Equipment and Controls Used in Studies of Artificial Recharge in the Grand Prairie Region Arkansas

By R. T. SNIEGOCKI, F. H. BAYLEY 3D, *and* KYLE ENGLER

ARTIFICIAL RECHARGE OF GROUND WATER—GRAND PRAIRIE REGION, ARKANSAS

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EQUIPMENT AND CONTROLS USED IN STUDIES OF ARTIFICIAL RECHARGE IN THE GRAND PRAIRIE REGION, ARKANSAS

By R. T. Sniegocki,[1] F. H. Bayley 3d,[2] and Kyle Engler [3]

ABSTRACT

Studies of artificial recharge have been underway in the Grand Prairie region since 1953. The studies have required the use of many different kinds of equipment and control procedures.

Recharge-well specifications were not available; therefore, well design was considered to be an integral part of this investigation. Certain generalities regarding well construction may be stated, but this study does not conclusively establish a design for recharge wells.

Much of the equipment and control used have been adapted to field conditions from standard methods. The practicality of recharge operations, with special regard for simplicity and cost, has been considered as much as possible in the field layout.

Essentially, the equipment and procedures used were satisfactory for conducting an experimental recharge operation. Some difficulty was experienced when attempting to repeat test conditions or maintain constant testing conditions for a prolonged period of time.

INTRODUCTION

PURPOSE OF THIS REPORT

In 1953 the Grand Prairie region of Arkansas was selected for an investigation of fundamental principles of recharging ground-water reservoirs through wells. Since that time, the work has consisted of collecting detailed hydrogeologic information in the vicinity of the recharge site, drilling two recharge wells, constructing water-treatment and conveyance facilities, and making a series of injection tests using the two wells. This report is one of a series covering distinct

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elements of the project; the reports have been prepared and released as the data and interpretative analyses became available. The purpose of this report is to present information about the equipment, controls, and control procedures used during a series of recharge tests using waters of different quality and two differently constructed injection wells.

LOCATION OF THE AREA

The Grand Prairie region in east-central Arkansas is in the Mississippi Alluvial Plain, a subdivision of the Coastal Plain. The region is an irregular, but continuous, tract of prairie lying between the White River and Bayou Meto. It extends northwestward, from near the confluence of the White and Arkansas Rivers, to a short distance beyond Lonoke, Lonoke County. Nearly all of Arkansas County and parts of Lonoke, Prairie, and Monroe Counties are included in the Grand Prairie region. (See fig. 1.) The Prairie in-

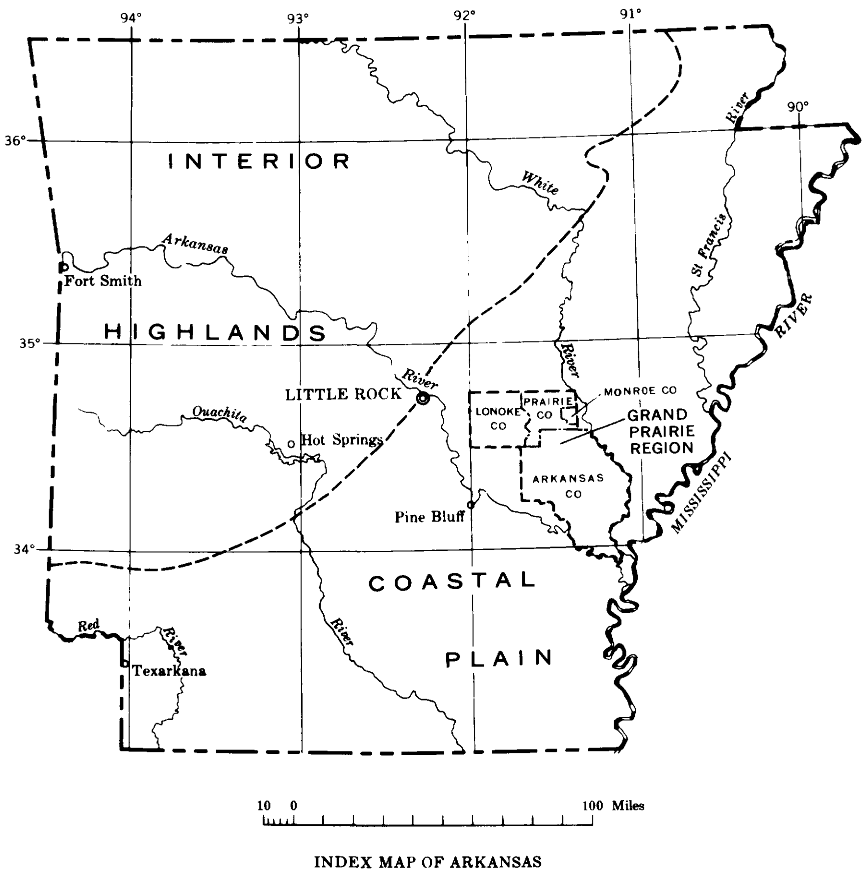

FIGURE 1.—Map of Arkansas showing the location of the Grand Prairie region.

cludes approximately 1,000 square miles, of which roughly 700 square miles or 450,000 acres is developed riceland.

The project area includes about 210 square miles of land in Arkansas county (areas A, B, and C fig. 2). The Rice Branch Experiment Station of the University of Arkansas is near the center of the area and is the site of the artificial-recharge tests.

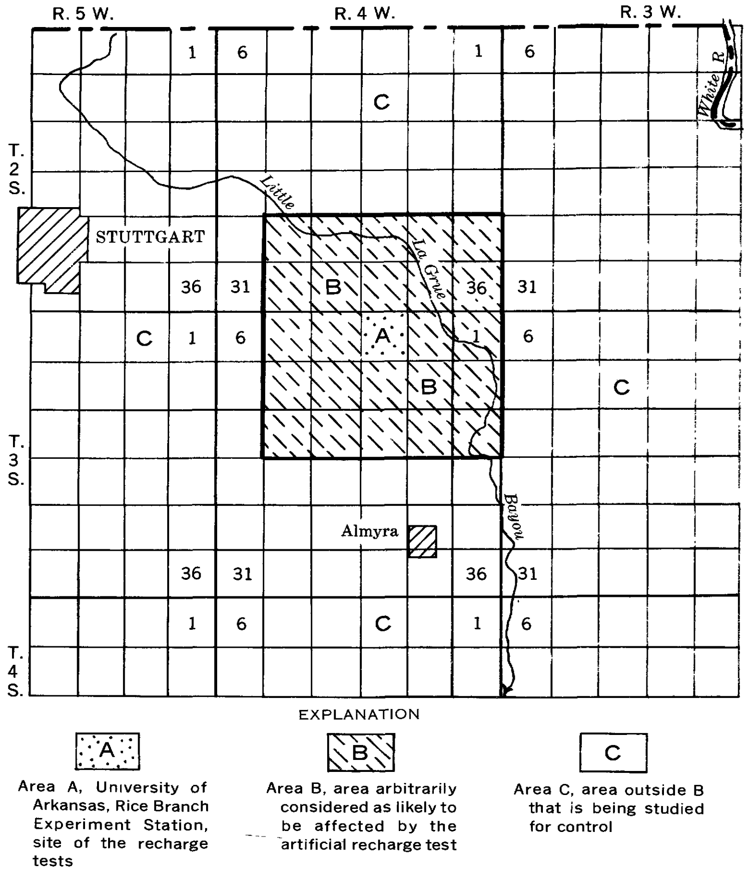

FIGURE 2.—Map of the artificial-recharge area showing the site of the tests.

ACKNOWLEDGMENTS

The cooperation, assistance, and advice given by many Federal, State, and city agencies, companies, and individuals are gratefully acknowledged. A detailed account of assistance is in the report "Studies of artificial recharge in the Grand Prairie region, Arkansas, environment and history" (Engler, Bayley, and Sniegocki, 1963).

RECHARGE WELLS

Research into the literature concerning artificial recharge through wells discloses meager data on recharge-well design. Closed-system recharge has been practiced for several years in New York, and return-well specifications are available. However, most of these wells are not used for recharge of a completely alien water—they return water to the same aquifer from which it has been pumped.

A recharge-well design has been patented, but, so far as is known, it has not been tested in the field and is considered by its inventor to make the cost of recharged water for irrigation too expensive for most users (Ross, Nebolsine, written communication, 1958).

Several recharge projects throughout the United States were visited by personnel working on the Arkansas project (Steinbrugge and others, 1954). Helpful suggestions and opinions were given, but definite recharge-well specifications were not available.

Aquifer collapse around recharge wells, clogging resulting from improper screen selection, and other operational difficulties caused by faulty well design were observed in previous studies of artificial recharge through wells. Experimentation with differently constructed recharge wells was made an integral phase of the investigation because recharge-well-design data were not available, and part of the failure of previous recharge attempts was caused by faulty well construction.

RECHARGE WELL 1

Two major considerations based on the aspect of practicability controlled the design of the first recharge well. First, a conventional irrigation well such as those now in use in the Grand Prairie region is economical to construct because material, equipment, and drillers experienced in the area are readily available. Second, if a well typical of many already in existence were found to be suitable as a recharge well, it would be a simple and economical matter for an irrigator to recharge through a production well during the nonirrigation season. Consequently, the construction of recharge well 1 is similar to many of the producing irrigation wells now in use in the Grand Prairie region (figs. 3–5). The design of a typical Grand Prairie irrigation well is discussed and illustrated in another report of this series (Engler, Bayley, and Sniegocki, 1960).

Construction of recharge well 1 was begun February 14, 1955, using a reverse-hydraulic rotary rig. The hole was drilled through the aquifer to the top of underlying clay deposits, and the screen and casing were set firmly on the clay.

About 3 cubic yards of gravel—grains 1/8 to 1/4 inch in diameter—was backfilled in the annular space around the screen. Sand was

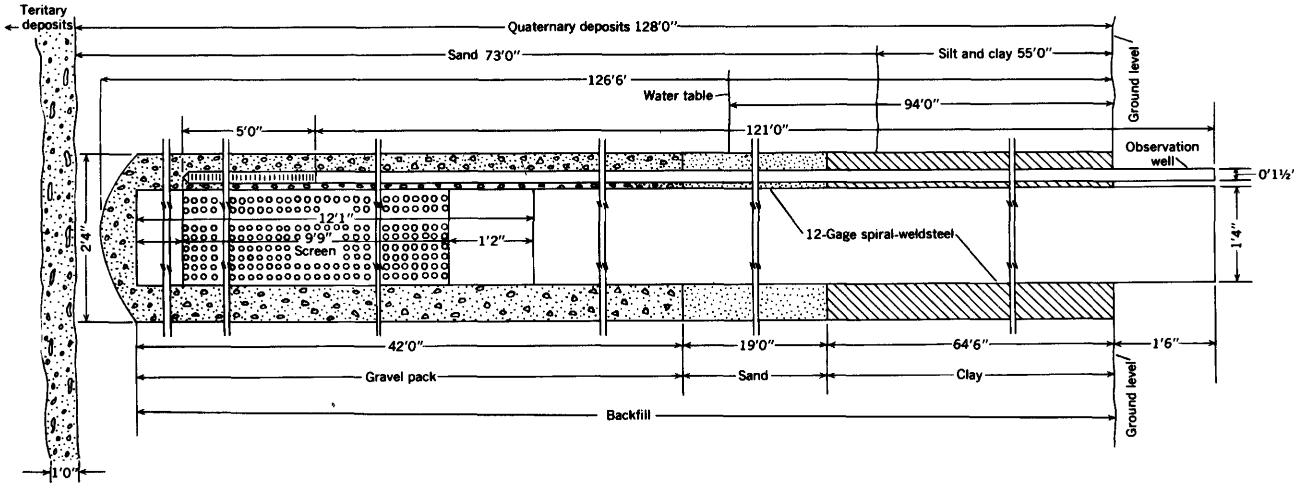

FIGURE 3.—Diagram showing construction of recharge well 1.

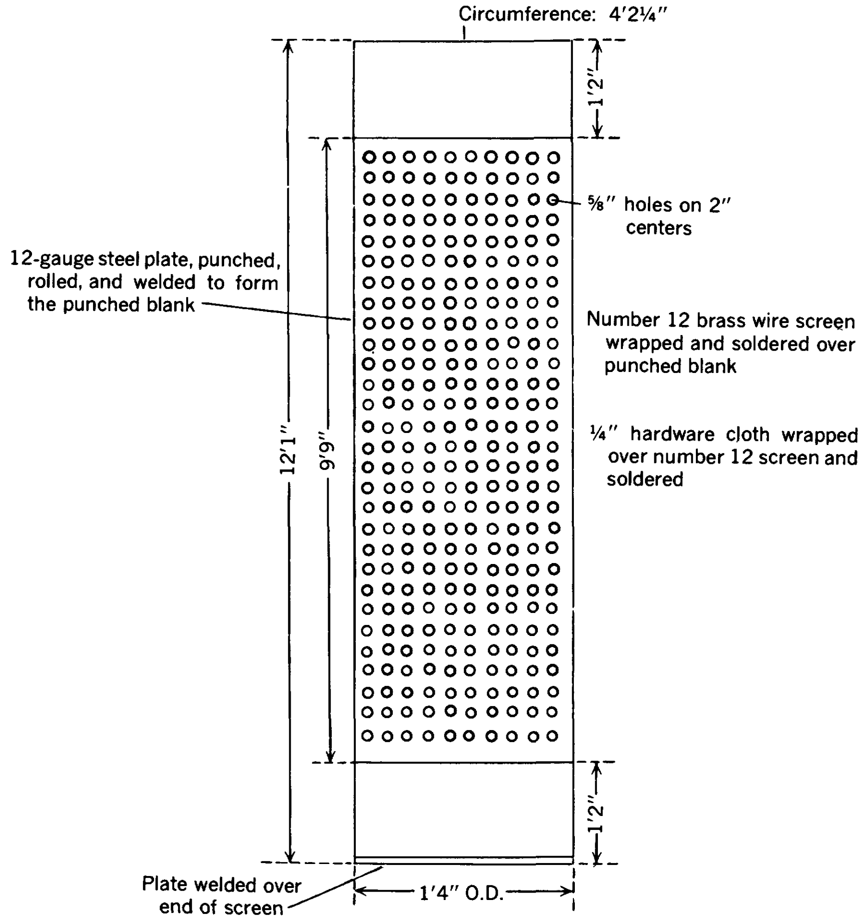

FIGURE 4.—Sketch of the screen used in recharge well 1.

used to backfill the remaining annular space to above the top of the aquifer, and clay was used to fill it from there to the surface.

Recharge well 1 was developed by surging and bailing. Sodium hexametaphosphate was added to aid in dispersing and removing clay particles. Final development was by surge pumping with a deep-well turbin pump temporarily installed for the purpose. The specific capacity of the well after development was about 21 gpm (gallons per minute) per foot of drawdown, and the static water level was about 95 feet below the land surface.

ACCESSORY EQUIPMENT

To obtain water-level measurements inside the recharge well, a stilling well of ¾-inch pipe was installed through a hole cut in the side of the upper part of the recharge-well casing. The pipe, slotted with

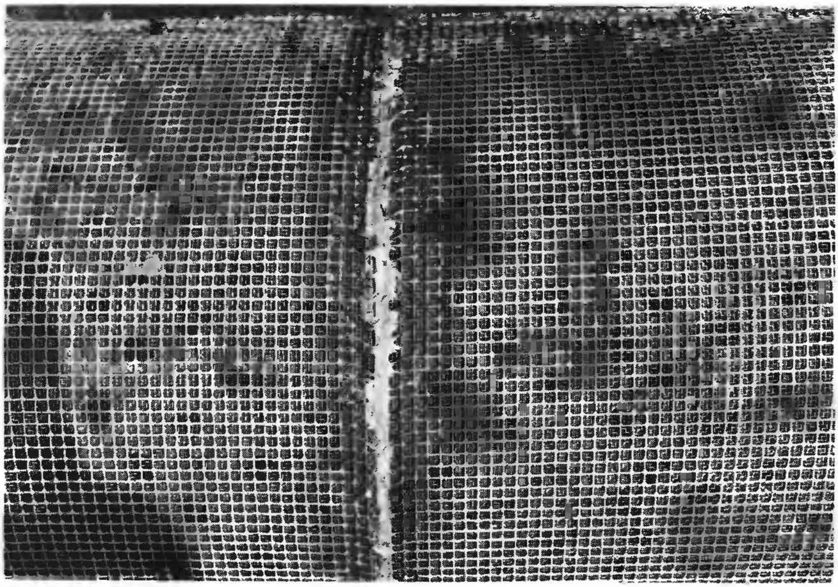

FIGURE 5.—Photograph showing the screen used in recharge well 1.

a hacksaw in the lower 3 feet, extended to the bottom of the recharge well. A collar on the upper part of the ¾-inch pipe was attached to the recharge-well casing, effectively sealing the casing and preventing surface water from leaking into the recharge well. This stilling well was designated as "I."

Before backfilling, a 1½-inch galvanized pipe, finished with 5 feet of slotted brass pipe, was lowered into the annular space outside the screen to provide access for water-level measurements in the gravel pack. This observation well was designated as "O."

A backflush or redevelopment pump and power unit were the last items required to complete construction of the recharge well. Suspended matter in the recharge water will eventually clog the interstices of an aquifer. Available evidence indicates that this clogging may occur at or very near the recharge-well screen and takes place rapidly or slowly, depending upon the recharge rate and the amount of suspended matter in the recharge water. Part of or all the clogging material can be removed by redevelopment of the well by pumping at twice the recharge rate or at higher rates (California Water Pollution Control Board, 1954, p. 8).

The redevelopment pump was a 3-stage, 12-inch bowl, deep-well turbine pump using 12 sections of threaded-coupling pump column, 8 inches in diameter; a tailpipe 0.1 foot long was installed. The tailpipe was approximately 1.3 feet from the bottom of the well. The pump has a rated capacity of 2,000 gpm against a total head of 130 feet. By limiting the recharge rate to 400 gpm or less, it was possible to pump the well at least 800 gpm for short periods during redevelopment.

The redevelopment pump was sealed in the recharge well by forming a tapered plug of burlap and hot asphalt around the pump column next to the pump base (fig. 6). The diameter of the plug at its widest part was a few inches greater than the diameter of the well. As the pump was lowered into place, the asphalt-burlap plug was squeezed into the well, making an airtight seal at the top of the well casing.

FIGURE 6.—Preparing the asphalt-burlap well seal.

A right-angle drive (gear ratio 2:3), with a nonreversing ratchet was installed to transmit power from an electric motor to the pump. Water was introduced into the well through the pump column, and the ratchet was necessary to prevent the pump shaft and impellers from rotating backwards as the injected water passed through the well.

A variable-speed electric motor was connected to the right-angle drive. A 3-phase, 200/440-volt, 60-hp motor provided a variation of 1,190 rpm to 1,755 rpm at the pump. With a static water level of about 96 feet, the equipment pumped approximately 200 gpm at 1,190 rpm, 550 gpm at 1,325 rpm, 815 gpm at 1,560 rpm, and 855 gpm at 1,755 rpm. The motor was not an all-weather type and therefore was protected by a wellhouse.

Four "feeder wells," 2 inches in diameter with 10-foot screens, were drilled equidistant from each other within 60 inches of the recharge well. (See fig. 25.) These wells were drilled primarily to introduce chemicals into the aquifier just outside the gravel pack of the recharge well for redevelopment if the recharge well were to become plugged. The feeder wells also furnished additional control points for water-level measurements and water-sample collection.

SUMMARY OF RECHARGE TESTS

A total of 17 tests were made using recharge well 1, the first test being made in March 1955 and the last in March 1958. Approximately 46 acre-feet of water treated in various ways was recharged at rates of 117 to 900 gpm in about 20 days. The specific capacity of the well was diminished as much as 19 gpm per ft by plugging during recharge. As a result of redevelopment after injection tests, the specific capacity ranged from 22 to 33 gpm per ft, indicating that the original specific capacity of the well (21 gpm) could be restored or even exceeded, although at times with difficulty.

During the latter part of the test series the screen was ruptured. Severe pumping and surging commonly brought up small quantities of the gravel-pack material. Rather than completely destroy well 1, a new recharge well was constructed, and well 1 was converted into a water-level control point by installing a recording gage.

RECHARGE WELL 2

The design of recharge well 2 was based on experience gained by the injection tests in recharge well 1. The construction of well 2 and some of the accessory equipment is shown in figure 7.

A comparison of the construction of recharge wells 1 and 2 shows very few similarities. Well 2 has a diameter of 26 inches. This was considered desirable for two reasons. Additional space was needed inside the well to install accessory equipment such as the butterfly valve. Also, the larger diameter allowed the installation of a shorter screen with no decrease in the area of screen opening, as compared to well 1.

The screen, of the wire-wrapped type, was about 5 feet in length and 26 inches in diameter with slot openings of 0.016 inch. (See fig. 8.) Stainless-steel screen was selected to prevent as much corrosion as possible, thus increasing well life. The wire-wrapped construction permitted more exact control over the size of screen openings as well as more open area per foot of screen length.

The longer screen of recharge well 1 permitted the injected water to be distributed over a greater vertical section of the aquifer. When a cone of depression was created around recharge well 1 during re-

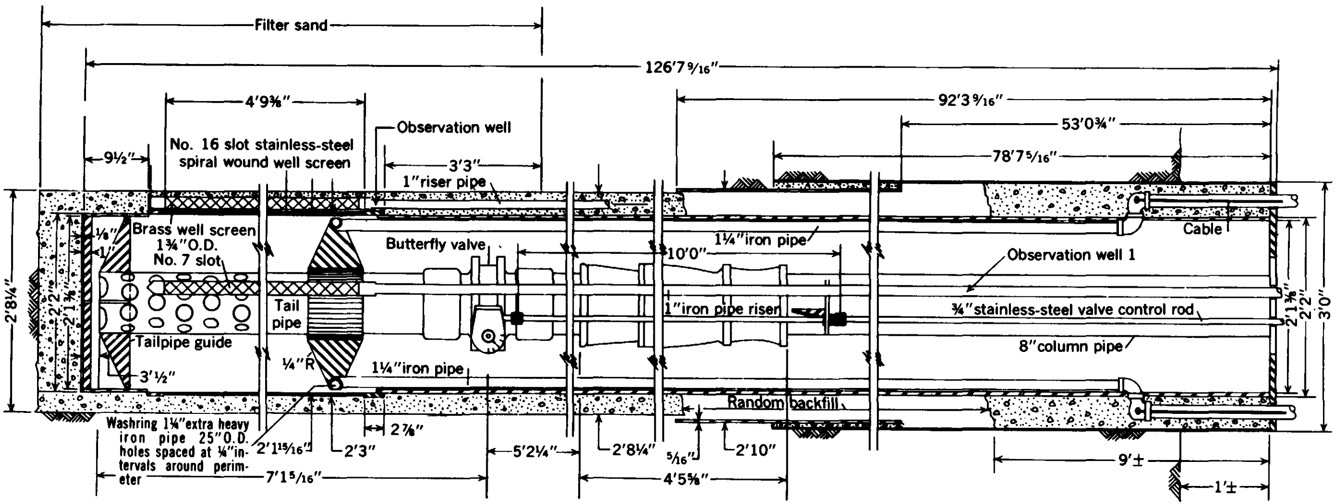

FIGURE 7.—Diagram showing construction of recharge well 2.

FIGURE 8.—Photograph showing the screen used in recharge well 2. Screen and casing are ready for lowing into the drill hole. Note observation well "O" attached to the side of the screen and casing.

development at the maximum pumping rate, the part of the aquifer in contact with the upper part of the screen was unwatered. Water could be moved through the upper part of the screen only by decreasing the pumping rate, thus decreasing velocity of flow and probably diminishing the effectiveness of backflushing.

Concrete was grouted in place around the casing just above the screen of recharge well 2 to insure that the flow of water was through the screen into the acquifer. The gravel pack of recharge well 1 extended several feet above the screen, and because of less resistance to flow, much of the injected water probably moved out through the screen, up the gravel pack, and out into the aquifer. This condition increased the section of acquifer through which the injected water moved and further diminished potential backflushing effectiveness. The concrete grout used in recharge well 2 insured the movement of water through the section of the aquifer adjacent to the screen, whether recharging or pumping.

So far as could be determined, the gravel pack of recharge well 1 permitted injected water to move sediment to the gravel pack-aquifer interface, where plugging was more severe than it was farther out in the aquifer. Velocity of water flow at the gravel pack-aquifer interface was not as great as at the screen, and redevelopment possibilities by backflushing were diminished. High permeability and maximum filterability of the gravel pack very near or at the screen should be desirable features to incorporate in a recharge well. In achieving these features, the aquifer should be completely stabilized to prevent aquifer collapse and shifting and mixing with any pack material used.

Two methods of obtaining an optimum balance between permeability and filterability of the material adjacent to the screen of recharge well 2 were considered—natural development in the aquifer and sand packing. The aquifer section at which the screen would be placed ranged in composition from fine to coarse sand (0.125 to 2 mm), consisting predominantly of quartz ranging in diameter from 0.25 to 0.5 mm. The well could have been developed by removing the fines from the aquifer close to the screen, leaving a medium to coarse sand in contact with the screen. This would have created a zone of relatively higher permeability adjacent to the screen and would have provided higher filterability than the gravel pack of recharge well 1. However, natural development would have prevented concrete grouting and other desirable constructional features designed to establish and maintain aquifer stability.

Measurements of water levels in observation wells "I" and "O" showed a significant head loss, increasing with time, between the two wells during certain recharge tests utilizing recharge well 1. This was interpreted as indicating plugging between wells "I" and "O," probably on the interior of the screen.

A degree of success in development of newly installed wells has been experienced by various drillers using a high-pressure jetting tool. The jet head is lowered into the well, and a stream of water is directed against the interior of the screen by rotating the jet nozzles at different depths. Chemicals may be used in this procedure to further accelerate well development. Development generally is effective as much as 1 foot into the aquifer where wire-wrapped or similar types of screens are used.

Because the injection characteristics of recharge well 1 indicated that most of the plugging was on the inside and within a few inches of the outside of the screen, a jetting device was installed in recharge well 2. If the jetting device (washring) proved effective in well redevelopment, it would reduce the amount of water pumped from the well when removing clogging material.

A carefully graded sand, such as that utilized in rapid sand filters, was placed next to the screen in well 2. The sand was composed of subangular to well-rounded quartz grains ranging in diameter from about 0.7 to 1.4 mm with a uniformity coefficient of less than 1.6. Thus, in the section in which the screen was placed, the aquifer consisted principally of quartz sand 0.25 to 0.5 mm in diameter, the sand pack consisted of quartz grains 0.7 to 1.4 mm in diameter, and the screen had slot openings of 0.41 mm. These conditions provided the best compromise possible in achieving maximum permeability and filterability at the pack-screen interface and maximum stability of the aquifer.

Construction of recharge well 2 was begun July 7, 1958, using an auger and bailer for drilling. A large-diameter hole was augered to a depth of about 78 feet, and a 36-inch diameter casing, extending from the land surface to the bottom of the hole, was installed (fig. 7). A 34-inch-diameter casing about 39 feet long was placed inside the 36-inch casing. By bailing inside the 34-inch casing, it was possible to place the lower end about 92 feet below the land surface, thus, creating an overlap of about 25 feet between the bottom of the 36-inch-diameter and the top of the 34-inch-diameter casing. A section of 32-inch-diameter casing was placed inside the 34-inch casing. By bailing and adding additional lengths as the hole was deepened, the 32-inch-diameter casing was placed to extend from the land surface to the bottom of the aquifer. A 26-inch-diameter casing with the screen attached to the lower end was carefully centered inside the 32-inch casing. After sand packing and concrete grouting, the 32-inch casing was pulled.

Recharge well 2 was developed by block surging and bailing. Sodium hexametaphosphate was added to aid in dispersing and removing clay particles. Final development was by surge pumping with a turbine pump. The specific capacity of the well after development was about 27 gpm per foot, and the static water level was about 97 feet below the land surface.

ACCESSORY EQUIPMENT

To obtain water-level measurements inside recharge well 2, a stilling well similar to that used in well 1 was installed. A 1-inch pipe finished with a brass well screen was attached by brackets to the pump column. The screen, number 7 slot, was 5 feet in length and 1¾ inches in diameter. The saw-slotted pipe used for the stilling-well screen in recharge well 1 caused difficulty after about 2 years' use when it became encrusted with rust; hence, the use of a longer brass screen with more open area per foot of length in well 2. This observation well was designated as "I."

A well identical to "I" was attached by brackets to the outside of the final well casing before backfilling to provide access for water-level measurements in the sand pack. This observation well was designated as "O."

The pump column was used to convey recharge water into recharge well 2 as in well 1. However, two notable changes in the tailpipe

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assembly in recharge well 2 were made to accomodate a washring and a butterfly valve. (See figs. 7 and 9.)

The butterfly valve was added to provide more adequate control of injection rates. A shaft attached to the valve and extending to the surface provided full-range manual valve control.

A washring and attendant facilities, as shown in figures 7 and 9, were installed in well 2 at the same time the deep-well turbine was lowered into place. A large crank was attached to the washring feed pipes by cables to permit raising and lowering the ring the length of the screen. A high-pressure centrifugal pump was used to force water through the washring. Redevelopment chemicals could be recirculated in the recharge well by pumping the chemical solution from the well with the turbine and forcing the solution back through the washring with the high-pressure centrifugal pump.

The tailpipe extended to the bottom of well 2 to provide a means of guiding the washring as it was raised and lowered. Holes were drilled in the sides of the tailpipe to permit free movement of water in and out of the pump column (fig. 9).

The electric motor, right-angle drive, and deep-well turbine used for recharge well 1 were reassembled and used for recharge well 2. The well casing extended above the land surface sufficiently high to prevent any surface water from draining into the well, and sealing was not necessary.

FIGURE 9.—View of the tailpipe and the washring assembly used in recharge well 2, showing tailpipe with washring in raised position.

"Feeder wells" were not drilled near recharge well 2; however, an observation well not more than 10 feet from the recharge well was considered a necessity. Recharge well 2 was drilled near a well that had been cased with 2-inch galvanized pipe and screened with an 80-mesh drive point.

SUMMARY OF RECHARGE TESTS

Five injection tests have been made using recharge well 2, the first test being made in January 1959 and the last in January 1960. Approximately 26 acre-feet of water treated in various ways was recharged at rates of 37 to 313 gpm. The time spent in injecting the water was about 37 days. Testing procedures were similar to those used on recharge well 1, except that fewer but much longer tests were completed.

The specific capacity of the well was diminished as much as 18 gpm per foot by plugging. As a result of redevelopment after injection tests, the specific capacity ranged from about 13 to 21 gpm per foot, never regaining the original specific capacity of 27 gpm per foot.

HYDROLOGIC INSTRUMENTATION AND CONTROL

OBSERVATION WELLS

Several observation wells (5S, 4S, 3S, and 2N, fig. 14; and 2SW, 2SE, 1SW, 1SE, 1N, and PW, fig. 25) provide for observation of hydrologic and chemical changes in the aquifer during recharge tests. Each hole was drilled to the bottom of the acquifer to provide details on the character of the entire section. Twelve of the wells were cased with 2-inch galvanized pipe and finished with 60- or 80-mesh drive points, 2 inches in diameter and 48 inches in length.

Three wells were drilled and cased with 5-inch galvanized-iron 24-gage casing. Each of these wells was screened at the bottom of the aquifer with a 30-inch slotted section of the casing. The larger diameter casing was used to permit the installation of a recording gage having a 4-inch float (fig. 10).

Recharge well 1 was equipped with a recording gage after recharge well 2 was completed. The gage was installed with a 12-inch float and proper gearing for an expanded time scale.

One additional well (so-called dry-sand well) was installed about 20 feet from recharge well 1. This well was cased to a depth of 78 feet with 1¼-inch galvanized-iron pipe. The lower 3 feet was slotted with a hacksaw, and a pipe cap was placed on the end. This well was screened in the unwatered part of the aquifer intentionally to permit measurements of any changes in air pressure in the dry zone above the ground-water surface. If the aquifer could be recharged for a sufficient period of time, the cone of elevation would saturate this

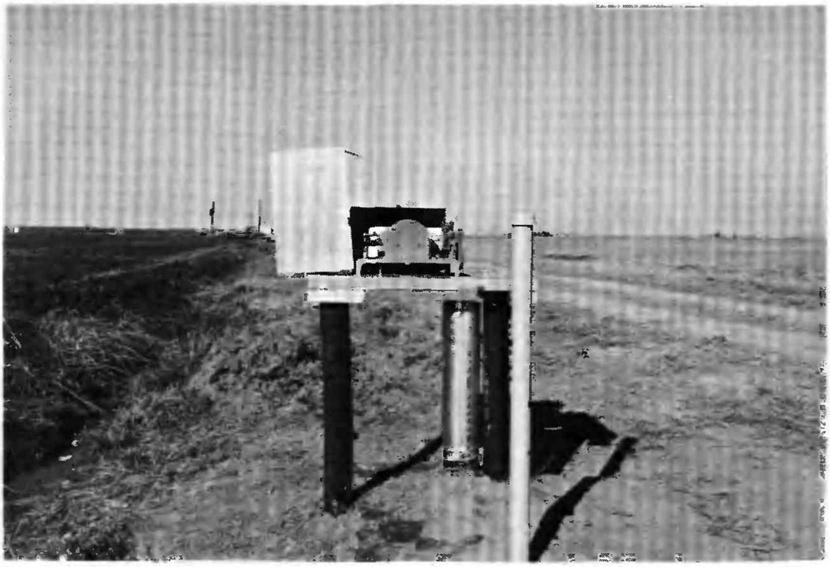

FIGURE 10.—View of a completed observation well in which a recording gage has been installed.

part of the unwatered aquifer. The dry-sand well would furnish access for water-level measurements under such conditions. Thus, this well was installed for a dual purpose.

Three irrigation wells (designated as east, middle, and west irrigation well, fig. 14) were drilled on the Rice Branch Experiment Station before beginning this project. These wells also furnished access for water-level measurements.

WATER METERS

Whether recharging or discharging, control and observation of rates of water transfer were necsssary during all tests. It was decided to recharge at a rate as constant as possible while measuring changes in water levels rather than to recharge at a constant head and observe rate changes. This method was chosen to allow more latitude for experimental variation. Furthermore, high rates of recharge, such as those at the beginning of a constant-head test, seemed undesirable, because backflushing and well redevelopment apparently would be more difficult.

Impeller-type flow meters were coupled into the injection-discharge lines where needed (fig. 11). The cumulative gallons of water transferred during a test were read directly from the meter, and a stopwatch used in conjunction with the sweep hand on the meter dial made spot checks of rates possible.

FIGURE 11.—Impeller-type flow meter used during recharge tests to measure rates and quantities of water injected.

MEASUREMENT OF ATMOSPHERIC PRESSURE

Widespread and continuous fluctuations of the water levels in wells in the Grand Prairie are due to changes in the atmosphreric pressure (Sniegocki, 1959). Water levels fluctuate from a fraction of an inch to about a foot over periods ranging from a few hours to several days. To correct water-level measurements for changes in atmospheric pressure, a barograph was maintained at the test site.

WATER-QUALITY INSTRUMENTATION AND CONTROL

pH AND RESIDUAL CHLORINE

In all recharge tests the water was chlorinated before injection, samples were collected, and a colorimetric comparator was used in conjunction with ortho-tolidine solution to determine total chlorine residual. The pH of water samples was determined in the field using the same equipment as used for chlorine residual, with a change in indicators. Samples of water collected for chemical analyses were retested for pH, but this was done at a later date in a laboratory.

TURBIDITY

Turbidity of recharged or discharged water was measured during tests by a Hellige turbidimeter. The measurement of turbidity with this instrument is based on the comparison of a beam of transmitted light with the scattered light produced by a lateral illumination of the water sample by the same light source (Rainwater, and Thatcher, 1960, p. 70). All results were recorded in parts per million. One or more turbidity determinations generally were made on the raw surface water before pretreatment and on the pretreated settled water. More frequent determinations were made on the water after chlorination and filtration, just before it entered the recharge well.

Recharge tests were made under specified, controlled conditions. In some tests, the turbidity of the recharge water was not limited, and the turbidity data were collected and recorded as the test progressed. In other tests, injection was discontinued when the turbidity exceeded a specified test limit.

TEMPERATURE

An automatic temperature-recording gage was used to obtain records of the temperature of the injected and recovered water. Generally, the injected water was removed from the aquifer after a particular test. The difference between the chloride and sulfate content of the ground water and recharge water was useful in indicating when this removal was essentially complete. Recharge tests were made when the temperature of the recharge water was less than that of the ground water. A comparison of the temperature observations with the chloride and sulfate content established the dependability of temperature differences in distinguishing between the two waters. An example of the type of record obtained during and after a recharge test is shown in figure 12.

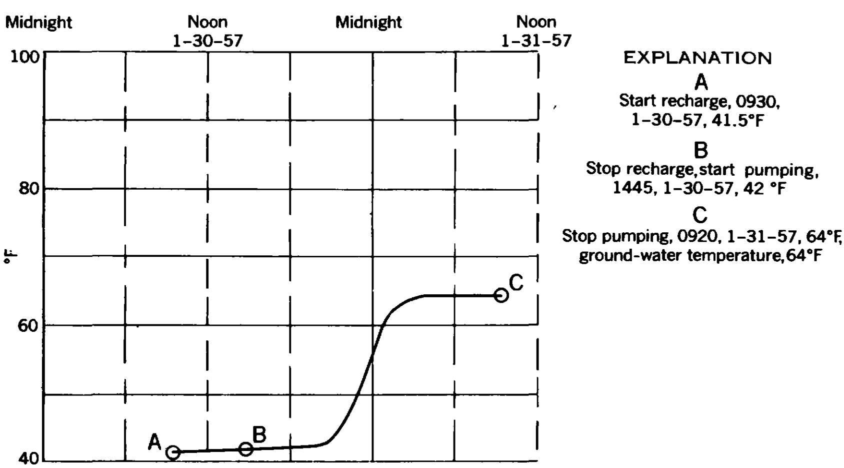

FIGURE 12.—Graph taken from the temperature-recording gage showing changes in water temperature during recharge and discharge.

MICRO-ORGANISM COUNTS

The identification and number of micro-organisms in recharged water are essential control data where the quality of injected water and test results are compared. Sedgewick-Rafter equipment was used in the field laboratory to identify and count micro-organisms as tests progressed.

MILLIPORE FILTER

A portable apparatus was developed by Felsenthal and Carlberg for testing the quality of oilfield injection waters (Felsenthal, and Carlberg, November 1956, p. B–53–55, B–58). The apparatus was especially useful for evaluating how effectively suspended solids are removed from oilfield injection waters by field-treating systems.

Need for additional data on the quality of injected water used during recharge tests in this project was recognized, and an apparatus based on specifications by Felsenthal and Carlberg was constructed.

The components of the apparatus are shown in figure 13. The unit may be tied into a field water system at any desired point, but in these studies it was attached to a sampling valve in the injection line at a point where the recharge water entered the well.

The filter element, a disk 47mm in diameter and having 0.45 micron pore openings, permitted collection of practically all suspended material in the water.

COAGULANT TESTING

From the analysis of a water, it is not possible to predict the quantity of coagulant required for optimum coagulation of injection water. Coagulation problems were varied because of changing raw water characteristics such as temperature and pH differences, changes in bacterial and micro-organism content, and varying amounts of suspended solids. A standard variable-speed laboratory stirring device was used to determine optimum coagulant concentration. A procedure similar to that used in standard water-treatment plants was followed, thus providing efficient and economical coagulation treatment.

BACTERIOLOGICAL SAMPLING AND TESTING

Samples of the injected water and ground water were collected each time a recharge test was made. These samples were collected according to methods prescribed by the Arkansas State Health Department. Each sample was tested by the State Health Department to determine whether or not the sample contained coliform organisms. Presumptive and confirmatory tests were the only examinations made.

Special water-handling facilities were needed to obtain representative water samples for bacteriological examination. The depth to

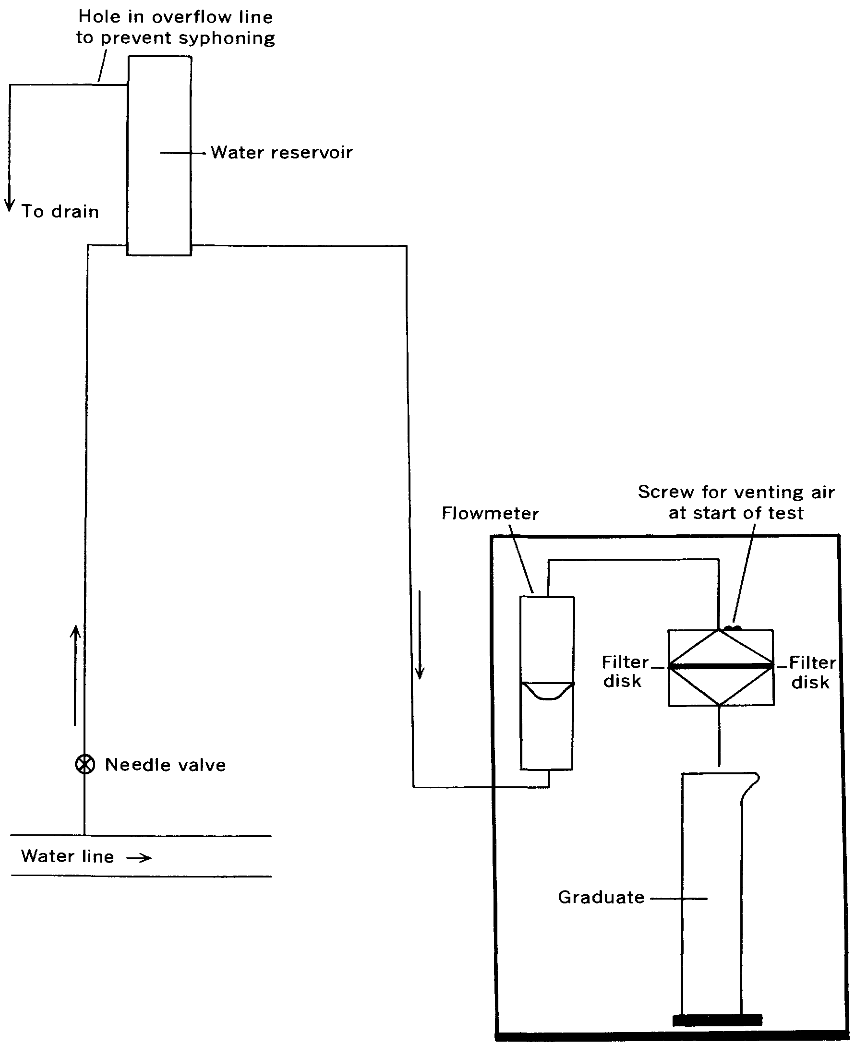

FIGURE 13.—Diagrammatic sketch of the Millipore-filter test assembly.

water exceeded the suction limit of centrifugal pumps, and bailer samples were difficult to obtain without the sample becoming contaminated from the bailer. Small single-pipe jet jumps were installed in three of the 2-inch observation wells. These wells were less critically needed for water-level measurements and were readily convertible to water-sampling control points. Each pump was sealed inside the well casing, and contamination by seepage of water down the outside of the casing was prevented by a concrete apron at ground level and a small shelter over the entire assembly. Total yield of these pumps was less than 5 gpm, but the yield was adequate for sampling for bacteriological examination as well as chemical quality.

Kerosene lanterns and, later, thermostatically controlled heat lamps, were used to prevent freezing during the winter; therefore, it was not necessary to drain the pumps and risk contamination from an outside source when repriming the pumps for the next test.

The injected water was sampled for bacteriological examination by installing a small valve in the injection line at the point where the water entered the recharge wells.

SAMPLING WELLS

Samples of water from many points around the recharge wells were occasionally needed for chemical analysis. These were obtained by use of a small bailer that would operate inside a 2-inch well. Later work indicated the need for at least one permanent sampling point within a 20-foot radius of the recharge wells. All inexpensive pump capable of pumping about 3 gpm was installed in one of the 2-inch wells.

WATER-TREATMENT EQUIPMENT AND PROCEDURES

The equipment and procedures described herein were not necessarily used in all injection tests. Generally, every effort was made to "polish" the surface water to be injected to the highest degree possible, whereas in other tests, one or more of the treatment steps were varied or omitted. In general, the equipment used and procedures followed were field adaptations of conventional water-treatment practices.

WATER SUPPLY

Reservoirs on the Fred Hoskyn farm adjacent to the Rice Branch Experiment Station were used as the source of surface water for the recharge tests. A tributary of Little LaGrue Bayou collects runoff water from about a 4-square mile area. Mr. Hoskyn pumps this water into his reservoirs, where it is stored for rice irrigation. (See fig. 14.) The Hoskyn canal system was connected to that on the experiment station by a new canal about 1,200 feet long, providing gravity flow of water from the reservoir to the recharge wells.

MICRO-ORGANISM CONTROL

Knowledge and control of microscopic organisms are important to waterworks officials because of the effect these organisms have upon the taste and odor of water. Nearly all the domestic supplies of water in the Grand Prairie region are pumped from the same aquifer in which the recharge wells are screened; therefore, palatability of the ground water should be maintained. However, with respect to

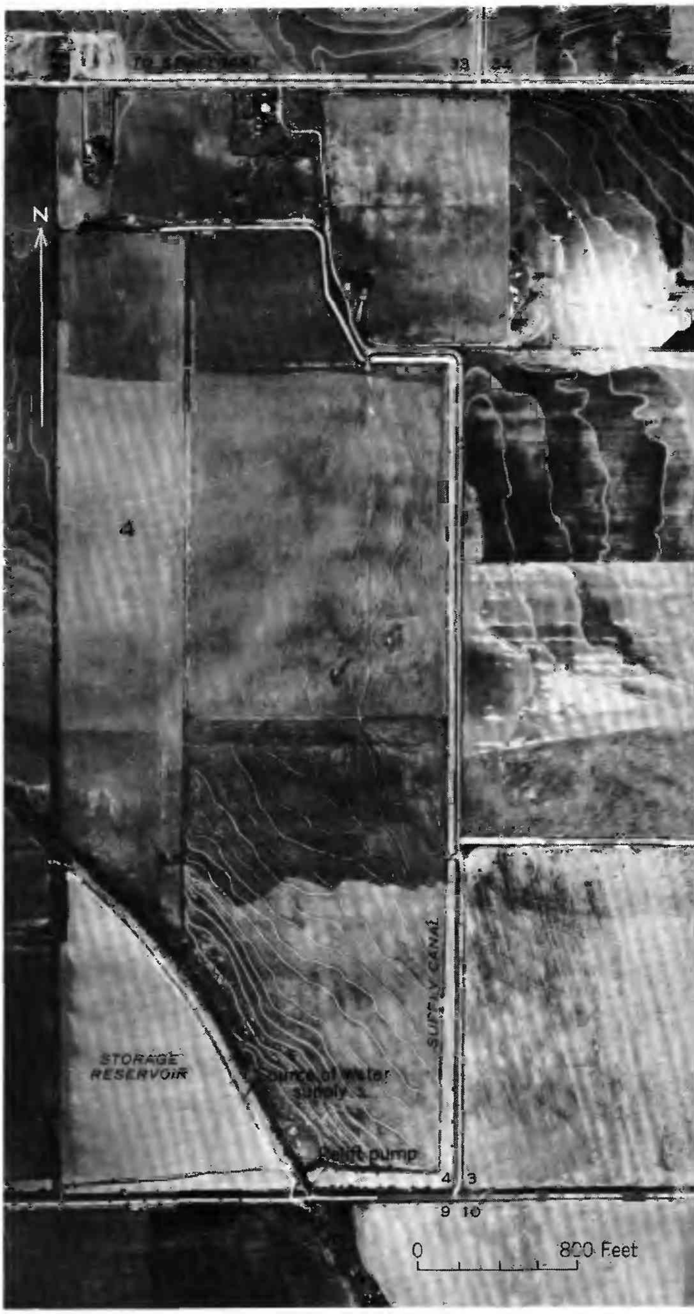

FIGURE 14.—Aerial photo

test site, 1960.

recharge operations, an additional important consideration is the potential plugging of the well and aquifer that could be caused by microscopic organisms in the injected water. *Synedra ulna*, one of the Diatomaceae is an example of a microscopic organism that can cause serious trouble in rapid-sand filters by plugging the filter bed, thus increasing the frequency of backwashing operations. Similar plugging could occur in an aquifer when artificial recharge is attempted.

Several methods of micro-organism control have been used throughout the testing periods at the recharge project. The simplest manner of control was to drag burlap bags containing copper sulfate through the water in the canals and reservoir. Copper sulfate, dissolved in water, also was sprayed over the surface of the water.

Other control methods utilized a small pump, such as those used in chlorinating swimming pools, to inject calcium hypochlorite solution into the water supply. This treatment was done before coagulation at a point in the supply canal where water velocity furnished mixing.

The variety and numbers of micro-organisms in the water were checked to determine effectiveness of the treatment. The best treatment was achieved when copper sulfate and calcium hypochlorite were used together.

COAGULATION

The canal facilities on the Rice Branch Experiment Station were used as much as possible in the water-treatment process. A relift pump was installed (fig. 15) to pump water from the Hoskyn canal into the canal on the experiment station. This afforded a means of controlling the level of the water in the canal and also provided a convenient place for mixing the coagulating agent with the turbid water. A dry chemical feeder was installed in a shelter spanning the canal (figs. 16 and 17). Two sections of 48-inch concrete culvert were placed on end in the canal adjacent to the feeder as an initial mixing chamber. By operating the relift pump and feeder simultaneously, the coagulating agent and raw water were thoroughly mixed. Alum was used as the coagulant in all tests involving pretreatment of the surface water.

Recent tests in the High Plains region of Texas indicated excellent results when using a product called Separan AP 30 as a coagulating agent (The Cross Section, June 1959, p. 2–3). Separan AP 30 was spread over lakes by crop-dusting methods; 1 pound per acre-foot of water produced relatively clear water in 24 hours. Water tested in the laboratory at the project site apparently was of a different character than that in the High Plains, and alum proved to be a cheaper and more effective coagulant than Separan AP 30.

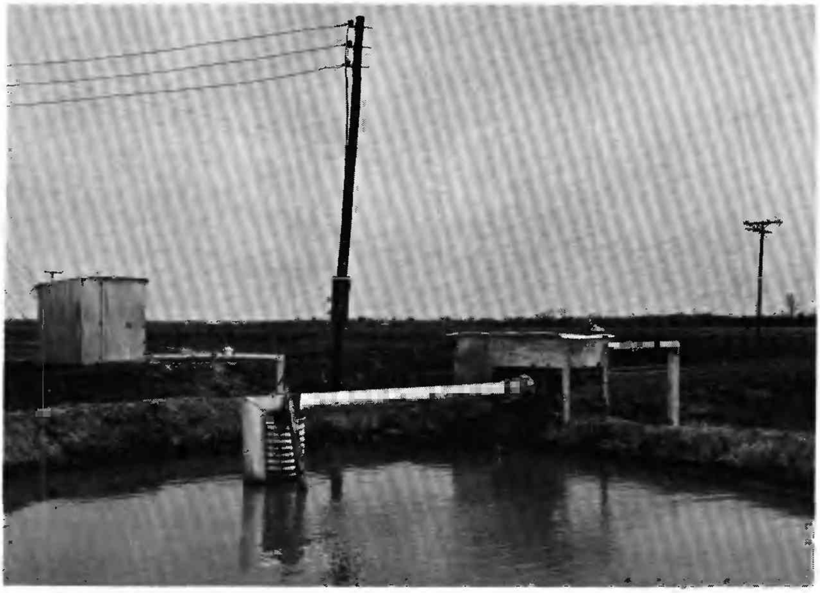

FIGURE 15.—View of the water-handling facilities at the raw-water pickup point, showing the complete relift and pretreatment installation.

FIGURE 16.—Pretreatment equipment used at raw-water pickup point, showing pretreatment installation with culvert mixing chamber in operation.

FIGURE 17.—Pretreatment equipment used at raw-water pickup point, showing the mechanical feeder in operation, using alum as a coagulating agent.

SETTLING BASIN

The suspended material in the water was flocculated and settled in the canal after the addition of alum, as the water slowly moved to other treatment facilities near the recharge wells.

Wave action against the levee banks caused a change in turbidity from 3 or 4 ppm (parts per million), after pretreatment, to as much as 15 to 20 ppm. Cypress lumber was used to build 18 baffles, each one long enough to span the width of the canal. Each baffle was constructed so that a strip of wood 4 inches wide projected above the surface of the water as the baffle floated in the canal. They were anchored at about 100-foot intervals, at right angles to the length of the canal, by means of nylon cords and stakes driven into the levee banks. This arrangement allowed the baffles to rise and fall with the change in stage of the water in the canal and prevented wind from forming large waves.

The removal of accumulated floc from the settling basin was considered. If the floc could not be pumped or flushed into adjacent fields, the problem would be serious. Several agricultural authorities were interviewed and a search was made of related literature, but no information was available as to whether alum floc applied to cultivated fields would be detrimental to crops.

Greenhouse facilities were used to test the germination and growing of rice on soils treated with various percentages of alum floc. No detrimental effects were observed, and the floc may actually improve the soils under some conditions (Dr. Kenneth Olson, oral communication, 1957).

A sketch of the construction details and view of a completed baffle are shown in figures 18 and 19.

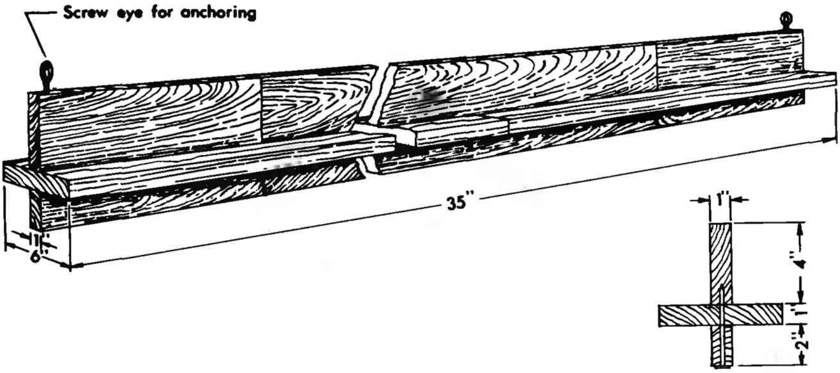

FIGURE 18.—Construction of baffle used to subdue wind action in settling basin.

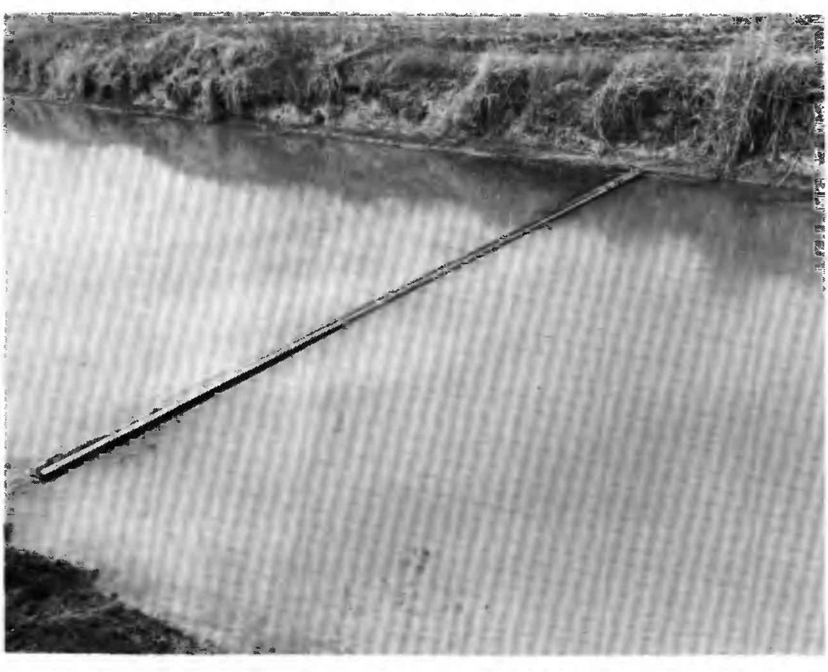

FIGURE 19.—Photograph showing baffle as installed in settling basin.

The Rice Branch Experiment Station used ground water for irrigation of rice each growing season. Consequently, it was necessary to empty the canal distribution system each recharge-testing season and replace the ground water with surface water before testing could be started. A low-lift pump, weighing 100 pounds and driven by a small air-cooled gasoline engine, was used to remove ground water from the dead storage space in the canals. The pump, mounted on wheels for portability, had a 6-inch discharge pipe and a maximum pumping rate of 700 gpm.

CHLORINATION

After flocculation and settling, the water was chlorinated before filtration with a vacuum-type solution-feed chlorinator. This type was chosen because it is of medium capacity and will treat a relatively uniform, continuous, or interrupted flow of water. Records of chlorine weight were maintained. These data provided a means for computing the total chlorine supply on hand, as well as furnishing a check on the quantity of chlorine used during a particular test.

FILTRATION

Final treatment of the surface water was passage of the water through a rapid-sand filter (fig. 20). The filter had a radius of 8 feet, 4⅜ inches, was 9 feet 6 inches high, and had a manifold-type under-

FIGURE 20.—View of the interior of filter tank before placing of filtering medium, showing the manifold, laterals, and wash troughs.

FIGURE 21.—Primer installed on the filter-intake line.

drain system. The maximum capacity was approximately 600 gpm. The coarse filtering material consisted of siliceous pebbles, graded with a 5-percent tolerance as follows: 1-inch to ¾-inch (8 cubic yards, gravel); ¾-inch to ½-inch (4 cubic yards, gravel); and ¼-inch to ⅛-inch (4 cubic yards, gravel). The fine filtering material consisted of quartz sand and was graded as follows: 0.45 mm- to 0.55 mm- grain size, with a uniformity coefficient of less than 1.6 (16 cubic yards). The various sizes of filtering media were placed in the filter, grading upward from coarse to fine, without separating screens.

A 10-inch centrifugal pump, with a rated capacity of about 3,000 gpm against a head of 60 feet, and a 180–hp industrial 8-cylinder engine, with carburetion arranged so that Butane could be used as fuel, were installed to lift the water into the filter and backflush the filter when the medium became plugged.

All waterlines were fitted in place by welding or with couplings. Because the testing periods were not continuous and winter temperatures frequently were low enough to cause freezing, it was necessary to drain the pumps and pipelines. Priming of the pumps was necessary after each draining and was difficult until the diaphragm-priming devices shown in figure 21 were installed.

CLEAR WELL

A later addition to the water-treatment facilities was a clear well (figs. 22 and 23), which was 5 feet deep and 13 feet in diameter, and

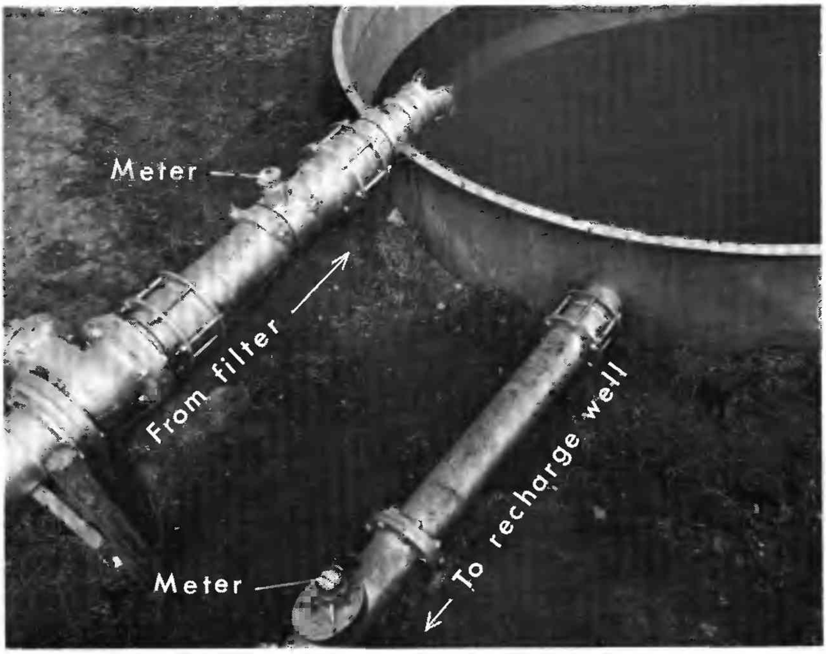

FIGURE 22.—View of the clear well used to collect filtered water, showing discharge line from filter and line from clear well to recharge well. Note meters used for measuring rates and quantity of water flow.

FIGURE 23.—View showing electric pump (far side of tank) used for cleaning and emptying clear well shown in figure 22.

was made of steel. The purpose of the clear well was to receive filtered water and provide a break in the closed system in the injection line when the filter was connected directly to the recharge well. By moving water from the clear well into the recharge well, the siphon effect created during injection was not operative on the filter.

SUPPLEMENTAL EQUIPMENT AND CONTROLS

TESTING SEASONS

Many ground-water projects are controlled somewhat by weather, accessibility of the project site, the length of the pumping season, time of the year, and other factors. The testing season on the artificial-recharge project was rigidly controlled by hydraulic conditions within the aquifer, the availability of surface water for injection, and farming activities on the Rich Branch Experiment Station.

The rice-growing season in the Grand Prairie region occurs from April through October. During this period most of the irrigation wells in the region, as well as those on the experiment station, are pumped. The season drawdown of the regional water level varies from place to place according to the concentration of wells, well yields, and the hours of pumping. The complexities of hydraulic conditions within the acquifer, caused by pumping, make it difficult to analyze recharge results.

Water used during recharge tests was taken from a reservoir in which runoff water had been stored for crop irrigation. Rainfall is distributed unevenly in the region, and the reservoir owner must conserve his water supply during the irrigation season to insure the availability of water for crops. Consequently, a supply of surface water for recharge tests was not available during the rice-growing season.

Many of the structures on the Rice Branch Experiment Station, particularly the canal system, were utilized during recharge tests. The canal system was designed for distribution of irrigation water to the various plant-testing plots and had to be used for this purpose during the growing season.

Recharge work during the nongrowing season (November through March) did not interfere seriously with experiment station activities. Rainfall generally was adequate during these months, and, because water was not needed for irrigation, an ample supply of surface water was available for injection tests. By the latter part of December, hydraulic conditions within the aquifer generally were stabilized, and pumping influence on water levels was at a minimum. This period, November through March, constituted the testing season.

The cyclic nature of the testing period was advantageous in that the summer was used for equipment maintenance and revision, and time was available for analysis of results and test planning.

TIMING OF OBSERVATIONS AND NOTE KEEPING

During each test, all activities and observations were recorded in a log of operations. This log contained filtration, chlorination, and turbidity data, as well as any other information that might be helpful in analyzing test results.

A stopclock with an 8-inch face was used to time all water-level measurements made by the wetted-steel-tape method. The flow meters were timed with stopwatches to make spot checks of the injection or discharge rates. All time notes made in the log of operations were based on the 24-hour clock. This was particularly advantageous when a test period covered several days.

SPECIFIC-CAPACITY TESTS

Specific-capacity tests were used throughout the project to determine the effectiveness of redevelopment procedures after injection tests. The specific capacity of the recharge wells was as low as 2 gpm per foot at the end of a recharge test and as high as 33 gpm per foot after redevelopment.

A specific-capacity test was started by making a series of water-level measurements in the recharge well several minutes before starting the pump. This established any short-term trend of the nonpumping water level in the vicinity of the recharge well and was used to indicate the static water level during the specific-capacity-test period.

For most tests, pumping was started at about 300 gpm and held constant for 1 hour. The pumping rate was then increased to about 500 gpm and again held constant for 1 hour. Water-level measurements in the recharge well were made throughout the pumping period. Figure 24 illustrates the manner in which collected data were plotted. Note that the drawdown curves were extrapolated to 100 minutes so that the effect of time of pumping on drawdown would be cancelled out. The performance of the well during each step and each test was then compared with the previous test.

Specific capacity is expressed as follows:

$$SC=\frac{Q}{s_c}$$

in which

SC=Specific capacity in gallons per minute per foot of drawdown or buildup,

Q=Pumping or recharge rate in gallons per minute,

s_c=Drawdown or buildup, in feet, corrected for fluctuation of the water level caused by atmospheric-pressure changes.

From figure 24, the specific capacity during the first step at 300 gpm was 23.6 gpm per foot. During the second step, when the rate was increased by 248 gpm, the specific capacity was 23.2 gpm per foot.

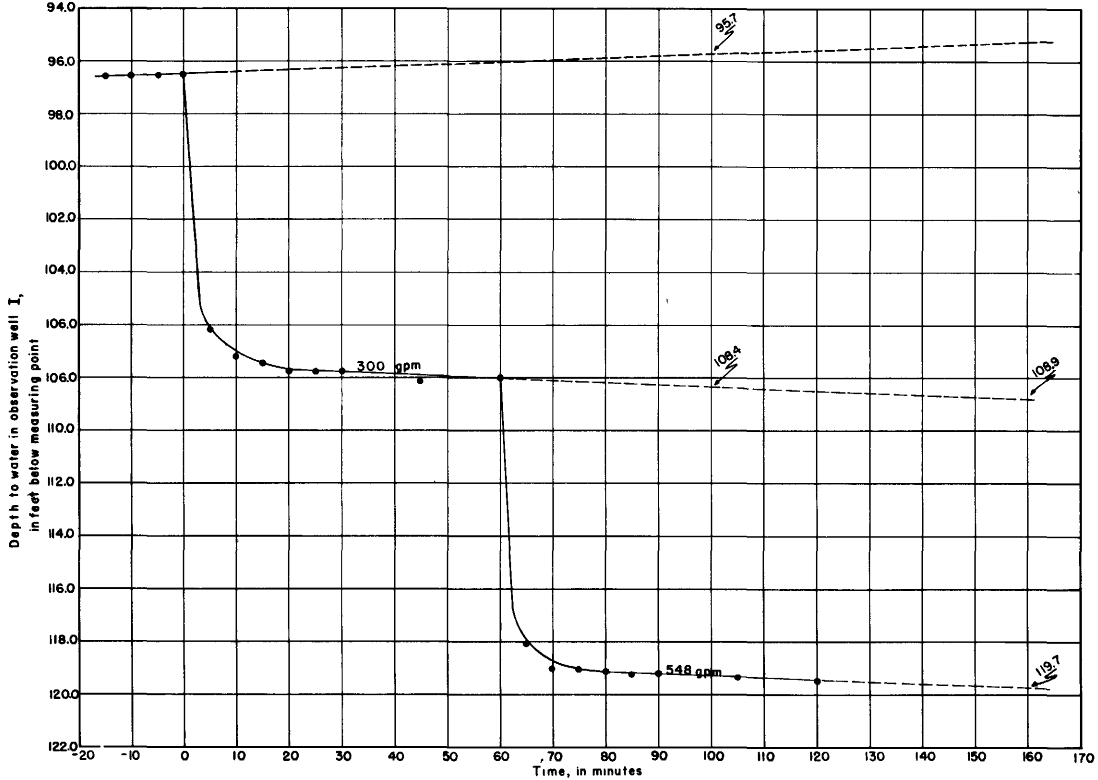

FIGURE 24.—Curves obtained during a step-drawdown test of the recharge well

PROJECT LAYOUT

A project layout map (fig. 25) shows the location of the various control and water-treatment facilities used during injection tests. The pretreatment equipment had been placed over the canal about 1,800

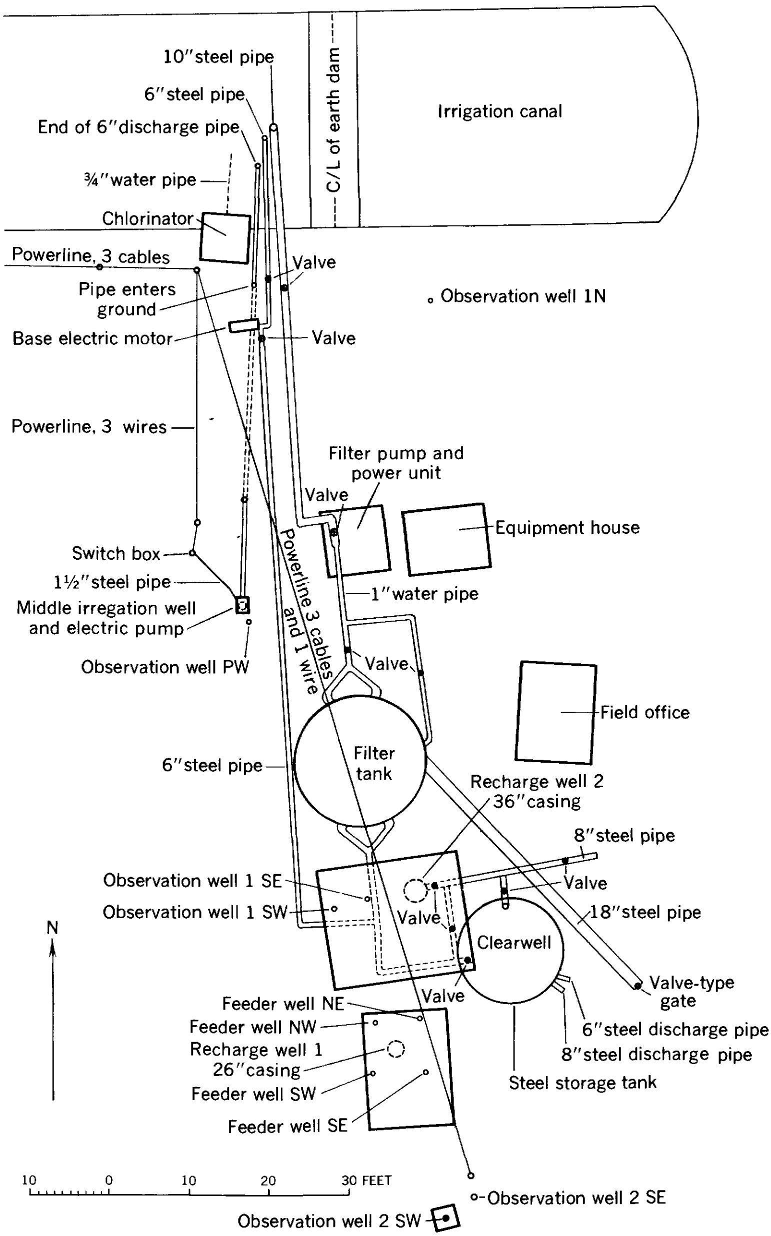

Figure 25.—Map of the artificial-recharge site showing layout of equipment.

feet from the recharge wells. Experience proved the distance too great. Coagulation results were excellent, but wind action and fish and turtles in the settling basin caused the clarified water to regain a suspended-solids load almost equal to that of the raw water by the time it reached the filter pickup point. The dry chemical feeder, mixing culverts, and relift pump were moved down the canal toward the recharge wells, making the settling basin approximately 900 feet long. This distance proved satisfactory, and water of greatest clarity was observed at the filter pickup point.

CONCLUSIONS

The recharge tests have not conclusively established the proper construction for a recharge well. However, certain generalities may be stated.

All recharge wells should include a means of measuring the water level or well-head pressure inside the well and immediately outside. The Grand Prairie tests have shown that the first and most severe plugging was in or very near the injection well. Measurements of water levels inside the recharge well will permit early detection of plugging. Observations noted only at a distance from the recharge well will not show evidence of plugging until recharge has been in progress for long periods of time, and by then redevelopment becomes difficult.

The backflush pump did not completely restore intake or discharge capacities of the recharge wells but was a definite aid that could not be omitted. The 2-inch holes drilled in the side of the tailpipe used in recharge well 2 prevented maximum drawdown inside the well, and redevelopment by use of the pump was less effective.

Most irrigation wells in the Grand Prairie have the pump sealed in the well. Suction lift created by the pump is supposed to increase the well yield and retard breaking suction. Sealing the recharge well was of no apparent benefit except in preventing runoff surface water from gaining entry around the pump

The use of the pump column as a means of introducing recharge water to the well was satisfactory and perhaps furnishes additional justification for installing a backflush pump. Unless recharge is practiced at a constant head with the water level at the ground surface, an entry line should be used to prevent free fall of recharge water into the well.

The effectiveness of the "feeder wells" in redevelopment procedures cannot be stated with certainty. Less trouble was experienced in redevelopment of recharge well 1 where the feeder wells were located. However, for the most part, the character of the water injected in recharge well 1 was significantly different from that of the water injected into recharge well 2, as was duration of the tests. At least in theory, the use of feeder wells is sound, and positioning them closer to the recharge well may have made their utility more apparent. The use of feeder wells as control points for water-level observations and sample collection justifies installation in an experimental operation, but their value in an operational project is questionable.

If water is to be recharged at a controlled rate, some means of eliminating the siphon effect in the injection system should be included. The butterfly valve installed in well 2 served this purpose.

The use of the wire-wrapped stainless-steel screen is recommended. Rigorous procedures that may be needed to redevelop an injection well require a screen of structural strength and of a composition to withstand surging, bailing, acidizing, and the addition of other chemicals. The life of a recharge well generally will be less than that of a production well. Corrosion and erosion should be minimized as much as possible by using a screen of suitable material that has an optimum open area.

Perhaps initial development of recharge well 2 was more complete than that of recharge well 1, but development differences can account for only part of the initially higher specific capacity of recharge well 2. The well and screen diameters, screen type, and method of installing and finishing the well were the major factors resulting in the higher specific capacity.

The sand pack used in recharge well 2 was more effective than the gravel pack used in recharge well 1 in confining or trapping clogging material near the screen. However, the sand-pack well was more difficult to redevelop. Apparently, the clogging material became more tightly embedded in the pack interstices. Test duration was longer and injected water "polish" generally was poorer when using recharge well 2. This may have caused most of the greater redevelopment difficulties with recharge well 2. Consequently, conclusive data are not available to establish the relative merits of gravel-pack versus sand-pack recharge wells.

No apparent beneficial results in redevelopment were obtained by the use of the jetting device installed in recharge well 2. The quantity and pressure of the jetted water may not have been great enough to be effective in removing clogging material. No malfunctions in manipulations of the washring were encountered.

All other accessory equipment used in the recharge wells, such as the electric motor, right-angle drive, and nonreversing ratchet, was satisfactory in operation and amply served its purpose.

Arrangements for observation of water levels inside and immediately outside a recharge well are considered mandatory in specifications whether a project is operational or experimental. Observation wells in the recharged aquifer also are required at greater distances from the injection well. Well spacing should be based on hydrologic characteristics of the aquifer and injection procedures. These wells should be designed for collection of water samples as well as for making water-level measurements. A minimum of three wells are required, the first well being close enough to the injection well to be influenced at least 2 or 3 feet by the cone of elevation. These wells will be useful in long-term observations of recharge operations. Most of the suspended matter in the injected water affects the aquifer in the immediate vicinity of the recharge well. However, chemical changes in the water and bacterial contamination may cause plugging at greater distances. Unless water levels and water-quality data are available at a distance from the injected well, long-term recharge effects cannot be determined or predicted, and procedures to overcome undesirable effects cannot be formulated.

Measurements of rates and quantities of water are major factors in the development of any ground-water supply and are essential in recharge operations. Several types of metering equipment are available and should be as satisfactory as those used on this project.

The turbidimeter used during the tests was satisfactory except when samples of the raw water were examined. The suspended solids of raw water frequently exceeded 200 or 300 ppm, and in this range the possibility of observer error is great.

The temperature-recording gage was satisfactory; however, the instrument should have been calibrated to allow readings to the nearest one-tenth degree.

It may be inferred from temperature changes observed during recharge and pumping that very little native ground water remained near the recharge well after a few minutes of injection. The injected water merely replaced the native ground water. Even so, the usefulness of temperature data as a method of distinguishing between two waters may be limited under certain conditions. Obviously, this is true when the temperature of the recharge water and the ground water are nearly the same. Also, differentiation between waters would be difficult if the recharge water is left in the aquifer for a long period of time and allowed to become warmed or cooled to a temperature near that of the ground water. No systematic attempt was made to collect data regarding the rate of temperature change of the two waters in the aquifer after recharge. A 2-week contact period resulted in approximately 2° rise in the temperature of the injected water when the temperature differential between the two waters was about 7° F.

One not so obvious limitation to the usefulness of temperature data as a method for distinguishing between recharge and ground water has been observed during the recharge studies made in California

(California Water Pollution Control Board, 1954). Bacterial contamination and activity in the injected water may cause a significant rise in the temperature of the water after injection into the aquifer.

In the Grand Prairie recharge studies, reliance has been placed upon temperature differences as a means of distinguishing between recharge and ground water when recovery of the injected water is started immediately upon completion of a recharge test. Immediate withdrawal of the injected water should preclude most of the warming effects of bacterial action and contact with warmer rocks and water. Precise identification of injected water and native ground water would require finer calibrated temperature observations or the use of other methods such as water tracers.

The Millipore filter apparatus was not used until several tests had been completed. In an experimental project of this type, it is highly recommended that the apparatus or an adaptation of the apparatus be considered for use.

The Millipore filter permits collection of practically all suspended material in the water. This material then becomes available for chemical, bacteriological, X-ray, or other types of examination. In a long series of tests, the data soon become voluminous and unwieldy to examine. The Millipore filter unit makes it possible to rate water quality with a single number by observing the decline of flow percent in a given period of time (Felsenthal and Carlberg, 1956).

The equipment and controls regarding coagulant testing, bacteria sampling, chlorination, and water supply were adequate. Some of the effectiveness of copper sulfate as a micro-organism control chemical was nullified, presumably by precipitation as insoluble copper carbonate and hydroxide. Copper sulfate and chlorine used together were more effective than either chemical used alone, although chlorine provided acceptable control.

The baffles, installed in the settling canal, prevented the formation of large waves, but their effectiveness in reducing pickup of turbidity was not as great as anticipated. Maintenance difficulties such as waterlogging of the wooden baffles, collection and entrapment of algae, and interference with the Rice Branch Experiment Station's normal irrigation activities were encountered. The baffle system did not reduce the pickup of turbidity in the coagulated water enough to justfy maintenance or continued use. A more permanent baffle extending to the bottom of a settling canal might be considerably more effective.

The filter was satisfactory in most respects. Even distribution of the backflush water would have been more easily obtained in a rectangular tank. Proper wash-trough spacing also was difficult in the cylindrical tank. The clear well, which received filter effluent served its purpose satisfactorily.

Recharge facilities should be kept as compact as possible. Economical use of space and transportation of water by gravity flow will reduce the cost of the recharge operation, permit the use of more automatic controls, and minimize difficulties in manipulating recharge equipment.

In general, the equipment and operation procedures used were satisfactory. Some difficulty was encountered when attempting to repeat testing conditions and maintain constant injection conditions for a prolonged period of time. Many problems were created by weather; however, weather changes would affect any field recharge operation.

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