chemical precipitation and adsorption.

Selenium, which is particularly important in connection with possible potable reuse of reclaimed water, was reduced from 6-9 $\mu g/l$ (seasonal averages) in the recharge effluent to <1-2 $\mu g/l$ in wells 61 and 63 which pump 100% recharged effluent (Figure 13).

Effluent Quality After Groundwater Recharge. The effect of percolation through the upper 2 m of soil on effluent quality is moderate and fluctuating for most parameters, presumably because of the limited adsorption capacity of the dune sand and rapid effluent flow through this zone. The only exception is the chemical stability of the effluent - as indicated by pH, alkalinity and Langelier Saturation Index - which is significantly improved in this zone.

The effect of passage through the entire unsaturated zone and the aquifer on effluent quality is substantial and of a wide scope. Three groups of quality parameters can be distinguished[6,7]:

- constituents affected only by dilution, which are not removed by the soil-aquifer system (e.g. chlorides); the concentration of such constituents in the groundwater will reach levels similar to those in the recharged water after a relatively short transition period;

- constituents removed by physico-chemical processes in the soil-aquifer system such as adsorption (e.g. boron) or ion exchange (e.g. sodium); the concentration of such constituents will reach levels similar to those in the recharge effluent after a longer period of time, when the adsorption or ion exchange capacity is exhausted;
- constituents that are affected mainly by biological processes in the soil-aquifer system, such as bacterial degradation of carbonaceous matter (e.g. filtered COD or $KMnO_4$ consumption); the concentration of such parameters will reach a certain peak during the acclimatization period of the microbial population, but will then decrease to levels which can presumably be maintained for an indefinite period of time.

The effect of groundwater recharge on effluent quality is illustrated in Table 3 for some major wastewater parameters.

Functions of Groundwater Recharge

The groundwater recharge system, as part of a wastewater reuse scheme, fulfils a variety of functions which are briefly described below.

Seasonal Storage. In Israel, where most of the reclaimed water is to be used for irrigation of agricultural crops during part of the year (mainly in summer), the storage of the effluent during the remaining part of the year is indispensable. Surface storage of the effluent is generally impractical because of the high evaporation and seepage losses it would incur.

Multi-Annual Storage. While the natural climatic conditions dictate the amount of water needed for irrigation during a certain year, the amount of effluent available from municipal wastewater is relatively unaffected by the yearly climatic fluctuations. If the effluent is recharged to the groundwater, the aquifer fulfils the function of multi-annual storage reservoir and, thus, the amounts of water withdrawn in a certain year are not directly and immediately related to the amounts of effluent recharged during that year.

Effluent Treatment. The capacity of the soil-aquifer system to provide for additional treatment of the effluent, both during rapid percolation through the unsaturated zone and during slow movement through the saturated zone was discussed and illustrated in detail in the previous sections of this paper.

Dilution. Despite its high quality, the recharged effluent has higher concentrations of inorganic dissolved solids, mainly chloride and sodium salts, than the natural groundwater. The dilution of the effluent with high-quality natural groundwater reduces the TDS concentration, which is only slightly affected or not affected at all by common wastewater treatment processes. This reduction is particularly significant in the transition period of the recovery wells when the recharged effluent constitutes only a small fraction of the well water.

Safety Barrier. The time lag between the recharge of the effluent and the pumping of the reclaimed water by the recovery wells, which is in the order of magnitude of several years, provides an important safety barrier against any unpredictable effluent quality deterioration, e.g. that resulting from plant operation failures.

The observation wells located between the recharge basins and the recovery wells provide a warning and prediction system with respect to the quality of the water to be pumped from the recovery wells.

System Reliability. The fluctuations in effluent quality which occur in any wastewater treatment plant are greatly attenuated by groundwater recharge. The water quality in observation wells pumping 100% recharged effluent is much more stable than that of the effluent quality prior to recharge. As water quality changes in the aquifer are relatively slow,the frequency of groundwater sampling and analysis can be relatively low (e.g. once per month; as it has been in the observation wells close to the recharge basins).

Economic Return. Pumping of native groundwater from an aquifer, into which effluent recharge is planned,can start several years prior to the completion of the wastewater treatment scheme, on account of the effluent that will be recharged. Thus income from water sales is acquired prior to, or simultaneously with, the bulk of investments required for the implementation of the reuse scheme (as opposed to other large engineering projects, such as dams, where benefits lag several years behind costs).

Gradual Development. The exchange of fresh water for reclaimed water from the Dan Region Project implies conversion of the agriculture in the south of the country (with its variety of crops) from irrigation with fresh water to irrigation with reclaimed water, which has a different chemical composition. The recharge of the effluent to groundwater and the pumping of gradually increasing amounts of reclaimed water, mixed with natural groundwater, will facilitate a gradual adaptation of the agriculture to the new water composition and will allow time for the undertaking of corrective measures (if necessary).

Psychological Effect. The indirect reuse of the effluent via groundwater recharge has an important psychological effect, since the consumers will be supplied from wells pumping groundwater (which contains the recharged effluent) and not with effluent flowing out of the wastewater treatment plant.

Conclusion

For a sanitary engineer, who has been educated in the spirit of environmental protection and water pollution control, the intentional recharge of treated wastewater into a potable groundwater aquifer is a most delicate undertaking. This is particularly so in Israel, where groundwater supplies about half of the country's water requirements.

Nevertheless, groundwater recharge with effluent should be incorporated in any wastewater reuse scheme (where it is feasible) because of its multiple benefits, some of which were presented in this paper. The success of a recharge program with municipal effluent depends, to a great extent, on the fulfilment of three basic conditions:

(a) The quality of the recharge effluent should be compatible with the treatment capacity of the soil-aquifer system, so that pollution of the groundwater aquifer will not occur.

(b) A detailed hydrogeochemical monitoring of the aquifer in the recharge area should be carried out in order to follow the movement of the recharged effluent in the aquifer as well as the changes in the physical, chemical and biological quality of the groundwater.

(c) The recharge basins should be surrounded by a suficient number of adequately-spaced recovery wells, which should pump the bulk of the recharged effluent to uses compatible with its quality.

The Dan Region Reclamation Project in Israel, which incorporates groundwater recharge by spreading basins, provides an excellent example of the advantages of groundwater recharge in connection with reclamation of municipal wastewater for uses which require high-quality water. Despite the public opposition to groundwater recharge with municipal effluent, which at times has been regarded as an "idee fixe" of the Dan Region Project's planners, the effluent of the First Stage of the Dan Region Project has been successfully recharged to the aquifer for a continuous period of almost 3 years; groundwater recharge with effluent in another geographical area, with the same soil and aquifer characteristics, will also be adopted for the Second Stage of the Project. Direct effluent supply, after sand filtration if necessary, which has been repeatedly suggested as an alternative to groundwater recharge, would arouse less controversy but lacks the numerous advantages of a groundwater recharge system, with respect to effluent treatment, storage, safety of supply and system reliability.

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REFERENCES

1. IDELOVITCH E., Wastewater Reuse by Biological-Chemical Treatment and Groundwater Recharge, Jour. WPCF, 50:12:2723 (Dec. 1978).

2. IDELOVITCH E., TERKELTOUB R., BUTBUL M., FRIEDMAN R. and MICHAIL M., Groundwater Recharge with Municipal Effluent, Dan Region Sewage Reclamation Project, Annual Report - 1977, Tahal - Water Planning for Israel Ltd., Sewage Reclamation Department, Tel Aviv (March 1978).

3. IDELOVITCH E., TERKELTOUB R., BUTBUL M., MICHAIL M. and FRIEDMAN R., Groundwater Recharge with Municipal Effluent, Dan Region Project, Second Recharge Year - 1978, Annual Report, Tahal - Water Planning for Israel Ltd., Sewage Reclamation Department, Tel Aviv (April 1979).

4. IDELOVITCH E., ROTH T., MICHAIL M. and COHEN A., Advanced Treatment and Reuse of Municipal Wastewater, Dan Region Pilot Plant, Summer Operation, Tahal - Water Planning for Israel Ltd., Sewage Reclamation Department, Tel Aviv (April 1976).

5. IDELOVITCH E., ROTH T., MICHAIL M., COHEN A., and FRIEDMAN R., Advanced Treatment, Groundwater Recharge and Reuse of Municipal Wastewater, Dan Region Pilot Plant, Winter Operation, Tahal - Water Planning for Israel Ltd., Sewage Reclamation Department, Tel Aviv (March 1977).

6. IDELOVITCH E., ROTH T., MICHAIL M., COHEN A. and FRIEDMAN R., Dan Region Project in Israel: From Laboratory Experiments to Full-Scale Wastewater Reuse, Paper presented at AWWA Water Reuse Symposium, Washington D.C. (March 1979).

7. ROBERTS P.V., McCARTHY P.L., REINHARD M. and SCHREINER J., Organic Contaminant Behaviour During Groundwater Recharge, Paper presented at the 51st Annual Conf. WPCF, Anaheim, California (Oct. 1978).

8. IDELOVITCH E., MICHAIL M. and BUTBUL M., Quality Changes by Soil Purification in the Wastewater Seeped from the Dan Region Oxidation Ponds, Tahal - Water Planning for Israel Ltd., Sewage Reclamation Department, Tel Aviv (in Hebrew) May 1977).

9. BOUWER H., LANCE J.C. and RIGGS M.S., High-Rate Land Treatment II: Water Quality and Economic Aspects of the Flushing Medows Project, Jour. WPCF, 46:5:844 (May 1974).

10. RHOADES J.D., INGVALSON R.D. and HATCHER J.T., Adsorption of Boron by Ferromagnesium Minerals and Magnesium Hydroxide, Soil Sci. Soc. Amer. Proc. (Nov. - Dec. 1970).

TABLE 1: QUALITY OF RECHARGE EFFLUENT

Parameter	Year			
	1977		1978	
	Winter*	Summer	Winter	Summer
Suspended Solids, mg/l	36*	11	20	13
BOD, mg/l	9	8	7	8
COD, mg/l	80	75	59	68
TOC, mg/l	22	24	17	18
Ammonia as N, mg/l	5	1	5	2
Total Nitrogen, mg/l	11	7	11	10
Phosphorus, mg/l	2.6*	0.9	1.0	0.6
pH	9.8	10	10.3	9.5
Alkalinity as $CaCO_3$, mg/l	180	100	155	105
Chlorides, mg/l	175	225	215	305**
Dissolved Solids, mg/l	610	640	620	760**

* Prior to $MgCl_2$ addition to the high-lime process

** Affected by accidental intrusion of sea water into sewerage network

Winter = December through April

Summer = May through November

TABLE 2: EFFLUENT RECARBONATION DURING VERTICAL PERCOLATION THROUGH UPPER 2 M SOIL MANTLE

	Date*	Recharge Effluent				Percolated Effluent at 2 m Depth				Theoretical CO_2 Consumption Within 2 m Depth, mg/l
		pH	Alkalinity as $CaCO_3$, mg/l			pH	Alkalinity as $CaCO_3$, mg/l			
			OH^-	$CO_3^=$	HCO_3^-		OH^-	$CO_3^=$	HCO_3^-	
Experimental period No. 1	July 1977	9.9	3	53	18	8.3	0	5	73	25
	Aug. 1977	10.3	7	58	5	9.5	0	26	28	13
	Sept. 1977	10.5	14	58	3	9.2	0	17	30	18
	Oct. 1977	9.7	11	31	32	8.2	0	0	75	24
	Nov. 1977	9.3	0	40	50	8.0	0	0	85	15
	Dec. 1977	9.9	0	110	15	8.0	0	0	85	31
	Overall average	10	7	53	16	8.8	0	11	54	20
Experimental period No. 2	Sept. 1978	9.5	0	44	59	9.0	0	19	74	7
	Oct. 1978	9.2	0	28	50	8.6	0	4	68	8
	Nov. 1978	9.4	0	38	46	8.0	0	0	71	11
	Dec. 1978	9.3	0	54	88	8.0	0	4	122	15
	Jan. 1979	9.1	0	58	97	7.8	0	2	133	16
	Feb. 1979	9.2	0	75	83	7.9	0	4	142	26
	Mar. 1979	9.6	0	70	26	9.1	0	30	51	11
	Overall average	9.3	0	53	70	8.3	0	8	101	14

* Monthly averages were calculated from available data (1 to 5 per month). Overall average for each experimental period was calculated from all data available (19 and 24, respectively).

TABLE 3: EFFLUENT QUALITY IMPROVEMENT BY PERCOLATION THROUGH UNSATURATED ZONE AND FLOW THROUGH AQUIFER

Parameter	Recharge Effluent	Observation Well 61*
Suspended solids, mg/1	15	0
BOD, mg/1	8	<1
COD, mg/1	60	10
$KMnO_4$ consumption as O_2, mg/1	12	2
DOC, mg/1	15	3
Ammonia as N, mg/1	1-5	0
Total nitrogen, mg/1	7-10	5-8
Phosphorus, mg/1	1	0.02
pH	9.5-10	8
Alkalinity as $CaCO_3$, mg/1	130	120
Sodium, mg/1	180	25-170
Boron, mg/1	0.3-0.5	0.05-0.3
Selenium, μg/1	6-9	<1-2

* Pumping 100% recharged effluent

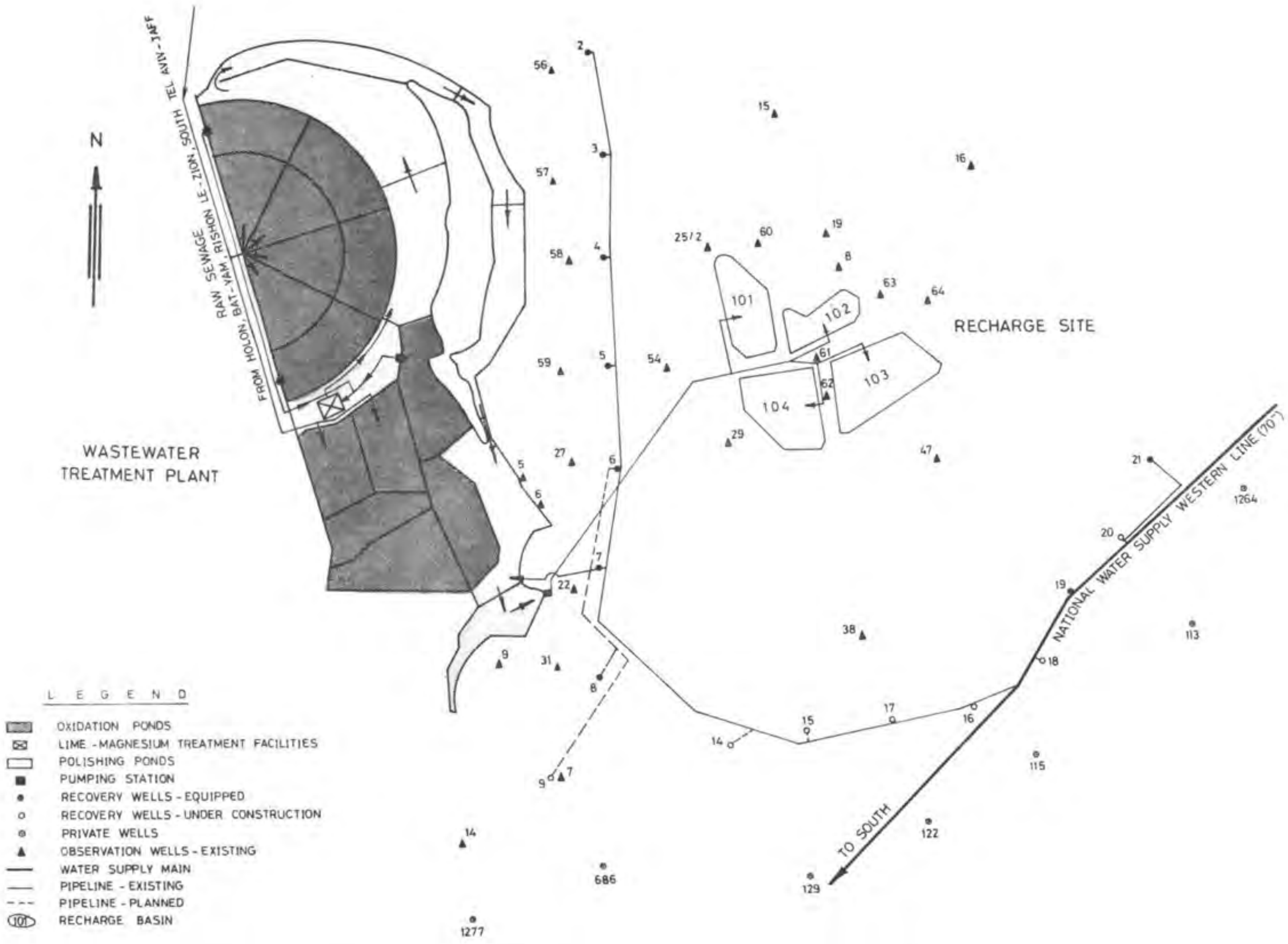

Fig. 1 Layout of Dan Region Sewage Reclamation Project

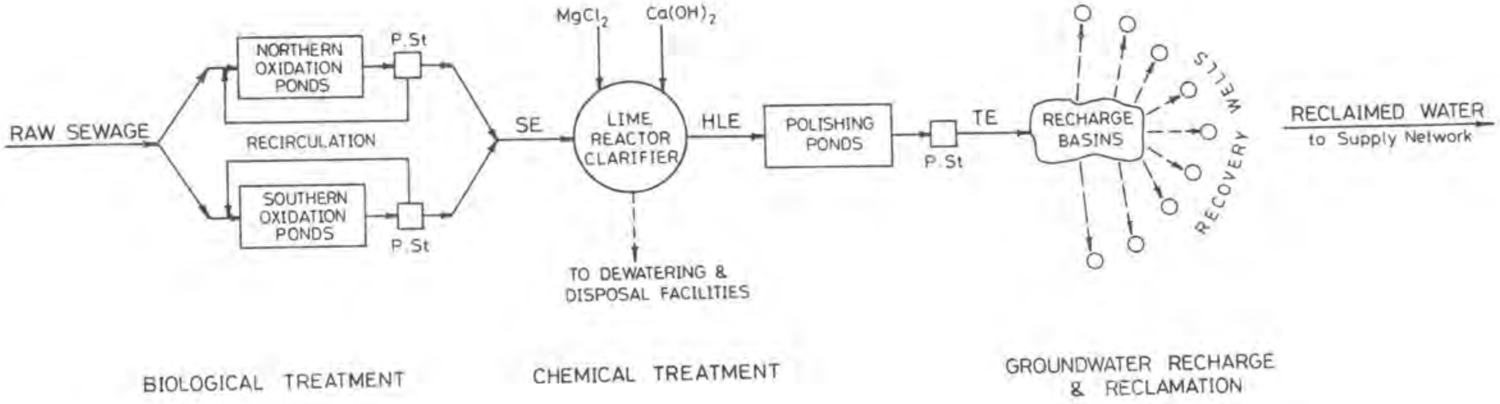

Fig. 2 Flow Diagram of Dan Region Sewage Reclamation Project
SE-Secondary Effluent; HLE-High Lime Effluent;
TE-Tertiary Effluent; P.St.-Pumping Station

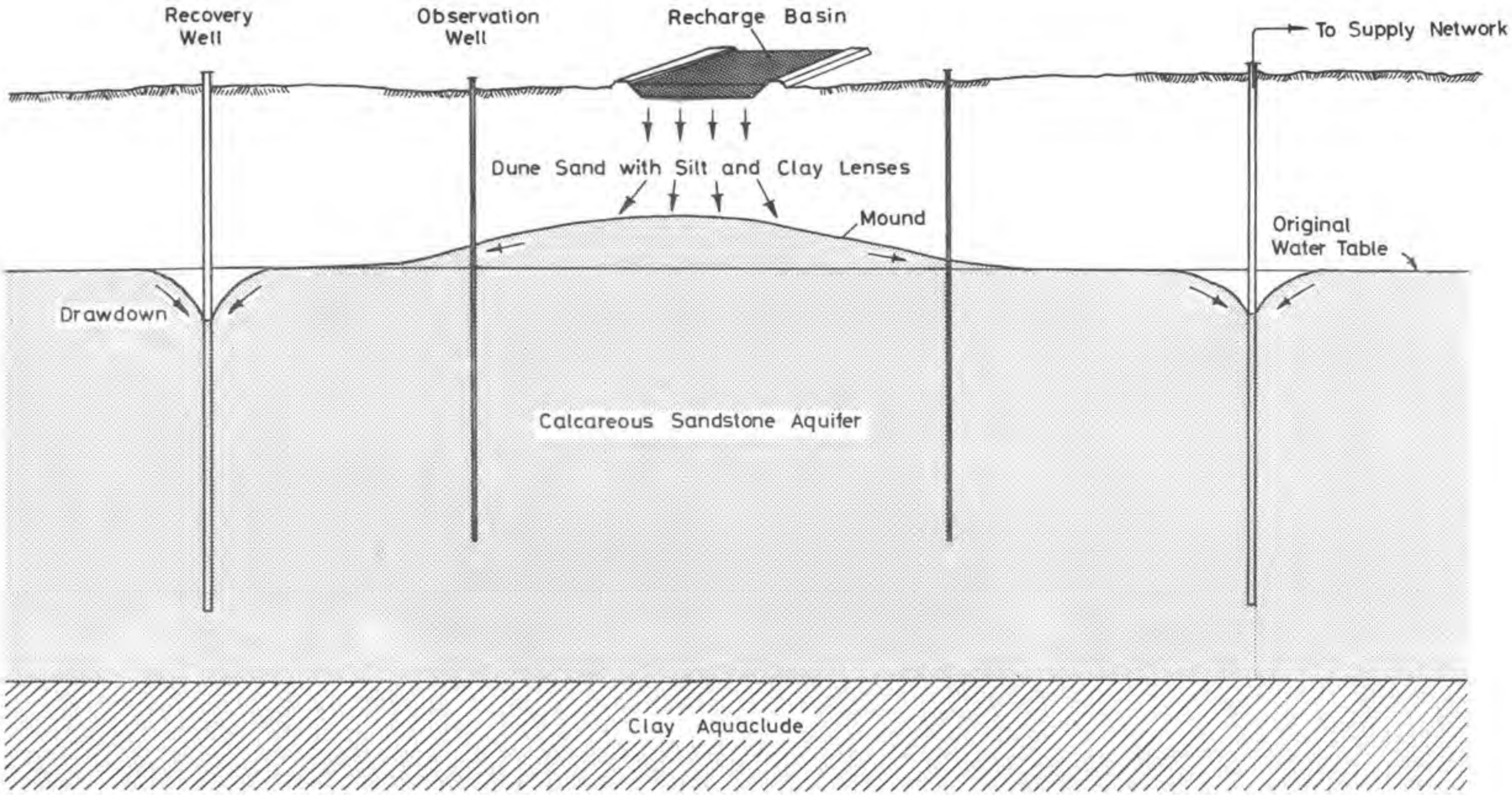

Fig. 3 Basic Diagram of Recharge-Recovery System

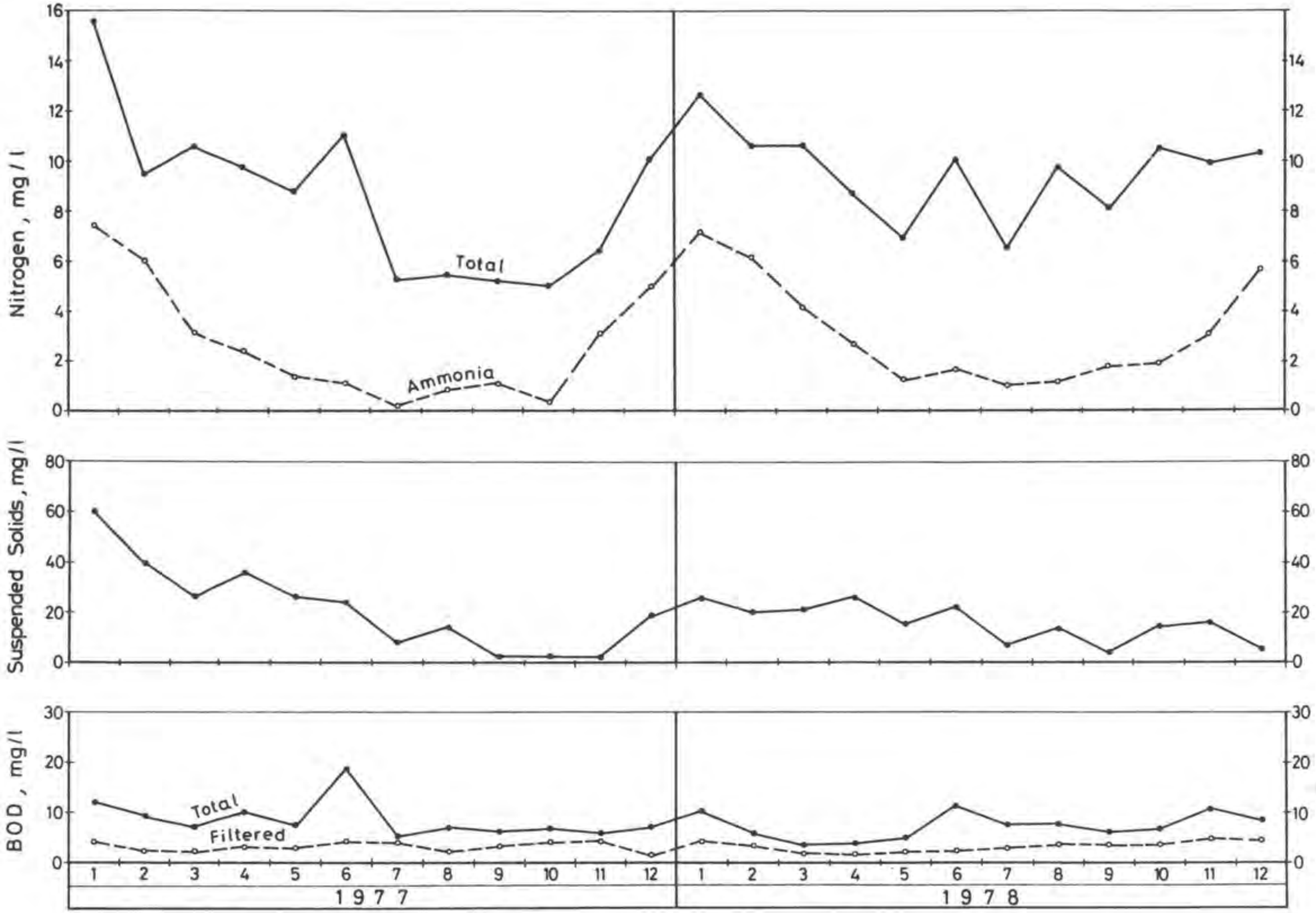

Fig. 4 Quality of Recharge Effluent

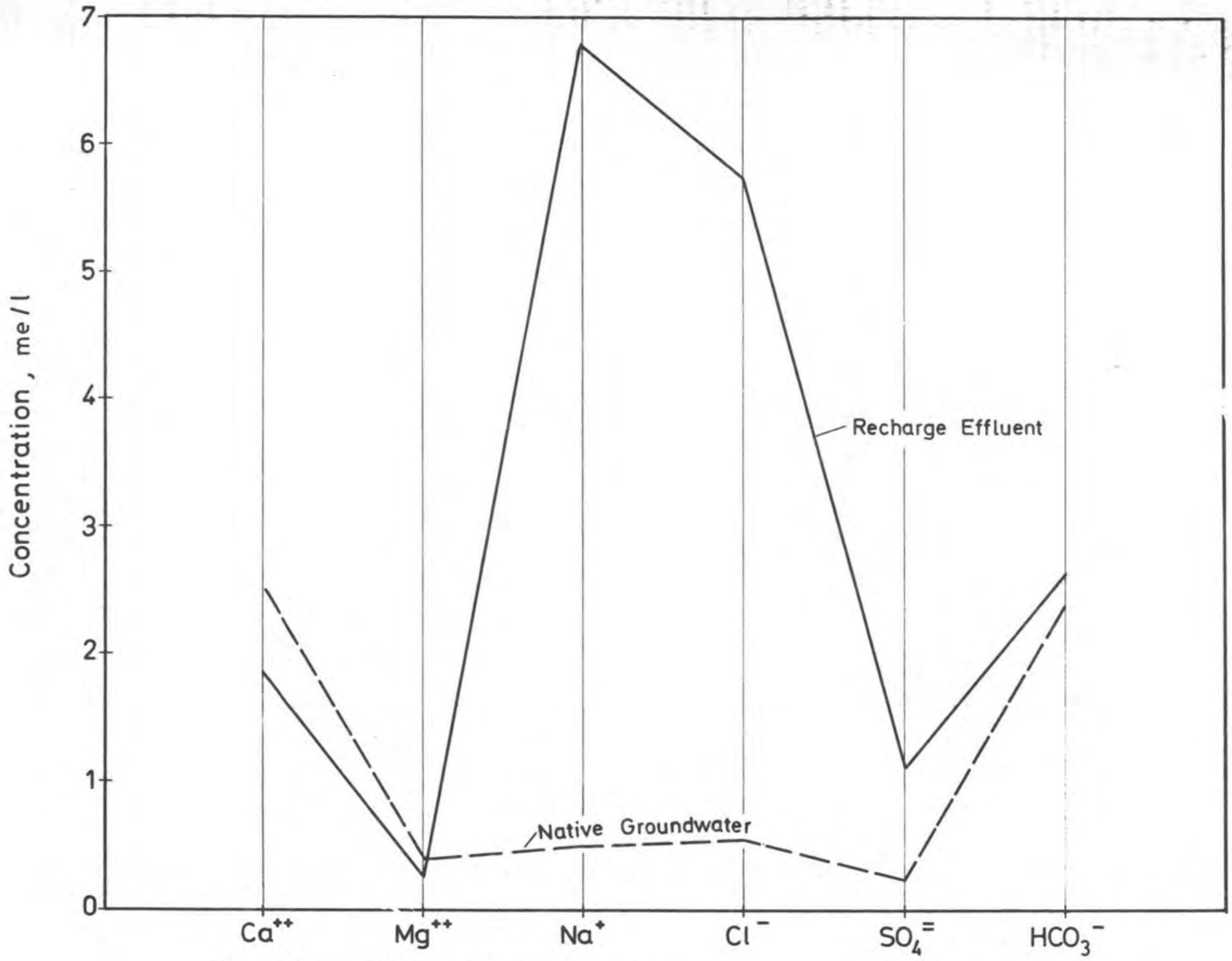

Fig. 5 Schoeller Diagram of Major Ions in Recharge Effluent and Native Groundwater

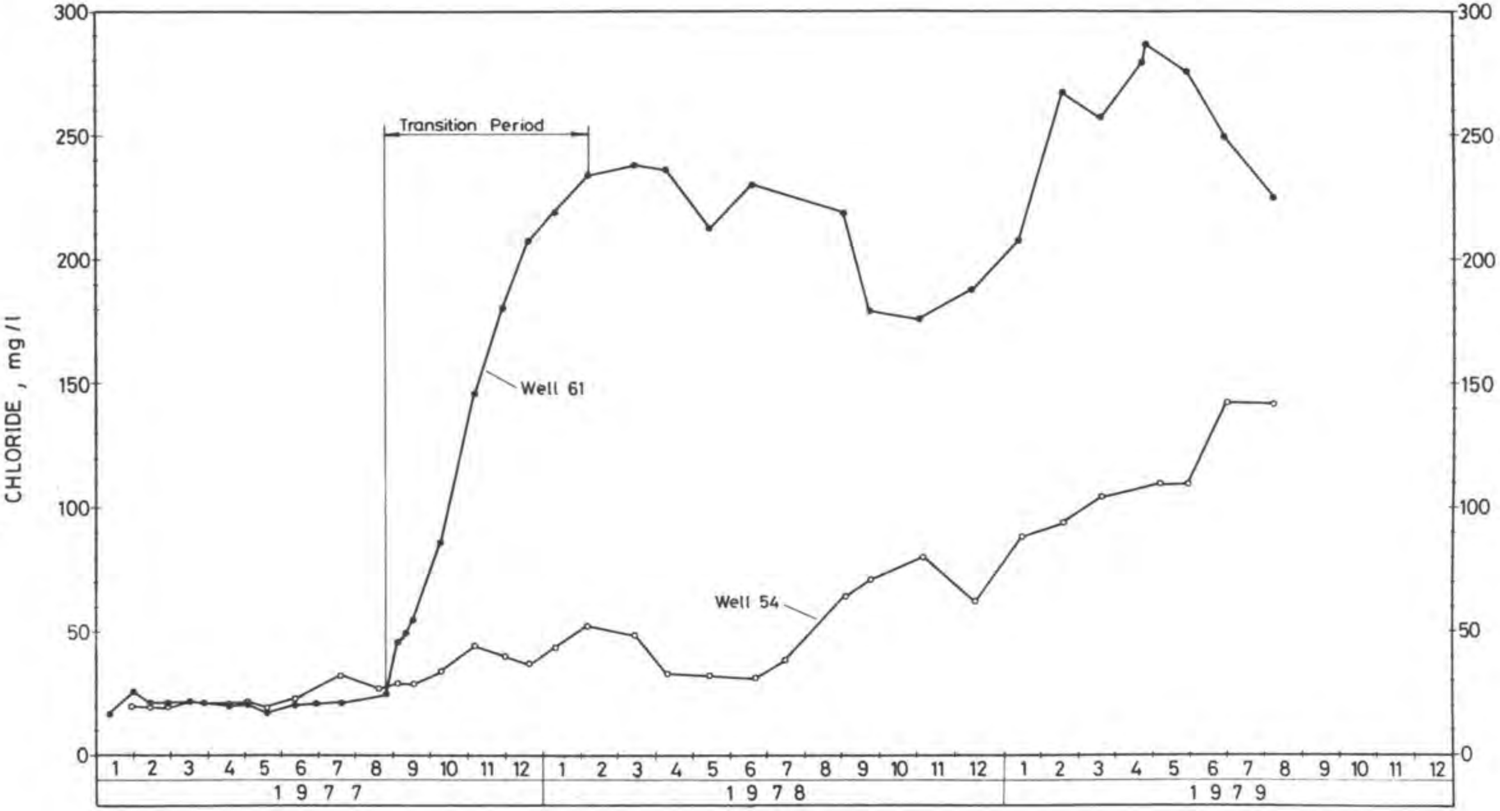

Fig. 6 **Chloride Concentration in Observation Wells Affected by Recharge**
Transition Period is the Time between Initial Arrival of Recharged Effluent and Complete Displacement of Native Groundwater

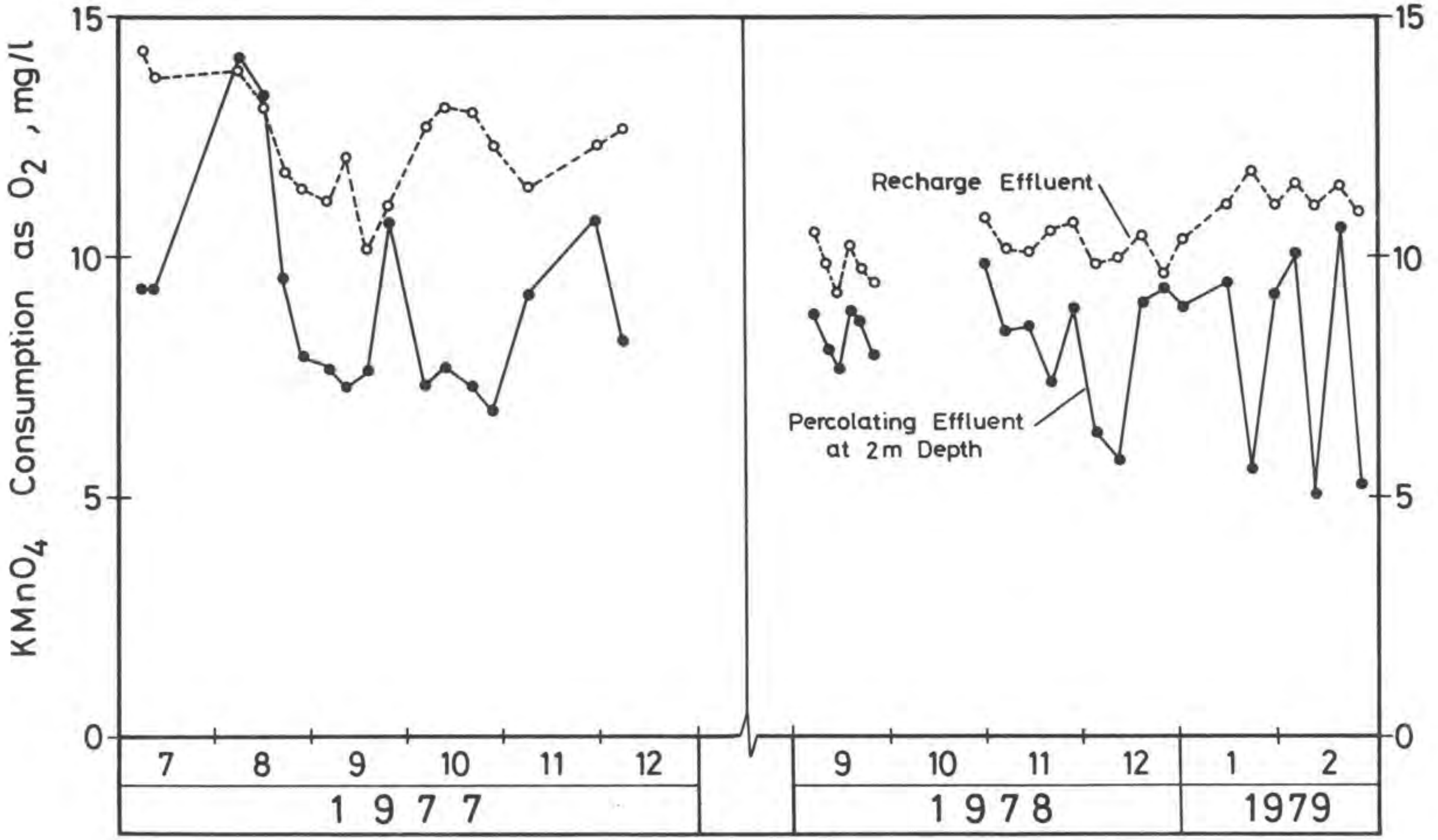

Fig. 7 Effect of Percolation Through Upper 2 m of Soil on Organic Content ($KMnO_4$ Consumption) of Recharge Effluent

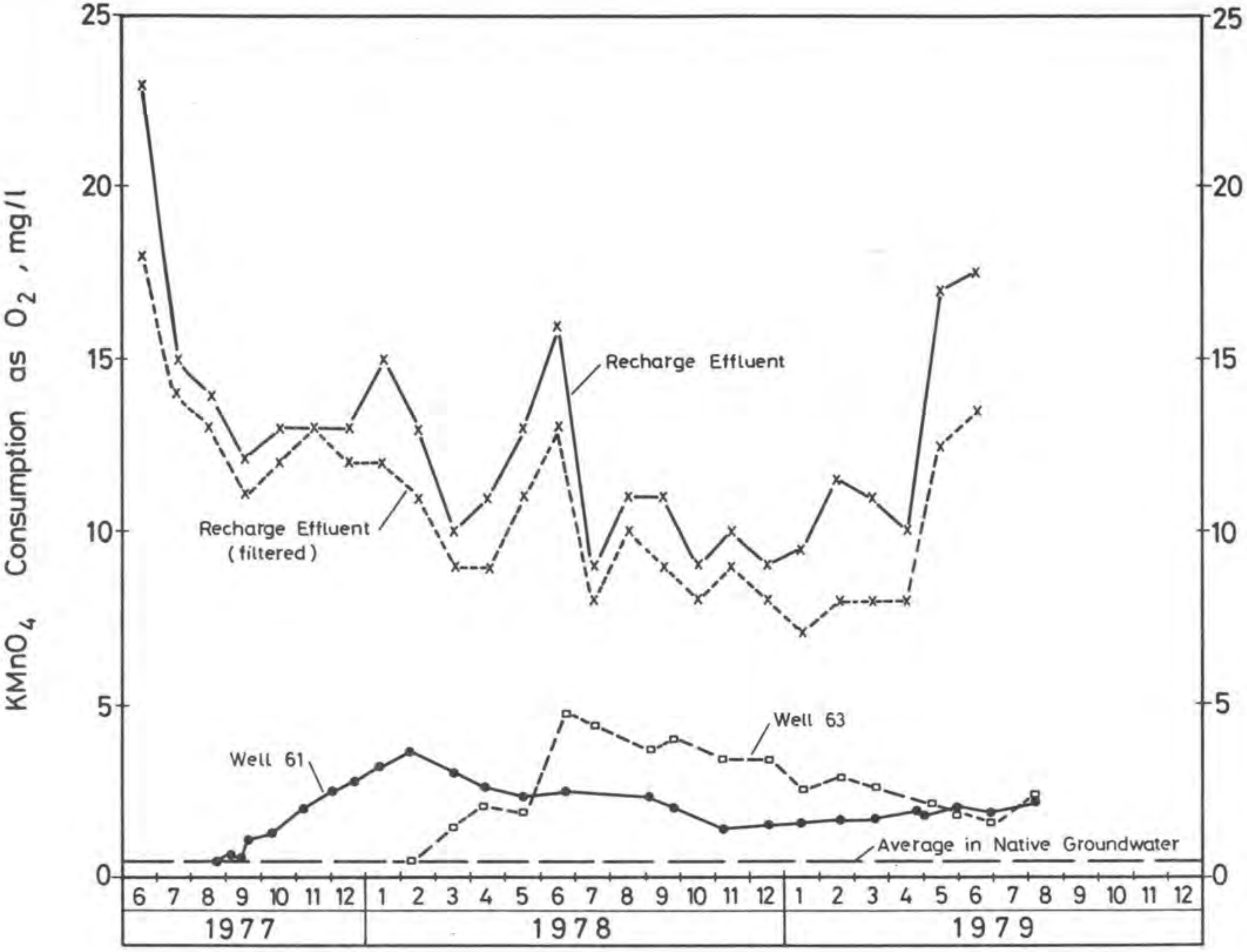

Fig. 8 Reduction in $KMnO_4$ Consumption of Effluent by Groundwater Recharge

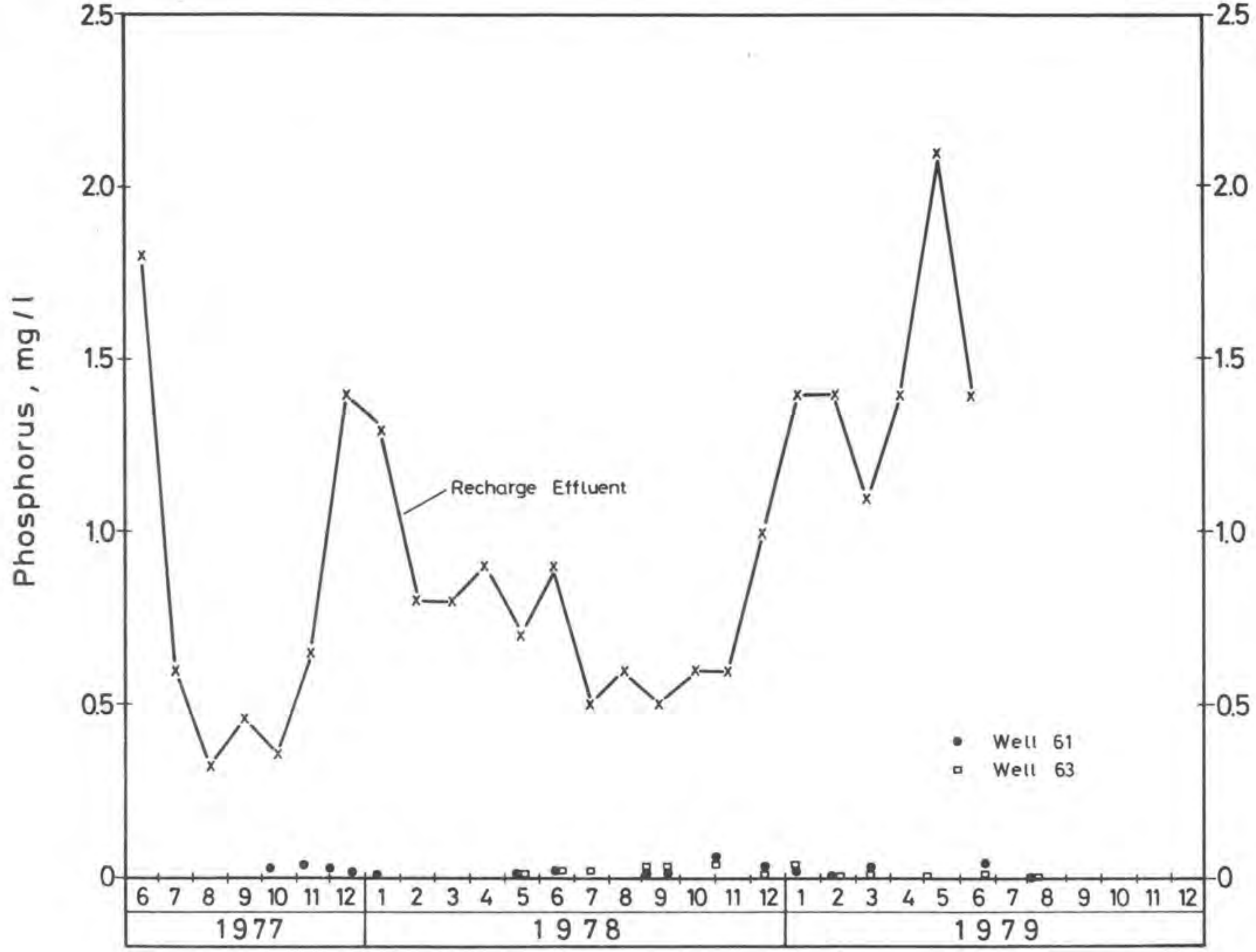

Fig. 9 Phosphorus Removal from Effluent by Groundwater Recharge
Average Concentration in Native Groundwater is 0.01 mg/1

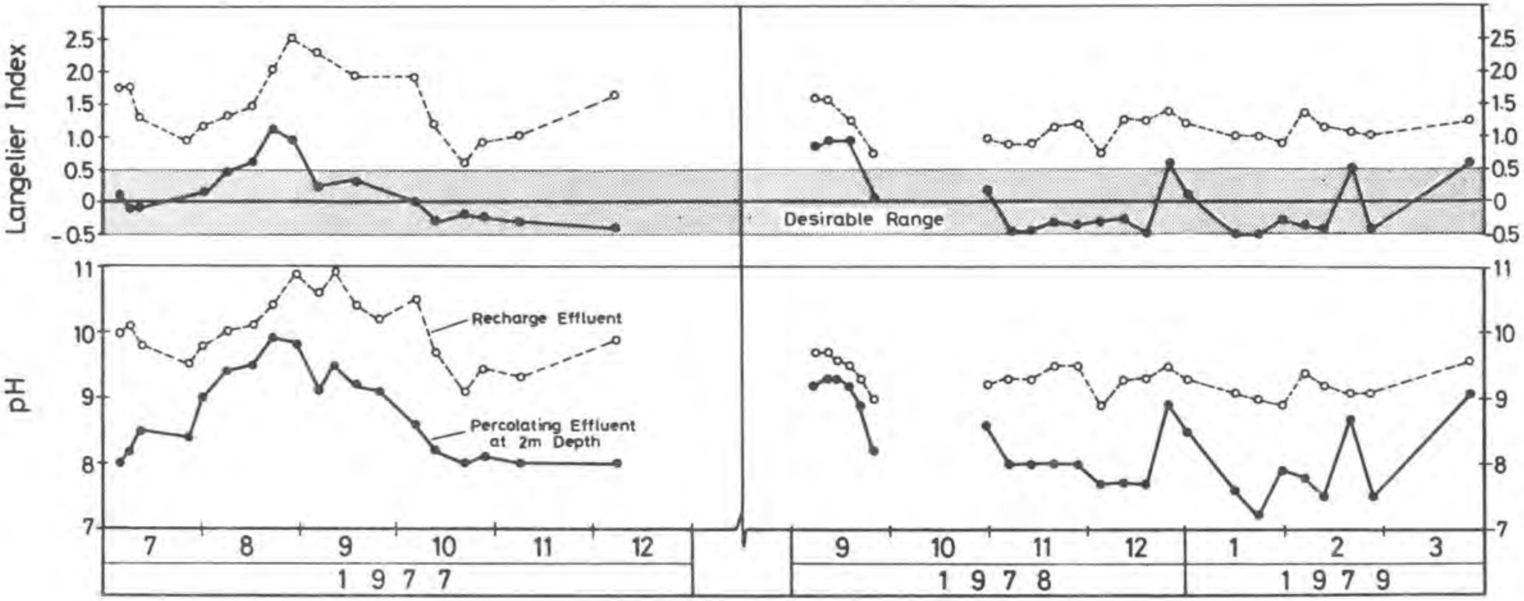

Fig. 10 Effect of Percolation Through Upper 2 m of Soil on pH and Langelier Saturation Index of Recharge Effluent

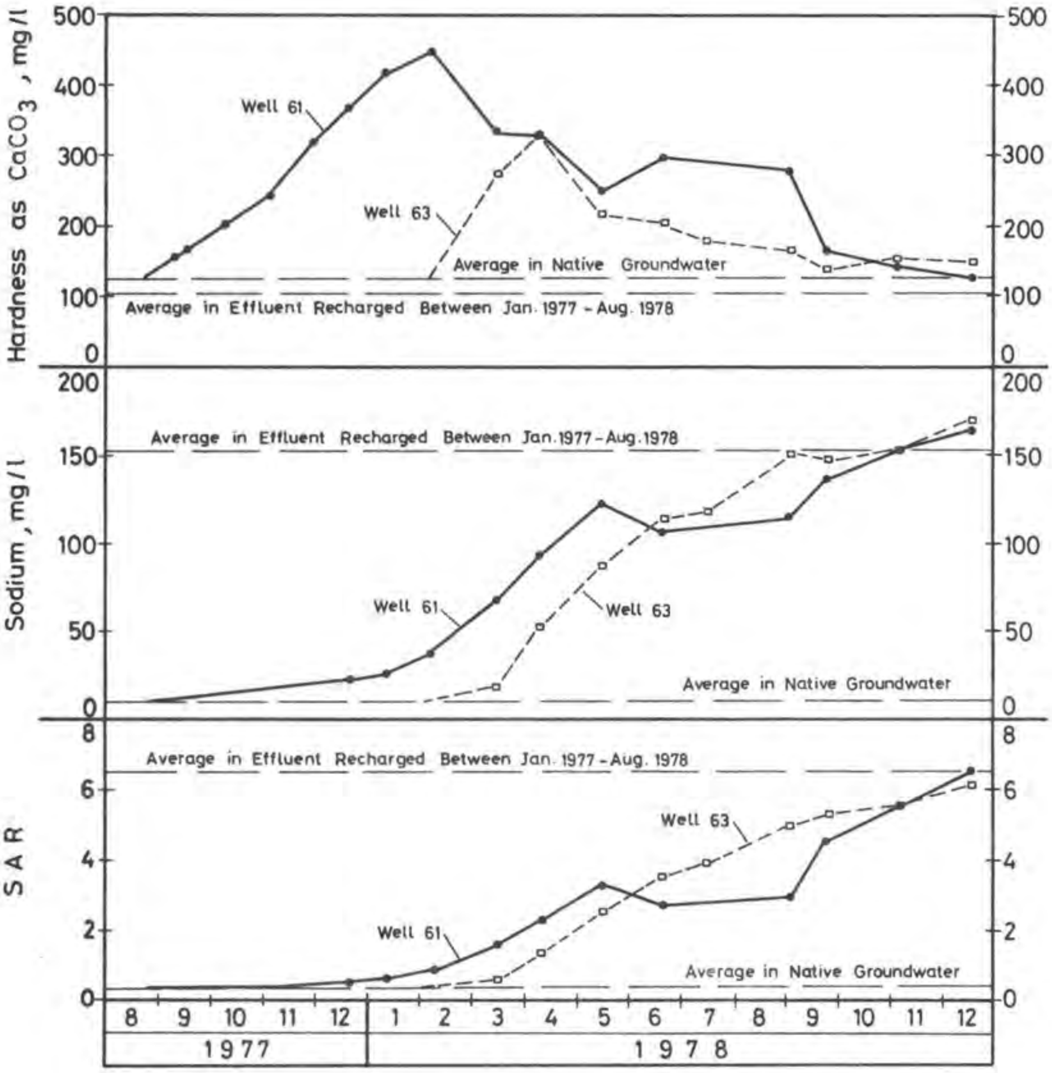

Fig. 11 Changes in Sodium, Hardness and SAR of Effluent by Groundwater Recharge

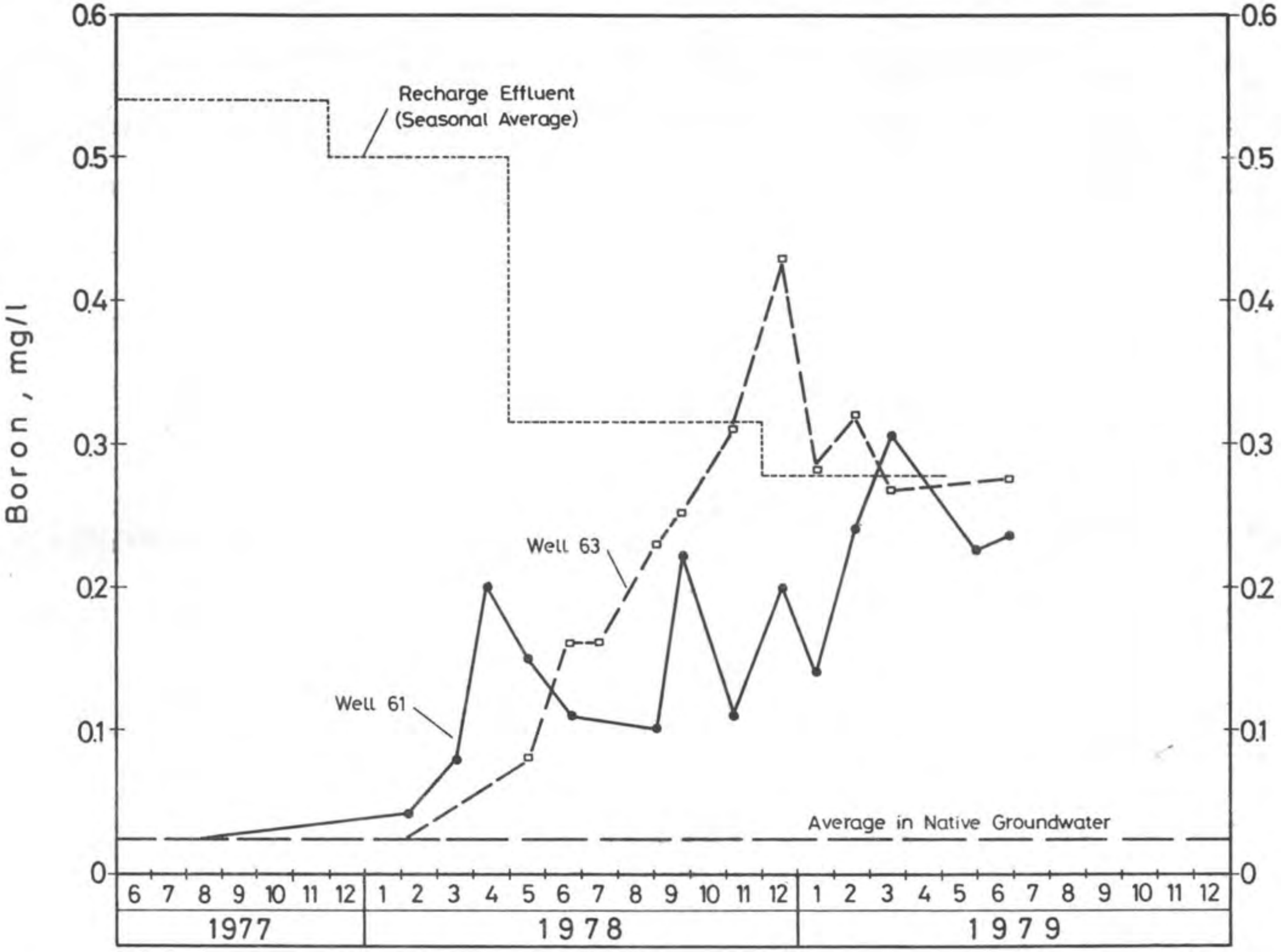

Fig. 12 Boron Removal from Effluent by Groundwater Recharge

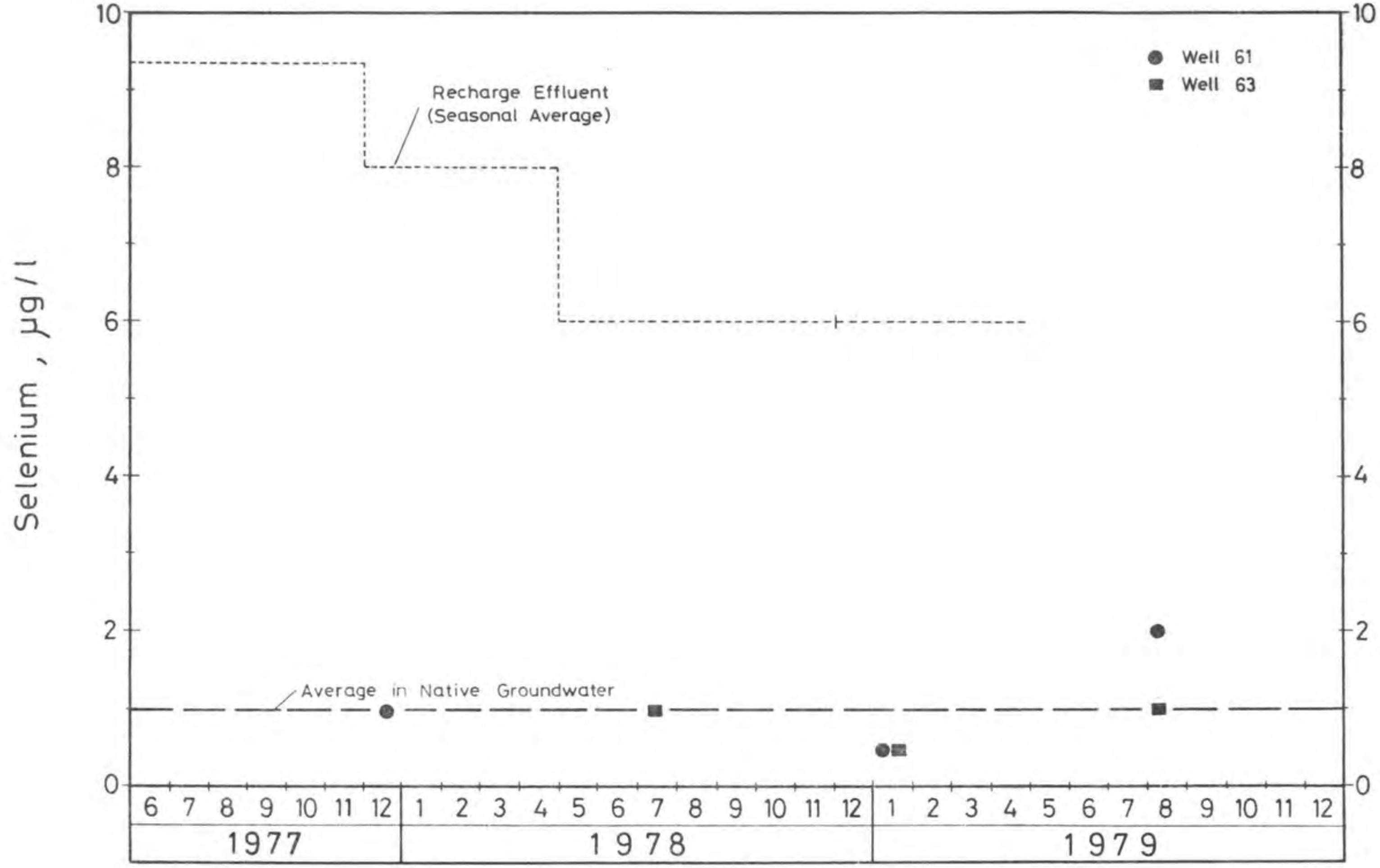

Fig. 13 Selenium Removal from Effluent by Groundwater Recharge