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High-Rate Recharge of Ground Water by Infiltration

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14

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High-Rate Recharge of Ground Water by Infiltration

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THE need for study and solution of the problem of high-rate ground water recharge by infiltration has been encountered in Peoria, Ill., where approximately 60 mgd of ground water is pumped from glacial drift and alluvium above an impervious shale bedrock. As a result of this pumpage, ground water levels have been receding at such a rate that in the industrial area today they are about 20-25 ft below the pool level of the Illinois River. Wells located on territory with high bedrock are already dry or much reduced in their yield. From the recession measured over 10 years of close observation, it was estimated that pumpage in excess of the natural recharge was about 8-10 mgd. The Illinois River, which has a bottom that is highly silted, contributes nothing to the recharge at the regulated-pool stage and only little during floods.

Relief Measures

Several measures were available to reduce or compensate for the overpumpage, and even to build up a reserve for municipal and industrial growth. Possible measures for the reduction of ground water pumpage included replacement of ground water by river water, and recirculation of used ground water (including eventually conservation by means of cooling towers). Development of new well fields and new recharge techniques was also considered.

Although industrial pumpage was successfully reduced, part of the benefits thus achieved was offset by an increase in municipal pumpage. Nor did the development of new well fields prove a feasible relief measure. Although new well fields of high yield do exist in the neighboring area, they are either too remote or else yield water of unfavorable composition (high in iron and manganese). The water of the deeper bedrocks is likewise unsuitable because of high salt content and the presence of hydrogen sulfide.

Artificial recharge was, therefore, considered an important remedial measure. Only the water of the Illinois River is useful for this purpose. The side creeks are flashy and sometimes nearly dry, whereas the river has a minimum flow of about 5,000 cfs.

The quality of the Illinois River water has been thoroughly studied. Locally this river water still has, in general, a bad reputation, derived from conditions existing 30-40 years ago, when the river was badly polluted and void of game fish. For the last 20 years, however, the river has been appreciably cleaner. The dissolved-oxygen content never goes below 5.0

ppm and is often at saturation level. The bacterial count is normally about 26,000 per milliliter, and it was found that, above the town, about 3 per cent of the 1-ml sample tubes have no *Esch. coli.* The turbidity is less than 100 ppm for an average of 300 days per year. After consideration of these data and the cost of fitration, it was decided to try artificial recharge using chlorinated river water.

In studying the known methods of recharge, however, it was found that considered an important possibility, and efforts were subsequently made to determine the suitability of the raw water and the design of the pit required.

When, in 1947, funds became available for a hydraulic laboratory in Peoria, engineers found a lot bordering the Illinois River, on which a small recharge pit could be built. Through the Peoria Association of Commerce, local industries contributed about $75,-000 for the construction of a larger pit

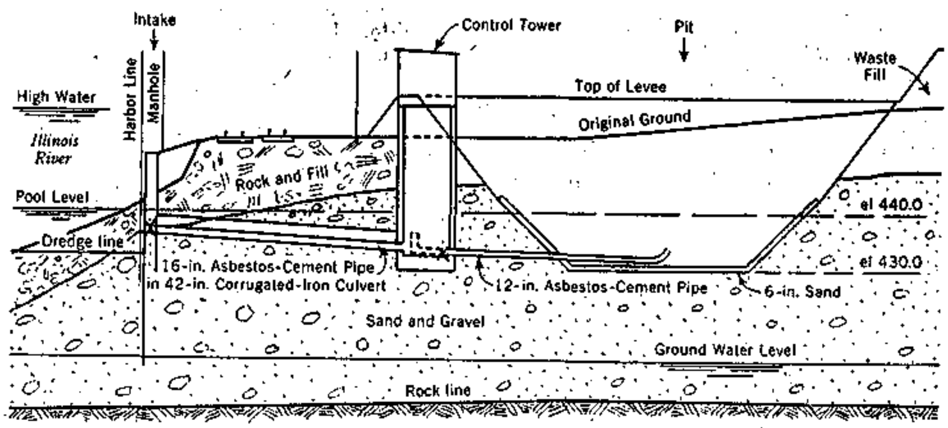

Fig. 1. Profile of Recharge Pit

In the fourth season of operation (1954-55) the sand filter material was replaced with 4-5-mm pea gravel, more than doubling total infloiv per season.

insufficient ground was available for filtration operations at the common rate of 0.5 mgd per acre. The need for considering possible means of achieving a higher rate of recharge was evident.

Some preliminary tests made in 1941 in an abandoned gravel pit on a local industrial property showed that, with a pumping rate of 1,400 gpm, infiltration rates of 37 mgd per acre could be obtained. This was in clean gravel, with less than 0.5 per cent passing a 200-mesh screen. As a result of these tests, high-rate infiltration was which could be employed not only for research but also, if successful, for recharging a commercially useful volume of water. It should be noted that the state of Illinois, although concerned, of course, that its industries have sufficient water, plays no part in furnishing it, but is active only through its contributions to research in this field.

Pit Design and Construction

It was hoped that a pit could be built to carry an average annual inflow of 1 mgd. As the pit was expected to operate only during the 6-7 months when the Illinois River water has a temperature of less than 60° F, the daily inflow during the operating season would have to be about 2 mgd.

Test drilling at the proposed site showed that the material was much more silty than that of the 1941 gravel pit, with 2.1 per cent passing a 200-mesh screen. The design, therefore, provides only for an inflow of 15-20 mgd per acre.

The pit, shown in profile in Fig. 1, has a 40 X 62½-ft bottom (2,500 sq ft) at an elevation of 430 ft, or 10 ft below the pool stage of the Illinois River. This is still 10-12 ft above the ground water level and allows inflow by gravity from the river. The slopes up to el 442 are 1:2 and have, as does the bottom, a 6-in. layer of filter material. The higher parts are at a 1:1.5 slope.

The intake consists of a sheet piling at the harbor line, as shown in Fig. 2, with a coarse screen and a 16-in. pipeline (with valve) to the control tower. The top of this pipe at the intake is 4 ft below pool level to avoid ice effects. The control tower contains chlorinating and measuring equipment, fine screens, and a valve.

During the operating season hourly water level readings are made on the river, at the control tower, and in the pit; river water temperature is recorded; and a small sample is collected for a composite chemical analysis and turbidity test. Dissolved oxygen is measured daily, and bacteriological tests are made 4 days a week. Temperature, DO, and chemical composition are also determined daily from a sampling of a well in the laboratory building. In addition, ten observation wells around the pit (from 50 ft to ½ mile distant) are equipped with level recorders, and four nearby industrial wells are also used for water level measurements. All these activities provide a record of the operation of the pit sufficient for research purposes.

Filtration Techniques

The pit has been in operation for four seasons and is ready for a fifth. During the first 3 years 1-ram sand was used as filtering material. This sand clogged considerably because of the silt in the river water and, in the first year, had to be replaced twice. Although this procedure was costly, it produced an average inflow of 1.78 mgd or a rate of 12.5 mgd per acre. In more recent years fresh filter material was introduced only before operating the pit. Cleaning with a swimming pool cleaner was attempted; the goal, of course, was to remove the silt, but not the sand. This required many adjustments of the bearing surface of the cleaner and of the rate of pumpage. In spite of all this work average rates of inflow of only 1.03-1.05 mgd were obtained. This is the equivalent of 7 mgd per acre, about half the designed rate.

A radical change was made in the 1954-55 season. Instead of sand, 6 in. of 4–5 mm pea gravel was used as filter material. Some engineers warned that it was too coarse to filter out silt, and no references to its previous use for filtration were found. Tests of this material, however, showed that a considerable reduction in turbidity occurs when water passes slowly through it. For each 1-mgd inflow into the pit, the velocity through the filter is only 0.012 fpm, which is the necessary slow flow. The use of pea gravel as filter material was a success, raising the average inflow to 308 mgd, or about 22 mgd per acre. This is the average for the whole season. The reduction of the normal inflow (excluding effects of floods) was only 12.5 per cent with the gravel, compared to 58 and 64 per cent experienced in seasons when sand was used.

Proof that the pea gravel removes the silt was also obtained by special tests made at the time of shutdown, when a thorough inspection was possible., It was found that the silt builds up a coat 1-2 in. thick on top of the pea gravel. Some silt penetrates the gravel but settles out mainly in the top layer; and no silt was found in the underlying original ground. As a quantitative test, 100 ml of the wet material from different layers at six different places in the pit was washed with distilled water. The wash passed through a 40-mesh screen, and the residue in the filtrate was weighed after evaporation.

The top silt contained 50.2 g of dry material, the top 2-in. layer of gravel 16.3 g, and the bottom 2-in. layer, 6.8 g. A saturated mixture, in which all pores in the gravel were filled with silt, held 20 g of dry material. These figures indicate that the top material still had open pores. Where the swimming pool cleaner had passed, the top 1 in. of gravel held only 2.4 g of dry silt.

Quality Control

In the first three seasons the chlorination dose averaged 8.8 ppm. This amount was used for safety, as it produced a water of satisfactory quality at the well. For economy, however, the least possible amount that would produce the desired result should be used. Applying chlorine at various rates showed that a water of satisfactory quality could be obtained with only 3 ppm chlorine. When only 2 ppm was used, the number of bacteria in the water at well No. 19 in the basement of the laboratory almost tripled. When no chlorine was used in a 3-day test period, the bacteria count increased considerably. A 10-ppm chlorine dose was used after this test to disinfect the soil and ground water.

Bacteria counts were also made on river water samples taken 4 days a week. The counts varied between 12,000 and 66,000 per milliliter with an average of 26,000. Some tests were made for *Esch coli.* In previous years, when a high chlorine dosage was used, *Esch. coli* could often be confirmed with BGB media; during the last season, however, when a smaller chlorine dosage was used, no such confirmation was found. Also of interest is the fact that, following a. period of rain and high turbidity in the river, the total bacteria count dropped after the first day or two, even though the turbidity remained high. Thus, high turbidity and high bacteria counts are not necessarily concurrent: rather, the first rain appears to flush a large number of bacteria into the river, but they soon die or are carried downstream.

Chemical tests demonstrate minor differences between river water and ground water, so that the effect of the recharge on the composition of the ground water cannot always be traced, especially such factors as hardness, alkalinity, sulfates, and chlorides. The river water contains dissolved oxygen, but the normal ground water does not. The first indication of an effect of the recharge is the disappearance of iron in the well water near the pit; later, some dissolved oxygen appears. After shutdown, the reverse process occurs.

Traces of residual chlorine were found occasionally during the period of operation, but these could not be correlated with the daily chlorine dosage. The highest residual chlorine (up to. 0.1 ppm) was obtained after shutdown of the pit.

Operating Procedures

It was originally planned to use the river water only when its turbidity was less than 100 ppm. During periods of higher turbidity, however, a shutdown not only causes an immediate loss of inflow, but also may prolong this loss by the freezing of ground in the emptied pit. On one occasion, a full month of operation was lost ,in this way. With the use of the cleaner, the high-turbidity clogging effect is reduced, and turbidity factors no longer require operating attention.

Special water level gages were developed for use in the pit. These read to 0.1 ft and have the 1-ft interval painted alternatingly red and white: thus, they can be read with certainty from long distances and during snow storms, even where set out in the water.

In the construction and preseasonal reconstruction of the pit, care must be taken not to compact the bottom. The construction must be done in a somewhat retreating way, so that no bulldozers or draglines need travel over the finished bottom; otherwise the soil may be compacted to a hard impervious material. In the first two years of operation, the Peoria pit bottom had to be loosened several times by blasting.

Clogging of the screens can occur easily. The fine well-screen is usually cleaned by a spray ring: however, when small dead fish lock in the slots of the screen, they cannot be removed unless the velocity through the slots is less than 0.6 fps. The best procedure then is to close the valve, remove the fish and resume operations: a task which can be done in 5 min.

From the hourly measurements taken, it was possible to plot the loss of head against the flow resulting from such shutdowns. The points show a wide spread, but also a limiting line. This line represents the minimum loss of head for a certain flow. Whenever a plotting falls on this line it indicates that all elements building up the loss of head—pipelines, bends, valves, screens, venturi tube, and so forth—are in perfect order. Unfortunately, few points fall on the line, and this is ordinarily an indication that the screens are partially clogged.

Comparison of Results

When comparing the operations during the various seasons, use can be made only of the average of the results in the second and third seasons, when sand was used as filter, and those of the fourth season, when pea gravel was used, as only these periods had uniform conditions.

Periods when the river level is above pool always cause an increase in the rate of recharge, although the reasons are not yet clear. For example, a 4-ft rise in the river nearly doubled the inflow, although causing only a 0.1-ft rise in the level in the pit. It is difficult to believe that this small rise in the pit level, which increased this wet area about 2 per cent, could cause an 82 per cent increase of the flow. Inasmuch as flood periods are completely irregular and beyond experimental control, comparisons of the various years have to be made carefully.

The average inflow in the second and third seasons was 1.04 mgd and the average total inflow per season **211** mil gal. In the fourth season an average inflow of 3.08 mgd and a total inflow of 508.4 mil gal were obtained. Of this increase, 87.5 mil gal was the effect of having the river level above pool level; 38.1 mil gal, the result of cleaning the pit with the swimming pool equipment; and 219.9 mil gal, due to the use of pea gravel instead of sand. Thus it can be seen that the use of pea gravel had the greatest effect on increasing the rate of flow.

The use of pea gravel alone, however, does not produce a high rate of recharge. Much of the effect was also due to the type of pit, in which the wet side area is larger than the bottom area. Some simple reasoning shows that only as much water can flow through the bottom and walls of the pit as can flow away from the pit unless there is a special collecting tunnel underneath, as in Des Moines. The flow through the sidewalls is nearly unrestricted, whereas the flow through one small section of the bottom is always under some backwater effect caused by the flow in the neighboring section. Thus, the larger the bottom area, the smaller the inflow per unit area through the bottom.

Experiments on a model show that this flow per unit area reduces almost proportionally to the square root of the area, whereas the flow through the walls is proportional to the wall area itself. High rates of inflow can therefore be obtained by pits with small bottom and large side areas—that is, with deep water. Tests on the model of the Peoria pit show that, under its conditions, three-fourths of the inflow occurs through the side areas, although these represent only two-thirds of the wet area. Flow through the bottom is equal to that which can flow away around its circumference. In a large bottom, it is probable that more water can infiltrate than can flow away; and in a very small bottom; that more water can flow away than can infiltrate. The ratio depends in part on the inflow facilities and the permeability of the soil. The highest rate, however, occurs when both flows are used to their maximum capacities—although the theoretical conditions for such a design have not yet been established. On the other hand, the flow through the sidewalls has a much smoother flow-away path and it is here that the entrance conditions govern the rate of inflow.

It is believed that a great part of the success obtained with pea gravel is due to its facilitation of the passage of water into the ground. How this is done is not yet clear, but it may be that it provides a suitable transition flow between the open water and the finely distributed ground water flow, and thus reduces entrance resistance.

Much more could be said, if space allowed—about the effect of ice, of algae, of temperature phenomena, and of the characteristics during emptying of the pit, as well as of other phases, all connected with the problem of high-rate recharge, either by reducing it or by verifying its effectiveness.

A recharge pit with the high rate of 20-25 mgd per acre was achieved in Peoria. Much has been learned of the methods by which this was accomplished, but much also cannot yet be explained. It is hoped that future investigations may help to further understanding.