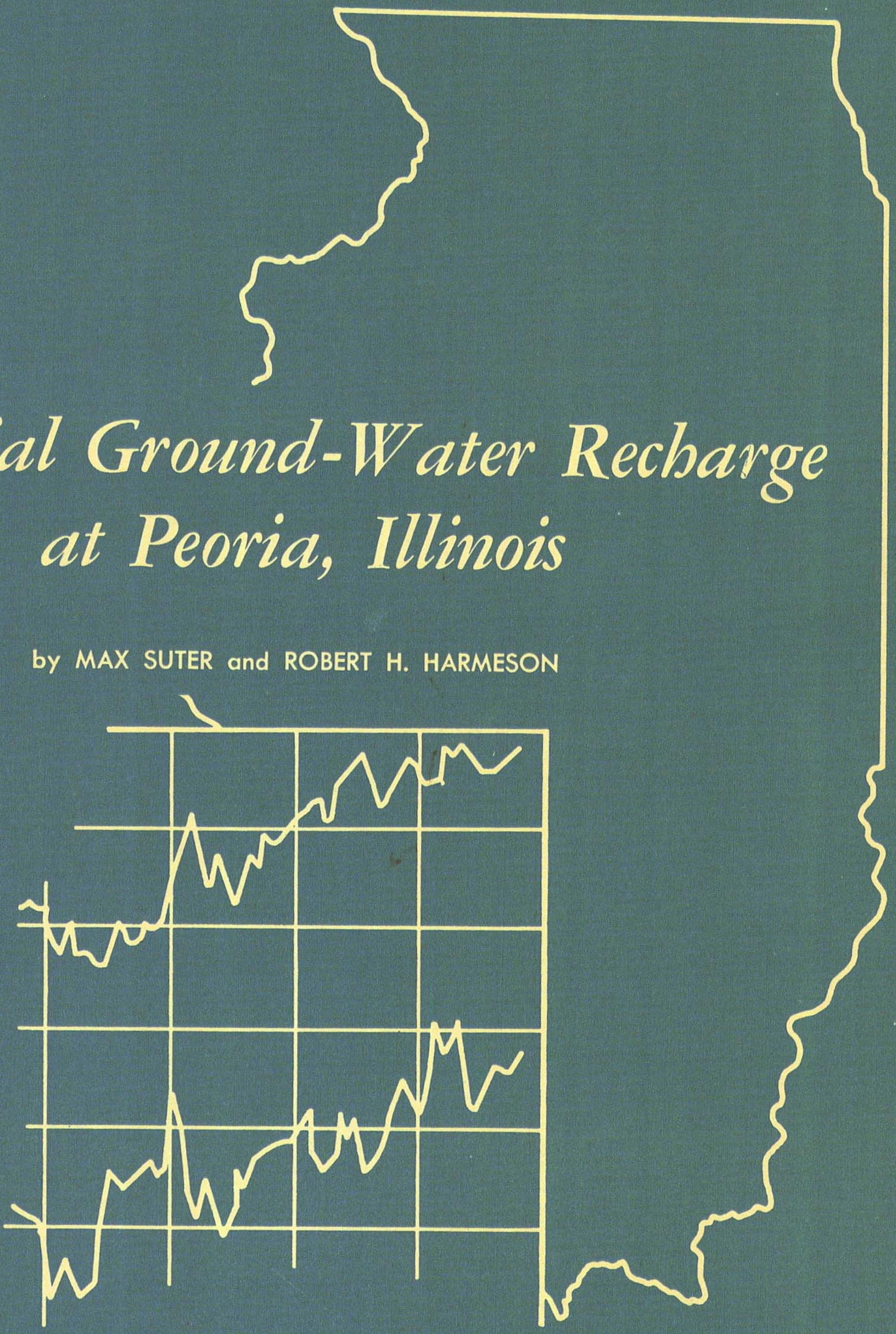
BULLETIN 48

STATE OF ILLINOIS
WILLIAM G. STRATTON, Governor

DEPARTMENT OF REGISTRATION AND EDUCATION
VERA M. BINKS, Director



Artificial Ground-Water Recharge at Peoria, Illinois

by MAX SUTER and ROBERT H. HARMESON

ILLINOIS STATE WATER SURVEY
WILLIAM C. ACKERMANN, Chief

URBANA
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Printed by authority of the State of Illinois

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ABSTRACT

This report summarizes research and demonstration of the pit method of artificial recharge at Peoria and its contribution to solution of the problem of declining ground-water levels. Excessive withdrawals from the glacial drift aquifer at Peoria had resulted in progressive decline of the ground-water levels and remedial measures were urgently needed.

Ground-water resources at Peoria are developed from three well fields and must meet the demands of the municipal supply as well as a variety of major water-using industries. Prior to 1959, most water needs were furnished from these ground-water resources. Since that time treatment facilities have been developed for direct use of water from the Illinois River.

Described in this report are the types of recharge pits and operating techniques developed by the Illinois State Water Survey and those which were built by local industries. Summaries of operating records over an eight-year period show capacity and cost information.

ARTIFICIAL GROUND-WATER RECHARGE AT PEORIA

by Max Suter and Robert H. Harmeson

INTRODUCTION

The City of Peoria in central Illinois is located in an urban area which is rich in water resources. Included in the area are Peoria, Peoria Heights, East Peoria, Creve Coeur, and Bartonville. The water resources support a population of approximately 150,000 as well as an industrial concentration of distilleries, breweries, and manufacturers of earth-moving equipment, steel products, and chemicals. All these industries use large volumes of water and many of them require low-temperature water for their processes.

Population growth together with increasing per capita consumption of water, vigorous industrial development, and the requirement for low-temperature water contributed to the creation of a water shortage despite the large resources. The Illinois River, which flows through this metropolitan area with a minimum recorded flow of 2300 cubic feet per second (cfs), was used only to a limited extent as a source of water, owing to its traditional pollution and its high temperatures during the summer. The Peoria Water Works Company and most of the industries used ground water from the local alluvial and glacial deposits.

As a consequence of the ever-increasing demand for low-temperature ground water, the water levels in well fields receded steadily because pumpage exceeded replenishment by natural recharge and, by 1940, had reached such an alarming level that the Water Survey Division was requested to make a study of the situation. The results of this study were published in a bulletin (1) which presented the geologic, hydrologic, and chemical conditions of the local ground-water area; determined the over-pumpage of ground water to be between 8 and 10 million gallons per day (mgd); and demonstrated the need to adopt conservation measures and some method of artificial recharge.

Ground-water law in Illinois gives exclusive rights for use to the landowner, even though such use may deprive others of their supply. The landowner is restricted from unlawful pollution or malicious depletion of the supply. The fact that the well owners of the Peoria area were able to practice self-imposed conservation measures is a tribute to their cooperative approach to the existing water supply problem. The development and use of artificial recharge, as part of the solution to the problem, was delegated to personnel of the Water Survey Division. Although the immediate objective was relief from the existing ground-water shortage, the Survey hoped to obtain information on artificial recharge methods and techniques that could have application in other areas of the State.

PURPOSE AND SCOPE

This report is based on the historical and technical development of artificial recharge at Peoria and presents the results obtained from eight years of operation. Certain theoretical analyses and developments are deferred pending completion of further laboratory and field research.

Undertaking a study of artificial recharge at Peoria presented certain requirements. The first was an adequate source of water of satisfactory sanitary and chemical quality. In addition, the recharged water must be cool enough not to increase substantially the normal ground-water temperatures. In the industrial areas, where artificial recharge was most urgently needed, open land for use in recharge operations was extremely limited. Consequently, it was necessary to develop a method of recharge that would give a high unit rate of inflow, produce economically a satisfactory quality of infiltered water, and provide sufficient accumulation in storage during the operating season to help meet the pumpage demands of an entire year.

Prior to actual research operations, it was necessary to study the literature on ground-water recharge methods, examine the operation of existing installations, investigate the suitability of the Illinois River as a source of supply, and explore hydrologically and geologically the recharge potentials of the local area.

ACKNOWLEDGMENTS

Investigations were carried out under the general administration of William C. Ackermann, Chief, State Water Survey Division and his predecessor, Dr. A. M. Buswell. Many members of the Division have contributed to the development and operation of the Peoria recharge pits. Particular credit is due the personnel of the Peoria Laboratory who have been involved in various aspects of the work and have contributed substantially in the collation and analysis of the collected information.

Valuable support and assistance in the project have come from individuals and organizations in the Peoria area. Through the efforts of its Water Resources and Flood Control Committee, the Peoria Association of Commerce solicited funds which supplemented those of the State and helped provide for the construction of the first of the Survey's two recharge pits. The Association's Water Conservation Committee drafted and sponsored a Water Authority Act(2) which was passed by the State Legislature in 1951. The Association has shown a continuing interest in solving the area's water problems and maintains strong support of the recharge project.

Both within and outside the framework of the Association, business andindustry have made many contributions. Survey personnel also have enjoyed an atmosphere of close cooperation with City government. Communication locally on technical and practical matters was frequent and effective.

METHODS OF ARTIFICIAL RECHARGE

Artificial recharge of ground water includes a number of methods by which the rate and the amount of natural infiltration are increased. In the broad sense, contour farming and irrigation might be considered as methods of recharging except that they are primarily intended to increase the water content of the upper, unsaturated strata for agricultural use rather than raise the saturated ground-water level.

INDUCED INFILTRATION

Induced infiltration, whereby increased flow from natural water bodies is sought by the creation of a negative head through the use of galleries or horizontal wells, might be classed as artificial recharge. Induced infiltration does not increase the amount of ground water in storage, but permits a higher than normal rate of withdrawal under favorable circumstances. Such infiltration cannot itself reverse ground-water recessions by increasing the local rate of infiltration and simultaneously augmenting the ground-water storage. To accomplish both of these aims, it is necessary to employ one of the following methods of artificial recharge.

LANDFLOODING

Landflooding involves inundating a tract of agricultural or waste land, which is bounded by adjoining hills, dams, or levees. The literature reports the use of areas varying in size from one-half to more than one thousand acres. The depth of flooding is reported to vary from six inches to six feet. Some basins are flooded by gravity flow while others require pumping, and the water to be recharged may be circulated through the basin or it may be completely stagnant. In many basins, the natural ground surface serves as the bottom, while in others the ground surface is first scarified or treated with a fibrous material. Since most landflooding basins are used to capture excess storm water, rates of inflow vary considerably and in most cases are reduced substantially during a period of recharge. Initial rates are reported as high as 14.9 feet per day, which is the height of a column of water filtering into a unit of surface area during twenty-four hours. Generally, the initial rates are five to six feet per day with final rates falling as low as one inch per day. Average rates of recharge for this method are estimated between 0.5 and 1.5 feet per day. Estimation is necessary due to the scarcity of published data.

There seems to be no established practice for the preparation and maintenance of landflooding basins. Some basins are planted with grass; some are stripped of vegetation; and in others the soil is tilled. Nearly all basins require regularly scheduled periods of reconditioning and maintenance. On the basis of published information it is difficult to generalize on the rate of reduction in recharge and the frequency with which the basins must be reconditioned. The character of the applied water and the soil differ too greatly between localities to permit such generalizations.

Published data on landflooding indicated that this method was not applicable in Peoria, where the total yearly quantity of recharge needed would average 10 mgd. Since recharge could be practiced only during the six coolest months of the year, it would be necessary to recharge at a rate of 20 mgd, or 61.4 acre feet per day, in order to obtain the desired total annual amount. At an estimated average rate of one to two feet per day, the landflooding method would have required from 30 to 60 acres of space. An area of this size was not available in the Peoria industrial section where recharge was needed.

CHANNELS

Channels, which have been used to an extent in California and Colorado, require modification of the stream channel to increase the wetted streambed area. This method was not considered applicable in Peoria because land area for suitable channel modification was not available where there was an adequate and satisfactory supply of surface water for recharge. On the other hand, where land was available, there was no satisfactory source of water.

RECHARGE WELLS

Recharge wells and shafts are used to increase the flow into an aquifer. Some recharge wells have high capacities, such as those at Louisville, Kentucky, where rates up to 1.7 mgd have been obtained. However, all of the reports in the literature stipulate that recharge wells must receive clear water or they will eventually clog. There are reports of recharge wells having lost 50 percent of their initial capacity in periods of time as short as. one week to two months. Successful recharge wells either receive filtered water or serve as return wells for clear water from cooling systems. In the latter case, the returned water will, in general, raise the temperature of the ground water.

Recharge wells from cooling systems were not considered a satisfactory method of recharge in Peoria because of the possibility of raising the ground-water temperatures. The cost of filtration equipment for clarifying river water would have exceeded the amount of funds available for recharge research.

RECHARGE PITS

Recharge pits differ from landflooding in that the topsoil is removed in the construction of pits, although in some instances the difference is only nominal. Recharge pits are excavated into the water-bearing porous material or into bedrock and are usually equipped with a layer of filtering material for protection against silt intrusion of the aquifer. Abandoned gravel pits may be used to save excavation costs.

In Sweden, many recharge pits have been dug into the tops of eskers, which are the local outwash deposits from moraines. The material forming the esker is used as storage space for the recharged water which is eventually extracted by wells around the bottom of the esker. The rate of infiltration in Swedish pits varies from 5 to 53 feet per day.

A recharge pit is effective only if the water in it is at a higher elevation than the surrounding ground water. For this reason it is quite often necessary to pump water into pits for recharge.

Although construction costs per unit area are higher for pits as a rule than for landflooding operations, pits have a higher rate of inflow and occupy a smaller total area than landflooding installations of comparable capacity.

SELECTION OF METHOD AT PEORIA

During the search for a method of recharge, suggestions were received for using the Illinois River as a means of recharging the aquifer underlying the industrial section of Peoria (Fig. 1). These suggestions invariably proposed dredging the impervious bottom deposits to permit infiltration from the river through exposed gravel. All such proposals were rejected for a number of reasons. The extent and thickness of the impervious silt deposits were uncertain, but it was clear that the silt could not be completely dredged out. Maintenance of exposed, clean gravel would have been virtually impossible due to constant redeposition of silt. In addition, observed dredging operations had shown no apparent effect on the ground-water levels nearby. No control or check could have been exercised over the rate of recharge, the temperature of the recharged water, nor the amount of chlorine needed for disinfection.

Selection of the method for artificial recharge at Peoria was governed by the prevailing local conditions. The need for ground water that is below 65° F. required that artificial recharge should be carried on during a limited part of the year in which temperatures in the Illinois River were relatively low. Secondly, because no large land areas were available for use in recharge, and because there was a limited period of time available annually for recharging, the method selected had to be capable of high sustained rates of recharge. It was important that the recharged water be transmitted readily to the aquifer and into storage without risk of substantial loss back to the river.

Recharge pits were selected as the method which showed the most promise of recharging at high rates during the periods of low river water temperatures. Recharge wells were eliminated from consideration because they required high clarity, or treated, water for successful operation, whereas it was assumed that pits could operate successfully using river water carrying normal turbidity loads.

Topographic and hydrologic conditions were such that the pit method seemed capable of operating without substantial loss of recharged water to the river. The ground-water aquifer of the Central Well Field (Fig. 1) is under a shallow soil cover and the existing ground-water levels were 20 to 25 feet below the normal river elevation of 440 feet above mean sea level (m.s.l.) and about 8 to 13 feet below the bottom of the river. These ground-water levels provided a large storage space for refilling before overflow to the river could occur. Information was gathered on the amount of natural recharge from the river in order to estimate the loss of recharge during transmission from the pit to the existing ground-water levels, and the loss from storage in the event ground-water levels rose above the river bottom or normal pool stage.

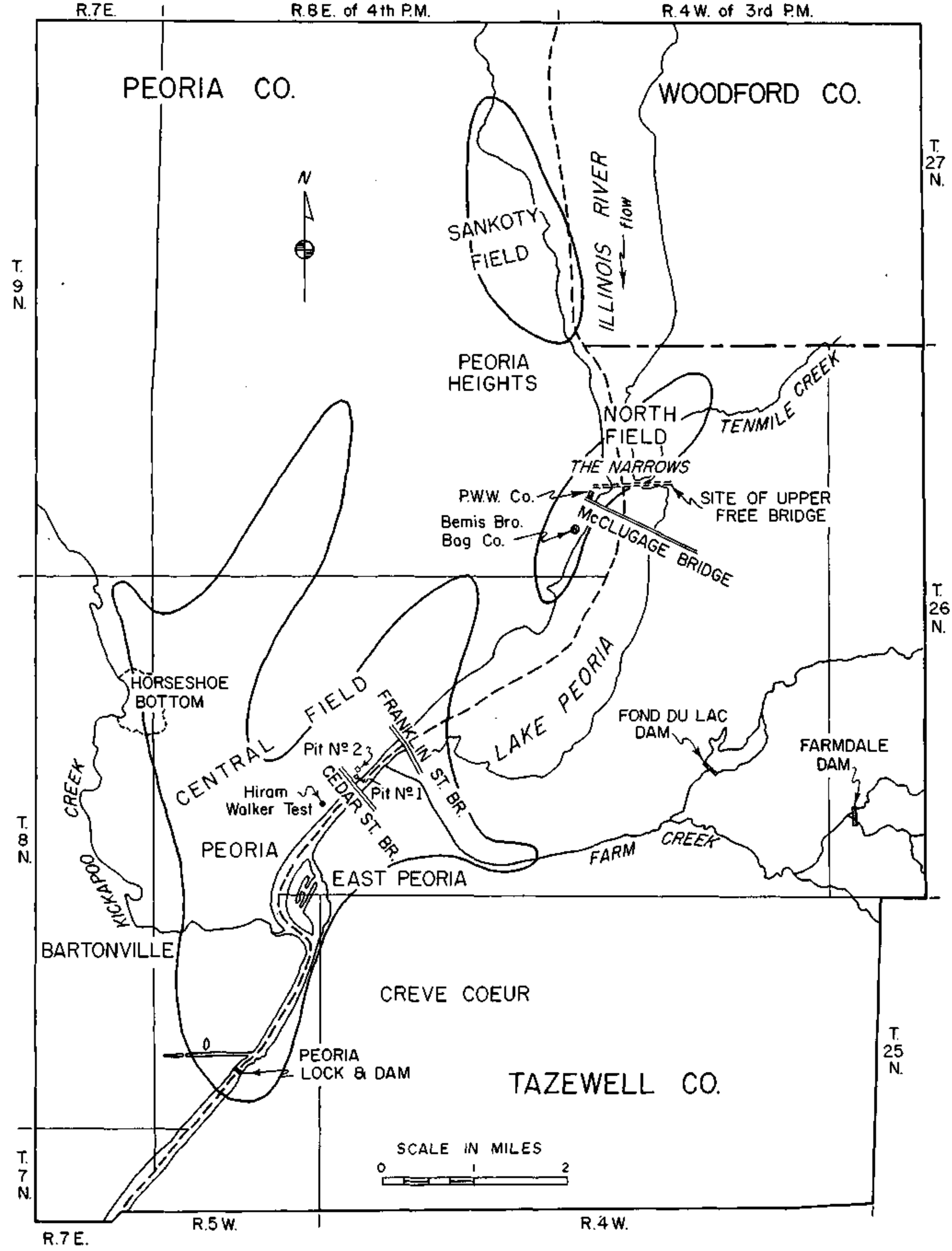

FIGURE 1 LOCATION OF MAJOR WELL FIELDS IN PEORIA

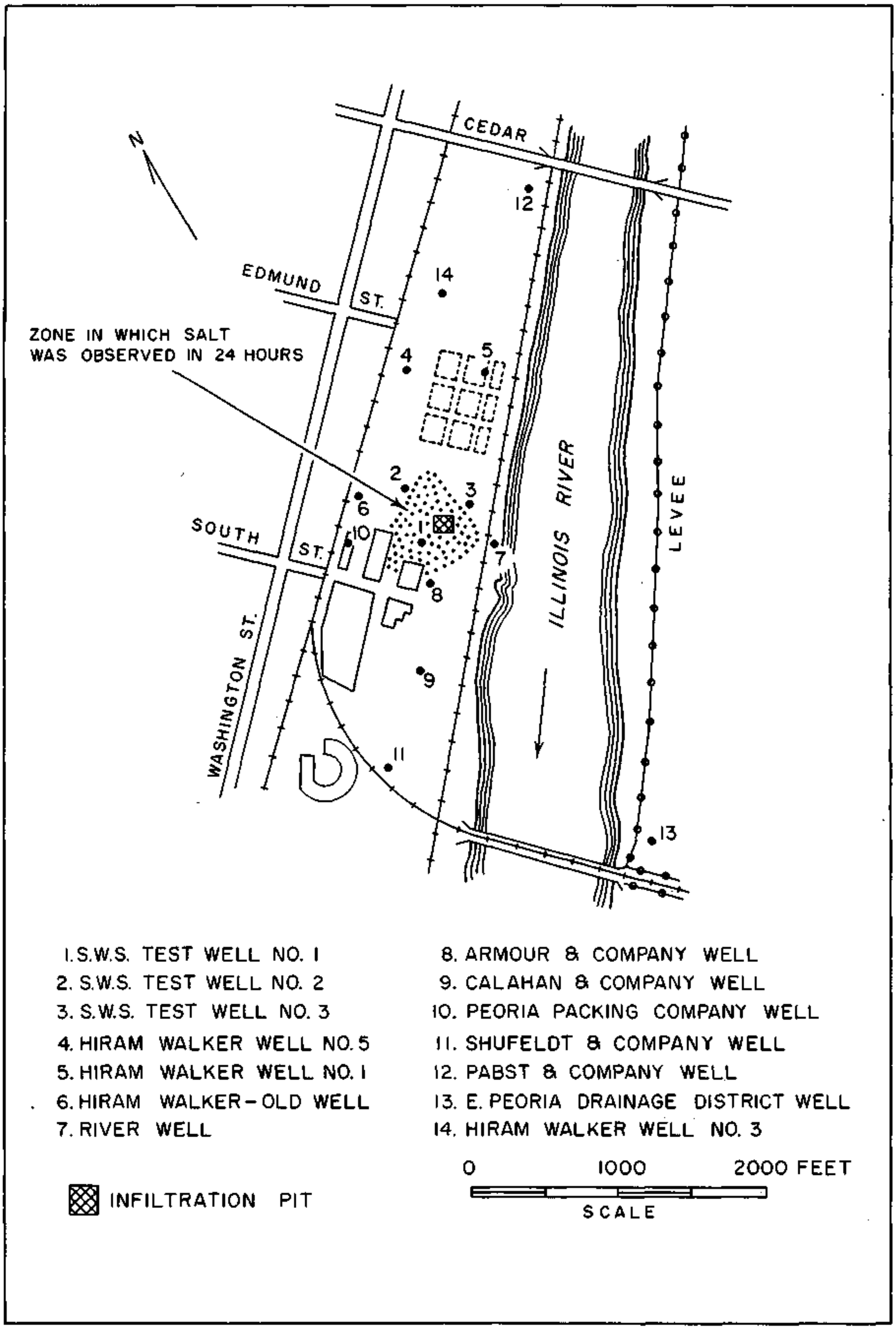

FIGURE 2 LOCATION OF FIRST ARTIFICIAL RECHARGE EXPERIMENT

Available information indicated that there was little natural recharge from the Illinois River when it was at normal stage since the lowest ground-water levels were found near the river and the loss in ground water was progressing at a constant, undiminishing rate. Additional information obtained during dredging operations gave support to this theory of little natural recharge at normal stage. Test drillings for bridge con, struction showed that the Peoria Lake bottom consisted of about 20 feet of clay. During construction of the McClugage Bridge in 1940, the clay in the lake bottom was found to be so tight that a sample at two-foot depth contained only 12.5percent water. Tests on three undisturbed samples of this clay indicated permeabilities of 0.6, 0.75, and 1.0 ml per 12 hours against 10 feet of head. These permeabilities were calculated to yield a maximum natural recharge of about 1 mgd for the Peoria Lake area.(1) At no time during construction of the McClugage Bridge, nor later during dredging operations at LeTourneau-Westinghouse and below the Franklin Street Bridge, were any increases in water levels recorded in observation wells near the construction sites. Two auger holes of 6 feet and 9-1/2 feet depths, drilled three feet from the pool stage water line at the Water Survey recharge pit construction site, penetrated the silt layer and were dry. Water, which was splashed into the two holes from waves, disappeared through the bottom of the holes within two minutes.

The interpretation of all of this information indicated that the operation of recharge pits should result in very little loss during transmission of recharged water, and that losses from storage would probably be slight.

TEST OF SELECTED RECHARGE METHOD

A preliminary test was made in 1941 of the possibilities of recharging the aquifer with river water by the pit method. Hiram Walker & Sons, Inc. suggested the test and agreed to provide the necessary operating personnel, materials, and laboratory tests, with the Survey providing supervision and responsibility for collection of hydrologic data. The test was made in an abandoned gravel pit on Hiram Walker property, which is shown in Figure 1.

A vertical suction, 2500 gallons per minute (gpm), centrifugal pump was mounted on a barge in the river. This pump discharged river water through a 12-inch steel pipeline to the gravel pit. Discharge was metered through an orifice set in the pipeline. A three percent solution of calcium hypochlorite was applied to the water at an average rate of 4.5 parts per million (ppm) available chlorine. Analyses of the river water had indicated that 12 ppm would be required for breakpoint chlorination.

To obtain information on the effects of the infiltration test, the Water Survey installed a staff gage in the gravel pit and drilled three 8-inch observation wells. These wells were located 430 to 450 feet apart at the corners of an approximately equilateral triangle around the pit. These wells, and a well of the Pabst Brewing Company located upstream at a distance of 2300 feet from the pit, were equipped with Stevens recording gages for continuous measurement of ground-water levels. Temperature readings were taken of the river water as it entered the pit, of the ground water in the three observation wells, and of wells belonging to Hiram Walker & Sons, Inc., Armour and Company, and the Peoria Packing Company. Figure 2 shows locations where observations were made of the movement of chlorides and bacteria through the aquifer.

Recharge was limited to four separate short periods in August and September, 1941. This was necessary because protracted periods of recharge would have resulted in raising the ground-water temperatures above 65°F. The periods of testing were from August 4 to 9, from August 12 to 14, from August 27 to 30, and from September 10 to 12. Testing was frequently interrupted for the purpose of cleaning snails and debris from the intake screen. The amounts of water recharged and the chlorine dosage are shown in Table 1, and the effects of the tests on surrounding ground-water levels are shown in Figure 3.

TABLE 1

RESULTS OF RECHARGE TESTS AT GRAVEL PIT OF HIRAM WALKER & SONS, INC.

Period	Recharge (MG)	Avg. Chlorination (ppm)
Aug. 4-9	6.2	4.9
12-14	5.6	4.8
27-30	9.1	2.5
Sept. 10-12	6.9	7.6
Total	27.8	

The results of these four tests indicated a high rate of recharge could be expected. River water pumped at 2200 gpm was recharged into a gravel area of 3628 square feet, giving a recharge rate of 118.8 feet per day. Due to the short duration of the tests and to the clean gravel used, it was assumed that this rate could not be maintained for extended periods of time nor obtained at all other locations.

The hydrographs of observation wells presented in Figure 3 show the rapidity with which ground-water levels in the immediate area responded to artificial recharge and give an indication of the area influenced. Water levels in observation wells 1, 2, and 3 began to rise within ten minutes of the start of recharge and continued until recharge was stopped. The effects of these tests on the more distant Pabst well were not so pronounced nor so immediately apparent.

At the beginning of the tests on August 4, 1941, the river temperature was at 84°F. and decreased to 70°F. by September 13. Observed ground-water temperatures varied between the limits of 56°F. and 66°F. The first and last test periods produced no appreciable increase in ground-water temperatures. The two intermediate tests raised the temperature of the ground water 8°F. and 10°F., respectively, in the Armour and Company well.

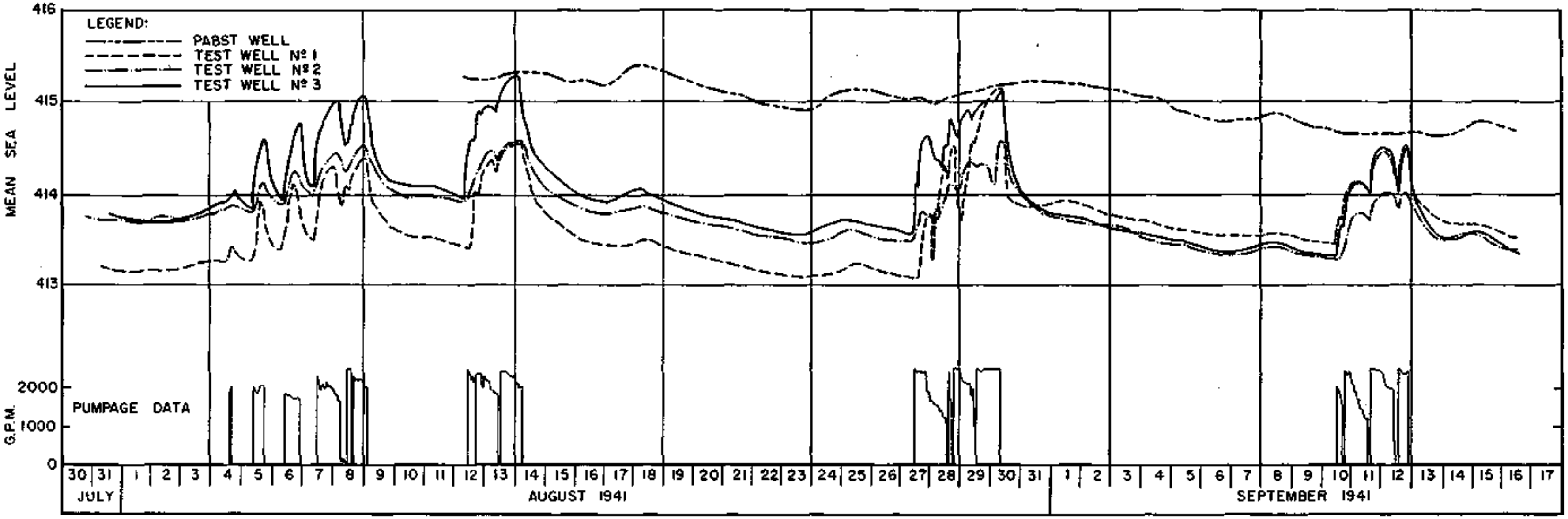

FIGURE 3 EFFECTS OF FIRST ARTIFICIAL RECHARGE ON GROUND-WATER LEVELS

Several tests were made in an attempt to measure the velocity of flow of the recharged water through the ground-water aquifer. On August 12, sacks containing five tons of sodium chloride were placed in the pit before starting to recharge. During the test, samples of water collected from the three test wells and the Armour and Company well were analyzed for chloride content. None of these analyses indicated the presence of chlorides in excess of the natural content. On August 27, five more tons of sodium chloride were spread over the bottom of the pit. As soon as recharge started, hourly samples were taken from the test wells and continued over a period of six days. The progress of the recharged water, as identified by concentration of chlorides, could be detected reliably only in Survey Test Wells No. 1 and No. 3, and to some extent at the wells of Armour and Company, Calahan and Company, and at the well on the river bank. These tests with sodium chloride indicated velocities of travel of 200 to 275 feet per day toward the southwest and 75 to 130 feet per day toward the east.

Water from four of the observation wells was analyzed for bacterial quality. Of the four, only the well at Armour and Company showed that it was contaminated as a possible result of the recharge tests. Bacteriological analyses made from that well during the tests indicated higher total plate counts and a greater number of positive presumptive coliform tests than had been observed prior to recharging.

As a result of these preliminary recharge tests, it was concluded that the pit method was applicable at Peoria. It was estimated that the recharge rate which could be continuously maintained would be approximately 60 feet per day instead of the 118.8 feet per day which was observed in the brief experiment. It was also assumed that the surface of any pits constructed would have to be covered with a layer of sand for filtration of the recharged water. The operational difficulties experienced with the river water pump indicated that the gravity inflow to pits might be more desirable. Pretreatment of river water by sedimentation was not considered a necessity as long as limits on temperature and turbidity were observed.

Following the 1941 test of artificial recharge by the pit method, the Peoria Association of Commerce employed the consulting engineering firm of Alvord, Burdick, and Howson to make a comprehensive report on the local ground-water situation. Mr. Burdick's report, presented to the Association on January 15, 1942, was prepared from information provided by the State Geological Survey and the State Water Survey, supplemented by the firm's experience with infiltration and landflooding at Des Moines, Iowa. The report recommended immediate use of the gravel pit located on the property of Hiram Walker & Sons, Inc., for artificial recharge with subsequent acquisition of an additional 200 acres for landflooding operations. Cost estimates provided for an investment of $40,000 in the pit with a monthly operating cost of $3500. Investment in landflooding was estimated to be $15,000 with a monthly operating cost of $2500. On the basis of production, the pit method was estimated to cost $11.50 per million gallons and the proposed landflooding operations $8.25 per million gallons.

No immediate action followed the Alvord, Burdick, and Howson report since the urgency of the ground-water situation was partially relieved by several seasons of abundant precipitation and high river stages. Recognizing that the excess precipitation could not continue, the Water Survey proposed an artificial recharge project on a scale sufficiently large to determine whether or not this method could economically correct the local ground-water problems and provide information of value for use in other areas of the state. The Survey's proposal was formalized in a report by Jacob A. Harman and J. J. Woltmann on October 16, 1945. No definite steps toward artificial recharge evolved from this report, but studies were started on methods of financing such projects. A later outgrowth of these studies was the approval by the State Legislature of an Act,(2) sponsored by the Peoria Association of Commerce, to provide for the establishment of Water Authorities and to determine their powers and duties.

PEORIA LABORATORY

In 1947, the legislature provided the Water Survey with $250,000 for the construction of a laboratory in Peoria. A site on the river front, north of the Cedar Street Bridge, was acquired in 1948 and a three-story laboratory and office building was completed in 1949. This building was constructed for the study of water resource problems and contained space and facilities for administrative, engineering, chemical, and bacteriological activities.

USE OF ILLINOIS RIVER WATER FOR RECHARGE

QUANTITY OF WATER

Discharge records of the U.S. Geological Survey indicated that the quantity of water available in the Illinois River was always greatly in excess of the amount required for recharge. Withdrawal of 20 mgd for recharge would amount to about 1.3 percent of the minimum flow of 2300 cfs recorded in 1943.

QUALITY OF WATER

Sanitary quality of the Illinois River had been the subject of extensive investigation for more than 20 years.(3, 4, 5, 6) Early studies were made in connection witn the project of the Metropolitan Sanitary District of Greater Chicago to divert sewage and dilute it with water from Lake Michigan. The opening of the Chicago Sanitary

TABLE 2

DAYS PER YEAR AVAILABLE FOR ARTIFICIAL RECHARGE FROM ILLINOIS RIVER AT PEORIA AS LIMITED BY TEMPERATURE AND TURBIDITY, 1935-1945

	Temperature		Turbidity		Temperature and Turbidity			
	60°F.	65°F.	100ppm	200ppm	60°F. and 100ppm	60°F. and 200ppm	65°F. and 100ppm	65°F. and 200ppm
Maximum Number of days per year	236	261	343	356	180	223	203	238
Minimum Number of days per year	181	207	270	327	123	169	150	205
Mean Number of days per year	210	236	299	346	149	192	175	219

and Shipping Canal in 1900 was the prelude to numerous periodic and systematic surveys of the Illinois River.

The quality of the river has varied over a wide range since 1900 and has been greatly influenced by the quantities of water diverted from Lake Michigan, by the amount of sewage discharged from Chicago, and by the degree of treatment given to Chicago's sewage.

Until about 1920, the quality of the Illinois River deteriorated despite diversions of as much as 7400 cfs from Lake Michigan.(7) The steady development of a sewage treatment program by the Metropolitan Sanitary District of Greater Chicago brought about gradual improvement of the quality of the river despite a decree by the U.S. Supreme Court in 1930, limiting diversion to 1500 cfs after 1938.

In order to use Illinois River water for recharge at Peoria, it was necessary first to determine whether its quality was satisfactory and then to overcome the prejudice of the people against its use. Results of an investigation by the United States Public Health Service from 1920 to 1922 were among the first in which standardized methods of analysis were reported. (8) The Peoria office of the Metropolitan Sanitary District of Greater Chicago furnished valuable records of temperature, turbidity, dissolved oxygen, biochemical oxygen demand, and ammonia nitrogen analyses of samples which had been collected over a period of years. Regular bacteriological analyses of river samples were made in the laboratory of the Peoria Water Works Company from 1942 until 1950. Following completion of the Water Survey's Peoria Laboratory, tests for physical, chemical, and bacteriological quality of the river water were performed in this laboratory on samples collected at the site.

Temperature and Turbidity

Daily temperature and turbidity data on river water were available from 1935. A study(9) of these data for the period 1935 to 1945 furnished an estimate of the time intervals during which recharge could be undertaken within arbitrarily imposed limits on temperature and turbidity. Maximum, minimum, and average number of days available within given temperature and turbidity limits are shown in Table 2.

Dissolved Oxygen

Records of the Metropolitan Sanitary District of Greater Chicago give information on dissolved oxygen concentrations in the river since 1933. Analysis of these data for monthly maximum, average, and minimum values, indicated that the river at Peoria normally contains satisfactory quantities of dissolved oxygen and occasionally exceeds saturation values. Beginning in 1936, average monthly values of dissolved oxygen, shown as the heavy line in Figure 4, never fell below 4.5, although minimum values for short periods have declined to as low as 2 ppm.

Biochemical Oxygen Demand

Figure 5 shows that average monthly biochemical oxygen demand values of samples analyzed by the Metropolitan Sanitary District of Greater Chicago ranged from 1.5 to 8.5 ppm. Since B.O.D. values alone have little meaning, they were considered together with the dissolved oxygen values. In this light they presented no serious interference to use of the river water for recharge.

Ammonia

Although no limits on ammonia are set by the U.S. Public Health Service Drinking Water Standards of 1946,(10) high values are commonly assumed to be characteristic of recent pollution. Since 1949, the free ammonia content of the Illinois River has risen from an average of about 0.55 ppm to about 1.4 ppm. Much of this rise may have resulted from increased use of commercial fertilizers on agricultural lands within the Illinois River watershed.

Bacteria

Bacteriologic examinations to judge the quality and suitability of the river water were limited by lack of facilities and personnel. These examinations were confined to the presumptive test for the presence of members of the coliform group and the standard plate count. All of the presump-

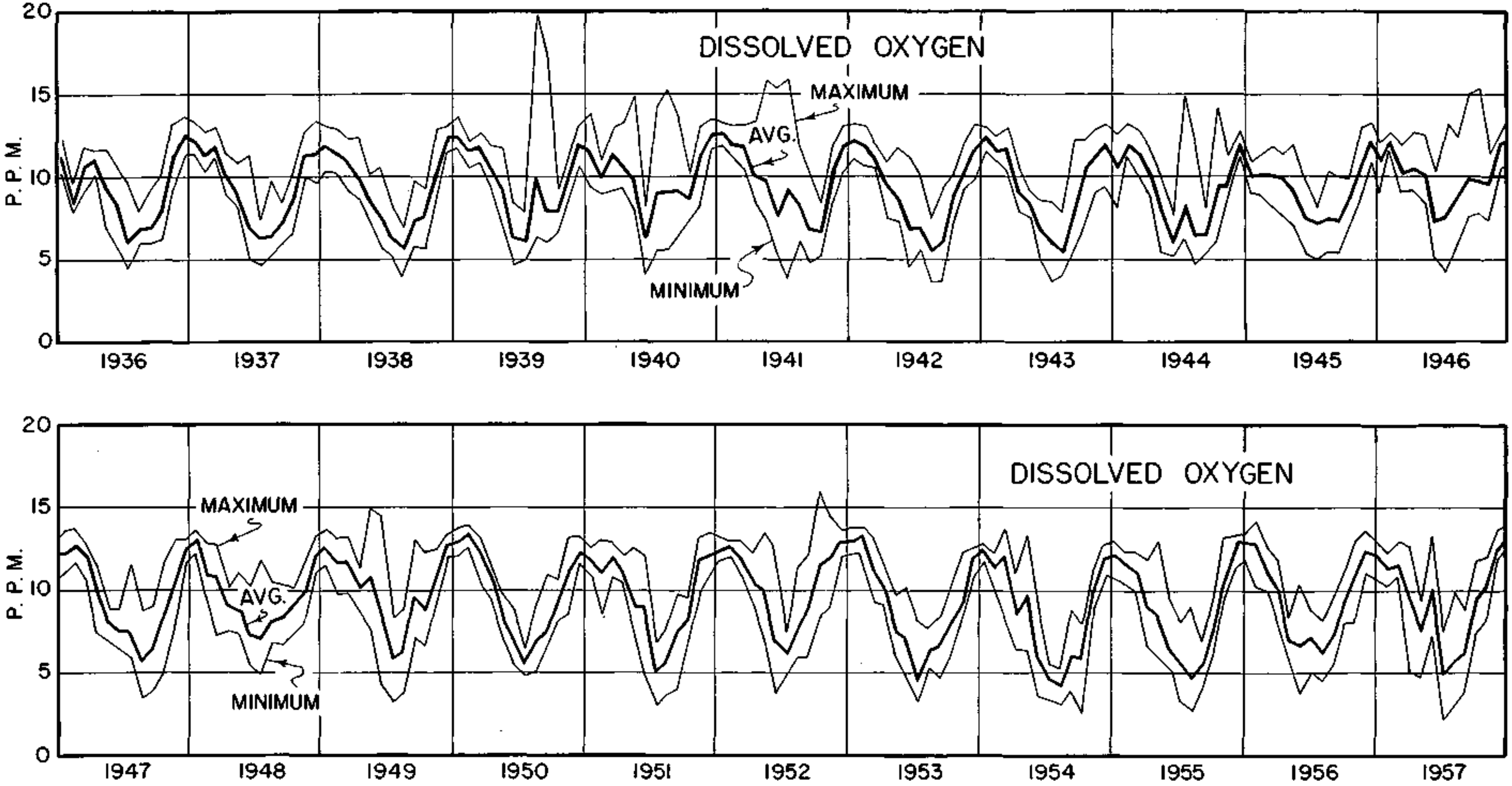

FIGURE 4 DISSOLVED OXYGEN VALUES IN ILLINOIS RIVER AT PEORIA, 1936-1957

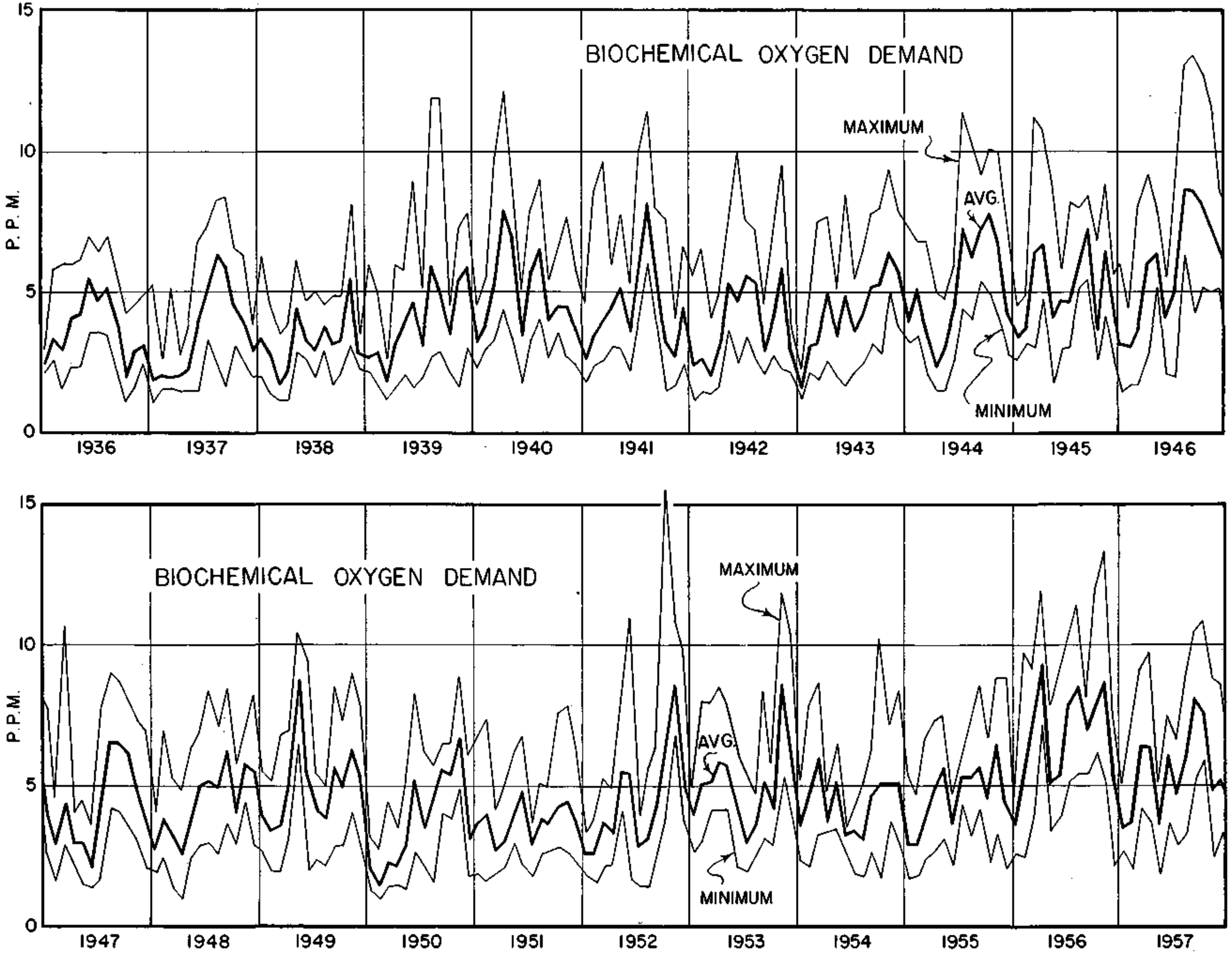

FIGURE 5 BIOCHEMICAL OXYGEN DEMAND VALUES IN ILLINOIS RIVER AT PEORIA, 1936-1957

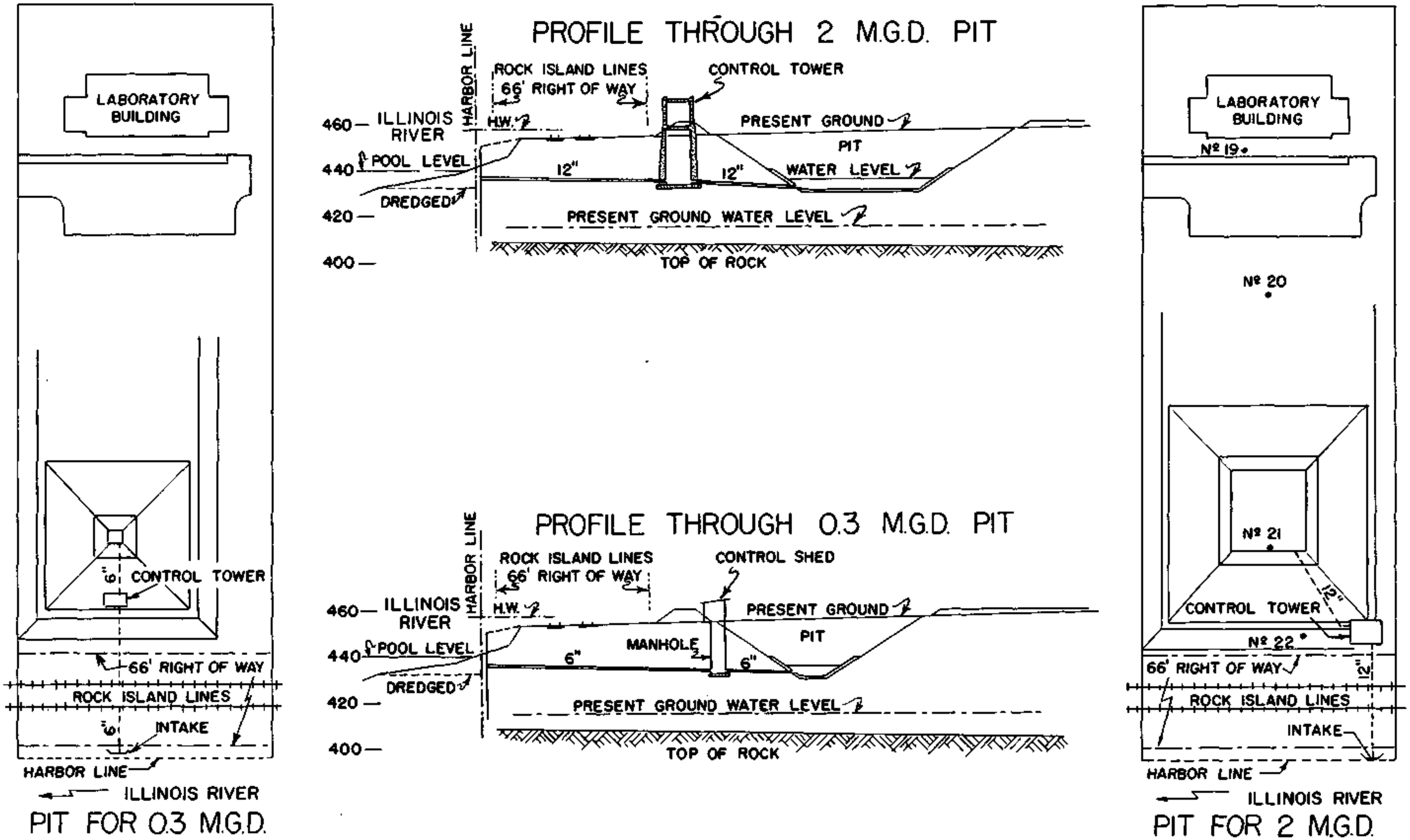

FIGURE 6 PROPOSED DESIGNS FOR WATER SURVEY RECHARGE PIT

tive tests, initially made in the laboratory of the Peoria Water Works Company and later in the Water Survey Laboratory, were positive. Standard plate count results were more encouraging. Whereas plate counts as high as 3 million per milliliter had been recorded during the early 1920's, later analyses revealed that the plate counts had since declined to a much lower value.

PIT NO. 1 AND RECHARGE FACILITIES

In 1949, the Water Survey proposed expenditure of $25,000 in appropriated funds for construction and operation of a research pit with a capacity of 0.3 mgd. In order to obtain substantial groundwater replenishment in addition to experimental and developmental information, the Water Resources and Flood Control Committee of the Peoria Association of Commerce solicited approximately $ 70,000 from local business and industry with which to supplement the State's appropriation and to aid in financing construction of a larger recharge pit. Figure 6 represents comparative proposed sizes of the 0.3 and 2.0 mgd pits.

INTAKE STRUCTURE

With the exception of a portion of the intake structure and pipe line, the first pit and its appurtenances were built on the Peoria Laboratory property. Inasmuch as the strip of land only seven feet wide was available along the river between the harbor line and the Chicago, Rock Island and Pacific Railroad right-of-way, it was necessary to install the intake structure and valve manhole behind vertical sheet piling. The 16-inch intake pipe is protected by a coarse, bar rack built in the sheet piling. The 1/2-inch by 2-inch bars of the rack are spaced two inches on centers. A 16-inch gate valve is located in the manhole immediately behind the sheet piling.

CONTROL TOWER AND CAISSON

From the inlet bar rack, a 16-inch transite pipeline is laid in a 42-inch tunnel underneath the railroad tracks to the control tower building. The 16-inch inlet pipe is wedged in the tunnel to prevent floating and both ends of the tunnel are sealed with concrete headers. Location and construction details are shown in Figures 7 and 8. River water entering through the inlet pipe discharges into the control tower through a 45-degree cast iron elbow to maintain circulation in the tower. Invert of the intake pipe is at elevation 435.1 feet. The control tower is built in two parts: the lower part consists of a circular, concrete caisson and the upper part is a square building containing the operating rooms and equipment. The caisson has an inside diameter of sixteen feet and a depth of twenty-two feet, wall thickness of fifteen inches, and a foundation which is two feet thick. Elevation of the caisson floor is at 432.5 feet.

PIPE LINES

Chlorinated water from the caisson flows by gravity through a 12-inch transite pipe to Pit No. 1. This pipe is laid along the center line of the caisson and the inlet end was protected from clogging by a 26-inch length of 1/8-inch slot Johnson Everdur screen. The screen was difficult to clean when mounted in the horizontal position, and it was replaced in a vertical position on top of a 12-inch tee. It was then equipped with a movable flushing ring which is supplied with water under pressure. This ring can be moved up and down the screen by means of ropes leading down from the control room. The ring successfully cleans the screen except when flow conditions are such that velocities through the screen slots exceed 0.6 feet per second. High velocities bind particles of debris very tightly to the screen and wedge small fish into the slots. (11)

FLOW METERING EQUIPMENT

From the screen, water discharges to Pit No. 1 through a venturi tube and a 12-inch gate valve. Pressures at the intake and throat of the 12.125-inch by 9.35-inch venturi metering tube are indicated by water levels in 2-inch wells located above the intake and throat and are measured by compressed air from a small, stationary compressor through two 1/8-inch copper lines ending at identical elevations in the wells. The measured venturi tube pressure differential is transmitted by air pressure to the Republic flow meter recorder and integrator located in the operating room.

APPURTENANCES

The building above the caisson contains the Everson Type-K, Series-2500 chlorinator, air compressor, chlorine handling equipment, operating rooms, pump motor for Pit No. 2, and the flow recording and integrating instruments for both pits.

Chlorine is purchased in one-ton cylinders. The scale holds two cylinders, and storage space for two additional cylinders is available. Chlorine is applied to the water in the caisson by gravity feed through a rubber line terminating below the water surface.

The discharge line from the control tower to Pit No. 1 is a 12-inch transite pipe which terminates at the center of the pit in an upturned 90-degree cast iron elbow. The elevation of the top face of the elbow is one-half foot below the floor of the caisson in the control tower. A weep hole in the bottom of the discharge pipe provides for drainage of the line when the pit is not operating, The bottom of Pit No. 1 is a rectangle measuring 62.5 feet by 40 feet and its elevation is 430 feet, which is 10 feet below controlled pool level in the adjacent river. Side slopes up to elevation 442.0 are two horizontal to one vertical. Between elevations 442.0 and 460.0 the side slopes are one and one-half horizontal to one vertical. The bottom of the pit and side slopes to elevation 442.0 are covered with a 6-inch layer of filtering material, Sand was used during the 1951 to 1954 operating periods but was replaced by 3/8-inch pea gravel in subsequent seasons.

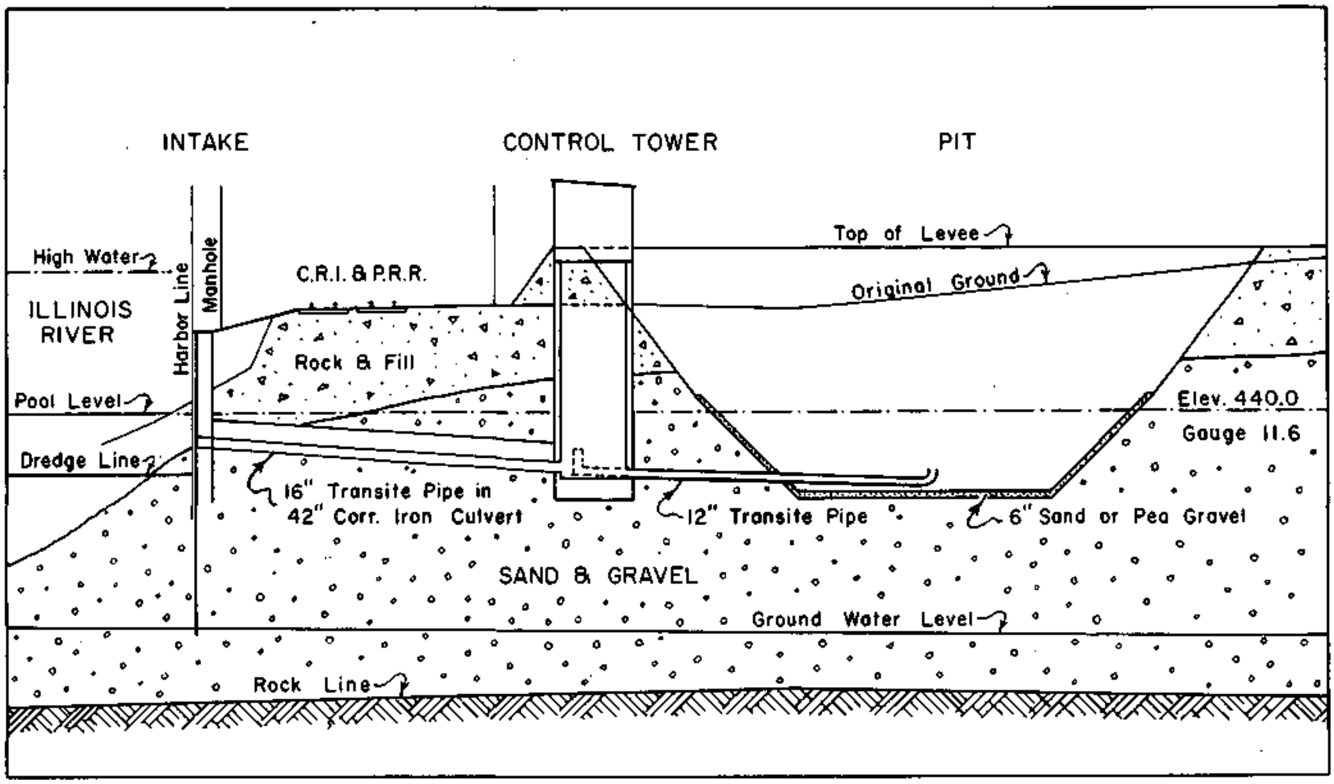

FIGURE 7 PROFILE THROUGH RECHARGE PIT

OPERATION OF RECHARGE PITS

Artificial recharge was started on October 4, 1951 using Pit No. 1. At the beginning, and for the ensuing eight seasons of operation,(12, 13, 14, 15, 16, 17, 18, 19, 20) the operating methods and techniques were designed primarily for the collection of basic information.(21, 22) With increasing experience, it was possible to improve upon the methods and techniques.(23)

TEMPERATURE-TURBIDITY LIMITS

The limits on turbidity and temperature, under which recharge could be practiced, were among factors that were changed as a result of operating experience. During the first season of 1951-1952, the pit was not operated when the river temperature was above 60°F. nor when its turbidity was greater than 100 ppm. As a result of this turbidity limit, it was often necessary to stop recharging during freezing weather. The surface of the pit would then freeze and recharge couldnot be started again until the pit had thawed. If the pit could have been operated continuously with water having turbidities higher than 100 ppm it would not have frozen, but its capacity would have been reduced by the deposition of silt. Comparisons of the reduction in recharge caused by silt deposition with the loss sustained when the pit was frozen indicated that the latter was probably the more limiting of the two. Eventually, no upper limit on turbidity of river water was observed and operation was carried on continuously.

FILTERING MEDIA

At the beginning of each of the first three seasons of operation, a 6-inch layer of clean sand, having an effective size of 0.3 to 0.4 mm and a uniformity coefficient of 2.0, was placed in the pit to serve as the filtering media. During the first season this sand was clogged rapidly by the silt in the river water and the amount of recharge decreased by as much as 60 percent within three months time. Because of the reduced infiltration capacity, the dirty sand was removed and replaced with clean sand. Replacement of the sand revealed that the original soil material in the bottom of the pit had been tightly compacted by the bulldozer used during construction. This compacted layer was blasted before the clean sand was installed.

ARTIFICIAL RECHARGE WITH ONE PIT

First Season. 1951-1952

The first season of recharge lasted from October 4, 1951 to April 28, 1952. Within this period, 258.7 million gallons of river water were recharged during 146 operating days. The pit was inoperative owing to high turbidity of the river water, freezing of the pit, or for purposes of cleaning on 62 days, or 30 percent of the operating season.

There were four periods during which the river stage was four or more feet above normal pool

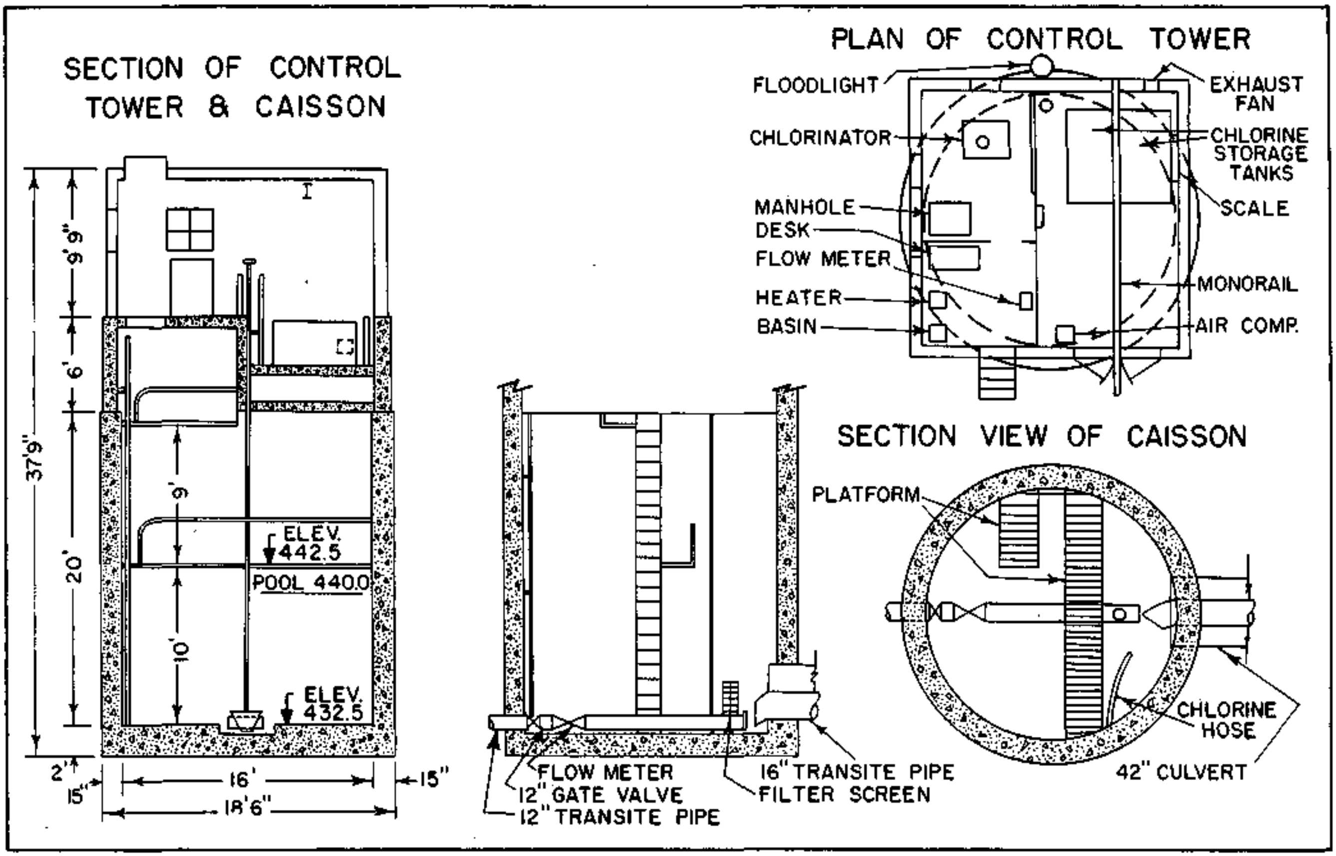

FIGURE 8 DESIGN OF CONTROL TOWER

stage. Each of these periods lasted for more than 15 days and each had decided influence on the artificial recharge. In each case the recharge rate was increasedalthoughnot in a mathematically consistent ratio to the increase in wetted infiltration surface in the pit. The river was one foot or more above pool level for 101. days and reached a stage of 7.1 feet above pool level in both March and April. The limit of one foot or more above pool is used because variations in the levels of ± 6 inches occur regularly due to flow changes, as the level is held constant at Henry, about 40 miles above Peoria. In winter, variations of ±1 foot occur when the river level is intentionally changed to break the ice cover. Therefore, only levels of one foot or more can be attributed unconditionally to flood occurrences.

Second Season, 1952-1953

In the second season of operation, the pit was used continuously without any cleaning of the sand filter. The calendar period of operation was from October 13, 1952, to May 13, 1953, during which time 214.6 million gallons were recharged in 208.75 operating days. No limit on river water turbidity was observed with the result that the pit was inoperative for only 1.7 percent of the period of operation. The average recharge rate was lower than that of the first year, and its reduction was attributed to several factors. The river was one foot or more above pool stage for only 13 days during the second season and did not exceed a maximum of 2.6 feet above pool stage. The sand filtering media was neither cleaned nor replaced during the entire season. The Johnson well screen protecting the 12-inch line from the control tower caisson to the pit, clogged frequently and was difficult to clean in the horizontal position in which it was installed. Since no limit on turbidity of the river was observed, a much heavier load of silt was carried into the pit and deposited on the surface of the filtering sand.

The effects of applying highly turbid water upon the pit were varied. Reduction of recharge by deposition of silt from water with turbidities less than 100 ppm amounted to between three and ten percent per month. Turbidities over 100 ppm caused different effects, depending to some extent upon the type of material producing turbidity in the river. During a 9-day period in November-December, 1952, turbidity in the river was high reaching a value of 235 ppm and resulting in a 30 percent reduction in recharge. In February, 1953, turbidity rose to 160 ppm during a 5-day period and resulted in a 16 percent reduction of recharge. In March, 1953, turbidities reached 280 ppm over a 12-day period, but the resulting reduction in recharge was only seven percent. Turbidities during the first two periods were due to high winds which stirred up very fine, slow-settling, bottom deposits of Peoria Lake, whereas turbidity occurring in the last period was from material washed into the river by runoff from rainfall. These observations indicated that the size and type of material causing high turbidities seem to have greater effects upon reduction of recharge capacity than the relative concentration of turbidity.

Tests made with a commercial swimming pool suction cleaner indicated silt could be removed from the top of the filtering sand layer with the result that the recharge rate was increased for a short period of time. Unfortunately the suction cleaner removed some sand as well as the accumulated silt. When recharge was terminated, measurements of the silt in the sand layer indicated very little penetration.

Third Season, 1953-1954

The third operating season was continuous with no replacement of the sand filtering media. With recharge conducted between October 26, 1953, and May 17, 1954, the actual operating time amounted to 199.25 days. Total amount of water recharged was 208.2 million gallons, giving an average rate of 1.05 million gallons per operating day. Average recharge rates varied from a maximum of 1.95 mgd to 0.8 mgd from the beginning to the end of the season.

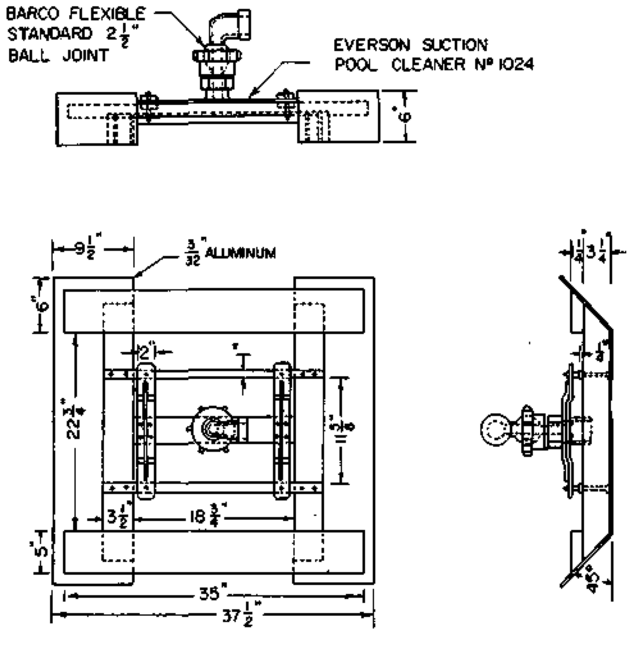

FIGURE 9 CLEANER FOR RECHARGE PIT

The swimming pool suction cleaner, which had been used experimentally the previous season, was mounted after considerable experimentation on a skid, as shown in Figure 9, and equipped with a gasoline motor driven pump with a capacity of 100 gpm against 80 feet of head. This arrangement provided better control than was previously available and prevented the removal of sand with silt. Lack of time prevented cleaning the entire pit with the modified equipment, but it was noted that an increase of between five and ten percent in the recharge rate resulted from cleaning one-fourth of the pit surface. The increase in recharge was of short duration as more silt was soon deposited on the surface.

Fourth Season, 1954-1955

In preparing for the fourth season of operation, it was found necessary to change the type of filtering media which was placed in the bottom and on the side slopes of the pit, because it was no longer possible to obtain a satisfactory, clean sand from local suppliers. As a result, a search was begun for a media which might prove more satisfactory than that previously used. Sand had been chosen primarily because of its traditional use in conventional water treatment processes, and its capacity for purification of water has been firmly established. However, in the first three seasons of artificial recharge the sand was a disappointment because it clogged rapidly and became the limiting factor controlling the rate of recharge. Laboratory measurements had shown that the soil in which the pit was excavated had a permeability of 8000 Meinzer units.* The clean sand which was placed in the pit at the start of each of the first three seasons had a permeability of 9000 Meinzer units, which was reduced by more than 50 percent. From these determinations it was apparent that while rate of infiltration was initially controlled by the permeability of the soil, the controlling factor rapidly became the permeability of the sand as it accumulated silt from the river water. Equally apparent was the need for a material capable of providing adequate filtration and of retaining a permeability of at least 8000 Meinzer units during a season of operation.

The first such material sought was a sand with a permeability of 16,000 Meinzer units. Laboratory studies in the course of this investigation had indicated that a uniform sand of 0.8 mm diameter would have this permeability but that it would be reduced by as much as 20 percent by the admixture of ten percent of finer material. Therefore, to provide a suitable margin of safety, a uniform sand having a diameter of 1.25 mm and the estimated permeability of 30,000 Meinzer units was selected as the ideal material. The selection proved impractical since no such material was available locally, and none could be specially screened at a reasonable price.

Finally, because of its availability, a 3/8-inch gravel or so-called pea gravel was accepted. This material ranged in size from 3.4 to 9.3 mm and its permeability was determined to be 155,000 Meinzer units. Since the literature on filtration media cited no examples in which sizes over 2 mm had been used in filters, some concern arose in connection with the possible failure of this relatively large size material. These fears were allayed by the realization that the underlying drift soils would retain any material which was passed by the filter media layer. Subsequent operating results, and tests by Heiple:(24) on coarse-media filtration, have proven these fears to be unwarranted and have shown the use of the coarse filter media to be worthwhile.

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* Meinzer unit is flow in gallons per day through a cross sectional area of one square foot under a hydraulic gradient of 100 percent at temperature of 60°F.

With the pea gravel installed, the pit was operated for 165.2 days during the period between November 8, 1954, and May 11, 1955. The pit was inoperative several times for the sole purpose of inspecting the condition of the pea gravel filter media. A total of 365.02 million gallons of water was recharged which gave an average daily operating rate of 2.21 million gallons.

This increase in average rate of recharge over that of 1.05 mgd for the preceding season could not be credited entirely to the use of pea gravel. There were 59 days during which the river was more than 1.0 foot, and as much as 3.8 feet above pool stage. These high river stages were reflected in the increased recharge rates in the pit. The pea gravel was given several partial and two complete cleanings with the suction cleaner, and each was followed by a slight increase in recharge.

Evidence was found indicating that the pea gravel functioned satisfactorily without excessive penetration of silt. After two weeks of operation a thin blanket of silt formed over the top of the gravel. After two months of operation the bottom two inches of the 6-inch gravel layer were still practically clean and more than ninety percent of the silt was accumulated in a surface layer and the upper two inches of gravel.

At the end of the season, the thickness of the silt blanket had increased to about two inches. Determinations were then made of the silt concentration per unit volume of material in the top, middle, and bottom 2-inch layers of the gravel. The top 2-inch layer of gravel contained 16.3 gm of dry, fine material per 100 ml volume of gravel, whereas only 6.8 gm of fine material per 100 ml volume were found in the bottom layer. All of the fine material was such that it passed through a 40-mesh screen.

Fifth Season, 1955-1956

During the period between November 1, 1955 and May 16, 1956, the pit was in operation for 195.81 days and 422.63 million gallons were recharged. Average recharge for this entire period was 2.16 mgd. The decline in average rate below that of the preceding year was attributed to lower river and pit stages.

Summer Operation, 1956

Temperature readings taken in observation wells throughout the Central Well Field had indicated the average ground-water temperatures did not exceed 52° to 55° F. during recharge with river water having temperatures of 60°F. or less. Since much of the industry in the well field can operate using water at temperatures as high as 60° F., the average ground-water temperatures of 52°F. to 55°F. suggested the possibility of recharging during a greater length of time each season without too great a rise in the temperature of the ground water. Therefore the pit was operated from July 12 to August 10 in order to study the effects of recharging with warm water.

During the test period, 65.93 million gallons of river water were recharged at an average rate of 2.27 mgd.[1] The filter gravel was not cleaned at the end of the preceding winter season and had not been replaced. The only preparation given the pit was the removal of all plant growth from the surface to be submerged. In spite of the silted condition of the filter gravel, the average daily recharge rate was slightly above that of the previous winter season.

Throughout this test the level of the river was within a few inches of normal pool stage. Turbidity in the river was less than 100 ppm and, with the exception of the first four operating days, was always less than 75 ppm. River temperatures rose an average of 0.21° F. per day from 76° F. to a maximum of 82° F.

Clogging of the screens by minnows and of the pit surface by algae growth were the most serious operating problems. Copper sulfate was applied to the river water at a rate of 20 pounds per day to control algae growths. The rate of recharge was reduced from about 2.5 mgd at the start to 2.0 mgd at the end of the test due to the interference by minnows and algae.

As a result of the summer recharge test, it was concluded that temperature limitations could be relaxed, and subsequently recharge was practiced with water temperatures as high as 65° F. without raising ground-water temperatures above those required for industrial operations.

PIT NO. 2 AND RECHARGE WITH TWO PITS

Sixth Season, 1956-1957

Pit No. 2 was constructed in 1956 on leased property adjoining the Peoria Laboratory. Consideration was given to the alternatives of Project "A" which provided for construction of an additional, separate pit, and to Project "B" which planned for an extension of Pit No. 1. Both are shown in Figure 10. An extension of the existing pit would have increased the total amount of artificial recharge but would not have resulted in significant changes in the rate or efficiency. Therefore, another pit of different design was constructed in the hope of gaining more efficiency of operation as well as information on interference between two adjacent pits.

The second pit was constructed with a rectangular bottom measuring 75 feet by 20 feet at elevation 435.0. Side slopes from the bottom to elevation 445.0 are three horizontal to one vertical, and from elevation 445.0 to 460.0 are two horizontal to one vertical. The size and shape of this pit were chosen partly to fit the dimensions of the available land area and partly to provide a higher percentage of wetted surface area in the side slopes per foot of water depth.

Water is pumped from the control tower to Pit No. 2 through a 12-inch transite pipeline by a single stage, 3 mgd, vertical mixed-flow propeller pump. Pumpage is measured by a Ratosleeve meter. The pipeline swings in a 75-foot arc around Pit No. 1 and terminates in an upturned elbow on the bottom of Pit No. 2 at an elevation of 436.3 feet. Water stages in both pits, in the control tower caisson, and in the river are read from gage boards calibrated in tenths of feet.

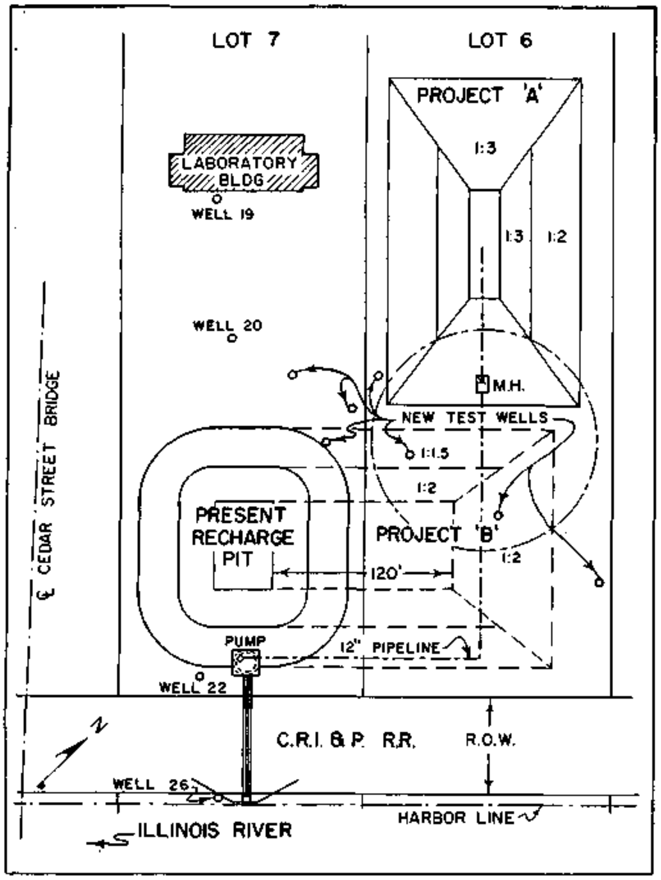


FIGURE 10 PROPOSED RECHARGE PITS AT GAS HOLDER PROPERTY

The second pit was operated from September 26, 1956, until May 25, 1957. Pit No. 1 was not started until October 16, 1956 and was stopped on May 25, 1957. Together the two pits recharged 1.08 billion gallons. Pit No. 1 recharged at an average rate of 1.76 mgd over a period of 210 operating days for a total of 3 70 million gallons. Pit No. 2 recharged at an average rate of 2.99 mgd during 235 operating days for a total of 710 million gallons.

This sixth season of operation was started with clean pea gravel in the two pits. Both were operated for the entire season without any type of cleaning being given to the gravel in order to obtain information on the reduction of capacity by silt deposition.

Three observation wells were drilled between the pits along a line intersecting the two. These wells were equipped with water-level recording devices and used to observe possible interference between the pits.

Seventh Season, 1957-1958

A few days before the start of the seventh season of operation, the silt, which had accumulated on the surface of the pea gravel during the 1956-1957 season, was raked down into piles in the bottom of each pit. Removing plant growth and raking the pea gravel were the only treatments used in preparation for the seventh season. The decision to operate the pits for a second season without cleaning or replacing the pea gravel was made for the purpose of comparing the relative economy of different operating conditions.

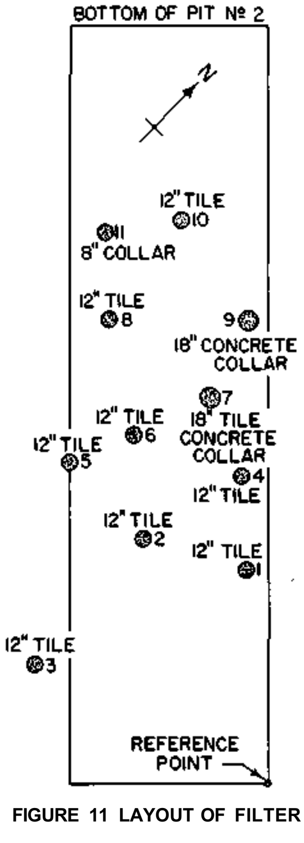
Pit No. 1 was in operation for a period of 213.12 days, during which 359.21 million gallons were recharged. Pit No. 2 was operated for 215.71 days during which it recharged 607.57 million gallons. Thus the average recharge rates for Pits No. 1 and 2 were 1.69 and 2.82 mgd, respectively, and the seasonal recharge totaled 966.78 million gallons. This quantity of recharge was extremely gratifying since this was the second season of operation without replacing the filtering gravel.

Eighth Season, 1958-1959

Because the silting of the pea gravelhad caused far less reduction of inflow than expected, the pits were again operated without cleaning or replacing the pea gravel. In addition to determining what effects the dirty gravel had on the sustained recharge rate, information was sought regarding the limits of silt saturation, or penetration, in the filter media layer. Pit No. 1 was operated for a period of 199.79 days at an average rate of 1.74 mgd. Pit No. 2 was operated for 197.26 days at an average rate of 2.87 mgd. The season's total of 915.32 million gallons was the result of recharging 347.81 million gallons in Pit No. 1 and 567.51 million gallons in Pit No. 2.

DISCUSSION OF RECHARGE OPERATION

Partial operating data for all seasons is shown in Table 3, which summarizes briefly the results of eight years of recharge.



OFFSETS TO TEST CYLINDERS		
WELL Nº	WESTERLY FT.	SOUTHERLY FT.
1	21.2	2.3
2	24.5	12.6
3	12.0	23.5
4	30.6	2.7
5	31.6	19.9
6	34.5	13.5
7	38.3	5.9
8	46.0	16.0
9	45.9	2.2
10	55.9	8.9
11	54.7	16.3

WELL Nº	TYPE FILTER MATERIAL
1	1" CRUSHED ROCK
2	3/4" PEA GRAVEL
3	1" PEA GRAVEL
4	5/6" PEA GRAVEL
5	1/2" PEA GRAVEL
6	3/4" CRUSHED ROCK
7	>1" PEA GRAVEL
8	>1" CRUSHED ROCK
9	5/8" CRUSHED ROCK
10	1/2" CRUSHED ROCK
11	.312" CRUSHED ROCK

FIGURE 11 LAYOUT OF FILTER SAMPLES FOR PIT NO. 2, 1956-1957

TABLE 3

PARTIAL OPERATING DATA FOR ALL SEASONS, 1951-1959

Season Number	Pit In Operation	Start of Season	End of Season	Total Operating Time, Days	Total Recharge, Million Gallons	Average Recharge, MG/Operating Day	Chlorine Used, Pounds	Average Chlorination, ppm	Chlorine Cost/100 lbs., Dollars
1951-1952[2]	1	10/4/51	4/28/52	146.0	258.7	1.78	9,405	4.36	9.50
1952-1953[1]	1	10/13/52	4/13/53	208.75	214.6	1.03	15,732	8.79	9.50
1953-1954[1]	1	10/26/53	5/17/54	199.25	208.2	1.05	15,292	8.79	8.00
1954-1955[3]	1	11/18/54	5/11/55	165.2	365.0	2.21	12,193	4.00	8.00
1955-1956[3]	1	11/1/55	5/6/56	195.8	422.6	2.16	18.612	5.28	8.50
1955-1956[5,4]	1	7/12/56	8/10/56	29.0	65.9	2.27	2,961	5.4	8.50
1956-1957[3]	1	10/16/56	5/25/57	210.5	370.0	1.76			
	2	9/25/56	5/25/57	237.75	710.0	2.99			
Total Both Pits.				224.1	1080.0	4.81	34,315	3.81	8.27
1957-1958[4]	1	10/4/57	5/13/58	213.12	359.2	1.69			
	2	9/26/57	5/14/58	215.71	623.61	2.89			
Total Both Pits.				214.4	982.81	4.58	34,621	4.23	8.00
1958-1959[4]	1	10/6/58	5/21/59	199.79	347.81	1.74			
	2	10/6/58	5/21/59	197.26	567.51	2.87			
Total Both Pits.				198.5	915.32	4.6	28,292	3.71	9.00

Superscript Numbers:
1 - Sand used as a filter media, cleaned and changed each season
2 - Sand changed once during operating season
3 - Clean gravel used as filter media
4 - Dirty gravel used as filter media
5 - Summer operating season

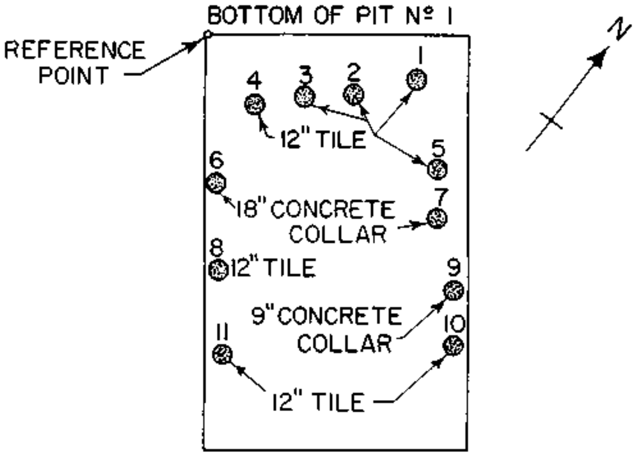
FACTORS INFLUENCING RECHARGE

Filter Media

Previous discussion has indicated some of the advantages and disadvantages in the use of different types of filter media. The sand which was used in the first three seasons served effectively as a filter but this advantage was practically nullified by its rapid clogging with silt. When the sand was dirty, its permeability was a major factor in confining recharge to relatively low rates. The trial of a coarser filter media revealed that higher permeabilities could be maintained together with effective filtration.

The possible use of filtering materials coarser than the 3/8-inch gravel was studied during the 1956-1957 and 1957-1958 seasons. In those periods, samples of gravel and broken limestone in graded sizes from three-eighths inch to more than one inch were placed in short tile rings of 12- to 19-inch diameters in the bottom of the two pits, at the locations shown in Figures 11 and 12. The tile rings, containing the material to be tested, were set in the bottom of the pit so that the top edge was even with the surface elevation of the pea gravel, and the flow of recharged water through them was under conditions identical to that through the 3/8-inch pea gravel. At the end of the season the test samples were analyzed for penetration of silt. These tests gave no conclusive determination of filtration efficiency but indicated that filter media of sizes larger than five-eighths inch will permit more penetration of silt with a consequent concentration in the lower layers.

Samples of the pea gravel filtering material were taken at the end of each of the last three seasons and examined for the amount of silt in them. Samples were taken in several locations and from the top, middle, and bottom 2-inch layers of the pea gravel. The silt from a 200 ml volume of each of these samples was washed from the gravel with distilled water and dried and weighed. Results of these determinations indicated the accumulation of silt in the pea gravel to be 2.28, 5.8, and 12.1 pounds per cubic foot in Pit No. 1 from May, 1957, to May, 1959. In Pit No. 2 the concentrations found were 5.45, 8.6, and 9.8 pounds per cubic foot for the three consecutive seasons. Attempts were made to relate the amount of silt accumulated on the surface and within the pea gravel, to the theoretical amount calculated from daily recharge records and turbidity measurements. In all cases the theoretical amount of



OFFSETS TO TEST CYLINDERS			TYPE FILTER MATERIAL
CYL Nº	EASTERLY FT.	NORTHERLY FT.	
1	6.9	32.4	5/8" GRAVEL
2	8.8	23.0	3/4" CRUSHED ROCK
3	9.2	15.5	3/4" GRAVEL
4	10.3	8.1	1/2" CRUSHED ROCK
5	20.3	35.9	5/8" CRUSHED ROCK
6	22.1	2.0	>1" CRUSHED ROCK
7	27.8	35.7	>1" GRAVEL
8	35.1	2.7	1" CRUSHED ROCK
9	38.1	38.3	.312" CRUSHED ROCK
10	46.7	38.7	1" GRAVEL
11	48.2	3.4	1" CRUSHED ROCK

FIGURE 12 LAYOUT OF FILTER SAMPLES FOR PIT NO. 1, 1957-1958

deposited silt exceeded the accumulation which was found through examination of pea gravel samples. This requires further study. Unquestionably there is some penetration of fine particulate matter into and through the pea gravel to the soil beneath the pea gravel layer. Hydrometer analyses of the silt washed from the pea gravel indicated that the lowest gravel layer contained the highest percentage of the finest material. Samples of soil taken from underneath the pea gravel show the highest percentages of finest material at locations in the bottom or on the sides below the seasonal high water line.

Size and Shape of Pits

The dimensions of Pit No. 1 were dictated, to a large degree, by available land area and location relative to the Illinois River and depth to the existing ground-water surface. Approximately 30 feet of excavation was necessary to penetrate the overburden and to reach an elevation permitting gravity discharge from the river, through the control tower caisson to the pit. The bedrock, at this location, is at an elevation of approximately 406 feet and the ground-water surface elevation in 1951 was at approximately 420 feet. This left ten feet or more of sand and gravel material between the bottom of the pit and the existing ground-water surface. At the time Pit No. 1 was constructed, very little published data were available which dealt with possible recharge rates, desirable soil conditions, and the effects on recharge of size, shape, or location of a pit.

The design and construction of Pit No. 2 in 1956 were largely influenced by experiences with the construction and operation of Pit No. 1. Several factors indicated that a major portion of recharge occurred through the side slopes. Compaction of the bottom of Pit No. 1 during construction undoubtedly was responsible for some restriction of the flow through it. Measurements of silt deposited in the pit indicated that the heaviest accumulation was on the bottom, which* would tend to favor flow through the relatively cleaner side slopes. Conditions of flow in the ground beneath the pit were not known, but if the volume of soil between the ground-water surface and the bottom of the pit were to become saturated, there would have been more flow through the side slopes. Therefore, Pit No. 2 was designed and built with these considerations in mind. Its bottom surface was made longer and narrower than that in Pit No. 1 and its side slopes were made flatter. In addition to making the most efficient use of the available land, this design provided a greater proportion of wettable surface area in the side slopes, per foot of submergence, than was available in Pit No. 1. The side slopes above the maximum water level in the new pit were graded two horizontal to one vertical in an attempt at overcoming some of the erosion problems encountered with the one and one-half to one side slopes of Pit No. 1. The second pit was deliberately located within 150 feet of the first in order to observe any possible interference which might occur between the two during simultaneous operation.

Daily unit area infiltration rates for the three seasons of operation beginning in 1956, shown in Figures 13, 14, and 15, indicated higher rates in Pit No. 2 than in Pit No. 1. Observations of the ground-water surface level in wells between the pits showed no formation of a mound of water due to interference. There was no increase in rate of infiltration in either of the pits when the other pit was not operating. Ground-water levels in all of the observation wells, shown in Figure 16, were essentially the same. A well point of 1-1/2-inch diameter, penetrating the side slope of Pit No. 2 and within the high-water line, yielded observations indicating that the soil between the ground-water surface and the bottom of the pit did not become saturated during the 1956 to 1958 seasons. Three additional well points were driven around the periphery and one through the bottom of Pit No. 2. Water elevations measured in these well points and in other wells near both pits showed that the ground-water surface never reached the elevation of the bottom of Pit No. 2 during the 1958-1959 season. However, for a period of about twenty-five days in March, and for about eighteen days in May, 1959, the ground-water levels below and around the pits were higher than the bottom of Pit No. 1.

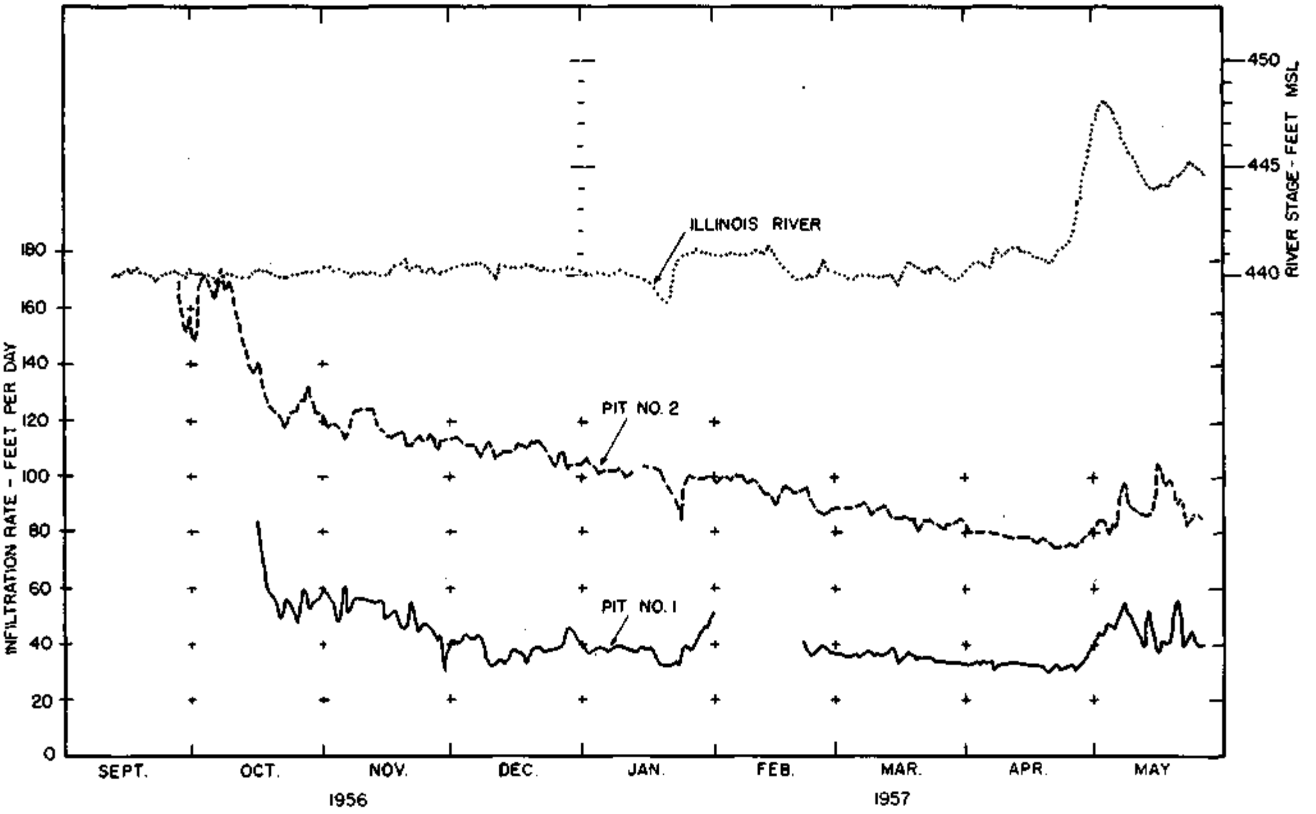


FIGURE 13 RIVER STAGES AND DAILY INFILTRATION RATES IN PITS, 1956-1957

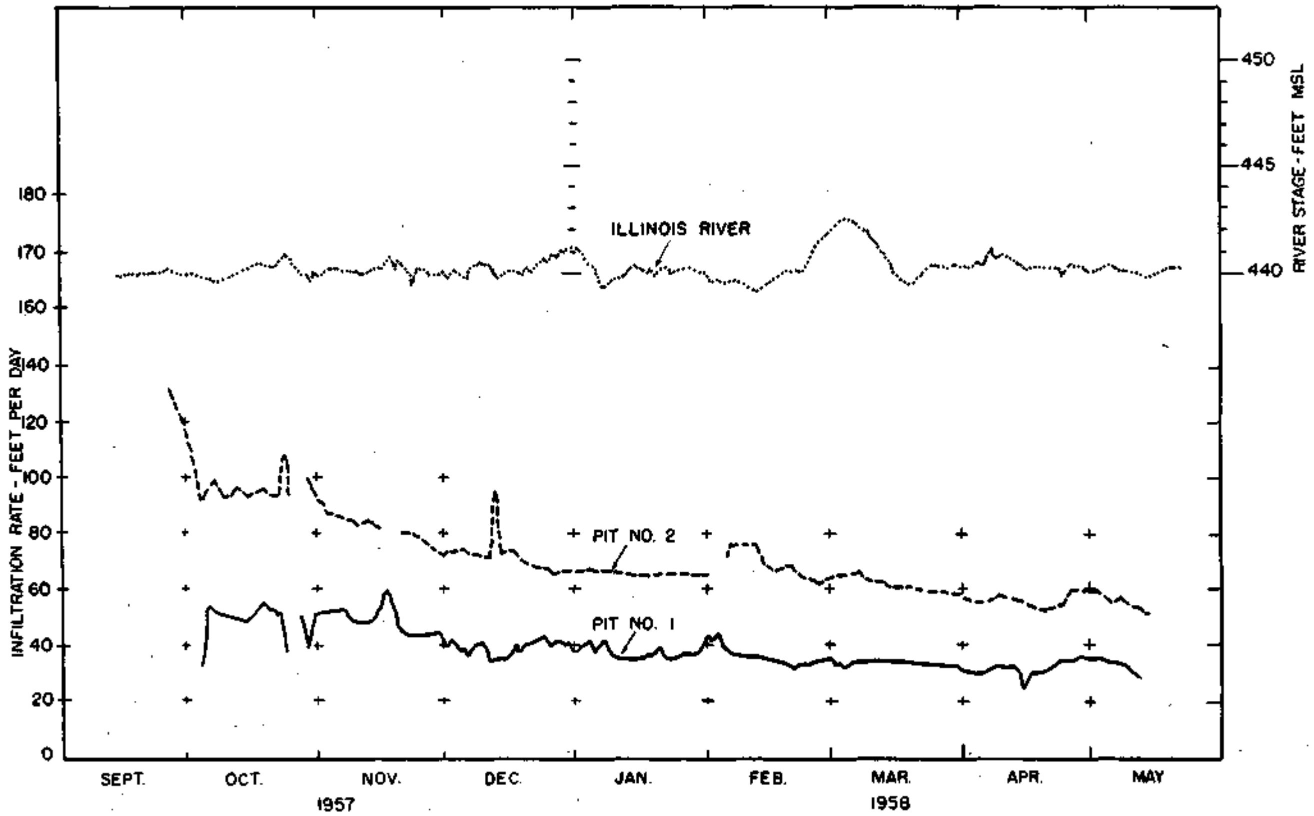


FIGURE 14 RIVER STAGES AND DAILY INFILTRATION RATES IN PITS, 1957-1958

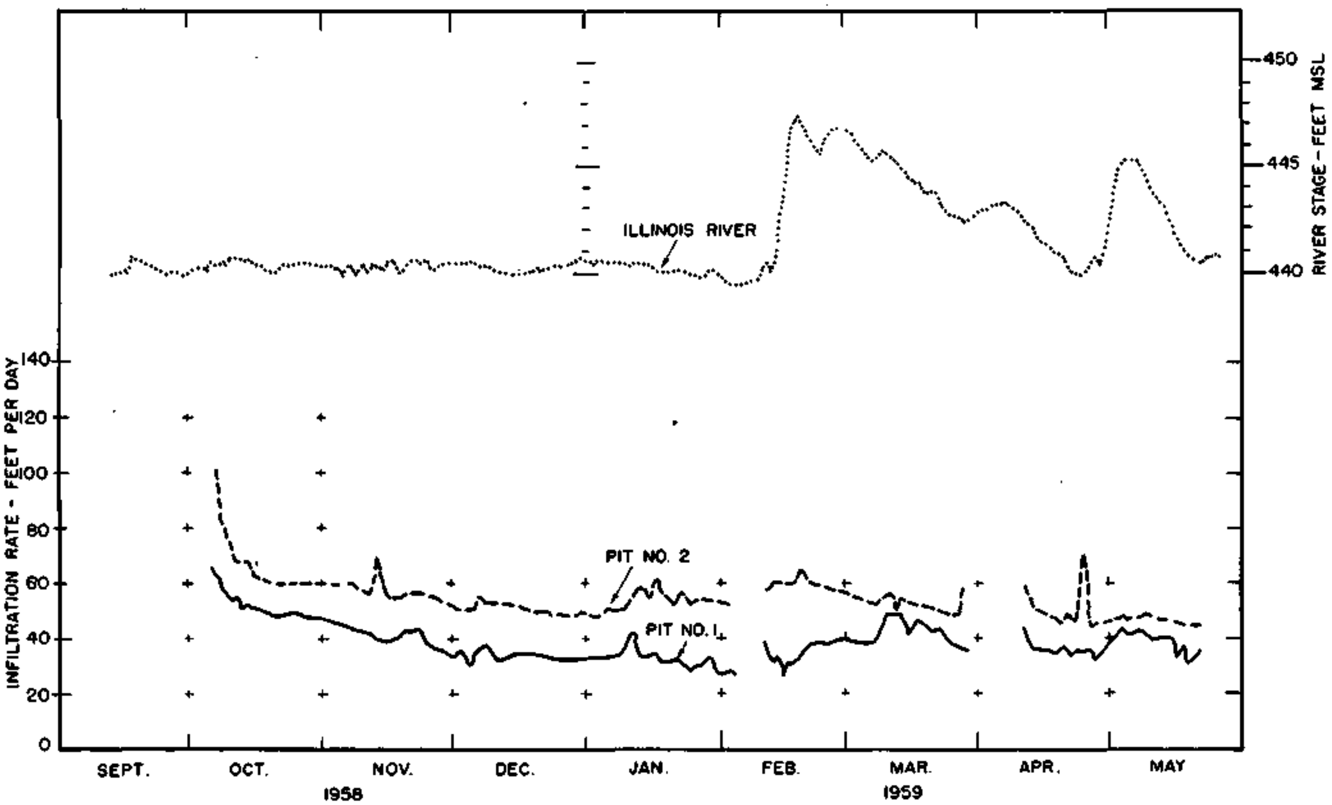


FIGURE 15 RIVER STAGES AND DAILY INFILTRATION RATES IN PITS, 1958-1959

River Stage

The effects of variations in river stage and floods on recharge are difficult to analyze and, in addition, differ for the two pits. Because Pit No. 1 is gravity fed, it responds strongly and readily to high river stages. Flow into Pit No. 2 is relatively constant since water is pumped into it. Slight variations in the second pit are due to changes in head on the pump and condition of the screen. During high water the increased recharge in Pit No. 2 is reflected by a lowering of the water level in the pit which represents increased inflow per unit area. Other factors such as turbidity of the river water, degree of silt deposition in the pits, and season of the year influence the amount and rate of recharge, but variations in these factors were not as closely observed as river and pit stages.

For the three seasons, during which both pits were operating (Figs. 13, 14, 15), comparison is made of the daily values of river stages and unit area infiltration rates. These figures show the reactions which the flood stages in the river had on the infiltration rates in the pits. In Pit No. 1 both the unit area infiltration rate and the pit stage, which is not shown in the figures, were increased by river flood stages in 1956-1957 and again in 1958-1959. Since Pit No. 1 is gravity-fed, the increase in depth of water during flood stages of the river is to be expected due to the increased head. During these river flood stages, Pit No. 2 did not show greater than normal increase in depth although there were increases in the infiltration rates.

Silt Removal

Deposited silt was removed from the pits by two general methods: either by using the swimming pool suction cleaner during the operating period, or by removing the dirty filtering layer and replacing it with clean material.

Removal of the silt with the suction cleaner resulted in small increases in the infiltration rate which lasted for short periods. The cleaner removed only part of the surface layer of silt. In addition, the cleaning process was both laborious and tedious. At least two men were required to operate the suction pump and to control the long ropes with which the cleaner was dragged back and forth over the pit surface. During most of the winter months, formation of a thick ice crust on the water prohibited use of the cleaning equipment.

Removal of the dirty filtering media and replacement with clean material was always effective in raising the infiltration rate. During the first seasons of operation, when sand was used as filtering material, the recharge rates diminished rapidly with the accumulation of silt. The reduction was so great in the first season that the sand was removed and replaced during the winter. Loss of recharge rate was much slower when pea gravel was used as the filtering media.

During the summer of 1956, Pit No. 2 was constructed and clean pea gravel was placed in it and in Pit No. 1. The two pits were then operated for the next three successive seasons without

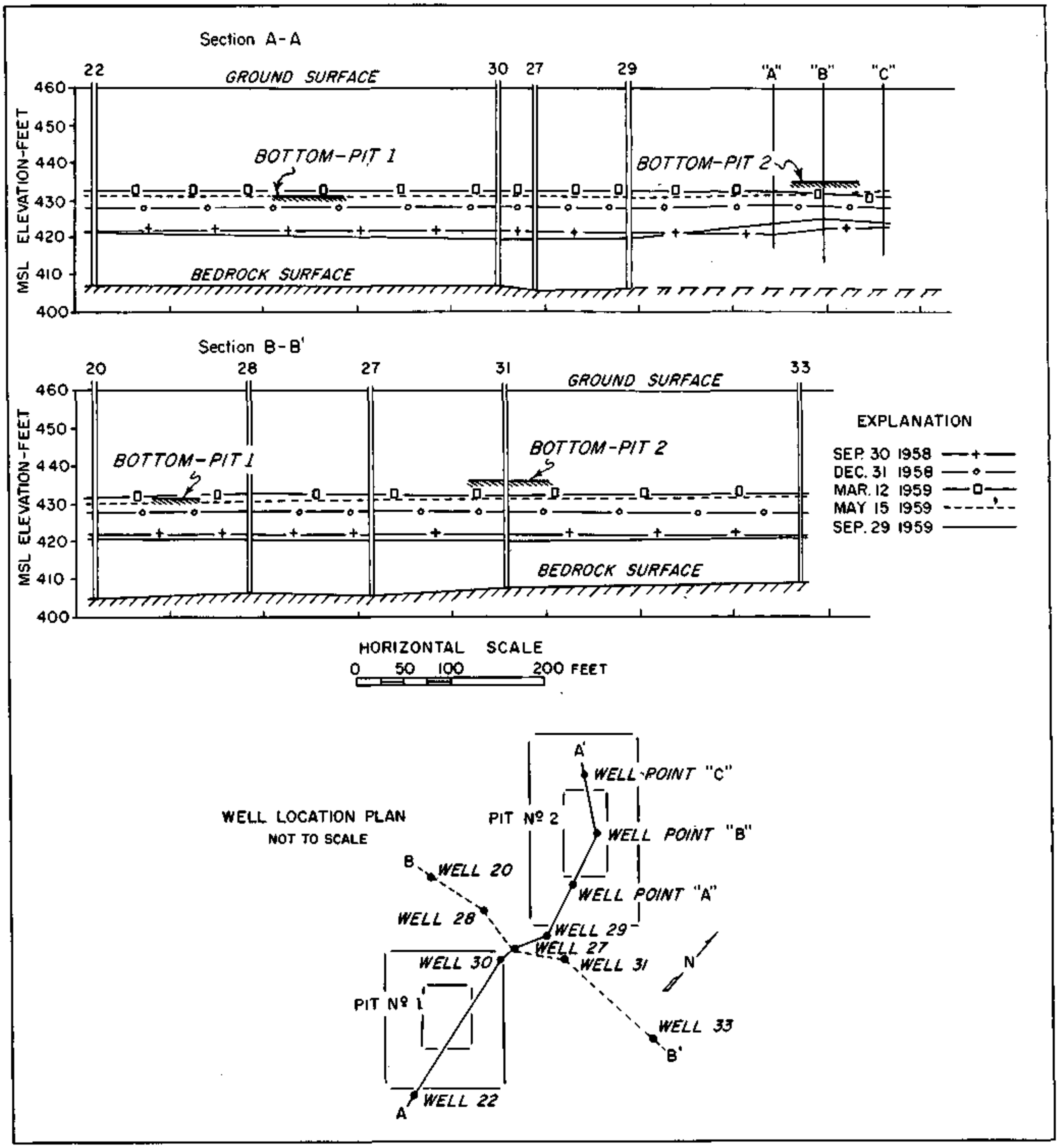


FIGURE 16 GROUND-WATER ELEVATIONS NEAR PITS

cleaning or replacing the pea gravel. Accumulated silt was raked into piles on the floor of the pits. Curves showing the progressive decrease in unit area infiltration rate with time are presented in Figures 13, 14, and 15. Temporary increases in the infiltration rate are attributed to the effects of flood stages in the river, particularly in the case of Pit No. 1. These curves show that in all cases the infiltration rates at the beginning of a season are higher than those at the end of the preceding season. During the interim between seasons, the accumulated silt had an opportunity to dry and crack, and the pea gravel seemed to regain some of the permeability which was lost in the preceding operational period.

Turbidity of River Water

Initially, recharge was practiced only when the turbidity of the river water was below an arbitrarily selected limit of 100 ppm, as read on the silica scale. During the 1951-1952 season there

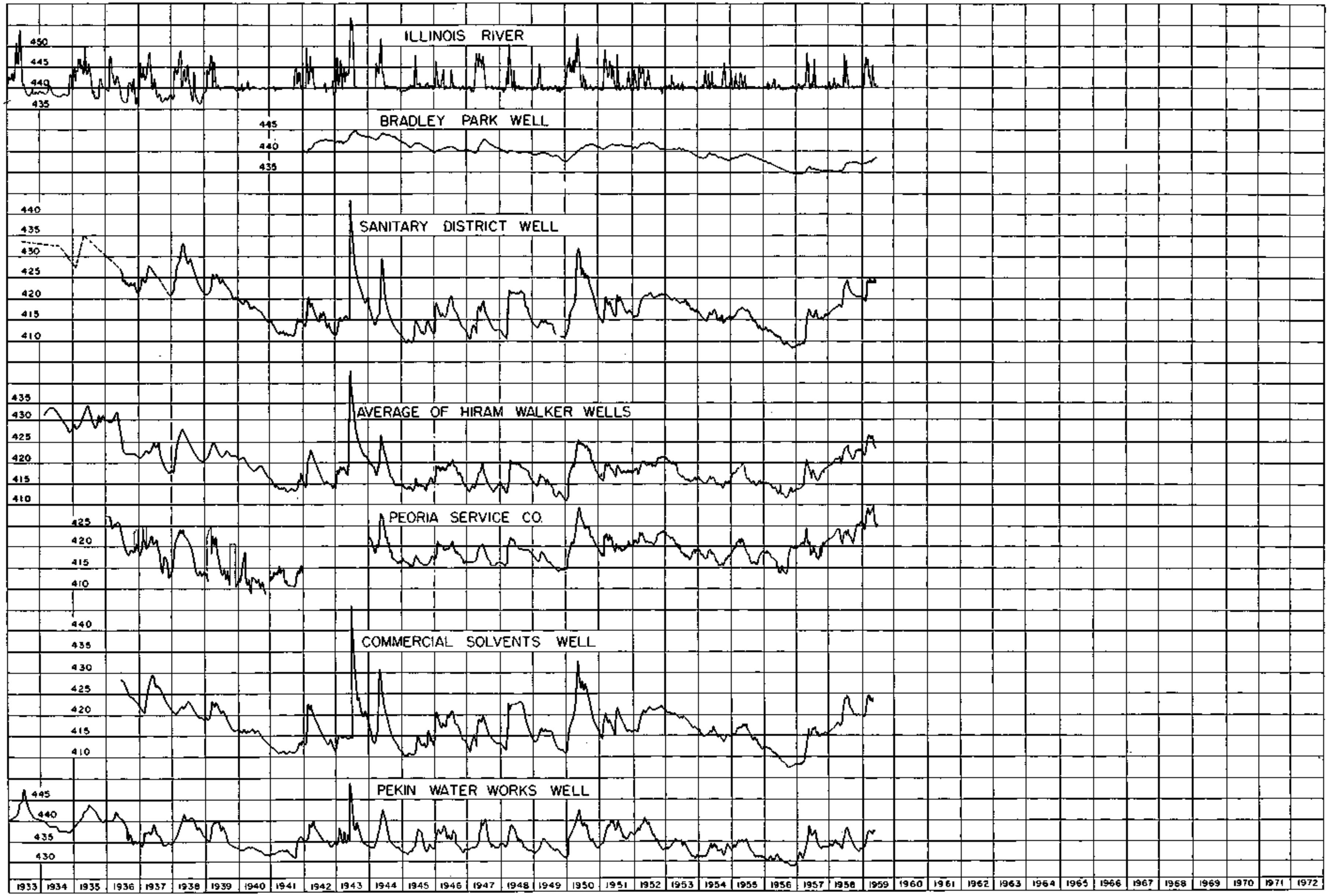


FIGURE 17 WATER ELEVATIONS IN RIVER AND WELLS AT PEORIA

were only 26 days on which the turbidity of the river water was over 100 ppm. However, the pit was inoperative for a total of 62 days, and consequently the pit was inoperative on 36 days due to reasons other than the turbidity. When operation ceased during cold weather, the surface of the sand froze and this condition accounted for most of the 36-day period.

In the second season, 1952-1953, no limit on river water turbidity was observed. As a result of recharging with more turbid river water, the average recharge rate per operating day was decreased by approximately 40 percent, and the total quantity recharged for the season was 19 percent less than during the first year.

The reductions in both total recharge and daily operating rate due to silt were considerably less from one season to the next when pea gravel was used. A comparison of the operating data in Table 3 for the three seasons from 1956 to 1959, when there was no interruption for periods of high turbidity, shows that the reductions in daily operating recharge rates which can be related to turbidity, and the consequent deposition of silt in the pits, were negligible in Pit No. 1 and were 2.7 and 1.4 percent for Pit No. 2.

In general, it has been observed that the types of silt materials in the river govern the effects on recharge to an extent equaling or exceeding the turbidity concentration. Strong winds create waves which scour the fine muds from the bottom of Peoria Lake. Turbidity created in this manner was persistent and rapidly clogged the filtering surface of the recharge pits. In many instances, higher concentrations of turbidity which were caused by excessive storm runoff were less persistent and had less effect on the recharge rate.

Other Operational Difficulties

Ice, fish, debris and algae are worthy of mention only because they were constant nuisances. Although the submerged river intake was protected by a screened bar-rack, and the two pipe lines from the control tower caisson were screened, a great proportion of the operators' time was spent in removing these miscellaneous materials which collected on the screens.

Seasonal algae growths invaded the recharge pits and contributed to minor reductions in the operating rate. These sporadic invasions were effectively overcome by the application of 15 to 20 pounds per day of copper sulfate.

FACTORS INFLUENCING GROUND WATER

River Stages

Natural recharge to the Central Well Field from the Illinois River is variable and its extent is debatable. A paper by Suter in June, 1947(25) described some of the effects which floods of the Illinois River in 1943, 1944, and 1945 had on ground-water levels in the Central Field. At that time, as in subsequent periods, it was observed that the ground-water level rises with a rise in the river stage and starts to recede almost immediately after the flood crest has passed.

Comparisons of the hydrographs of river and well stages, Figure 17, over a period of years prior to and during artificial recharge reveal several interesting aspects of natural recharge from the river. It appears that the river channel is relatively impermeable below normal pool stage because rises in the river of one foot or less have no significant effect upon water levels in observation wells throughout the Central Field. Water levels in the aquifer near and underneath the river have consistently been below the 428.4 foot level, which is the approximate mean sea level elevation of the bottom of the river. One exception is Test Well No. 25, located on the east bank of the river behind a levee. Maximum ground-water levels as high as 438.3 feet have been observed in this well. However these levels represent artesian rather than water table levels since the materials through which this well was drilled were completely impermeable down to an elevation of 411.5 feet.

River stages above 441.0 feet have significant effects upon the ground-water levels and are instrumental in adding to the ground-water reserves through the process of natural recharge. Although the rise in ground-water levels resulting from high river stages have been of considerable magnitude, the quantity and duration of naturally recharged water in recent years have not been sufficient to meet the demands made in the well field.

Precipitation

Precipitation has effects on ground-water levels which are closely related to effects of river stages, and these are difficult to separate. Figure 18 shows cumulative departure of precipitation from the normal, compared with river stages and ground-water elevations in several wells. Normal precipitation was arbitrarily selected as a base line for the cumulative departure curve because the comparisons are made on a relative basis during the period of observation. This figure shows close correlation between precipitation and ground-water levels in the Central Well Field. There are, of course, minor deviations that may be due to the influences of pumpage, artificial recharge, river stage, and climatological conditions. For the over-all period between 1933 and 1956, the trends of the departure from normal precipitation and the ground-water level curves are similar.

Temperature of Recharge Water

Prior to 1951, ground-water temperatures were measured in samples of water from production wells. After artificial recharge was started in 1951 periodic measurements of ground-water temperature were made at various levels in observation wells with a resistance-type Wheatstone bridge temperature indicator. Comparisons of the records of ground-water temperatures before and after artificial recharge are revealing. Table 4

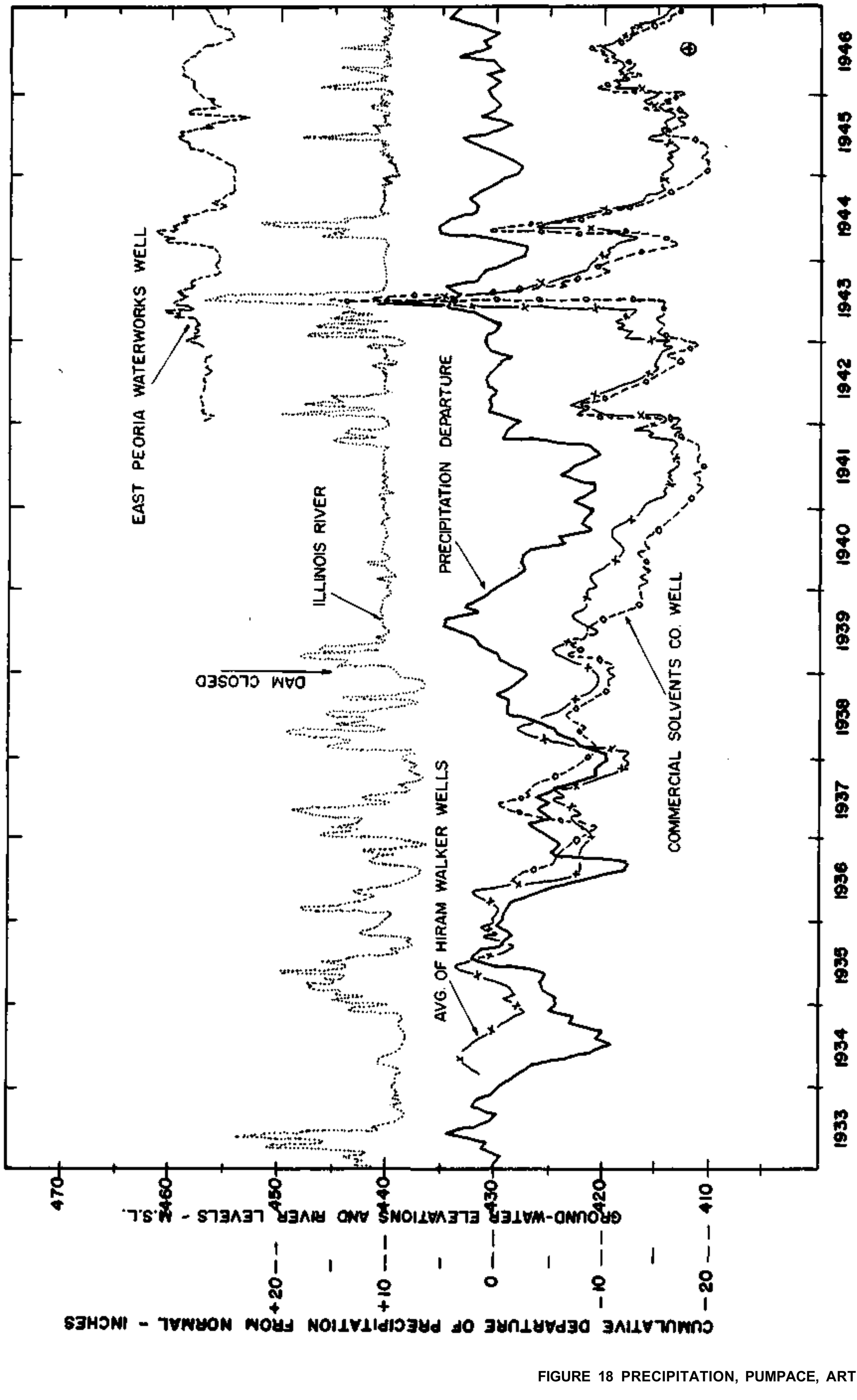
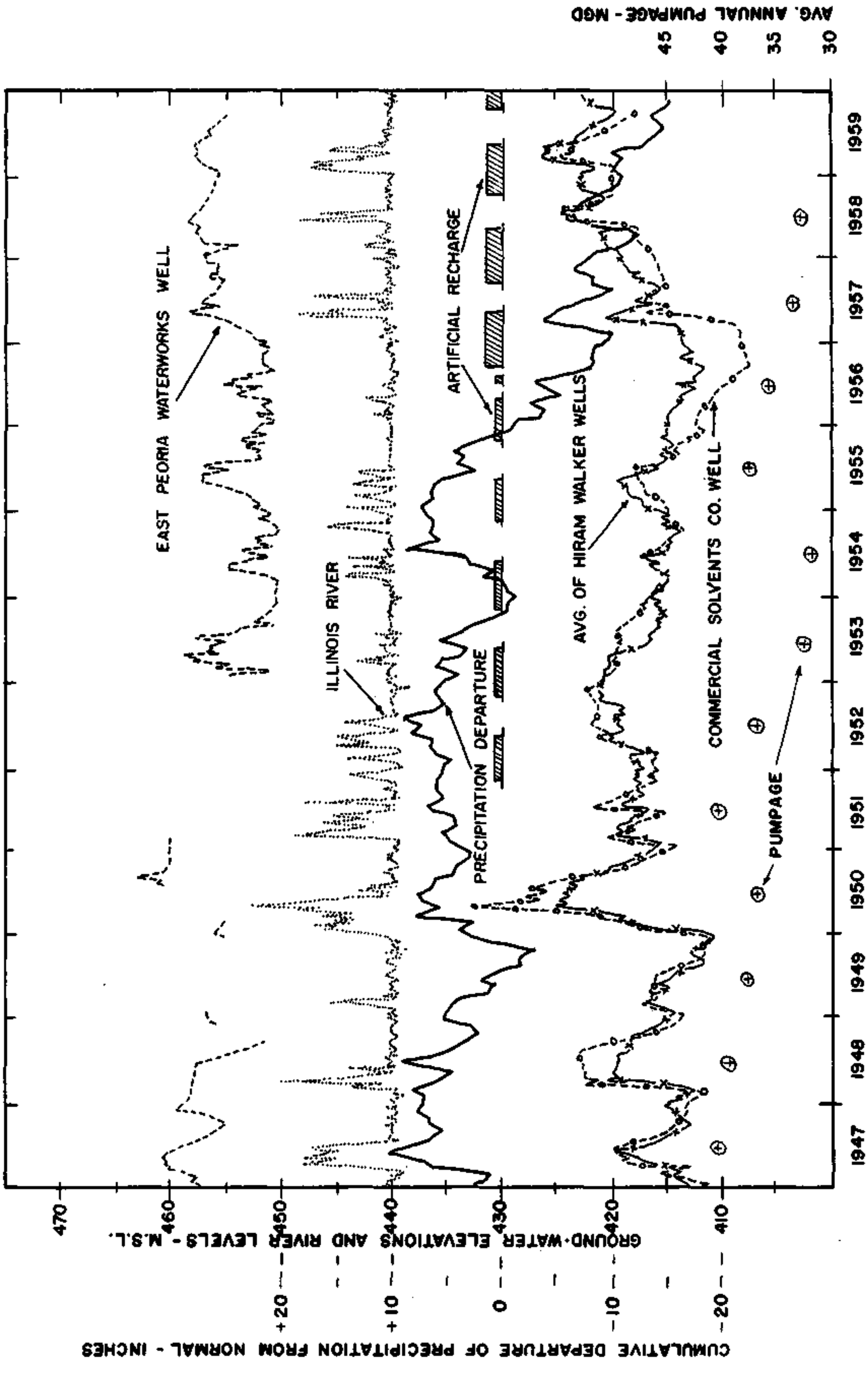


FIGURE 18 PRECIPITATION, PUMPACE, ARTIFICIAL RECHARGE,



AND WATER ELEVATIONS IN RIVER AND CENTRAL WELL FIELD

TABLE 4

TEMPERATURES OBSERVED IN GROUND-WATER SAMPLES FROM WELLS NEAR RECHARGE PITS

Range of Temperatures Observed in Hiram Walker Wells

Dates	Low Temperature Range	High Temperature Range
1947-1951	50°F.--54°F.	60°F.--69°F.
1952-1956	39°F.--50°F.	61°F.--67°F.
1957-1958	37°F.--50°F.	57°F.--64°F.
Date of Occurrence of:	**Lowest Temperature**	**Highest Temperature**
	1947-1951	
Hiram Walker Well No. 2	52°F. May, 1951	66°F. Nov., 1951
" " " No. 3	53°F. April, 1951	61°F. Jan. 4, 1948
" " " No. 8	50°F. July, 1947	69°F. Dec., 1949
" " " No. 5	54°F. July, 1951	64°F. Feb. 8, 1947
" " " No. 7	54°F. Sept., 1950	68°F. Nov., 1949
	1952-1956	
Hiram Walker Well No. 2	44°F. Mar., 1956	66°F. Dec., 1954
" " " No. 3	39°F. Mar., 1956	67°F. Aug., 1956
" " " No. 8	49°F. June, 1955	67°F. Jan., 1955
" " " No. 5	47°F. Apr., 1956	61°F. Nov., 1956
" " " No. 7	50°F. June, 1955	62°F. Jan. 12, 1956
	1957-1958	
Hiram Walker Well No. 2	41°F. Mar. 4, 1958	64°F. Nov., 1957
" " " No. 3	37°F. Mar., 1958	61°F. Nov., 1958
" " " No. 8	50°F. May, 1957-58	63°F. Dec., 1958
" " " No. 5	42°F. Mar., 1957	58°F. Nov., 1957
" " " No. 7	50°F. May 6, 1957	58°F. Nov., 1957

shows the ranges of minimum and maximum temperatures observed in samples taken from producing wells over three consecutive periods. These are the periods immediately preceding artificial recharge, during the operation of one recharge pit, and during the operation of two recharge pits. In addition, three successive periods during which the lowest and highest ground-water temperatures were observed in samples from five of the wells are given. These production wells are between 1093 and 2810 feet from the recharge pits. The wells are listed in the table in order of increasing distance from the pits. The apparent effects of recharge, using river water at temperatures below 65°F., have been 1) to lower both the minimum and maximum temperature range, 2) to move forward in time the date of occurrence of the high and low temperatures, and 3) to shorten the time periods during which the maximum and minimum temperatures occur.

Recharge with river water at temperatures below 65° F. has had the effect of lowering the average ground-water temperatures, at least in wells within 2000 to 3000 feet of the pits. For instance, the temperatures ranged from 54° to 58°F. and averaged 56° F. in Hiram Walker's Well No. 5 during 1951. By 1957, the annual range of temperatures had been changed to 42° to 63° F. and the yearly average temperature was down to 51°F. Although the influence of artificial recharge upon Well No. 2 is masked by some effects of natural recharge from the river, similar reductions in yearly average and range of temperatures were apparent. The 1951 range of 52° to 66° F. was reduced to 42° to 63° F. in 1957, and the average temperatures were 59° and 54° F., respectively.

During the summer operating period in 1956, temperatures were measured each week in observation wells near the pits at successive five-foot levels from the ground-water surface to the bottom of each well. Additional temperature measurements were made in samples collected from neighboring production wells. Recharge with high-temperature water (76° to 82°F.) increased the maximum observed ground-water temperatures in wells within a radius of 500 feet from Pit No. 1. Beyond that radius, the maximum was not increased over values previously observed.

The deviations from average ground-water temperatures and the differences between temperatures at successive five-foot levels are greatest in those wells nearest the pits. These effects may not be related entirely to the normal, inactive properties of the aquifer because all of the wells in which observations were made are subject to other variable and irregular influences such as natural recharge and pumpage. However, the trends are readily apparent.

Temperatures in wells nearest the river show interference from natural recharge during high river stages. In summer, when the pits are not operating, flood stages in the river produce higher than normal temperatures in the ground water in these wells. The same effect may be felt in wells more remote from the river, but it is not clearly evident.

Ground-water temperatures have given an indication of the direction in which recharge moves into and through the ground water. The most pronounced changes occur near the recharge pits, as would be expected. Based on the assumption that the magnitude and frequency of temperature change are directly related to quantity of recharge and direction of flow, the bulk of artificially recharged water moves in a southwesterly direction from the pits and roughly parallel to the river. It was also noted that recharged water remains on top of the existing ground water irrespective of their relative temperatures.

Mineral Quality

Periodic mineral analyses were made of samples collected from the river and Observation Well No. 19, which is located inside the Water Survey Laboratory building. Artificial recharge results in reductions of about 50 percent in total mineral content, alkalinity, hardness, and iron of the ground water in the vicinity of the pits. Manganese is completely eliminated. Concentrations of chlorides, sulfates, fluorides, nitrates, and dissolved oxygen are increased. There is no appreciable change in pH, and no increase in turbidity has been detected in ground-water samples by means of the direct light transmission method used. However, some of the local industries require high clarity in water for their processes and are making systematic nephelometric observations of the turbidity in ground-water samples.

During early 1959 at the request of the Robert A. Taft Sanitary Engineering Center, carbon filters were installed to collect samples at the river intake, from the Water Survey's Well No. 19 and from a well about 1,000 feet away. Taft personnel are conducting a study of organic contaminants. It was found that all of the waters are similar, that water from the Survey's Well No. 19 is practically undiluted recharge water during periods of operation, and that the water taken from the distant well is about 50 percent diluted.

Quantity of Recharge

Figures 19 through 36 show ground-water elevations in wells, along lines drawn through the well field parallel to and across the Illinois River Valley, revealing some of the changes which have occurred since 1933. These profiles demonstrate in part the effects of artificial recharge, but they do not permit the comparison of the effects of artificial recharge with those of other factors which prevail. It is significant to remember that elevations observed in Well No. 25, on the east side of the river, may not truly represent the free ground-water surface as this well was drilled through a confining layer of clay.

Artificial recharge results in immediate and substantial changes in the ground-water levels near the pits, both when it begins and ends. At distances over 1500 feet from the pits, effects are not so evident except when considered together with other factors which influence ground-water levels and during the period of time preceding and including artificial recharge. Reference to Figure 18 will show that the over-all trend of ground-water levels in the Central Well Field was rather sharply downward during the years between 1933 and 1950. There were, of course, minor fluctuations caused by such factors as temporary reductions in pumpage, floods, and heavy precipitation, but the general trend was persistently downward. At the end of this period, the curve showing the cumulative departure from normal precipitation had returned from below to above normal, and conservation measures had reduced total pumpage to a quantity within the estimated range of safe yield for the aquifer. During the period of 1950 to 1953, the area experienced one flood and river stages were high for a large proportion of the remaining time; one recharge pit was placed in operation; pumpage from the field was held close to the estimated safe range; and, the ground-water levels rose to elevations comparable to those of about 1939 or 1940. From 1953 through 1956, the ground-water levels again declined and in some cases reached their lowest recorded levels. Precipitation was below normal for three of these four years although the cumulative departure curve did not fall below normal until early 1956. The recession in ground-water levels continued throughout this period in spite of the operation of one recharge pit and despite further reductions in pumpage from the well field. Since late 1956, two recharge pits have been operated and ground-water levels throughout the Central Well Field have risen rapidly. This rise in ground-water levels has taken place in spite of additional deficiencies in precipitation and of annual withdrawals in pumpage approximately equal to those during the period of declining water levels from 1953 to 1956.

These observed trends and the influences exerted by recharge, precipitation, floods, and pumpage are apparent in the remote parts of the Central Well Field as well as in the immediate vicinity of the recharge pits. It appears logical to conclude that sufficient water is being recharged by the two pits to raise directly the ground-water levels in the immediate neighborhood; and, at the same time, to serve as the means of raising the storage level of naturally infiltered ground water in more remote parts of the well field.

ARTIFICIAL GROUND-WATER RECHARGE BY INDUSTRIES

The successful operation of the first of the Water Survey's two recharge pits led to the construction of similar installations in Peoria. Both the Bemis Bro. Bag Company and the Peoria Water Works Company pits are located in the North Well Field.

BEMIS BRO. BAG COMPANY

The Bemis Company obtains its water supply from two wells, in both of which the ground-water levels were dangerously low in 1955. In addition, the company pumps an estimated 2 mgd of river water through its condensers and returns this warmed water to the river. Because the well water which it uses must be warmed in manu-

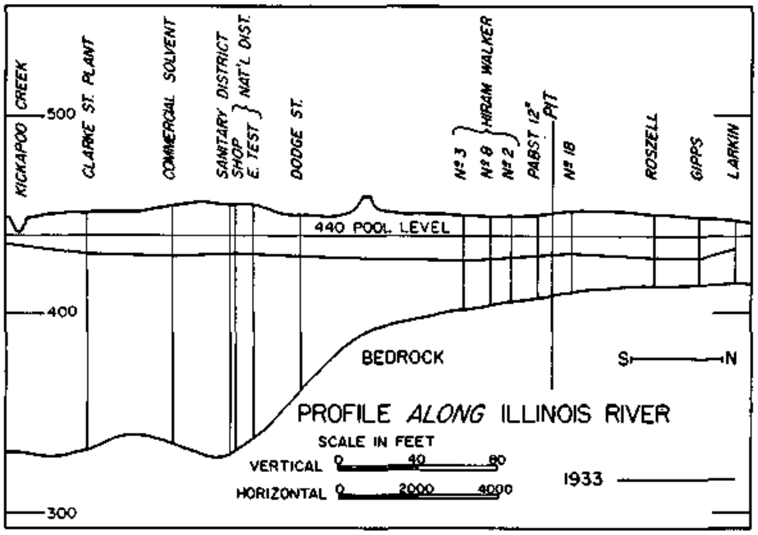


FIGURE 19 GROUND-WATER SURFACE PROFILE ALONG ILLINOIS RIVER VALLEY, 1933

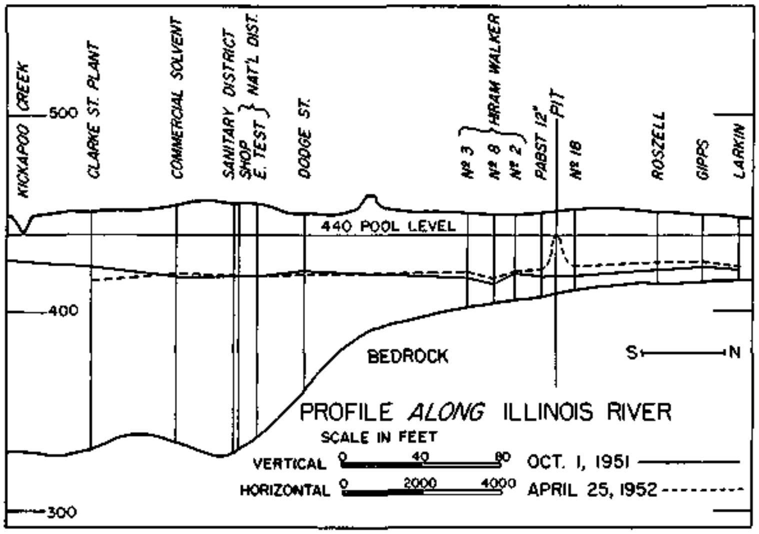


FIGURE 20 GROUND-WATER SURFACE PROFILE ALONG ILLINOIS RIVER VALLEY, OCTOBER 1951 TO APRIL 1952

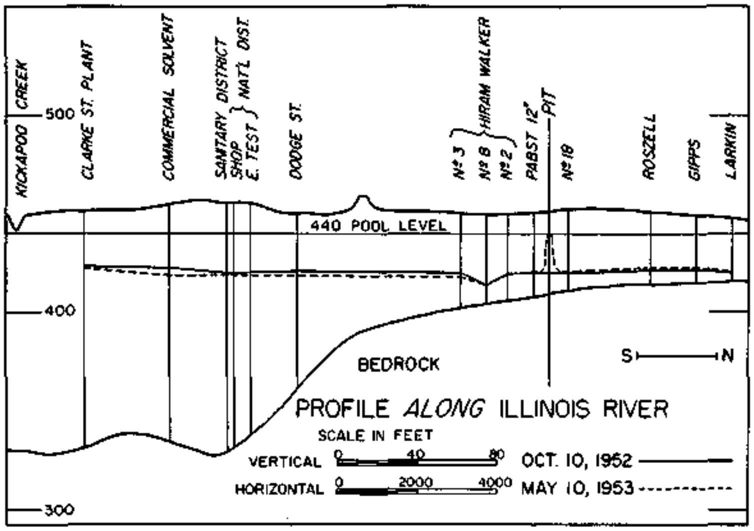


FIGURE 21 GROUND-WATER SURFACE PROFILE ALONG ILLINOIS RIVER VALLEY, OCTOBER 1952 TO MAY 1953

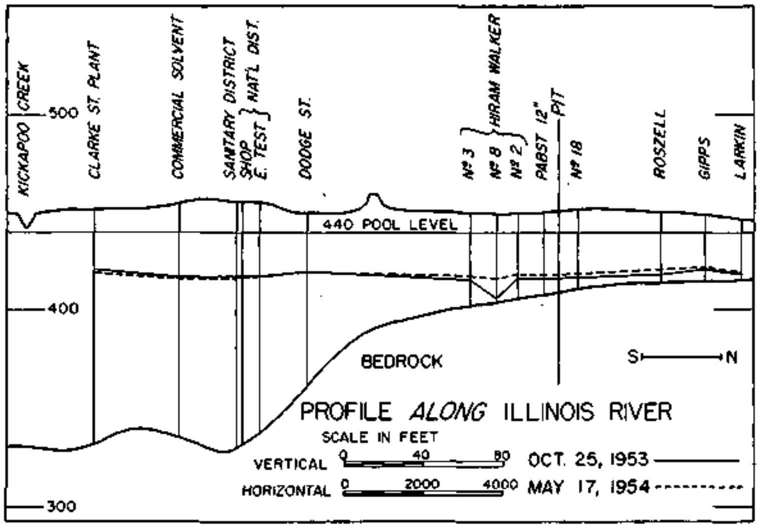


FIGURE 22 GROUND-WATER SURFACE PROFILE ALONG ILLINOIS RIVER VALLEY, OCTOBER 1953 TO MAY 1954

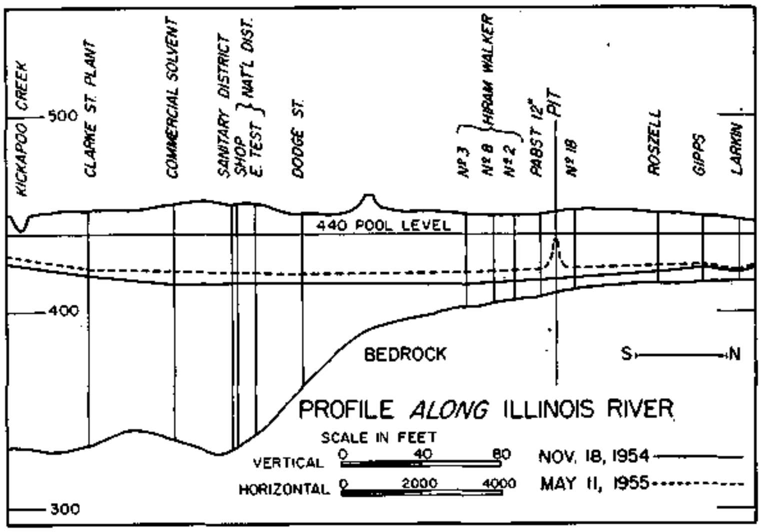


FIGURE 23 GROUND-WATER SURFACE PROFILE ALONG ILLINOIS RIVER VALLEY, NOVEMBER 1954 TO MAY 1955

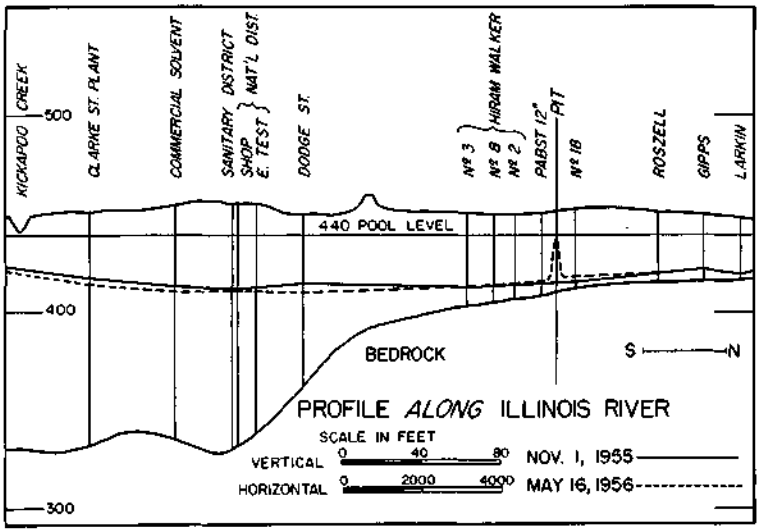


FIGURE 24 GROUND-WATER SURFACE PROFILE ALONG ILLINOIS RIVER VALLEY, NOVEMBER 1955 TO MAY 1956

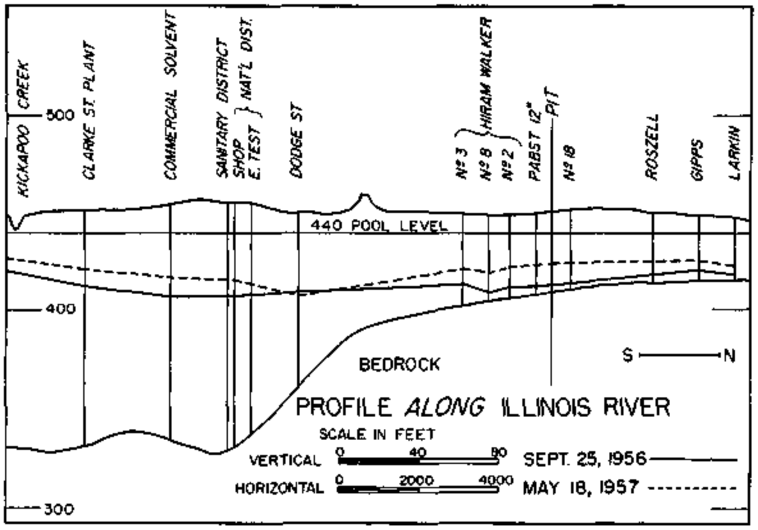


FIGURE 25 GROUND-WATER SURFACE PROFILE ALONG ILLINOIS RIVER VALLEY, SEPTEMBER 1956 TO MAY 1957

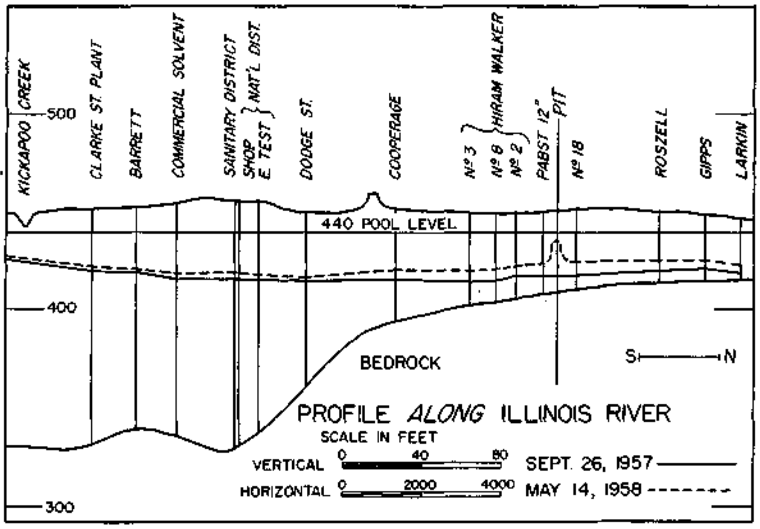


FIGURE 26 GROUND-WATER SURFACE PROFILE ALONG ILLINOIS RIVER VALLEY, SEPTEMBER 1957 TO MAY 1958

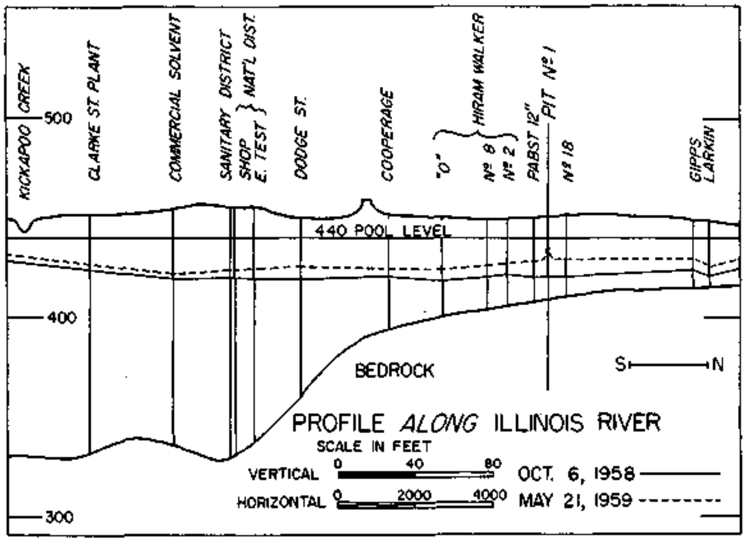


FIGURE 27 GROUND-WATER SURFACE PROFILE ALONG ILLINOIS RIVER VALLEY, OCTOBER 1958 TO MAY 1959

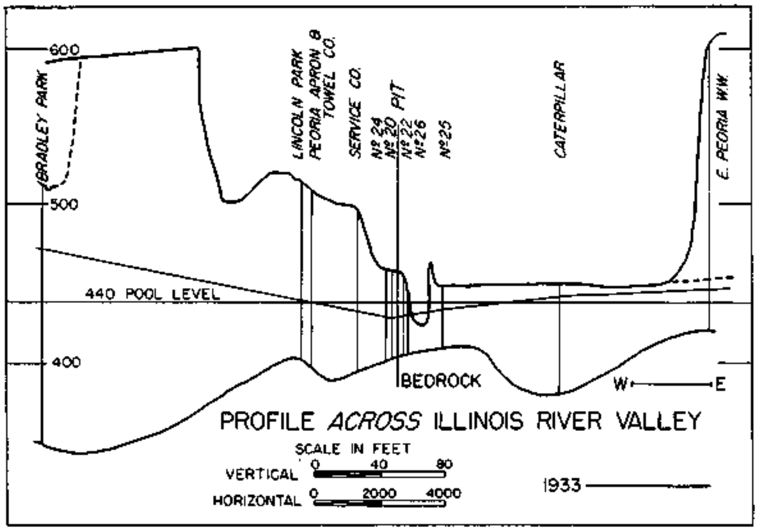


FIGURE 28 GROUND-WATER SURFACE PROFILE ACROSS ILLINOIS RIVER VALLEY, 1933

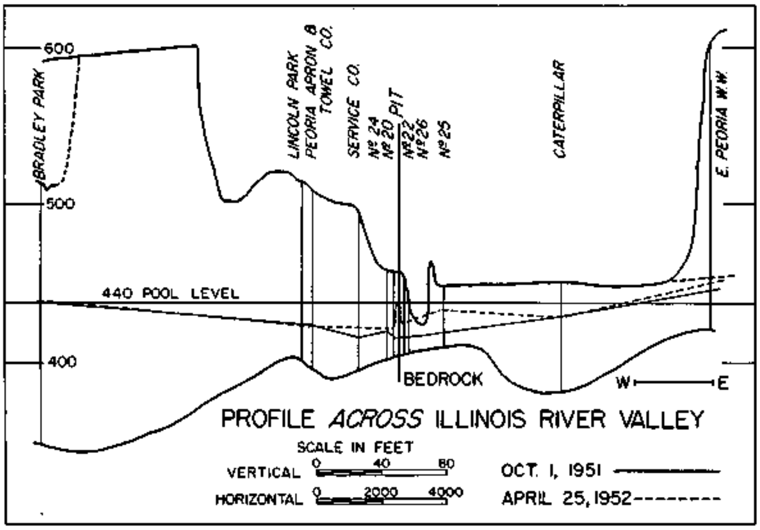


FIGURE 29 GROUND-WATER SURFACE PROFILE ACROSS ILLINOIS RIVER VALLEY, OCTOBER 1951 TO APRIL 1952

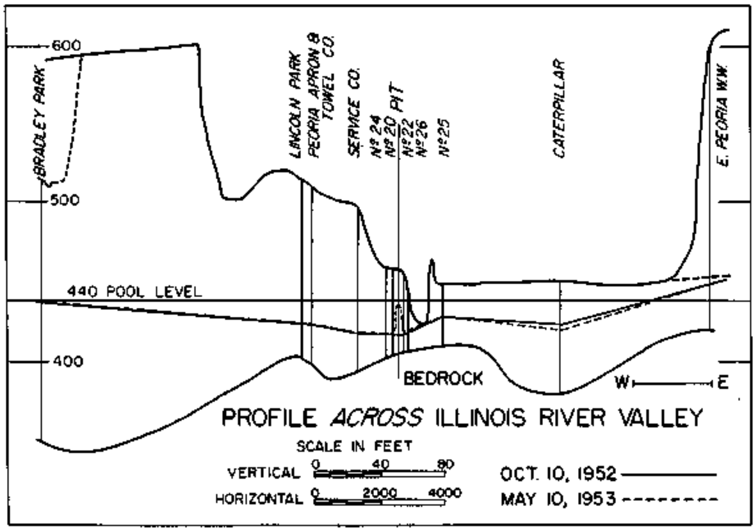


FIGURE 30 GROUND-WATER SURFACE PROFILE ACROSS ILLINOIS RIVER VALLEY, OCTOBER 1952 TO MAY 1953

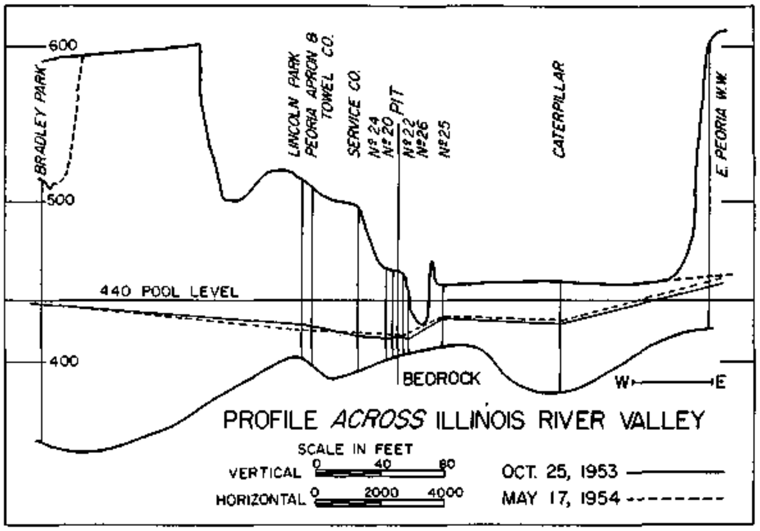


FIGURE 31 GROUND-WATER SURFACE PROFILE ACROSS ILLINOIS RIVER VALLEY, OCTOBER 1953 TO MAY 1954

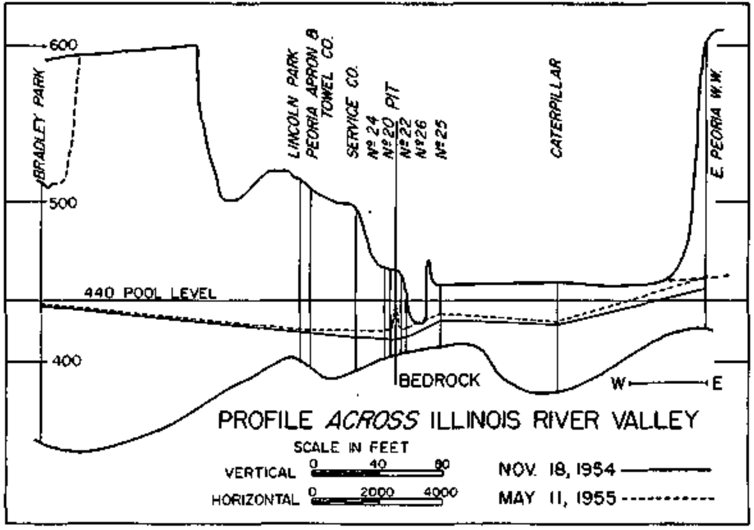


FIGURE 32 GROUND-WATER SURFACE PROFILE ACROSS ILLINOIS RIVER VALLEY, NOVEMBER 1954 TO MAY 1955

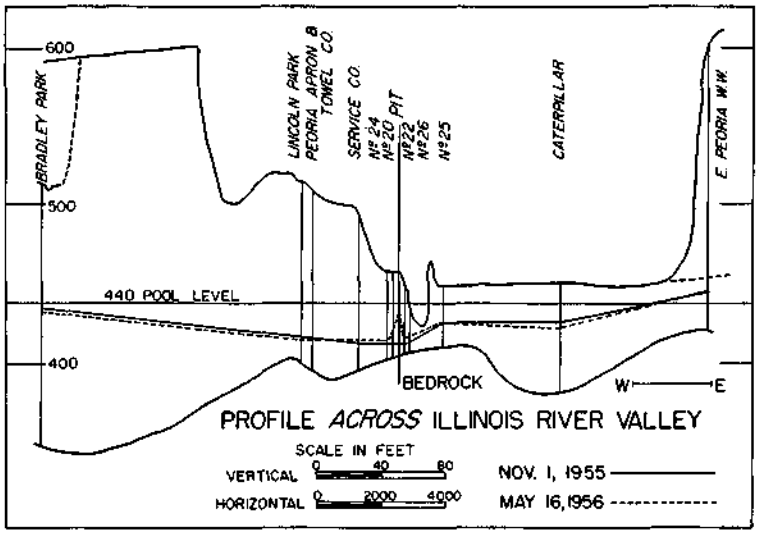


FIGURE 33 GROUND-WATER SURFACE PROFILE ACROSS ILLINOIS RIVER VALLEY, NOVEMBER 1955 TO MAY 1956

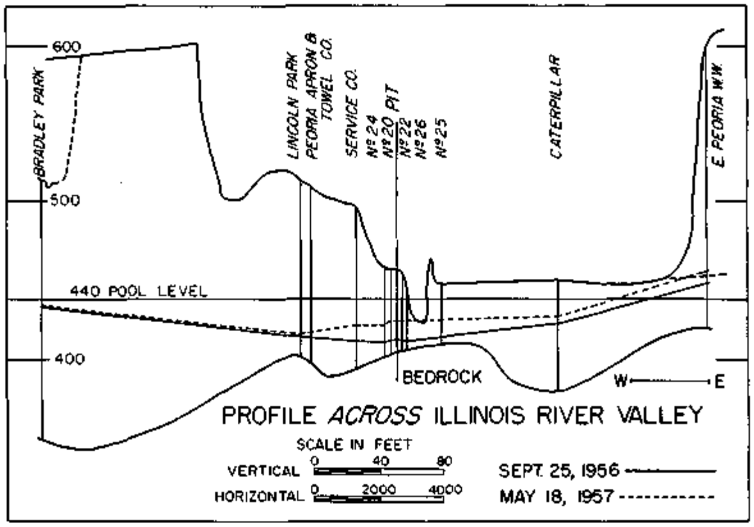


FIGURE 34 GROUND-WATER SURFACE PROFILE ACROSS ILLINOIS RIVER VALLEY, SEPTEMBER 1956 TO MAY 1957

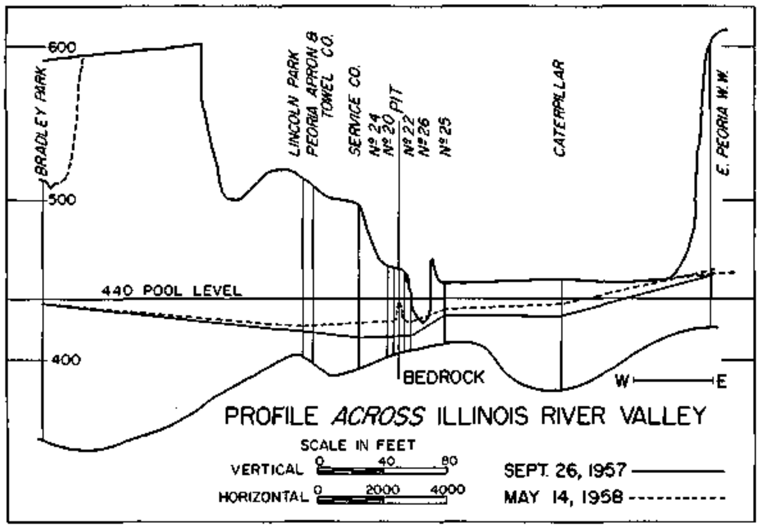


FIGURE 35 GROUND-WATER SURFACE PROFILE ACROSS ILLINOIS RIVER VALLEY, SEPTEMBER 1957 TO MAY 1958

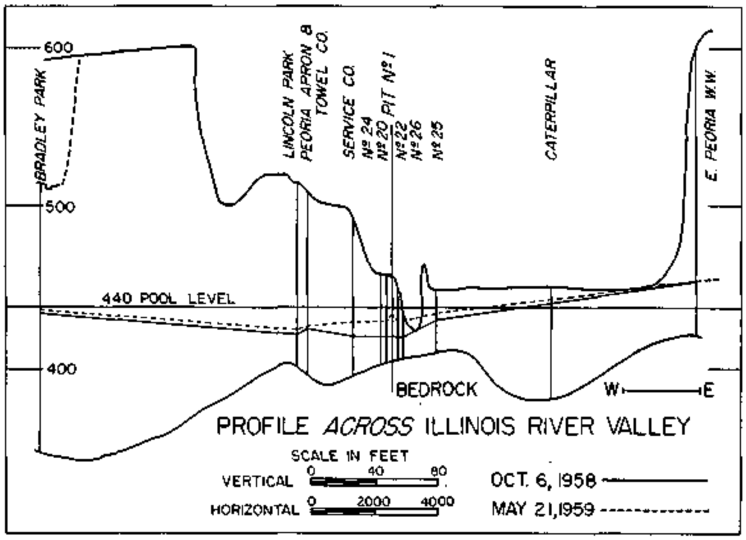


FIGURE 36 GROUND-WATER SURFACE PROFILE ACROSS ILLINOIS RIVER VALLEY, OCTOBER 1958 TO MAY 1959

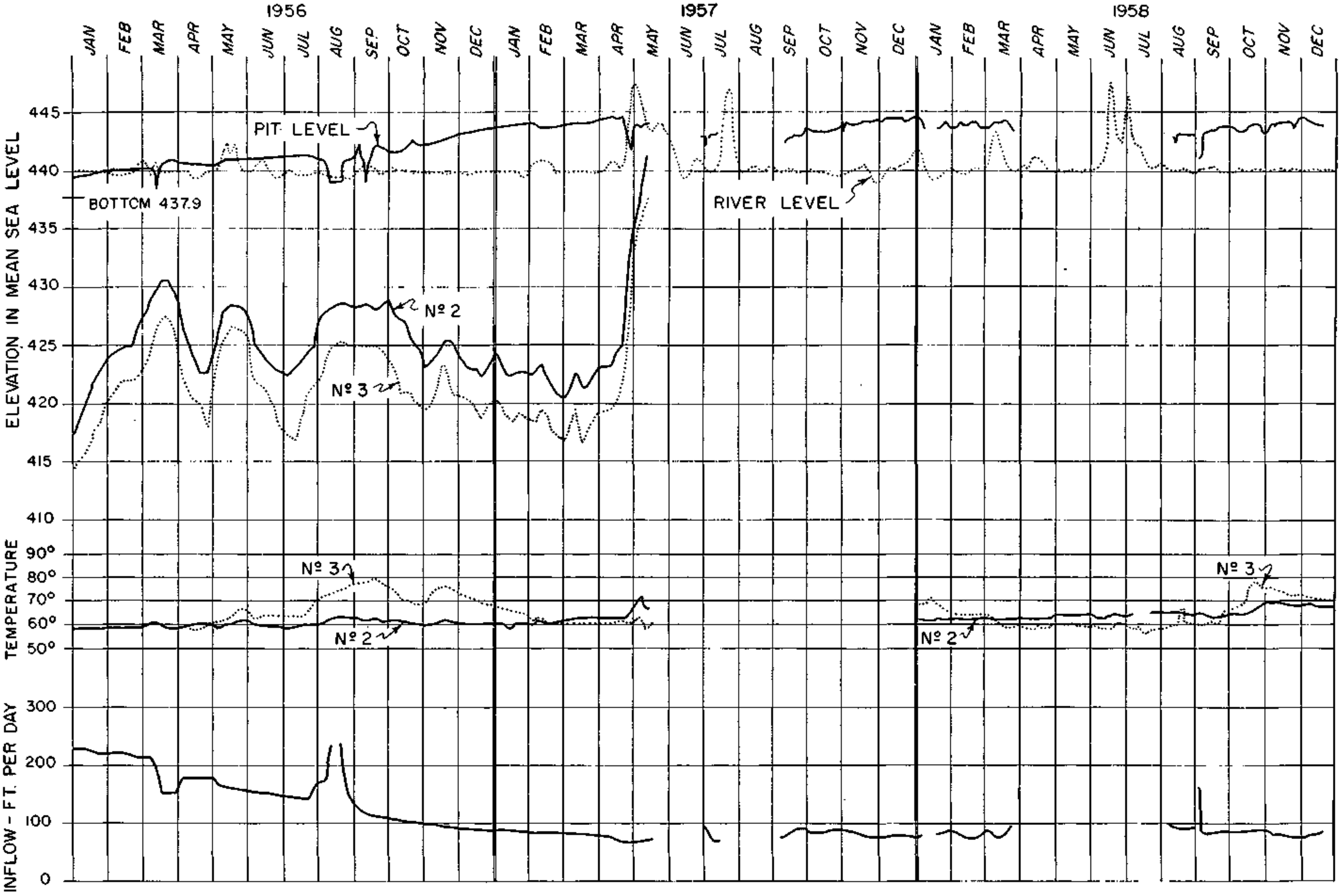


FIGURE 37 EFFECTS OF RECHARGE AT BEMIS BRO. BAG COMPANY

facturing paper, the Bemis Company designed and constructed a pit through which it could recharge the 2 mgd of warm river water which was being discharged from the condensers.

The design of this pit was based on the experience gained by the Survey from operation of Pit No. 1. The Bemis pit was constructed in 1955 with a ten by fifty-foot bottom, at elevation of 437.9 feet, side slopes of three horizontal to one vertical, and a 12-inch layer of pea gravel on the bottom and sides up to a maximum water depth of ten feet. Provisions were made for chlorinating the recharge water.

Artificial recharge was begun on December 30, 1955, and continued almost without interruption until May 12, 1957. Comparisons of river stage, pit stage, and temperatures in the two Company wells are shown in Figure 37. During this first, long operating period, the pit stage rose slowly and reached a maximum of 444.8 in April, 1957. The nonpumping ground-water levels in the wells rose almost fifteen feet by March, 1956. Subsequently these levels fluctuated due to variations in pumpage and spreading of the recharge effect, but they remained five feet or more above the 1955 levels.

Considerable variation was observed in temperatures in the two wells. The temperatures in the nearest well, No. 3, ultimately increased 20°F. over their 1955 values, but the average increase was about 10°F. The average increase in Well No. 2 was approximately 4°F.

Infiltration rates in this pit were high and have continued at relatively high values. The rate was more than 200 feet per day for about two months of operation and did not fall below 100 feet per day until after ten months. When recharge was stopped in 1957 for replacing the pea gravel, the rate was 54 feet per day.

Measurements were made to determine the amount of silt penetration in the pea gravel in May, 1957. The weight of silt found per unit volume of pea gravel was:

Top 2-inch layer	10.2	lbs.	per	cubic	foot
2- to 4-inch depth	7.6	"	"	"	"
4- to 6-inch depth	6.6	"	"	"	"
6- to 8-inch depth	6.4	"	"	"	"
8- to 10-inch depth	6.1	"	"	"	"

Since a cubic foot of pea gravel is estimated as being capable of holding 12.5 lbs. of silt, it is evident that some filtering capacity was still available. This pit has since been used periodically according to the demands put upon the ground-water reserves.

PEORIA WATER WORKS COMPANY

The Peoria Water Works Company built and operates a recharge pit in the North Well Field. This company supplies the domestic and some industrial needs of the community from wells in the Sankoty, Central, and North Fields. For the water company pit, emphasis was necessarily placed on the sanitary quality rather than the temperature of the recharged water. For this reason, the design and operation of its recharge pit might be considered more conservative.

The Sankoty Well Field was severely overpumped and artificial recharge in that area was needed. However, a test of landflooding there in 1953 had proven unsuccessful because the water-bearing strata are overlain by 20 to 40 feet of clay. Test borings in the North Field near the main well and pumping station revealed sands and gravels directly beneath the topsoil. Therefore, the Water Company built its recharge pit in this location. During both the winter season and the high demand period in the summer, a recharge rate of 5 mgd was desirable in order to reduce pumpage in the Sankoty Field.

This pit was excavated to elevation 446.0 feet. The bottom measures 200 by' 350 feet and the sides slope three feet horizontally to one vertically to elevation 460.0. Sand is used for the 6-inch thick filtering layer as a means of maintaining the ground-water quality.

Two intake structures have been used, and the location of the first was responsible for many operational difficulties. The first was located at the site of the former Water Company Well No. 4, near the river bank about 2500 feet upstream from the Bemis Bro. Bag Company. An eddy current sweeps past the Bemis plant and carried paper fibers from it to the Water company's intake. These paper fibers caused serious clogging of the filtering sand and reduced recharge to very low rates. During flood periods the intake structure was surrounded by water and could not be properly attended. The Peoria Water Works Company built a 10 mgd surface water treatment plant in 1959, at which time the intake for the recharge pit was re-located in the narrows above Peoria Lake. The problems caused by suspended fibers have been eliminated, and the intake is accessible at all times.

Due to its large size, the Water Company pit recharges between 3 and 5 mgd when it is in operation. However, the unit surface area infiltration rates have been low because the sands used for filtering have a lower permeability than pea gravel. Comparative sizes and shapes of the four pits in Peoria are illustrated in Figure 38. Volume-area curves for the four pits, which are useful in comparing relative unit area infiltration rates or efficiencies, are shown in Figures 39 through 42.

COST OF EXPERIMENTAL ARTIFICIAL RECHARGE

Table 5 gives a brief summary of the capital investment and operating costs for the Water Survey's recharge project at Peoria. The cost figures have not been prorated to the two pits, and consequently, they reflect more nearly a chronological expenditure or investment. For instance, the cost of land for Pit No. 1 has not been separated from the cost of acquiring land for the laboratory; the price of the land for Pit No. 2

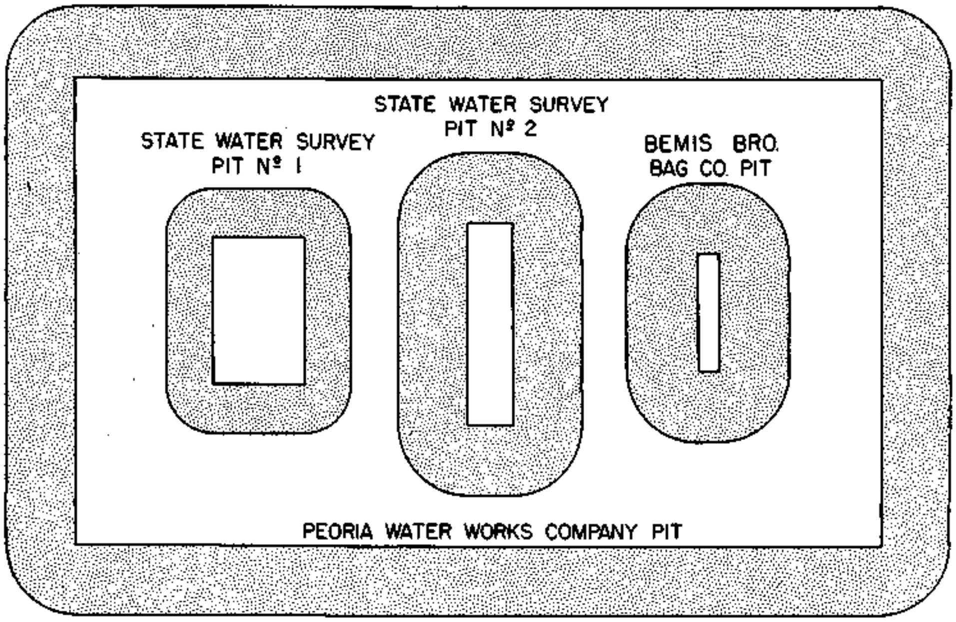


FIGURE 38 COMPARISON OF PIT SIZES

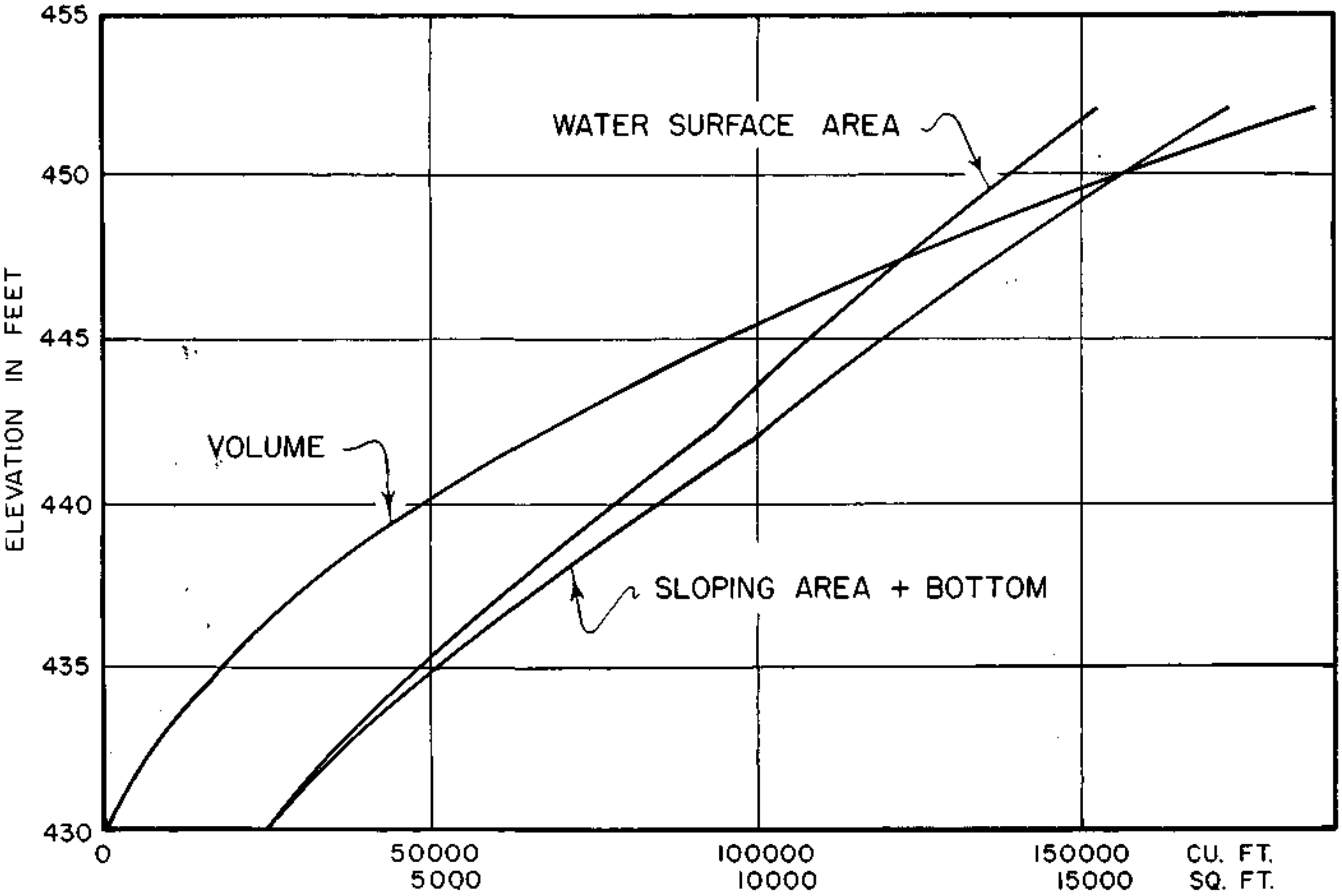


FIGURE 39 VOLUME-AREA CURVES WATER SURVEY PIT NO. 1

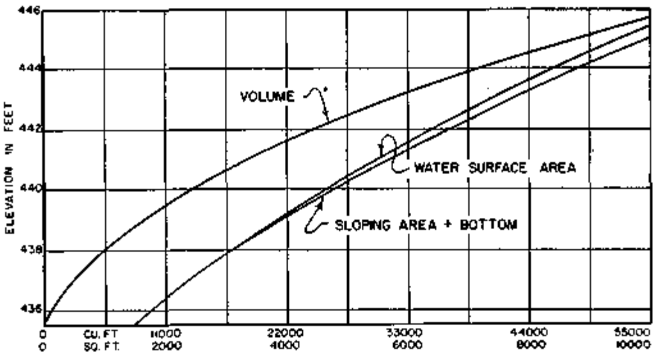


FIGURE 40 VOLUME-AREA CURVES WATER SURVEY PIT NO. 2

represents the cost of a grant of easement and not outright purchase. Operating rather than capital costs are compared owing to the difficulty of proportioning the land costs and estimating the effective life periods of the recharge pits.

In operating pits such as these, economies could probably be realized through automation, as full-time attendance by operating personnel would not be required if automatic chlorination, pumping controls, and mechanically cleaned screens could be provided. Further, for pits operated commercially, it is unlikely that round-the-clock attendance would be required as for these research pits. On the other hand, operating costs for the research pits do not reflect the salaries of professional persons directing the operation.

CONCLUSIONS

The problem of finding a method of recharge to meet the needs peculiar to Peoria has been solved. By means of pits, artificial recharge is conducted at high infiltration rates; operating costs are low in comparison to the cost of treating river water for direct use; practical methods of maintaining satisfactory infiltration rates have been developed; ground-water temperatures have been maintained within desirable limits; and a significant contribution has been made toward stopping the recession of local ground-water levels.

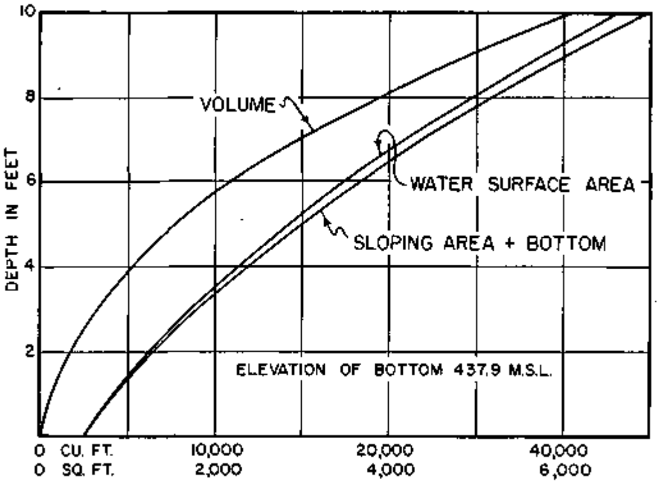


FIGURE 41 VOLUME-AREA CURVES BEMIS BRO. BAG COMPANY PIT

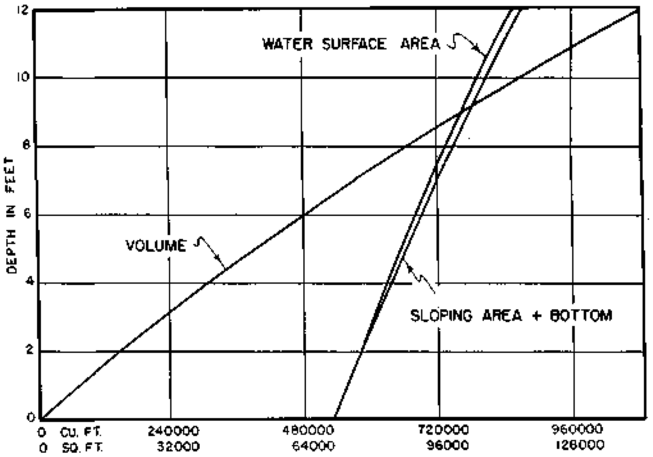


FIGURE 42 VOLUME-AREA CURVES

PEORIA WATER WORKS COMPANY PIT

Maximum infiltration rates of 175 feet per day have been reached in the experimental Pit No. 2 constructed by the Water Survey, and rates higher than 200 feet per day have been achieved in the pit of Bemis Bro. Bag Company. Mean annual rates for three successive seasons of concurrent operation of the two Water Survey recharge pits were between 102.8 and 54.5 feet per day in Pit No. 2 and between 41.2 and 38.7 feet per day in Pit No. 1.

Valuable information has been obtained relative to operating procedures and costs. The cost summaries show that the operating cost has been approximately two cents per thousand gallons recharged. This is substantially less than the limit of six cents per thousand gallons which had been estimated as the maximum to be attractive commercially. The unit cost of recharge was reduced during the years that both pits were operated for the reason that the quantity of water recharged was increased while the cost of supervision of operation remained almost constant. It appears that advantage lies with annual replacement of filter media because it enables higher recharge rates. Unit costs per thousand gallons recharged were almost identical whether the pit was cleaned annually or operated two or three years between cleanings.

Experience has demonstrated the ability of pea gravel to serve as an effective filtration media, while allowing a practical rate of infiltration over long periods of time. Bacterial analyses of samples taken since the pea gravel was first used have shown no deterioration in sanitary quality of the ground water. Repeated use of the pea gravel caused no significant reduction in the average daily recharge rate in Pit No. 1 and resulted in slight reductions in the rate of Pit No. 2. The pea gravel was replaced after three seasons of use because the concentration of silt was approaching the saturation limit of its void spaces.

Temporary increases in recharge rate can be obtained by removing part of the accumulated silt with a suction cleaner. Although the benefits of such cleaning are immediately apparent, they are

TABLE 5

COST OF ARTIFICIAL RECHARGE AT PEORIA

CAPITAL INVESTMENT			
Land and Laboratory	$300,000		
Pit No. 1			
Observation wells			$ 1,610
Sheet piling and intake			14,350
Control Tower			
Structure	$ 20,130		
Equipment	5,330		
Utilities	1,440		
	$ 26,900		$26,900
Pipe lines, piping			8,610
Pit excavation and sand			8,790
Fencing			3,040
Landscaping			100
		Total	$63,400
Pit No. 2			
Land			15,000
Pump, motor, flow meter, and other equipment			5,600
Installation			4,730
Pit excavation, gravel, pipe line			12,760
Observation wells			4,460
Fencing			2,050
Miscellaneous			150
		Total	$44,750

OPERATING COSTS

	One Pit		Two Pits		
	1954-55	1955-56	1956-57	1957-58	1958-59
Personal Services	$ 6,600	$ 7,500	$ 9,920	$ 9,425	$ 8,705
Contractual Services					
Water	300	410	500	465	900
Electricity	185	250	1,900	1,775	1,450
Gas (for heat)	130	135	100	105	100
Pit Cleaning	1,600	1,765	1,500	---	---
Miscellaneous	15	110	535	905	895
Commodities					
Chlorine	975	1,580	2,800	2,770	2,550
Copper Sulfate	---	---	45	50	50
Miscellaneous	60	415	85	30	90
Equipment	---	15	---	10	---
Totals	9,865	12,180	17,385	15,535	14,740
Unit Cost of Operation					
Recharge during season (million gallons)	365.02	423.63	1,079.86	966.78	915.32
Cost per 1,000 gals. recharged	$0.027	$0.029	$0.016	$0.016	$0.016

short-lived. Availability of personnel, weather conditions, and time limit the effectiveness of this method of improving and maintaining the recharge rate.

The effects of recharge on ground-water temperatures have been beneficial in general. Most industries using ground water from the Central Well Field prefer cool water. Approximately 80 percent of the entire recharge has been conducted when the temperature of the river is lower than the normal average ground-water temperatures. As a consequence, the ground-water temperatures are being reduced below those values which were observed prior to the use of artificial recharge. The observed values listed in Table 4 indicate this effect reaches as far as 2800 feet from the pits. The short period of recharge during the summer of 1956 produced higher than desirable temperatures within 500 feet of the pits but did not result in significant increases beyond that radius.

It appears that artificial recharge with the four Peoria pits has contributed materially to raising the ground-water levels in the wellfields in Peoria, and that continued operation of these pits is essential to maintaining the ground water at desirable levels.

In addition to the research and service benefits derived from the pit method of recharge at Peoria, valuable information was obtained bearing on the potential application of this method in other like areas of the state.

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