Experiments in Water Spreading at Newark, Delaware

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1594-B

Prepared in cooperation with the city of Newark and the Delaware Geological Survey

Boggess and Rima—EXPERIMENTS IN WATER SPREADING AT NEWARK, DEL.—Geological Survey Water-Supply Paper 1594-B

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By DURWARD H. BOGGESS *and* DONALD R. RIMA

ARTIFICIAL RECHARGE OF GROUND WATER

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1962

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

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By Durward H. Boggess and Donald R. Rima

ABSTRACT

Two experiments in water spreading were made at Newark, Del., to evaluate the prospects of using excess storm runoff to recharge the shallow water-table aquifer which serves the community. Water was diverted from 1 of the city's 3 production wells and released into an infiltration ditch near the municipal well field.

Although slightly more than 65,000 cubic feet of water (nearly 500,000 gallons) was spread in the infiltration ditch and allowed to seep into the subsurface, there was no indication that any appreciable amount of water reached the producing aquifer. Instead, a perched zone of saturation was created by the presence of an impermeable or slightly permeable bed above the water table. So effective is this barrier to the downward movement of water that within a period of less than 1 day, the apex of the perched zone rose about 10 feet to the level of the bottom of the infiltration ditch. As more water was added, the mound of saturation spread laterally.

On the basis of these experiments, it appears that the principal aquifer at Newark, Del., would not be benefited by spreading water in shallow infiltration ditches or basins. However, the absorptive capacity of the unsaturated materials which occur at a shallow depth, is sufficient to permit the disposal of large volumes of storm runoff.

INTRODUCTION

The city of Newark, Del., is faced with both a water surplus and a water shortage. This seemingly paradoxical situation stems from the city's need to dispose of large volumes of water from storm runoff, and at the same time, to obtain additional supplies of potable water to offset the effects of declining water levels in the Academy Street well field, the city's principal source of water supply in 1960. A seemingly logical solution to these difficulties would be to use the water from storm runoff to recharge the ground-water reservoir tapped by the municipal wells. Presumably, this could be accomplished by any one of a variety of methods of artificial recharge now in use in the United

States. The simplest procedure, however, would be to impound storm runoff in a shallow basin in the vicinity of the well field and to allow the water to infiltrate into the subsurface. This method of artificial recharge is called water spreading, and it is used successfully in areas where the earth materials through which the water must pass are fairly permeable.

To determine whether water spreading could be used successfully in the Newark area, an investigation was made by the U.S. Geological Survey in cooperation with the city of Newark and the Delaware Geological Survey. The investigation consisted of two experiments in which water was spread in a shallow ditch in the immediate vicinity of the Academy Street well field and allowed to seep into the subsurface. The objectives of the experiments were to determine (1) the recharge rate or rate of water entry into the ground and (2) the effects of recharge from the ditch on ground-water levels in the Newark well field. The results of these experiments are summarized in this report.

PREVIOUS EXPERIMENTS

In 1959, tests were made near the Academy Street well field (Groot, 1960) to determine the infiltration rate or the maximum rate of water entry into the subsurface. In these tests a double-ring infiltrometer was set at a depth of 3 feet beneath the land surface, and measurements of infiltration were made for a 20-day period. The results of these tests showed that the infiltration rate of the materials immediately underlying the surficial silt layer at the test site ranged from 2 to 8 feet per day. From this evidence it was concluded that the materials at shallow depth in the vicinity of the Academy Street well field were sufficiently permeable to absorb large volumes of water. It was realized, however, that a larger scale test would be needed to confirm the assumption that the infiltration rate as measured by an infiltrometer would be approximately equal to the recharge rate from a shallow basin at the same site.

ACKNOWLEDGMENTS

The writers are indebted to Mr. J. F. Neide, city manager, Mr. B. J. Campagna, public-works director, and Mr. R. L. Williams, waterworks superintendent, of the city of Newark for their generous donation of time, equipment, and facilities which materially aided in the successful completion of the experiments.

WATER SPREADING

DEFINITIONS

Water spreading is defined as the releasing of water over the ground surface for the purpose of increasing the quantity of water infiltrating into the ground and percolating to the water table (Todd, 1959, p. 252). It can be accomplished by flooding or spraying a tract of land, by impounding water in shallow excavations, or by damming and widening a natural stream channel. Essentially, water spreading supplements natural recharge by increasing the quantity of water available for recharge or extending the period of time that water is in contact with the soil.

The effectiveness of water spreading as a means of artificial recharge is largely dependent upon the permeability of the materials through which the water must pass in its downward movement to the water table. From a quantitative standpoint, however, the size of the spreading area, length of time that water is in contact with the soil, and the amount of suspended material in the water and its chemical quality are also important factors. In practice, the least permeable layer through which the water must pass will generally control the rate of downward movement of water, and the dimensions of the spreading basin and period of inundation will determine the volume of water that reaches the water table and becomes recharge.

Various terms are used to describe the seepage or downward movement of water into the ground. Infiltration refers to the downward entry of water into the ground. Infiltration rate is defined by Richards (1952, p. 85) as:

> the maximum rate at which the soil will absorb water impounded on the surface at a shallow depth when adequate precautions are taken regarding border or fringe effects. Defined as the volume of water passing into the soil per unit of area per unit of time it has the dimensions of velocity, (LT^{-1}).

As thus defined, the term "infiltration rate" is a maximum rate and applies only to the movement of water into the ground under a hydraulic gradient of 100 percent. Moreover, it can be shown that a gradient of 100 percent occurs only while the water entering the ground is moving directly downward. Should divergent flow occur, the prevailing hydraulic gradient would, of necessity, be less than 100 percent; hence, the rate of water movement would be less than the maximum. Under these latter conditions, the rate of movement of water into the ground is called infiltration velocity. Infiltration velocity is defined by Richards (1952) as the rate of water entry into the ground expressed as a depth of water per unit of time. It should be noted that both infiltration rate and infiltration velocity are usually reported in the same terms, such as inches per hour or feet per day (LT^{-1}).

DESCRIPTION OF TEST SITE AND FACILITIES

The site which was used for making the experiments described in this report is on the northeast side of the Academy Street well field (pl. 1). It is underlain to a depth of about 70 feet by unconsolidated sediments of Cretaceous and Pleistocene age, and at greater depths it is underlain by hard crystalline bedrock of Ordovician age. The unconsolidated sediments consist chiefly of permeable beds of medium- to coarse-grained sand and gravel that are separated by less permeable beds of silt or clay. Although the unconsolidated sediments are poorly sorted, they are considerably more permeable than the underlying bedrock, hence, the municipal wells are screened opposite the unconsolidated sediments, particularly in the lower part.

To prepare the site for the water-spreading experiments, an infiltration ditch was excavated by means of a front-end loading machine owned by the city of Newark. Upon completion, the ditch was 142 feet long and had an average width of 6.7 feet and an average depth of 4.7 feet. As shown in plate 1, the ditch was oriented nearly parallel to the contour lines on the water table. The side walls of the ditch were vertical to maintain a constant size for the area of inundation in order to simplify the analysis of the results. About 550 square feet or 60 percent of the bottom of the ditch was composed of a fairly permeable but poorly sorted mixture of reddish-brown sand and coarse gravel. The remaining 40 percent of the bottom consisted of a wedge of relatively impermeable gray clayey silt which thickened northward to about 2 feet at the north end of the ditch. The same type of material was exposed in the side walls of the ditch.

A network of 11 observation wells was used during the investigation to provide data on water-level fluctuations. The locations of these wells are shown on plate 1, and the pertinent details about the wells are given in table 1. Three of the wells (Ca55–1, Ca55–2, and Cb51–1) were used to record water-level fluctuations in the immediate vicinity of the pumping wells. The remaining eight wells, Cb51–26 through –33, were used to observe the fluctuations of water levels in the vicinity of the infiltration ditch. Wherever possible, water-level data were obtained by the use of continuous water-stage recorders, and elsewhere measurements of water level were made with a steel tape.

All the observation wells except Cb51–32 and –33 were screened in the water-bearing zone tapped by the pumping wells in the municipal well field. Wells Cb51–32 and –33 were screened in the unsaturated zone above the water table.

Facilities for transporting the water to the infiltration ditch consisted of a firehose (2½ inches inside diameter) which was connected to the discharge line from production well Ca55–5. A meter was used to record the volume of water diverted through the firehose to the ditch. The discharge end of the firehose was placed in a 55-gallon drum that was set on a latticed platform in the bottom of the ditch. Holes were punched in the bottom of the drum to disperse the force of the water entering the ditch (fig. 1). A water-stage recorder was installed over a stilling well in the ditch to record changes in water level in the ditch. As shown in figure 2, the entire ditch area was enclosed with a storm fence as a safety measure.

FIGURE 1.—Closeup view of infiltration ditch after first period of water spreading.

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FIGURE 2.—Northwest view of infiltration ditch during first period of water spreading.

TABLE 1.—*Record of wells*

Well No.	Driller	Year completed	Altitude of measuring point (feet)	Method of construction	Diameter of casing (inches)	Total depth (feet)	Length of screen (feet)	Remarks
Ca55-1	Ridpath & Potter	1906	106	Drilled	6	71.8		Observation well.
Ca55-2	do	1918	108	do	8	70.3		Do.
Ca55-3	American Well Drilling Co.	1920	109	do	10	64.5		Production well, yield 187 gpm, Feb. 1951.
Ca55-5	do	1931	102	do	16	63.5		Production well, yield 304 gpm, Feb. 1951.
Cb51-1	Ridpath & Potter	1917	104	do	8	66.9		Observation well.
Cb51-2	American Well Drilling Co.	1920	103	do	10	62		Production well, yield 166 gpm, Feb. 1951.
Cb51-26	U.S. Geol. Survey	1959	100	Bored	1	49.8	2.5	Observation well.
Cb51-27	do	1959	99	do	4	32	4	Do.
Cb51-28	do	1959	97	do	1	34	2.5	Do.
Cb51-29	do	1959	97	do	1	34.1	2.5	Do.
Cb51-30	do	1959	98	do	1	32.8	2.5	Do.
Cb51-31	do	1959	99	do	1	29.8	2.5	Do.
Cb51-32	do	1960	99	Hand auger	1	13.8	1.5	Observation well to check extent of lateral spreading.
Cb51-33	do	1960	99	do	1	9.2	1.5	Do.

A standard 8-inch rain gage was placed near the north end of the infiltration ditch to record the amount of precipitation. An evaporation pan at the University of Delaware farm about 900 feet south of the infiltration ditch (outside area of pl. 1) was used to obtain data on evaporation.

FIRST EXPERIMENT

The first water-spreading experiment was made during the 13-day period starting at 10:15 a.m. on May 24, 1960, and ending at 6:30 p.m. on June 5. After the initial filling of the ditch, water was added daily to insure that the bottom of the ditch was covered at all times, but no attempt was made to maintain a constant water level. Over this period more than 19,400 cubic feet of water was released into the ditch from well Ca55–5. In addition, a total of 1.09 inches of rain fell during thunderstorms on May 25 and May 29. This added 86 cubic feet of water to the ditch and raised the total volume of water that was used to about 19,500 cubic feet. Throughout this experiment the wetted portions of the side walls of the ditch crumbled and fell into the ditch. Some of the material was immediately taken into suspension and later settled out to form a thin layer of silt over the bottom of the ditch.

SECOND EXPERIMENT

On June 15, 1960, the material which had fallen into the infiltration ditch was removed, and, in addition, the ditch was deepened to remove the relatively impermeable wedge of clayey silt beneath the northern part of the ditch. Following this cleaning and deepening operation, the ditch was 137 feet long and averaged 6.8 feet in width and 5.8 feet in depth. The increased depth of the excavation exposed the reddish-brown sand and gravel mixture throughout the entire length and width of the ditch and in the side walls of the southern end of the ditch. The exposure of permeable materials in the side walls of the southern end of the ditch added about 140 square feet to the total infiltration area. As a result, the area of permeable materials exposed in the ditch was increased to 1,070 square feet, almost twice as much permeable materials as was exposed during the first experiment.

The second experiment was continued for 16 days beginning at 2:15 p.m. on June 15, 1960, and ending at 5:15 p.m. on June 30, 1960. One of the purposes of the second experiment was to determine if the increased size of the area of permeable materials exposed in the ditch had any effect on the infiltration velocity. Another purpose was to determine if, under the prevailing conditions, changes in the infiltration velocity were related to changes in the height of water in the infiltration ditch. The water level in the ditch was, therefore, allowed to fluctuate through a wider range than it was in the first test. During the second experiment, more than 45,600 cubic feet of water was added to the ditch. Although erosion of the side walls continued during the second experiment, it occurred at a much slower rate than before.

For this reason it is believed that computations based on data gathered in the second experiment are more reliable than those based on data from the first experiment.

RESULTS

EFFECTS OF WATER SPREADING ON WATER LEVELS

Water levels in the nine observation wells that tap the producing aquifer showed little or no evidence of recharge over the period of the two experiments. Instead, fluctuations of the water level in all nine wells consistently paralleled the changes in water level caused by pumping. This is evidenced by the hydrographs shown on figure 3. The hydrograph for well Cb51–1, which is about 5 feet from production well Cb51–2, most nearly reflects the changes in water level in the pumping wells. As shown in figure 3, similar fluctuations are recorded by the hydrographs for wells Cb51–26, –27, and –28 even though these wells are close to the infiltration ditch (pl. 1). Further proof can be found by comparing the hydrographs of these wells with the fluctuations of the water level in the infiltration ditch (fig. 3).

On the other hand, it will be noted from figure 3 that the water level in both the shallow observation wells, Cb51–32 and –33, fluctuated directly in response to the fluctuations of the water level in the infiltration ditch. Well Cb51–33, which is about 3 feet from the infiltration ditch, contained no water at 11:15 a.m. on May 24, 1960, 1 hour after the first period of water spreading began. A subsequent measurement at 2:00 p.m. showed that the well contained 1.1 feet of water. Well Cb51–32, which is about 12 feet from the infiltration ditch, remained dry during this same period; but at 8:30 a.m. on May 25, about 22 hours after spreading began, the well contained 1.8 feet of water. Both wells contained water over the remaining period of the first test as shown in figure 3. In the second experiment, after deepening the ditch, both wells contained water within 8 hours of the beginning of the test. The water level in well Cb51–33 fluctuated at a height above the bottom of the ditch for most of the second test period, while the water level in Cb51–32 rose to a height above the bottom of the infiltration ditch only during the latter part of the second experiment.

The presence of water in the two shallow observation wells, Cb51–32 and –33, indicates that a part of the permeable zone immediately beneath the infiltration ditch must have become saturated with water very early in each of the tests. Moreover, when the water level in well Cb51–33 rose to a position above the bottom of the infiltration ditch, it was assumed that conditions of saturated flow existed. This is further confirmed by the similarity between the fluctuations of water level in the ditch and those in the shallow observation wells (fig. 3).

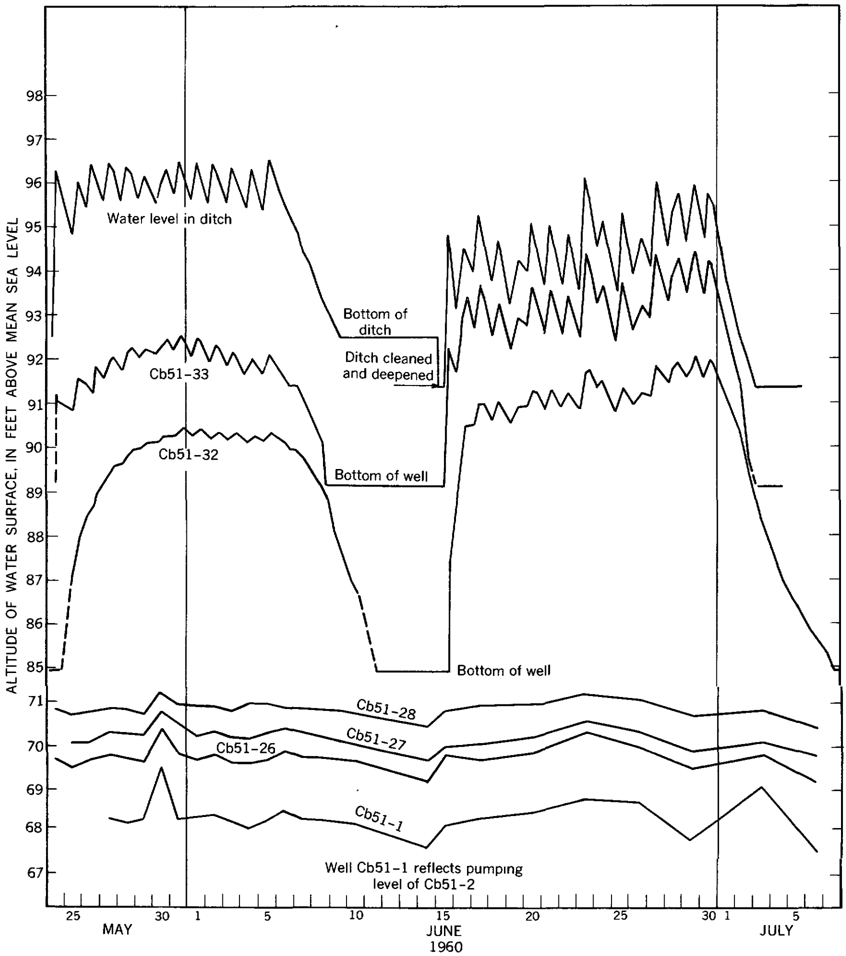

Figure 3.—Fluctuations of water levels in the infiltration ditch and in six selected observation wells during the periods of water spreading.

Throughout both experiments a considerable difference in head was observed between the 2 shallow observation wells and the other 9 observation wells that tap the producing aquifer. This difference suggests the presence of a barrier or partial barrier to the movement of water between the two zones tapped by the respective groups of observation wells. From this evidence and from a scrutiny of the lithologic logs of the observation wells, it was concluded that a relatively impermeable bed is present in the subsurface as shown in figure 4. Considering the nature of the sediments involved, it appears likely that the decreased permeability of the barrier or partial barrier zone is due to the presence of an increased amount of silt or clay in that zone. As evidenced by the well logs for wells Ca55–1, –2, –3, –5, and Cb51–1 and –2, the zone of low permeability extends throughout the well field and apparently thickens toward the west. Nevertheless, the presence of this zone of low permeability prevented or, at least, slowed the downward movement of water from the infiltration ditch. This created a perched zone of saturation as shown in figure 4.

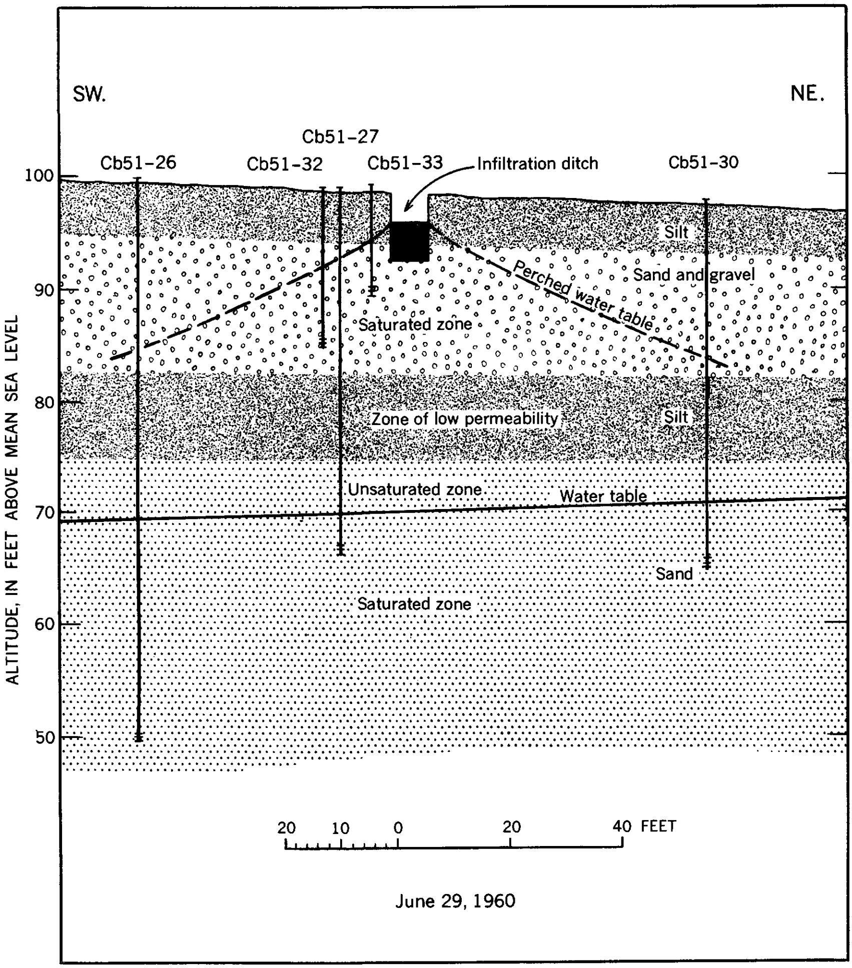

FIGURE 4.—Generalized cross section of the infiltration ditch area showing the upper and lower zones of saturation on June 29, 1960. Line of section shown on plate 1.

INFILTRATION VELOCITY

The daily infiltration velocities computed for the two experiments are shown in figure 5. As previously mentioned, infiltration velocity refers to the prevailing rate of water entry into the soil and is expressed as a depth of water per unit of time. It differs from the infiltration rate which is defined as the maximum rate of water entry into the soil. As the prevailing rate is only equal to the maximum rate when divergent flow or the lateral movement of water is negligible, the rate of water movement into the subsurface should be expressed in terms of infiltration velocity when divergent flow is known to occur. Because flow was divergent during the Newark experiments, the results are expressed as infiltration velocity.

Infiltration velocity can be determined by two basic methods. It can be determined simply by measuring the rate of subsidence of the water surface in an infiltration basin. This method, however, does not take into account such factors as the loss of water by evaporation, the addition of water from precipitation, or the changes in the size of the infiltration basin as the water surface descends. It is, generally, an unreliable index to the rate of water entry into the ground. A second method of determining infiltration velocity involves the use of the same formula as that used in computing infiltration rates, namely,

$$I_v=\left(\frac{V}{A}\right)T^{-1}$$

where:

I_v=infiltration velocity, in feet per day;
V=volume of water seepage, in cubic feet;
A=area of infiltration, in square feet;
T=time, in days.

To differentiate between the values obtained from these two basic methods in this report, the term "apparent infiltration velocity" is applied to measurements of the rate of subsidence of the water surface, and the term "specific infiltration velocity" is used for the results obtained from the equation.

Several refinements of the field data were necessary before the equation could be used to calculate daily specific infiltration velocities. To determine the volume of seepage, the volume of water entering the ditch was corrected by adding the amount of water gained from rainfall to the metered volume of water released in the ditch, and then subtracting from the total the amount of water lost by evaporation. Further adjustments were made for the differences in the volume of water stored in the ditch and for the apparent changes in the volume of the ditch that were due to the caving of the side walls.

The latter adjustment was determined from the magnitude of abrupt rises in the water level which were recorded by the stilling well recorder when large sections of the side walls slid into the ditch.

The size of the infiltration area was assumed to be equivalent to the area of exposure in the ditch of the permeable sand and gravel. As previously reported, in the first experiment, the area of exposure of the permeable materials in the ditch was 550 square feet, approximately 40 percent less than the area of the ditch bottom. In the second experiment the deepening and widening of the ditch exposed the permeable sand and gravel mixture throughout the entire bottom of the ditch and in a thin wedge-shaped section of the side walls. This effectively doubled the size of the exposure of permeable materials and correspondingly doubled the effective size of the area of infiltration.

As shown in figure 5, these adjustments resulted in the calculation of comparable values for daily specific infiltration velocities for both periods of water spreading. The values for specific infiltration velocities, which are shown in figure 5, are consequently, presumed to be a fairly reliable index of the absorptive capacity of the permeable sand and gravel mixture under the prevailing field conditions.

Figure 5 also shows the relation between the daily specific infiltration velocities and the corresponding daily averages of the depth of water in the ditch. In general, a rise in the average daily water level in the ditch resulted in an increase in the specific infiltration velocity. This is particularly evident from the graphs of the second experiment when the water level in the ditch fluctuated through a wider range than it did during the first experiment. Another feature which is evident from the results of the second experiment (fig. 5) is the dissimilarity of the overall trends of the graphs for water depth and infiltration velocity. Even though the graph of the average depth of water in the ditch shows an upward trend, the graph of daily infiltration velocities shows a downward trend. This is attributed to the gradual silting of the bottom of the ditch and possibly to increased bacterial action as the test progressed.

SUMMARY AND CONCLUSIONS

The infiltration of more than 65,000 cubic feet of water in the ditch area, over the period of the two experiments, would have saturated a considerable volume of earth materials. The minimum volume, if one assumes an effective porosity of 40 percent, would be about 163,000 cubic feet. This is more than enough to have caused a noticeable rise in water levels in the producing aquifer, especially in the area beneath the infiltration ditch. The fact that water levels in the

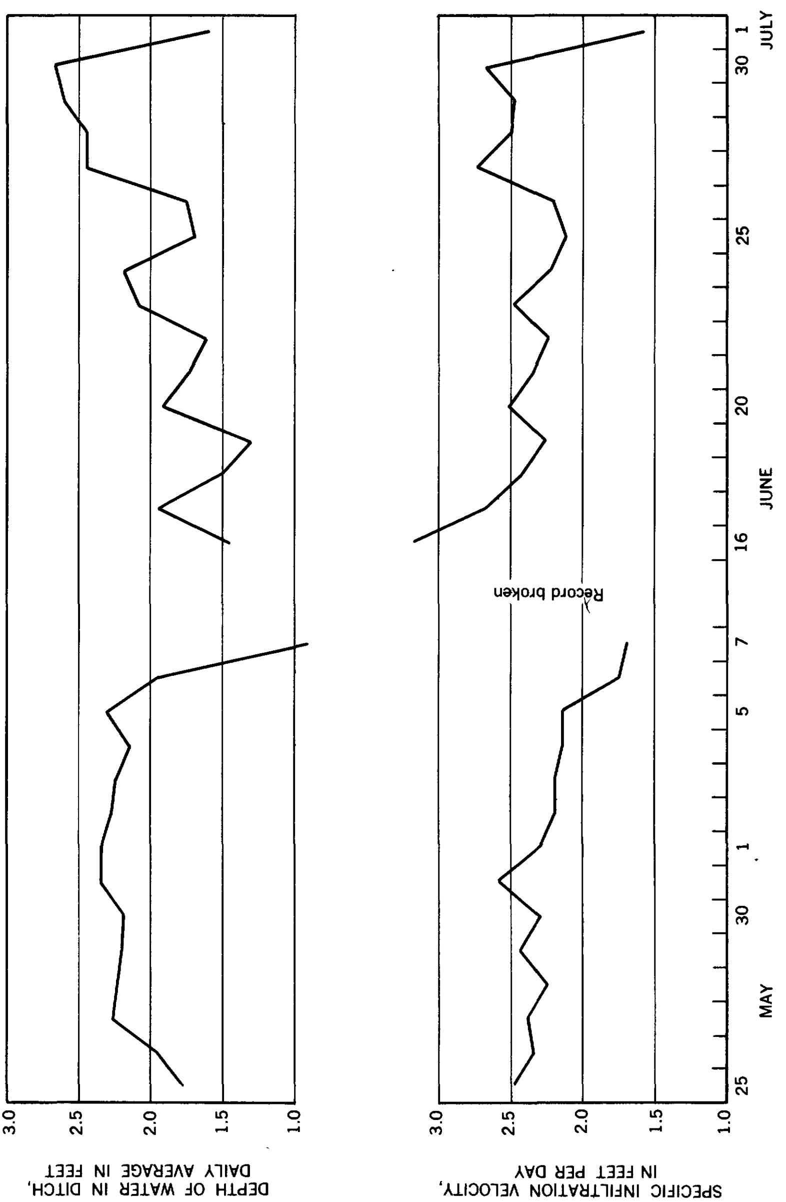

FIGURE 5.—Graph showing the relation between the daily average depth of water in the infiltration ditch and the corresponding specific infiltration velocities.

producing aquifier did not rise perceptibly indicates that no direct hydraulic connection exists between the shallow infiltration ditch and the producing aquifer at the Academy Street well field.

The existence of a barrier between the permeable sand and gravel mixture at shallow depth and the producing aquifer at the Academy Street well field makes it unlikely that water impounded on the surface would infiltrate to the producing aquifer in sufficient quantities to benefit the producing wells in the municipal well field. This, however, does not preclude the possibility or feasibility of using other methods. On the contrary, any method that involves breaching the barrier between the upper and lower permeable zones is worthy of consideration. Recharge wells have been used successfully in many areas and many have application in the Newark area. Gravel backfilled shafts similar to those used near Minter Field, Calif. (Schiff, 1955, p. 1015) may also prove to be a successful means of artificial recharge.

Another method which might prove successful in the Newark area is the use of open recharge pits or shafts similar to those used in Peoria, Ill. (Suter and Harmeson, 1960). This method consists of the construction of a rectangular pit of sufficient depth to encounter aquifer materials at the bottom. At Newark, the top of the producing aquifer is at a depth of about 25 feet in the vicinity of the Academy Street well field.

Perhaps a combination of two or more recharge methods could be developed which would offer a reasonable solution to both the problem of disposing of storm runoff and of recharging the well field. For example, a shallow basin could be used to store excess storm runoff both on the land surface and in the permeable sand and gravel bed which occurs at shallow depth below the land surface. Within the impounding basin, one or more recharge shafts could be constructed to expose the top of the producing aquifer and allow water from the surface and from the sand and gravel bed to infiltrate through the recharge shaft and into the producing aquifer below. This combined method would have the advantage of storing the maximum volume of excess storm runoff, which would assure the maximum benefit to the producing wells from artificial recharge.

Water spreading might be used successfully to dispose of excess storm runoff even though it would not solve the water-supply problem. The permeable sand and gravel zone that occurs at shallow depth could serve as a temporary storage reservoir for storm runoff. The volume of runoff that could be accommodated in a given period of time would be governed by the permeability of the sand and gravel zone and the size of the effective area of infiltration. From the results of the experiments reported herein, the permeability of the sand and gravel zone at the infiltration site is sufficient to accommodate from 2 to 3 cubic feet of water per day per square foot. By extension, it can be shown that each acre of exposure would accommodate from 1 to 1½ cubic feet per second (450 to 680 gpm) if the sand and gravel zone is fairly uniform throughout its extent in the Newark area. Although most of the water that seeps into the shallow sand and gravel zone would eventually discharge at the surface along present surface drainage channels, the water would move through the ground at a very slow rate. The overall effect would be to reduce peak flows and increase base flows of local streams and thus avoid the flash floods caused by excess storm runoff.

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U.S. GOVERNMENT PRINTING OFFICE: 1962 O—649967