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Effectiveness of Gravity Drains And Experimental Pumping For Drainage Delta Area, Utah

By O. W. ISRAELSEN
D. F. PETERSON, JR.
R. C. REEVE

Bulletin 345

UTAH AGRICULTURAL EXPERIMENT
STATION, LOGAN, IN COOPERATION
WITH THE U.S. REGIONAL SALINITY
AND RUBIDOUX LABORATORIES,
RIVERSIDE CALIFORNIA

345
Effectiveness of gravity
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FEBRUARY 1950

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SUMMARY

A STUDY was made in the Delta Area, Utah, during the 5 years 1945 to 1949, to determine the effectiveness of gravity drains and the possibilities of drainage by pumping ground water. Eight experimental sites were selected for the study of gravity drains; 7 in 1945 and 1946, and 1 additional site in 1948. A total of 170 piezometers were installed at the 8 selected sites to determine the draw-down and the lowering of the water table and direction of ground-water flow in the vicinity of open and tile drains.

The study shows considerable variability in the effectiveness of gravity drains. In some cases the drains are effective in lowering the water table at distances of 600 to 800 feet on both sides of the drain. In others the gravity drain influences the depth of water table to a distance of only 50 to 100 feet. These differences demonstrate the importance of ground-water flow studies in connection with the selection of location, depth, and spacing of gravity drains. In areas having considerable upward ground-water flow, as in some locations in the Delta Area, gravity drainage by means of tile and open drains is extremely difficult. In such areas special attention should be given to the feasibility of pumping ground water for drainage to maintain soil productivity.

Noteworthy features of the geology of the Delta Area in relation to pumping ground water are outlined. Details of experience in the drilling, development, and pumping of two experimental wells near Sutherland for drainage purposes are reported. Some of the experiences of irrigation and drainage associations in Arizona and California in pumping ground water for drainage and for irrigation are briefly reviewed.

The experience of many agencies in pumping ground water for drainage and irrigation in the West leads to the conclusion that pumping substantial volumes of water from deep wells is an effective method of lowering the water table. The water pumped from the shallow, low-capacity Delta Area experimental well, reported herein, caused appreciable lowering of the water table near the well and significant lowering at a distance of 800 feet.

Fluctuations of the water table because of irrigation may largely obscure the effect of the pumping, thus indicating that limited areas throughout the vicinity must be assigned to each of many wells for effective drainage by pumping.

FOREWORD

COOPERATIVE investigations on drainage and reclamation of salted soils in the Delta Area, Utah, were undertaken by the Utah Agricultural Experiment Station, the U. S. Regional Salinity Laboratory, and Millard County Drainage Districts under a memorandum of understanding effective January 1, 1946.

This investigation comprises project 250 of the Utah Agricultural Experiment Station, R. H. Walker, director; and project 50-46-1 of the U. S. Regional Salinity Laboratory, H. E. Hayward, director.

The objectives of the investigations covered by the memorandum of understanding were:

1. To study the effectiveness of present methods of drainage; tile and open drains.
2. To determine the possibilities of pumping from wells as a method of drainage in the Delta Area and the possibility of using the pumped water for irrigation.
3. To determine practical and economical methods of reclaiming unproductive saline and alkali soils of the area by leaching.

The leaching phase of these investigations has been completed and the results are reported in Experiment Station Bulletin 335 entitled "Reclamation of saline-alkali soils by leaching." The first and second phases concerned with the effectiveness of present drainage methods and the possibilities of pumping for drainage are included in this report. Drainage and leaching are inseparable and must be considered as integral parts of an overall reclamation program for areas in which salinity is a problem.

EFFECTIVENESS OF GRAVITY DRAINS AND EXPERIMENTAL PUMPING FOR DRAINAGE, DELTA AREA, UTAH

by
O. W. ISRAELSEN, D. F. PETERSON, JR., R. C. REEVE

INTRODUCTION

THE DELTA AREA is situated on the edge of a typical desert plain known as the Sevier Desert at the foot of the ancient Bonneville deltas of the Sevier River in Millard County which is located in west-central Utah. The topography is flat with a gentle southwesterly slope of 5 to 20 feet per mile. The soils of the area are deep and generally of fine texture and quite highly saline. There is considerable stratification which is common in soils formed of water-placed materials. A gross area of approximately 120,000 acres is included in the region; approximately 80,000 acres are included in 4 drainage districts, of which about 65,000 acres are under irrigation. A number of reports concerning the soils, agriculture, geology, irrigation, drainage, and economic and social aspects of the region have been written (6, 9, 10, 11, 12, 16, 19, 21, 22, 25, 27, 30, 31).

Irrigation began in the area about 1860 and was gradually expanded until 1905 when construction of extensive water-storage facilities at Sevier Bridge Reservoir gave impetus to rapidly increasing expansion which continued until about 1920. Because of irrigation development, the ground water eventually rose until agriculture in the area faced destruction without artificial drainage. During the period 1914 to 1918 four drainage districts were organized under the laws of Utah and gravity drainage systems of open drains and covered tile were installed in an area of about 80,000 acres at a cost of nearly three million dollars.

WATER SUPPLIES AND DRAINAGE

Favorable water-supply conditions recurring within the decade ending 1950, concurrently with a prosperous period for agriculture, made reconstruction and maintenance of drains profitable and has, during this period, resulted in considerable construction of open drains.

Irrigation water from the Sevier River is stored, diverted, and conveyed to the farms by four mutual irrigation companies. The water is quite saline, having about 1650 parts per million, or 2.2 tons dissolved solids per acre-foot.

Irrigation waters have been classified by Magistad and Christiansen (20), and others according to the degree to which plant growth will likely be inhibited because of salinity. On the basis of this classification, Sevier River water is class 2 water, which implies that it may be injurious to the more sensitive crops. Lack of drainage has the effect of causing increased salt concentration in the upper soil horizons, as well as of increasing the alkalinity because of precipitation of the calcium salts while the more soluble sodium salts remain in solution. Even though irrigation water may be of fair quality, waterlogging may induce excess salinity.

The major physical problem in the Delta Area is that of providing drainage for the irrigated lands. It is no doubt true that agriculture on the present scale would be impossible without artificial drainage. In their efforts to improve agriculture in the region, local leaders have promoted and contributed to research in both irrigation and drainage. The Delta Area Irrigation and Drainage Research Committee has long sponsored experimentation and research with the aim of conserving water and improving drainage methods.

OBJECTIVES OF DRAINAGE IN ARID REGIONS

Drainage of farm lands in arid regions is motivated by one or both of two major objectives:

1. To remove in reasonable time all excess water from the soil in order to improve soil productivity, to facilitate farm operations, to improve health conditions as well as to decrease transportation and highway costs, and,
2. To leach excess soluble salts from the soil as rapidly as possible in order to improve soil productivity at the earliest time practical (5, 8, 28).

Before the construction of the drainage systems in the Delta Area, many landowners were influenced strongly by both of these major objectives. Seepage of water from irrigation canals and deep percolation water losses from irrigated lands had contributed to the ground water supplies until the water table over large areas had risen to points near the land surface. The extreme aridity of the climate causes relatively high evaporation from the surface of moist soils. Soluble salts that are contained in the soil water do not evaporate but are deposited on or near the land surface (20). This concentration of salts on the land surface, if long continued, renders the soil entirely unproductive. Appreciably large areas of land in Millard County were thus affected before the drainage movement was begun in 1910.

DESIGN OF DRAINAGE SYSTEMS

The elements of major importance in the design of drainage systems are:

1. Selection of the type of drainage system to be used,
2. Capacity of the system, and
3. Depth, location, and spacing of drains (7).

The capacity of a drainage system, or of any part of it, is measured by the quantity of water per given area (usually expressed in cubic feet per second per square mile) that will flow from the soil into the drain and be conveyed from the land.

In irrigated regions, it is more difficult to estimate the required capacity of a drainage system than it is in humid areas. This is because of the wide variability in the irrigation practices of different individuals and of different communities with resulting wide variability in water contributions to drainage systems. It results also from the difficulty of measuring accurately the permeability of deep farm soils and soils through which irrigation canals and ditches are constructed.

As a result of the influences of the many variables that contribute to the required capacity of arid-region drainage systems, there are no generally-accepted bases for computing capacities. Consequently, engineers differ in their viewpoints concerning required capacity and rely largely on experience and personal judgement in designing drainage systems.

In irrigated soils it is usually desirable to place drains at greater depths than in humid-region soils. The water table must be kept at a greater depth in arid regions to prevent movement of salts to the soil surface. If the soil to be drained is substantially uniform in texture and in structure, deep drains need not be spaced as closely as shallow drains. Ordinarily, in this type of soil, the deeper the drain is placed the more effective it will be. In soils having an impervious layer at a small depth below the root zone soil, Kirkham (17) has shown that it is better to place the tile slightly above the impervious layer, sacrificing some depth, than to place it on the impervious material.

It is possible in some places to provide drainage of irrigated lands largely, if not entirely, by locating the drains so as to "intercept" the excess water and to convey it away before it reaches the lands that need drainage. In some areas topography and natural conditions may not be favorable to "intercept drainage." Where drains are widely distributed throughout an agricultural area, with a view to relieving the land of excess water, the method is known as the

"relief" method. Spacing and depth of drains are of special importance with this method (7).

DESIGN OF THE DRAINAGE SYSTEMS IN THE DELTA AREA

The drainage systems designed and constructed in the Delta Area were based largely on the "relief" method of drainage. Four independent and separate systems were installed by the four drainage districts. The systems consisted of networks of open drains which functioned as outlets for the clay tile feeder lines that drained a major portion of the area. The open drains ranged from about 7 to 10 feet deep and most of the tile drains were placed from 5 to 8 feet deep.

The drainage systems were designed on the basis of 1.0 cubic foot per second maximum capacity per square mile for main drains, 1.6 cubic feet per second per square mile for sub-laterals, with somewhat larger capacities of drains for intercepting lines adjacent to irrigation canals.

During 1922-23 discharges of drains were measured by Hart and Adams¹ under widely varying conditions of soil, diameter and length of drains, spacing of drains, and extent of lateral systems. The results of some of these measurements show that the discharge varied from 0.28 to 1.68 cubic feet per second per square mile for drains in the area. The mean discharge from the areas, which were largely irrigated, was 1.2 cubic feet per second per square mile.

The engineers had no previous drainage systems in the territory to use as guides for spacing the drains; consequently it was essential to base the design of spacing largely on judgment as guided by experience gained elsewhere. As the result of this situation, the spacing was developed on the theory that it was better to err on the side of too close, rather than too wide, spacing. In general, the original design provided for an average spacing of 660 feet.

EFFECTIVENESS OF GRAVITY DRAINS

A DRAINAGE SYSTEM is effective only insofar as it maintains the water table at a sufficient depth below the soil surface, and for a sufficient length of time during the growing season, to allow good aeration in the root zone of the soil and to prevent upward movement

¹ From an unpublished "Progress report, Millard County drainage investigations," by R. A. Hart, senior drainage engineer, and T. C. Adams, drainage assistant, Division of Agricultural Engineering, U. S. Department of Agriculture, 1924.

of saline ground water with subsequent deposition of excess salts in the surface soil.

The effectiveness of the gravity drains in the Delta Area during the first quarter-century of drainage activity was presented in Utah Agricultural Experiment Station Bulletin 255 (10) concerning drainage and irrigation conditions in the Delta Area. Some of the more significant factors relating to the effectiveness of the drains as presented in 1935 are summarized herein.

Studies made from 1945 to 1948 of water table conditions as related to the original tile and open drainage systems and of changes resulting from recent construction of open drains in the area, are a part of the present investigation. A brief review of previous work is presented after which the results of the present studies are reported.

PREVIOUS STUDIES

The effect of open drains, of tile drains, and of seepage from canals on the water table in the Delta Area was studied carefully in 1922-23 by Hart and Adams. Lines were selected at right angles to typical drains and canals and borings were made into the soil along these lines for the purpose of observing the position of the water table. The observation holes were closely spaced near the drains and ditches and were spaced farther apart as the distance from the drain or the ditch increased. Nineteen such observation lines or courses were established, along which 195 holes were bored. Detailed descriptions of each course and of the soil formation encountered at each boring, together with the position of the water table, are contained in the report by Hart and Adams. The results observed on three typical courses, including an open drain, a tile drain, and a canal, are presented here.

Open Drains

The water table elevation on a line 2,850 feet long just south of the Oasis-Holden road and one mile east of the road to Delta in District No. 4 was determined by making ten borings. This indicated that a spacing of one-fourth mile, or 1,320 feet, would have been adequate for the conditions prevailing at the time the profile was measured.

Tile Drains

Regarding the spacing of tile drains, Hart and Adams reported:

. . . in the original design for spacing, the engineers were well on the safe side, and it was recommended that serious thought be given to the proposal of increasing the spacing somewhat. Eventually this was done in several of

the districts, and in some places spacing as wide as 1000 feet, and even 1320 feet, was given. It is believed that the results are entirely satisfactory.

This report is dated January 1924, and was made after extensive drainage studies had been conducted during 1922 and 1923. The conclusion given above, being based on experimental data that were not available to the leaders during the formative period of the drainage districts, represents more maturity and reliability than the earlier point of view concerning the depths and the spacing of the drains.

The Delta Area experience in depth and spacing of drains seems to indicate that spacing the tile drains farther apart would have resulted in a satisfactory installation with some reduction in cost, although with the information then at hand, it was not possible to foresee that wider spacing would have provided adequate drainage. General statements as to the necessary depth and spacing of drains in arid regions are frequently misleading and erroneous when applied to specific drainage problems, because of the great variability encountered in the soil and water conditions. Comprehensive and thorough engineering investigations should precede the construction of every drainage system.

PRESENT STUDIES

During the 20 to 30 year period that the drains have been installed, many of the tile lines, especially the smaller ones (5 to 6 inches diameter), have become ineffective because of clogging with silt and the growth of roots in the lines. These conditions have resulted from a combination of many factors. Many tile drains were installed in quicksand deposits in which misalignment and silting of the drains occurred. The growth of greasewood and other native vegetation on virgin or abandoned land through which the tile lines pass has resulted in clogging of tile lines by roots. Insufficient and/or improper maintenance of drains, especially during the depression years, has also contributed to the development of adverse drainage conditions in local areas where tile and open drains have become ineffective. During the years 1940-50 the drainage districts have been active in a program of open drain construction to supplement the existing system and, in many cases, to replace or improve the functioning of tile drains that have become ineffective. In constructing open drains, existing tile lines are intercepted and cut, thus providing additional outlets and shortening the length of many tile drains.

The studies, initiated in 1945, were made to determine the effectiveness of existing drains and the effects of construction of new open drains.

Sites Selected — Drains and Piezometers

Four sites were selected to study the effectiveness of existing open and tile drains, and four other sites where construction of new open drains was contemplated. This was done to determine the effect of such construction on the water table, including the resulting improvement in effectiveness of existing tile drains that were intercepted and cut. The locations of the eight experimental sites are shown in fig. 1. Piezometers were installed at each location on lines parallel and perpendicular to open drains and to tile drains. Single piezometers were installed at each measurement station and periodic readings of water table levels were made. At two of the sites, site A and Hinckley site, several piezometers were installed at each station to various depths below the surface to obtain a pattern of ground water flow in the vicinity of open drains.

The first piezometer installations (26) were made in 1945 at two sites where new open drains were proposed. These were designated Oasis site and Drainage District No. 4 site. In 1946 piezometers were installed at sites designated E and F, where open drains were proposed, and at three sites designated A, C, and D to determine the effectiveness of existing drains. The studies at sites A, C, and D were made in connection with leaching experiments, and details of the effectiveness of drains at those locations were reported earlier (27). In 1948, at the request of local people, piezometers were installed in the vicinity of an open drain and several tile drains at Hinckley. Inadequate drainage and the resultant accumulation of excess salts in the surface soils had caused reductions in crop yields in this area.

Site E: Site E is located in Drainage District No. 1 in Sec. 16, T. 17 S., R. 7 W., in fields to the east of the Deseret-Sutherland road approximately one mile east and one mile north of Hinckley. A north-south line of piezometers, line I, was installed in early August 1946 along a fence line east of and parallel to the road and perpendicular to the open drain. A line 1400 feet long and parallel to the open drain, line II, was installed 500 feet north. The open drain was constructed during late autumn, 1946, and intercepted an 8-inch tile drain running north and south approximately 1250 feet east of the road. This tile line extends under the Deseret high canal to provide drainage for land north of the canal.

There was considerable difficulty in maintaining the piezometers at this site because of land-clearing and leveling operations. All damaged piezometers were replaced during the early summer of 1947 and all others were then flushed and cleaned. During the summer of

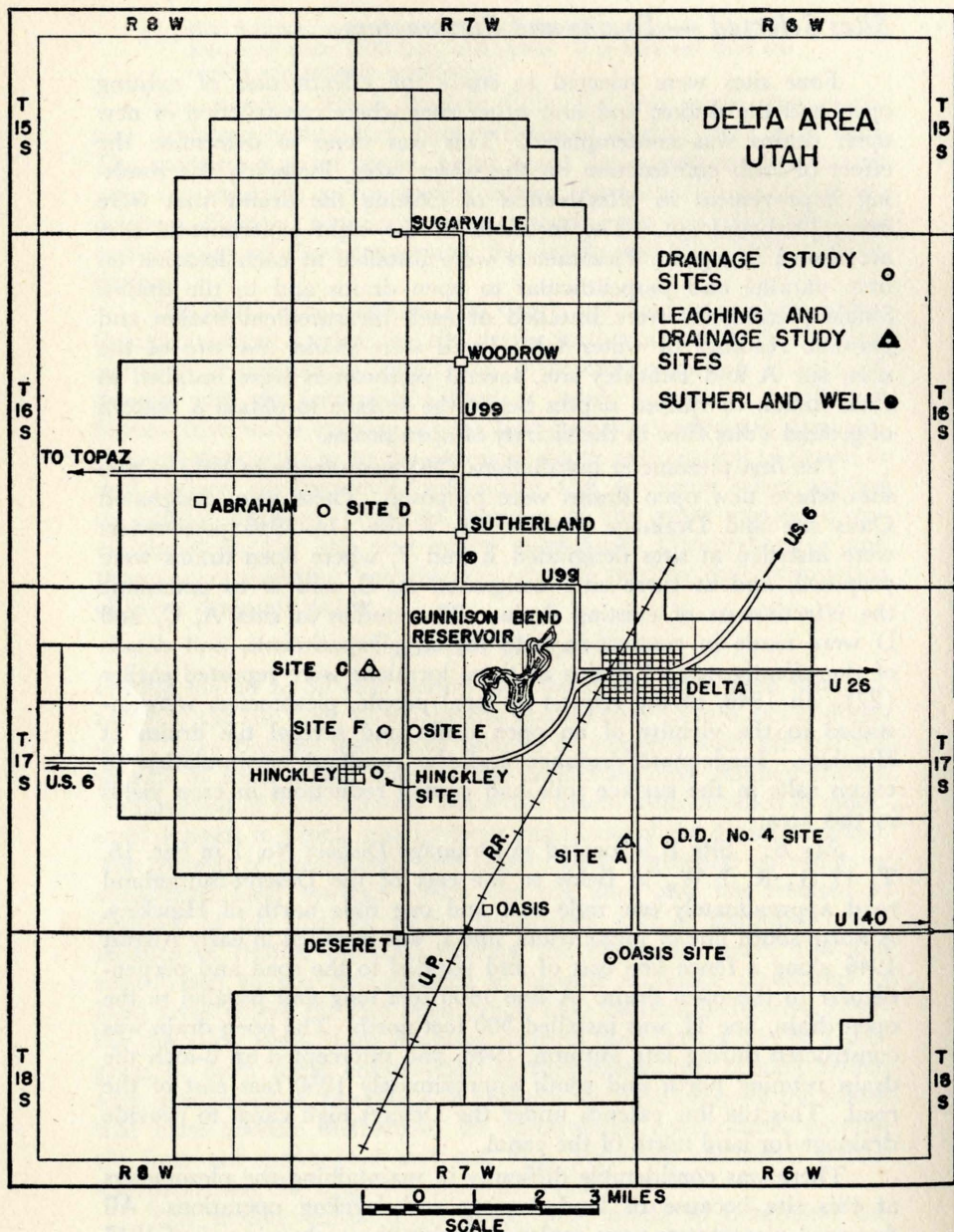


Fig. 1. Map of Delta Area, showing the locations of drainage study and experimental leaching study sites and the Sutherland experimental well.

1947, however, the piezometers south of the drain were again destroyed and were not replaced. Piezometer records are reasonably complete. There has been no irrigation at this site since the installation, except perhaps a late season irrigation in 1947.

Drainage District No. 4 Site: The Drainage District No. 4 site is located in the SW $\frac{1}{4}$ of Sec. 30, T. 17 S., R. 6 W. During July 1945, piezometers were installed in two intersecting lines as shown in fig. 2. Line I is perpendicular to the new open drain and line II is parallel to, and 338 feet from, the open drain. A tile drain lying adjacent and parallel to the south of line I of piezometers is intercepted by the open drain which was constructed during August 1945. In 1946, however, so many of the piezometers had been bent by tillage machinery that only infrequent observations were made. In June 1947, the piezometers were completely reinstalled and many observations were made in 1947.

The field to the south of the open drain in 1945 was planted to grain and alfalfa, while that to the north was idle brush land. During the summer of 1946, the northerly field was plowed and placed under irrigation.

Hinckley Site: The Hinckley site is located in the NW $\frac{1}{4}$ of Sec. 20, T. 17 S., R. 7 W. east of Hinckley. Two of the lines of piezometers extended into an area of vegetable gardens and small plots of alfalfa. Part of the land in this area had been levelled and diked but produced only weeds during the period readings were taken.

Piezometers were installed in two lines which formed a cross. The north part of the north-south line terminated at a 6-inch tile drain while the south part intersected a 10-inch tile drain which ran northeast. The east-west piezometer line intersected this same northeast tile drain in addition to intersecting an open drain toward the east which paralleled the tile drain. Six batteries of four piezometers each, with piezometer lengths of 7, 10 $\frac{1}{2}$, 14, and 21 feet, were placed on the east end of the east-west line. Single piezometers of lengths ranging from 7 to 10 $\frac{1}{2}$ feet were installed at the remainder of the stations.

A minimum of time was required to maintain most of the piezometers but the water levels in two of them lagged behind water level changes in the soil indicating that these piezometers were partially plugged at the bottom. The water table receded below the bottoms of two 7-foot piezometers for a period of several weeks during which time water levels at these two stations could not be measured. Longer piezometers would have prevented this occurrence. Other than this, no difficulties were encountered in maintaining the piezometers.

Oasis Site: The Oasis site is located at the Andrew Jensen farm in the SW $\frac{1}{4}$ Sec. 1, T. 18 S., R. 7 W. Three lines of piezometers shown in fig. 2 were installed in July 1945. Line I is perpendicular to, and line II is parallel to, the open drain which was constructed in August 1945. The third line, designated the "A" line, was installed perpendicular to a tile drain which was intercepted by the open drain.

Most of these piezometers have functioned well since their installation. They were flushed and checked during June 1947, at which time it was necessary to replace only three of them. Comprehensive records of piezometer readings were made, especially during the summer months. The field north of the open drain was planted to alfalfa, the field on the south was uncultivated and growing only greasewood.

Site D: Experimental plots were located two miles east of Abraham on the Morgan May farm. They comprised about one acre of land mapped as Gordon clay (31), located 102 feet south of a deep open drain in the NW $\frac{1}{4}$ SE $\frac{1}{4}$, Sec. 30, T. 16 S., R. 7 W. (fig. 3). The land at this site had been idle for some time; however, cultivation had been more recent at this location than at sites A and C. The water table was about 7 $\frac{1}{2}$ feet below ground surface prior to leaching.

Site A: Experimental plots were located three miles south of Delta on the Owen Gardner farm, formerly known as the Stapley farm. They comprised approximately one acre of land in a highly salted area mapped as Woodrow clay loam (30), and located 200 feet north of the center line of the open drain in the SE $\frac{1}{4}$ NE $\frac{1}{4}$, Sec. 25, T. 17 S., R. 7 W. (fig. 3). The field in which the plots were located had been idle for many years and was highly saline in the surface layers owing to the existence of a shallow water table which was 4 $\frac{1}{2}$ feet below ground surface in 1946. A white crust and salt puffs characteristic of a highly saline soil appeared on the surface.

Site C: Experimental plots were located two miles north of Hinckley on the Grant C. Robinson farm, formerly known as the Sawyer place. They comprised approximately one acre of land mapped as Oasis silty clay loam (30), located 358 feet south of a deep open drain in the SE $\frac{1}{4}$ NW $\frac{1}{4}$, Sec. 8, T. 17 S., R. 7 W. This land was cultivated at one time but had been out of production for several years. A white salt crust was evident and the water table was at a depth of about 5 $\frac{1}{2}$ feet below the surface in 1946.

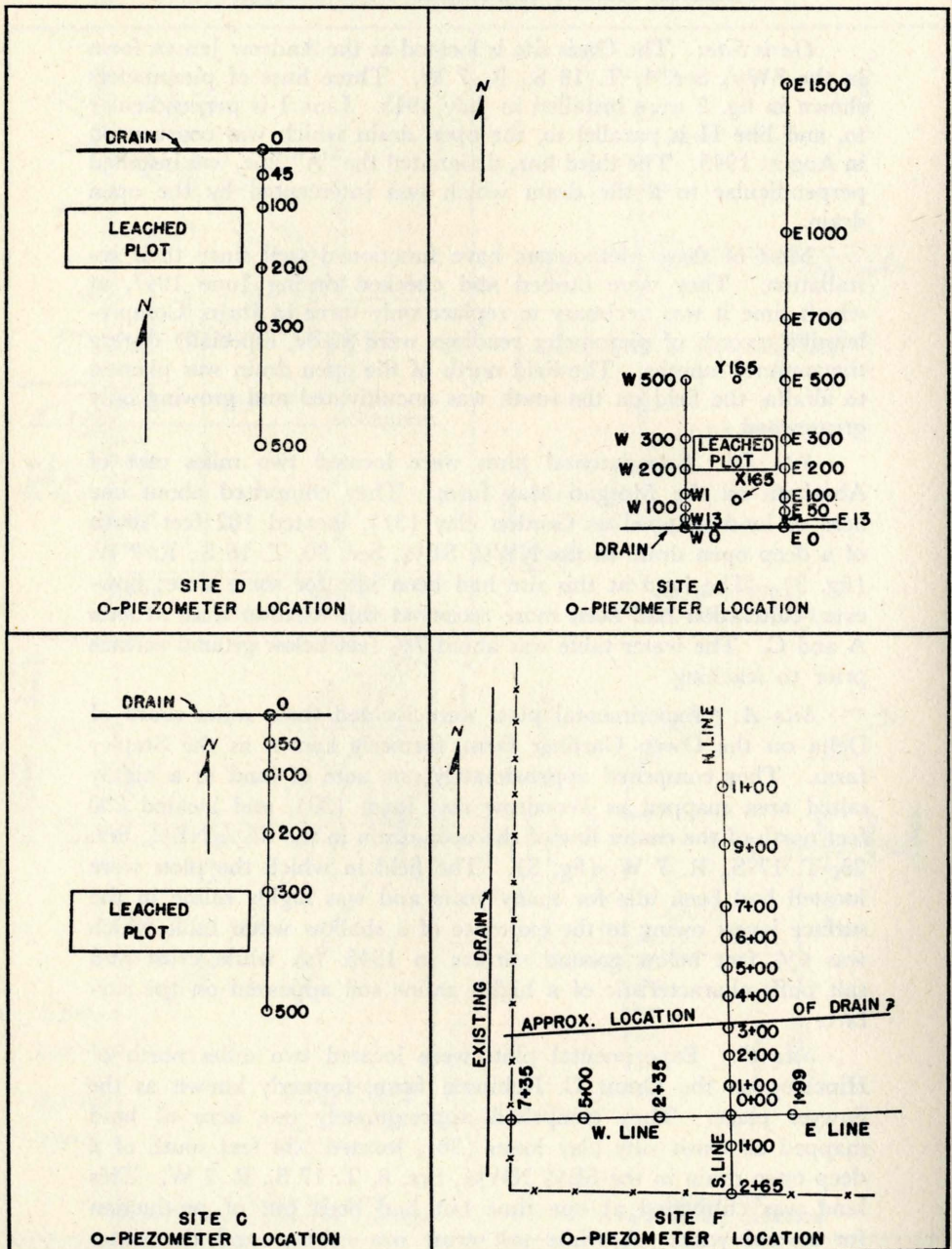


Fig. 3. Locations of piezometers for ground-water and drainage studies at the four experimental sites: D, A, C, and F

Site F: Site F is located in Drainage District 1 in the SW $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 17, T. 17 S., R. 7 W., as shown in fig. 3. During August 1946, prior to construction of an open drain into the area, piezometers were installed in the form of a cross to obtain ground water level observations parallel and perpendicular to the proposed open drain. The new open drain was constructed during the late autumn, 1946. This site is in an area in which there are excessive accumulations of salt in the surface soil. The area south of the drain is barren, dark-colored, wet, and deliquescent in appearance, although at the time of installation of the piezometers and construction of the open drain the water table was more than five feet below the ground surface. Most of the area had been previously cropped, but at this time a large part of it was idle. Consequently there was little irrigation in the immediate vicinity. A crop of grain was being grown adjacent to and north and east of the piezometer and drain installations. The records for the line perpendicular to the drain are relatively good. Some of the piezometers in the line parallel to the drain were destroyed, however, so that these records are not complete.

Results of Studies

By comparing the position and slopes of the water table prior to and following construction of drains, information on the effectiveness of the drains in removing the excess water was obtained. In general, two factors tend to add to the difficulty of evaluating the effectiveness of drains in the present study. These are:

1. Records prior to the installation of the open drains are generally quite short and therefore may not reflect other conditions strictly comparable to those after drainage.
2. In some instances, changes in the depths of water applied occur after drains are constructed. For instance, at sites E and F the water table was at relatively great depths for the Delta Area because of lack of irrigation in the immediate past. It is impossible to predict where the water table might have been if the lands had been cropped and the ordinary depths of irrigation water applied.

The analyses and comparisons include 5 major parts, namely:

1. Water table elevations on selected dates.
2. Minimum water-table elevations each season.
3. Lowering of the water table following irrigation.

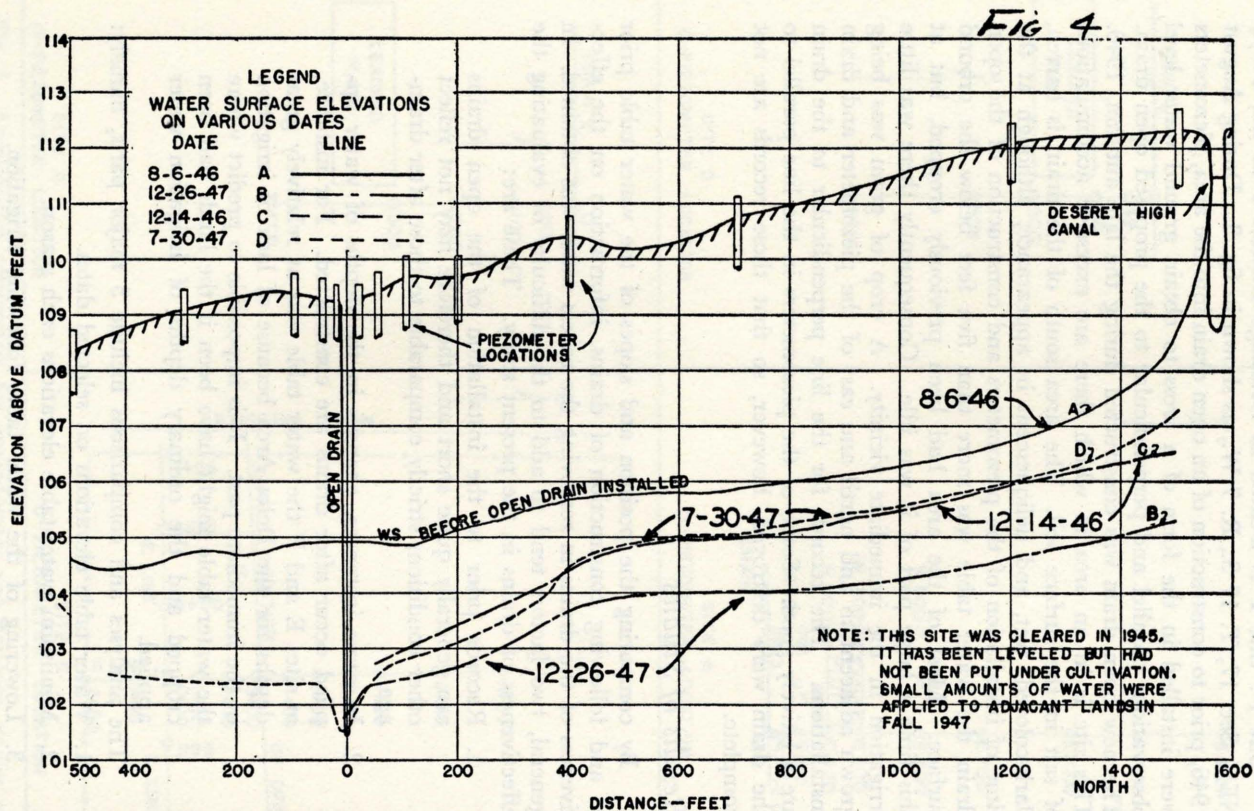


Fig. 4. Ground-water-surface profiles perpendicular to open drain (line 1) at site E

4. Time-averaged water-table elevations by seasons, and by distances from drains.
5. Flow-pattern studies.

Water Table Elevations on Selected Dates

Water table elevations are presented for 5 sites on selected dates.

The fields at site E were not irrigated after the piezometers were installed, except for some water application to small areas during the late fall of 1947. Water-table profiles perpendicular to the drain on representative summer and winter dates are shown in fig. 4. The water table profiles definitely show that the canal contributed to the ground water, and the open drain appeared to be effective in intercepting the flow. No estimate of the quantity of water contributed by the canal was made.

Ground water profiles on the line 500 feet north and parallel to the drain (not shown) indicate some contribution from the canal which is only 150 feet distant from the east stations of this line. The tile drains seem to have had little influence on the ground-water profile and probably were not functioning effectively. It is possible that the tile lines were flowing to capacity owing to drainage from the field to the north of the canal and from direct seepage from it.

Water table measurement at Drainage District 4 site indicated a definite lowering following construction of the drain at this site (data not shown), but the lowering is believed to have been entirely seasonal as far as the field to the south is concerned, since the hydraulic gradient was away from the drain. On September 28, 1945, the water was actually flowing out of the drain to the ground water.

The field to the north was probably benefited by the drain. The profiles showed a definite slope toward the drain. At the most distant station the water was approximately one foot higher than at the nearest station. Prior to construction, this difference does not seem so marked although the period of record is short.

A profile of the ground surface and the water table along the north-south piezometer line of the Hinckley site is shown in fig. 5. Water-table profiles are shown for the dates of July 24, 1948, September 30, 1948, and January 6, 1949. The two irrigation season profiles (7-24-48 and 9-30-48) slope toward both tile drains, indicating that both drains functioned to remove part of the ground water. The lower profile for 1-6-49, shows that the low water table was not affected by the 6-inch tile drain on the north, even though the drain was more than 6 feet below the ground surface.

The profile gradient of water flowing from the north to the 10-inch tile drain (at Sta. S 1216) is appreciably steeper than the gradient of the water flowing from the drain to the south, showing that the drain was removing some of the ground water. The

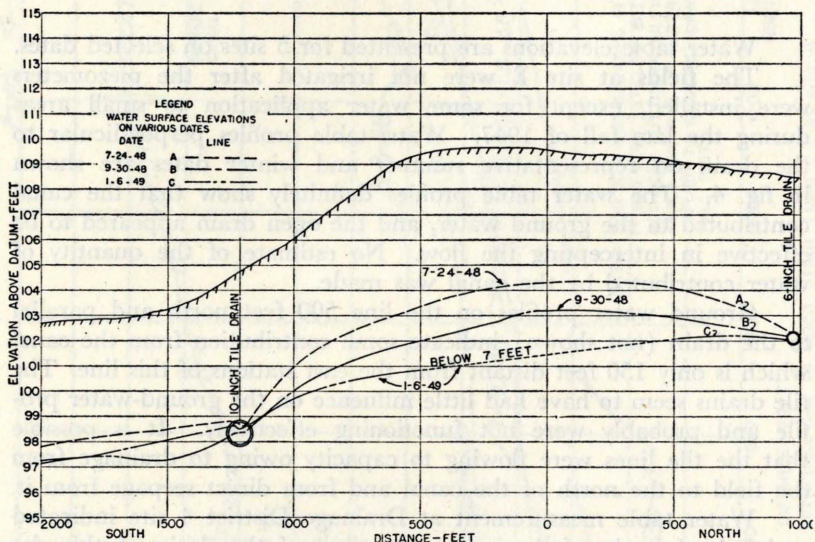


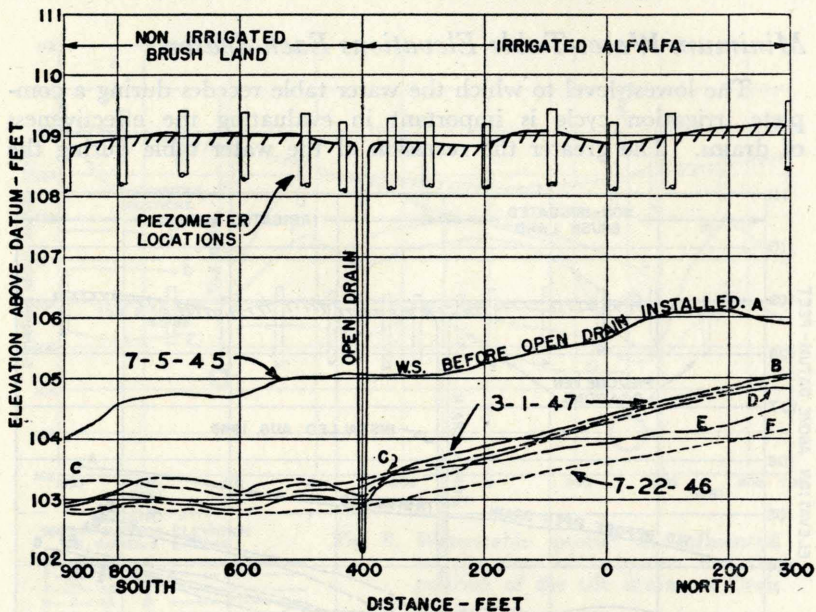
Fig. 5. Water-table elevations with reference to tile drains at Hinckley site

quantity removed is believed to be small, however, for a periodic inspection at a manhole next to the piezometer line revealed that the drain was largely filled with silt and the velocity of flow was low.

Water table elevations were compared at the Oasis site on dates chosen as near as possible to July 1 and March 15 of each year. July 1 was chosen because there did not appear to have been recent irrigation at that time in any year and therefore it represented a steady or stable condition. The March date was chosen because the water table was likely to be at its lowest annual elevation.

The water table profiles perpendicular to the drain, which was constructed during the first part of August 1945, presented in fig. 6, show that the water table was lowered approximately two feet by the construction of the open drain. The high water surface elevations (July of each year) after construction of the drain are not greatly different from the low water table elevations (March of each year) and neither of these have a high gradient toward the drain.

These facts indicate that the excess water, above the elevation of the bottom of the drain, is readily and efficiently removed by gravity flow at this location. The depth to ground water is about five feet after drainage, compared to three feet before drainage.



LEGEND

WATER SURFACE ELEVATIONS AT VARIOUS TIMES

| DATE | LINE |
|----------|-------------|
| 7-5-45 | A ————— |
| 3-22-46 | F - - - - - |
| 6-29-46 | D - - - - - |
| 3-1-47 | B - - - - - |
| 7-1-47 | C - - - - - |
| 12-27-47 | E - - - - - |

Fig. 6. Water-table profiles (Line I) perpendicular to open drain at Oasis site

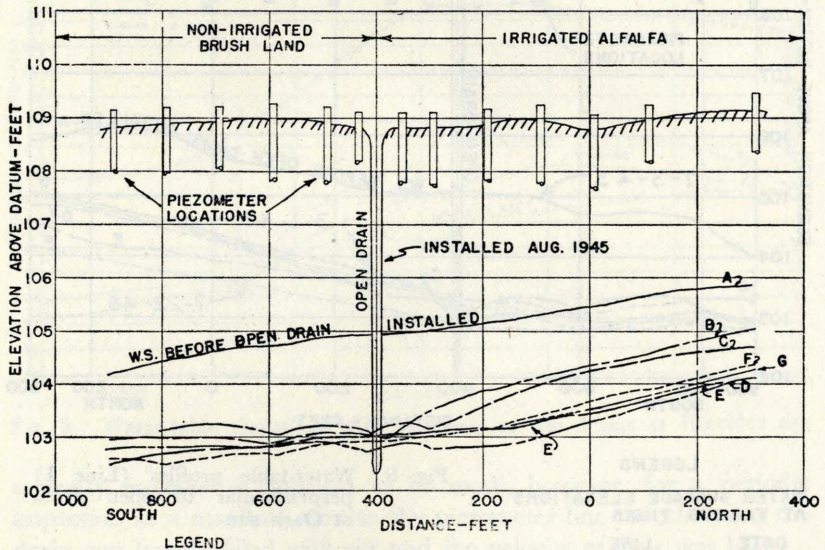
The water table profiles perpendicular to the tile lines (not shown) indicate that these lines do not greatly depress the water table in their vicinity. It is therefore likely that they do not have a marked effect on the position of the water table while the open drain functions. This is probably because of their shallow depth and the fact that the flow seems to take place readily through the soil if a difference in hydraulic head exists. However, they were effective in rapidly removing the excess water following an irrigation.

Observations taken both before and after the construction of the drain at site F indicated that it was not greatly effective in lowering

the water table at this site. These fields had been idle for some time, and there had been little irrigation in the immediate vicinity so that the water table was already lowered approximately to the elevation of the drain.

Minimum Water-Table Elevations Each Season

The lowest level to which the water table recedes during a complete irrigation cycle is important in evaluating the effectiveness of drains. The greater the recession of the water table during the



LEGEND

| | |
|-------------------------------------------|-----------|
| WATER SURFACE ELEVATIONS AT VARIOUS TIMES | LINE |
| TIME | |
| PRIOR TO DRAINAGE | A ——— |
| WINTER 1946-47 | B - - - - |
| SUMMER 1945 AFT. DRAINAGE | C ····· |
| SUMMER 1947 | D - · - · |
| WINTER 1947 | E - - - - |
| SUMMER 1946 | F - - - - |
| WINTER 1945-46 | G - · - · |

Fig. 7. Minimum summer and winter water-table elevations (Line I) perpendicular to the open drain at Oasis site

non-irrigation period the larger the ground water storage volume and hence the longer will be the time after irrigation begins each year before the water table may rise near enough to the surface to develop a drainage problem. Minimum water table elevations for summer (irrigation season) and winter (non-irrigation season) are presented in fig. 7 for the Oasis site. The water-table curves are obtained by plotting the lower water-table levels at each piezometer during each season. This is done in order to minimize irregularities in the water table caused by frequent local irrigation.

The results are similar to those obtained by comparing water tables at selected dates. The marked change in slope of the water table at the drain is evidence that the drain is intercepting ground water flow from the north. There was less than 1 foot difference in

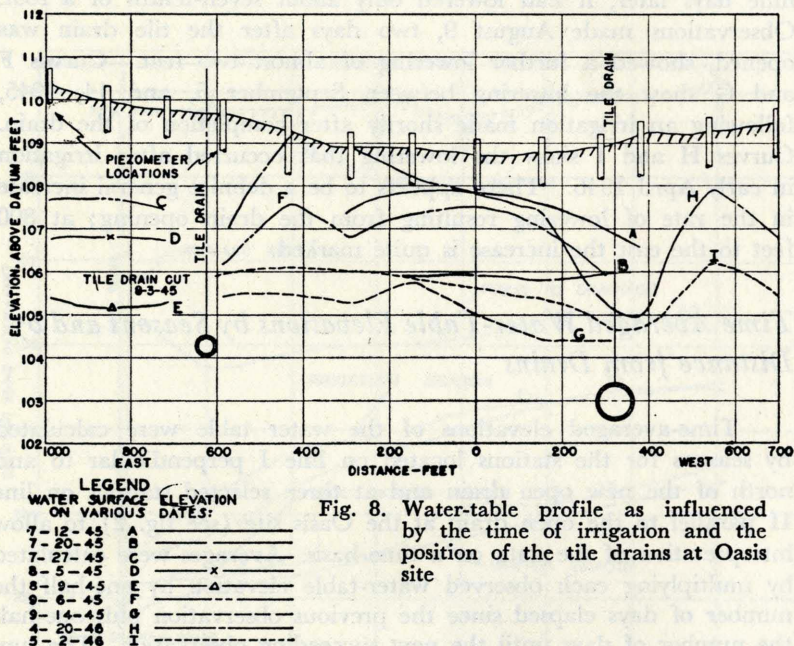


Fig. 8. Water-table profile as influenced by the time of irrigation and the position of the tile drains at Oasis site

minimum water tables in the summer as compared to the winter. This shows that the water table is lowered nearly as effectively during short intervals between irrigations in the summer as during the longer non-irrigation period in the winter.

Lowering of Water Table Following Irrigation

Studies were made of the time rate of lowering of the water table following irrigation at the Oasis site. Water table profiles perpendicular to tile drains at the Oasis site on several dates are shown by fig. 8. The line A (7-12-45) shows the position of the water table between 300 feet east and 375 feet west following an irrigation in the vicinity of the site. The line B (7-20-45), showing its position eight days later, indicates a lowering of two feet to a total depth of about three feet below ground surface. Both of

these curves represent conditions prior to construction of the open drain.

The elevation of the water table in the vicinity of 800 feet east on 7-27-45, following irrigation, is shown by curve C. On 8-5-45, nine days later, it had lowered only about seven-tenths of a foot. Observations made August 9, two days after the tile drain was opened, showed a further lowering of almost two feet. Curves F and G show the lowering between September 6, and 14, 1945, following an irrigation made shortly after completion of the drain. Curves H and I show the lowering that occurred after irrigation in early April 1946. There appears to be a definite general increase in the rate of lowering resulting from the drain opening; at 800 feet to the east the increase is quite marked.

Time Averaged Water-Table Elevations by Seasons and by Distance from Drains

Time-averaged elevations of the water table were calculated by seasons for the stations located on line I perpendicular to and north of the new open drain and at three selected stations on line II parallel to the open drain at the Oasis site (see fig. 2) to allow interpretation of the data on a time basis. Averages were calculated by multiplying each observed water-table elevation by one-half the number of days elapsed since the previous observation plus one-half the number of days until the next succeeding observation. The sum of these products was then divided by the total number of days. Time averaged water-table profiles by seasons perpendicular to the open drain (line I) are shown in fig. 9. Curve A shows the average elevation for the one-month period prior to construction of the drain, and curve F, the average for the two months following construction. Curves B, D, and C show the average water table for the seasons as follows: (B) winter 1945-46, (D) summer 1947, and (C) early winter 1947-48. In general the average seasonal water table was from one to two and one-half feet lower after construction of the open drain. The average prior to the construction of the drain is based on only five observations made during July and August 1945. The water table during July would probably be lower than during May and June. This was indicated by a comparison of observations made in May, June, and July, 1946. Therefore the time averaged water table for the season prior to construction of the open drain would probably be somewhat higher than shown by curve A, fig. 9.

Only one set of data covering a complete growing season is available; this is for the summer of 1946, from April 20 to October 1. These data, shown by curve F, fig. 9, are of particular interest in relation to the effect of distance from the drain on the average water-table elevation during the growing season.

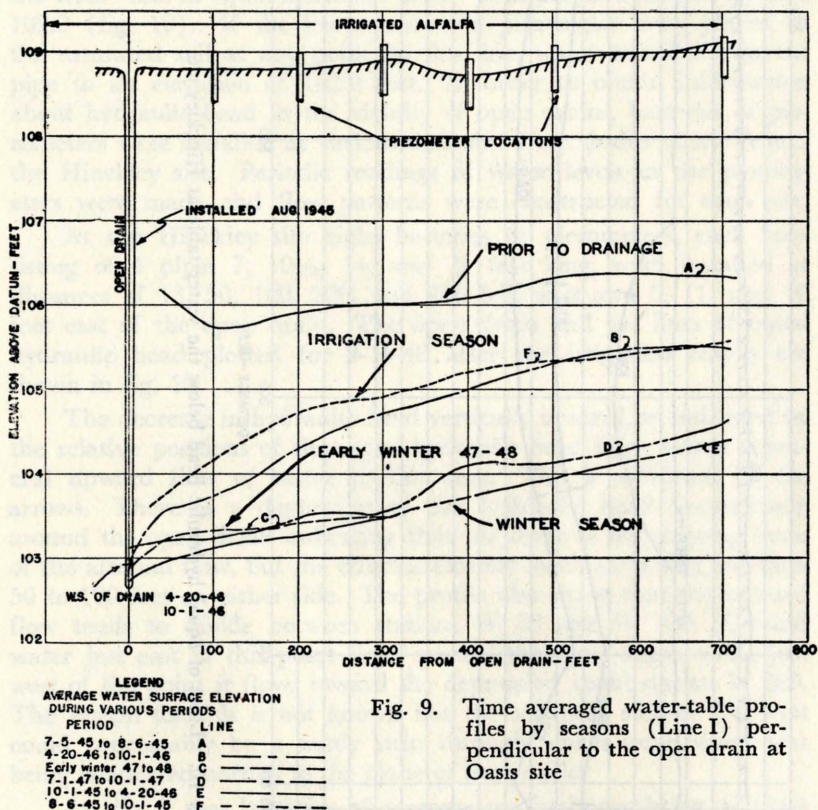


Fig. 9. Time averaged water-table profiles by seasons (Line I) perpendicular to the open drain at Oasis site

During the irrigation season, the average water-table profile increases in slope as the drain is approached; while during the winter months, when water application to the field becomes small or zero, the slope of the water table becomes uniform (see curve October 1, 1945, to April 20, 1946, fig. 9). The ground-water surface slope at the Oasis site is approximately 2.4 feet per 1,000 feet during the latter period.

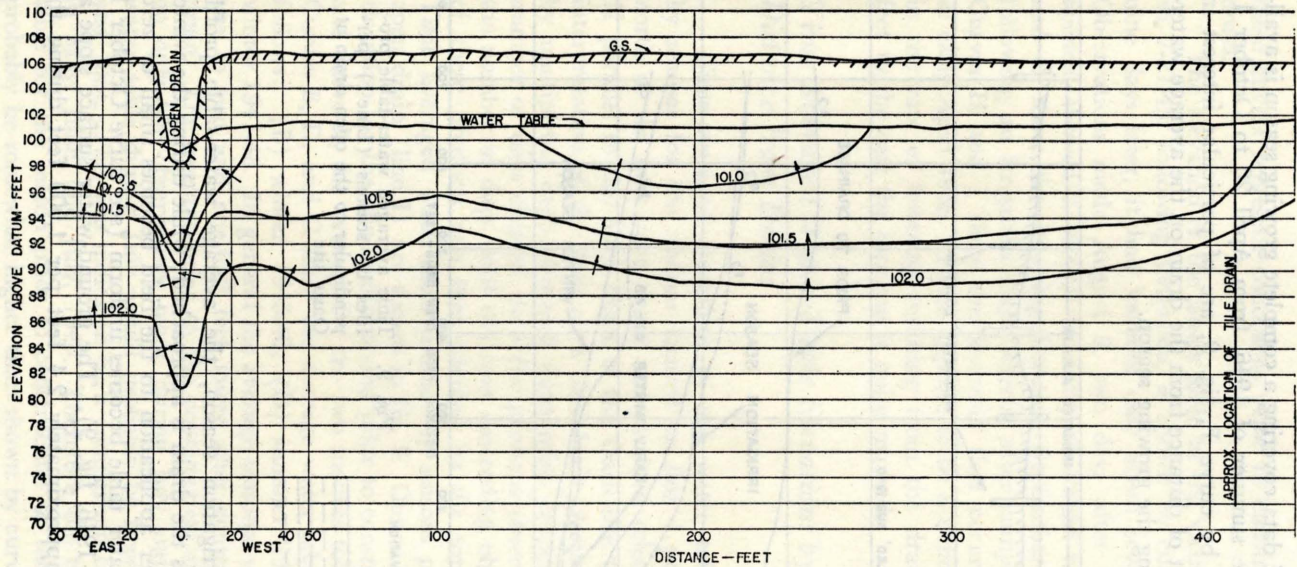


Fig. 10. Lines of equal hydraulic head below the water table at Hinckley site

Flow Pattern Studies

The hydraulic head, (pressure head plus position head) with reference to a selected datum plane, is represented by the elevation to which water will rise in a piezometer with its lower end opening at any desired point in the soil. As an example of the meaning of the term "line of equal hydraulic head"² consider the solid line marked 102.0 (fig. 10). If the lower end of a piezometer were placed in the saturated soil at any point on this line, water would rise in the pipe to an elevation of 102.0 feet. In order to obtain information about hydraulic head in the vicinity of open drains, batteries of piezometers were installed at various distances from drains at site A and the Hinckley site. Periodic readings of water levels in the piezometers were made and flow patterns were constructed for each site.

At the Hinckley site eight batteries of piezometers, each consisting of 4 pipes 7, 10½, 14, and 21 feet long, were installed at distances of 13, 50, 100, 200, and 400 feet west and 0, 11, and 40 feet east of the open drain. The open drain and the lines of equal hydraulic head plotted for 9-16-48 after the irrigation season are shown in fig. 10.

The decrease in hydraulic head vertically upward, as indicated by the relative positions of the equal hydraulic head lines, shows a general upward flow of water in this area. This is indicated by the arrows. There is a depression of the hydraulic head immediately around the open drain indicating that the drain is intercepting some of the artesian flow, but the effect is entirely local, extending less than 50 to 100 feet on either side. The profile also shows that the upward flow tends to divide between stations W 50 and W 100. Ground water just east of this point flows toward the open drain, while just west of the point it flows toward the depression about station W 200. The reason for this is not known but the soil near station 200 west could conceivably be a sandy strip through which some water was being conducted normal to the plane of the profile.

At site A two batteries of piezometers, each consisting of pipes 10½, 14, 21, and 28 feet long were installed; one battery in the drain and the other 100 feet north. In addition piezometers 10½ feet long were installed at greater distances from the open drain (up to 1500 feet) on a line perpendicular to the open drain. The flow patterns in the vicinity of the open drain at this site before and after irrigation are shown in fig. 11. Lines of equal hydraulic head are

² The term "equipotential lines" is used by some authors to denote lines of equal hydraulic head.

plotted by connecting points of equal hydraulic head, and the directions of flow in the plane of the profile are indicated by the arrows.

Equal hydraulic head lines of May 30, 1946, prior to irrigation, are shown by a solid line; those, after a local irrigation, which was

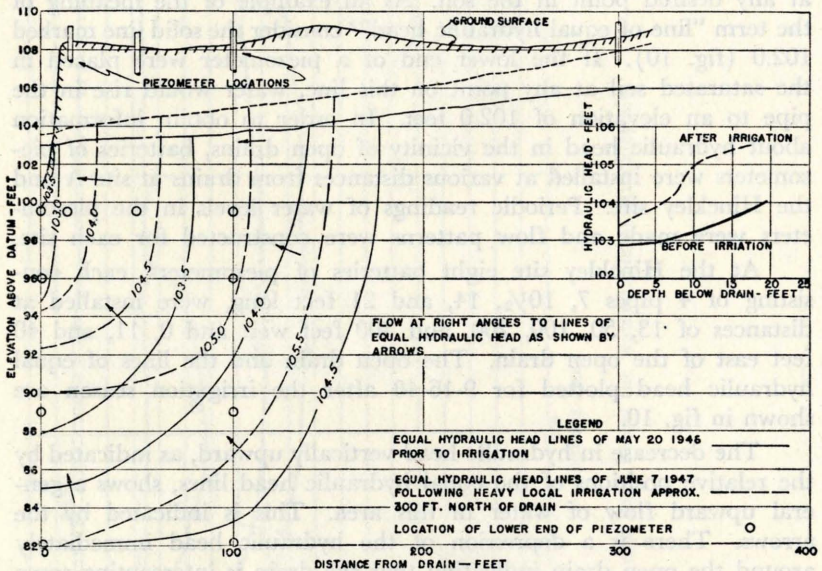


Fig. 11. Flow pattern showing lines of equal hydraulic head and direction of ground-water flow near an open drain before and after irrigation at site A

applied approximately 300 feet north, are shown by a broken line. This irrigation water was applied in connection with leaching studies (27) in which an average depth of 2.2 feet of water was applied to an area of approximately one acre in a period of slightly over two weeks. This irrigation of 2.2 acre-feet per acre increased the hydraulic head at depths of 10 to 20 feet below the drain by nearly two feet, as indicated in the graph in the upper right corner of fig. 11, which shows the variation of hydraulic head with depth below the bottom of the open drain. The direction of maximum velocity of flow of ground water in soils of uniform texture and structure is always along lines of the maximum decrease in hydraulic head, or maximum hydraulic slope. In other words, the direction of flow is at right angles to the lines of equal hydraulic head as shown by the arrows in fig. 11. The figure shows that as a result of local irrigation the hydraulic gradient

in the soil around the drain increased. As the velocity of flow is directly proportional to the hydraulic gradient, according to Darcy's law, the quantity of water flowing into the drain also increased in the same proportion.

Considering the flow vertically upward beneath the drain the average hydraulic gradient, over the depth for which measurements were made, increased from about 50 to 120 feet per 1000. The quantity of flow vertically upward into the drain was therefore increased in the same proportion or about doubled as a result of the irrigation.

CONCLUSIONS CONCERNING GRAVITY DRAINS

Water Table Lowering

Open drains were generally effective in lowering the water tables at the sites studied. The degree of effectiveness varied, however, from good at the Oasis site to poor at the Hinckley site. Studies at the Hinckley site definitely indicate that the effectiveness of gravity drains may be seriously impaired in localities having unfavorable subsoil conditions combined with upward ground-water flow from an artesian aquifer. Conditions similar to those at the Hinckley site are common to many other localities in the Great Basin area.

Effectiveness of Cutting Tile Lines with Open Drains

Providing additional outlets for the tile drains, by cutting through them with deeper open drains, did not seem to affect the ultimate position of the water table. These cuts undoubtedly increased the effectiveness of the tile drains, but most of these drains examined were clogged with silt, and their effectiveness, even after cutting, was low, except at the Oasis site where they were effective in rapidly removing the excess water following an irrigation.

Non-Irrigated Sites

Prior to drain construction, water-table elevations at non-irrigated sites were appreciably lower than those at irrigated sites. The rate of ground-water removal decreases as the height of the water table above the bottom of the drain decreases. It follows that the effectiveness of gravity drains will be lower for non-irrigated sites than for irrigated sites if effectiveness is measured by the lowering of the water table.

Short-Time Record Limitations

The short-time records now available do not permit evaluation of long-time factors such as the effect of hydrologic cycles and changes in irrigation practices.

Long-Time Records Needed

Water-table elevations should be correlated with (1) drain discharge, (2) changes in salinity of soils and in productivity of adjacent fields, and (3) irrigation applications to adjacent fields, over a period of many years in order to obtain reliable information about desirable depth and spacing of drains, effectiveness in removing salt, and economic benefits realized.

Water Table Above Drain — Seasonal Formula

At the Oasis site, during the irrigation season from April to October, the average height of the water table above the water surface in the drain can be represented as an exponential function of the distance from the drain. During the winter season, the average water surface profile at this site approaches a straight line having a slope of 2.4 feet per thousand feet away from the drain.

Upward Ground-Water Flow

Piezometric observations at several locations indicate increasing hydraulic head with depth. This increase is accentuated by the application of irrigation water to adjacent areas. Patterns of the lines of equal hydraulic head in the flow cross-section indicate that drainage involves vertical upward flow from depths of 25 feet, or more, below the ground surface in the vicinity of the drain.

Canal Contributions to Ground Water

Ground-water profiles for site E show that the Deseret Highline Canal contributes to the ground water in this area.

GEOLOGY OF THE DELTA AREA

IMMEDIATELY northeast of the Delta Area is a relatively level upland known as the Lynn Bench. This bench is essentially the delta of the Sevier River as it entered Lake Bonneville through Leamington Canyon during the Provo stage. The texture of the

Lynn Bench sediments is generally coarser than those in the valley bottom and consists principally of pebbles and sand interspersed with strata of clay and silt. Lake Bonneville contributed a major influence on the topography and the nature of the sediments in the Delta Area. During the Bonneville stage the valley bottom near Delta was covered with approximately 600 feet of water which receded to a depth of about 225 feet during the later Provo stage. The sediments in the area are no doubt derived almost wholly from the Sevier River and are probably many hundreds of feet deep. It is to be expected that the coarser sediments would occur near Leamington and that they would be progressively finer as the distance from Leamington Canyon increases. Mienzer (22) reports logs from 5 wells at increasing distances from Leamington Canyon which illustrate this condition.

WELLS IN THE DELTA AREA

GROUND water is the only satisfactory source of domestic water supply in the Delta Area. Except for the Delta municipal supply, domestic water is obtained from small wells, usually under two inches in diameter, drilled with a wash rig. Most of these wells tap strata of sand at depths between 100 and 200 feet, although many are between 200 and 300 feet deep and a few somewhat deeper. Many of these wells flow under artesian pressure, and in others the water invariably rises to within a few feet of the surface. The strata penetrated by these wells consists of many alternating beds of clay and sand with no boulders and little gravel. The clay beds predominate and the artesian pressure in the sand layers increases with depth. Mienzer in 1911 reported several hundred small wells of the type above described and many more have since been drilled.

Water found at depths of 95 feet and down to 300 feet or more is generally soft and of good quality. Water from the deeper wells may show some increased mineralization and is often charged with hydrogen sulfide gas but is generally of good quality.

Water obtained from shallow wells is of poor quality, somewhat more saline than the Sevier River water. Water in these shallower strata is believed to be residual water from deep percolation of irrigation water. Chemical analyses of some Delta ground-water supplies are given in table 1. These analyses show that salinity decreases markedly with depth below ground surface.

Mienzer reports that nearly all of the successful wells are within 10 miles of the margin of the Lynn Bench and that this terrace forms the catchment for all flowing wells in the area.

Table 1. *Analyses of Delta Area well water*

| | Delta*† domestic water supply | Nicholson †‡ railroad | Lynndyl § railroad well | Jensen§ artesian well | |
|-----------------------------------------------------------------|-------------------------------------|--------------------------|-------------------------------|-----------------------------|------|
| Depth below gr. surface ft. | 700 & 776 | 23 | 235 | | |
| Dissolved solids | ppm | 125 | 5475 | 559 | 581 |
| Percent sodium | | 58 | 61 | | |
| pH | | | 7.41 | | |
| Silica (SiO ₂) | ppm | 25 | 51.2 | 93 | 48 |
| Calcium (Ca) | m.e./1 | 0.78 | 7.54 | | |
| Magnesium (Mg) | m.e./1 | .81 | 16.55 | | |
| Sodium & potassium (Na+K) as sodium | m.e./1 | 2.18 | 38.35 | | 9.44 |
| Carbonate & bicarbonate (CO ₃ +HCO ₃) | m.e./1 | 2.50 | 7.30 | | |
| Sulfate (SO ₄) | m.e./1 | .58 | 16.07 | | 0.58 |
| Chloride (Cl) | m.e./1 | 1.13 | 39.20 | | 1.18 |
| Fluoride (F) | m.e./1 | .02 | .04 | | |
| Nitrate (NO ₃) | m.e./1 | trace | .12 | | |

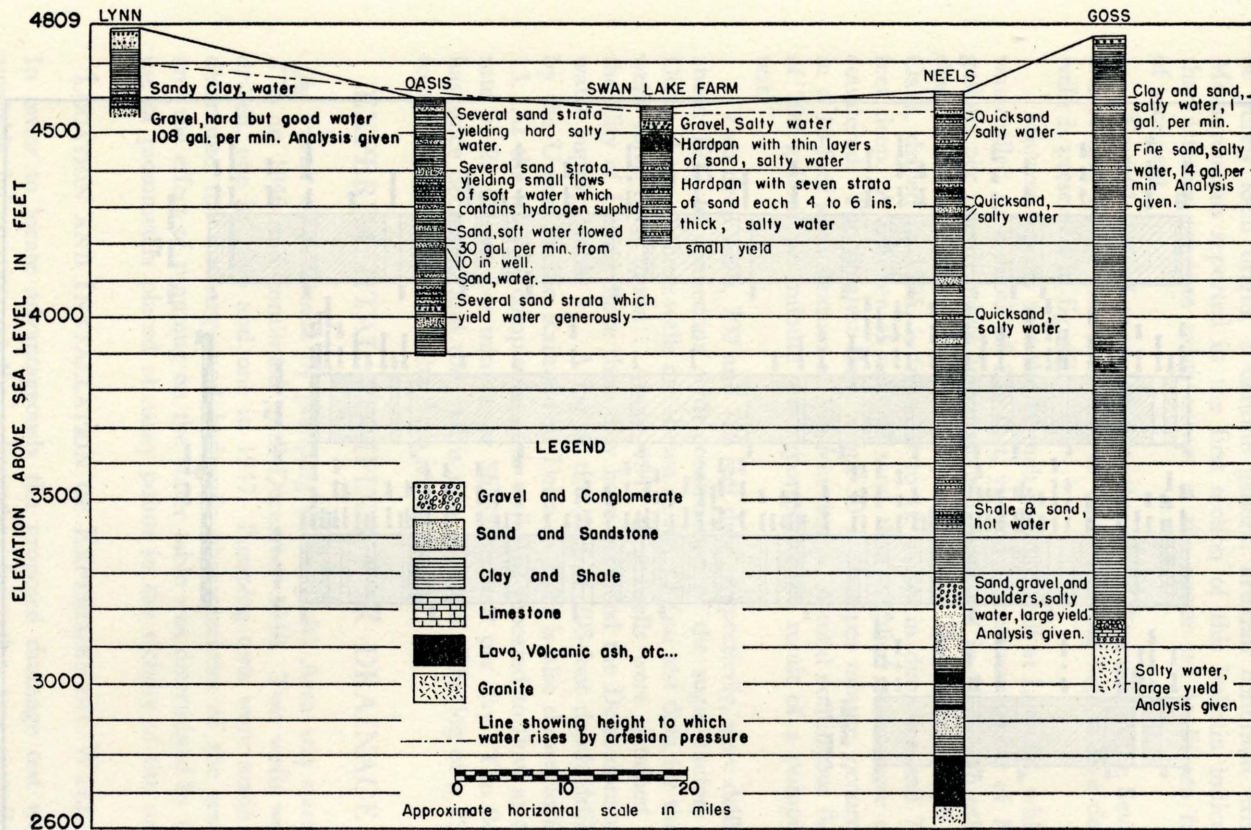
* Sugar factory wells No. 1 and 2.

† Analyses courtesy Utah Division of Public Health Engineering, converted from ppm to m.e./1.

‡ Location Sec. 11, T. 18 S., R. 8 W., Salt Lake B and M.

§ Deseret, Utah.

There is considerable evidence to support the conclusion that ground water in the top 50 to 100 feet of overburden occurs because of irrigation development in the area. This water is strongly saline, more so than the water used for irrigation. During the period 1900 to 1910, when the extensive irrigation development occurred, many cisterns from thirty to fifty feet deep were dug without encountering ground water. With the development of irrigation the water table rapidly rose until by about 1918 much of the area was completely waterlogged. Even though the water in these upper strata is evidently



WELL SECTIONS IN SEVIER DESERT AND LOWER BEAVER VALLEY

Fig. 12. Logs of wells in Sevier Desert and lower Beaver Valley (Courtesy U.S. Geol. Survey)

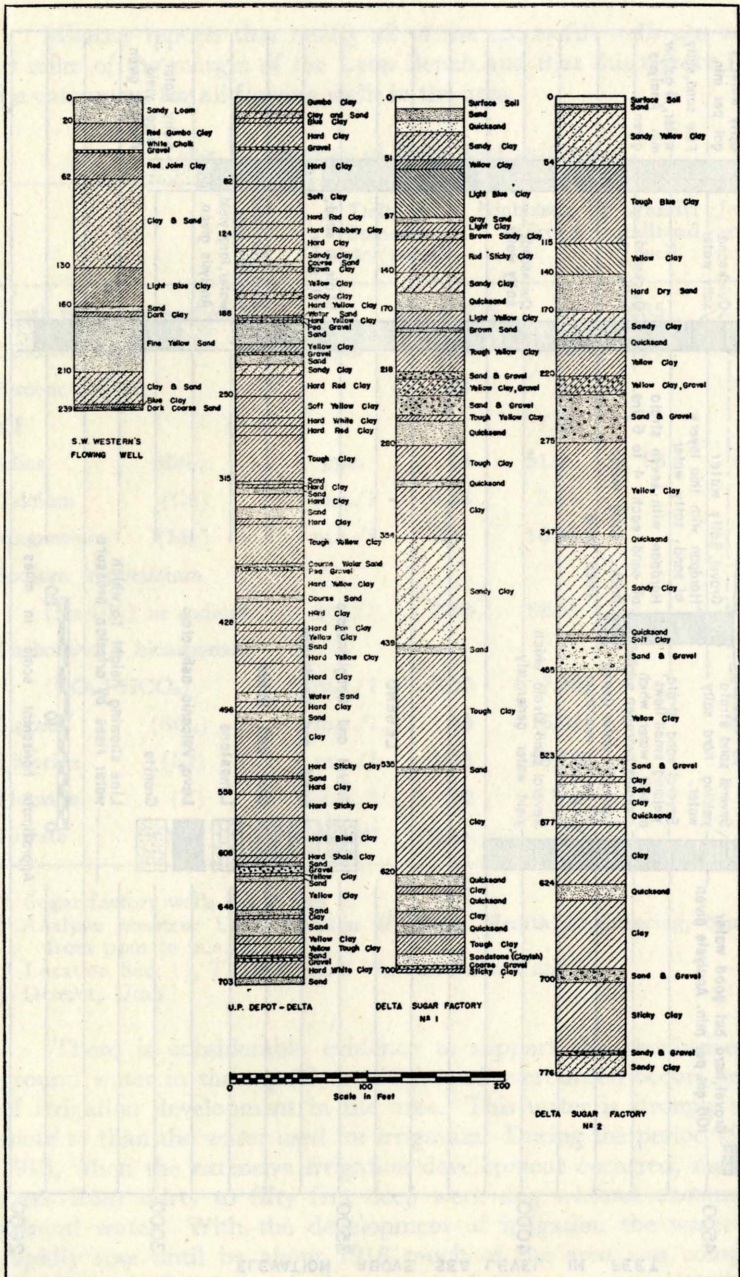


Fig. 13. Logs of a well nearly 250 feet deep and of 3 wells more than 700 feet deep—all near Delta, Utah (Courtesy U.S. Geol. Survey)

of purely local origin, a definite general artesian condition exists. Measurements reported in the first section of this bulletin indicate that artesian pressure exists except in the upper ten to fifteen feet of sediment.

A profile from Lynndyl in a southwesterly direction in the Sevier Desert and Lower Beaver Valley to Goss, showing logs of five deep wells is presented in fig. 12.

Mienzer reports that the 12-inch railroad well at Lynndyl, which was drilled to a depth of 235 feet, yielded a continuous flow of 108 gallons per minute when tested upon completion in 1905. No other deep wells have been drilled on Lynn Bench. The railroad well at Oasis, drilled in 1905, is from 10 to 12 inches in diameter and 710 feet deep. A number of beds of sand that supplied water were encountered. The greatest flow, about 30 gallons per minute, occurred in a 15-foot sand stratum at 335 feet depth. A total continuous flow of 200 gallons per minute was reported as the result of a pumping test.

Two deep wells, 700 and 776 feet deep, respectively, were drilled about 1917 in connection with construction of the sugar factory at Delta. Logs of these wells are shown in fig. 13 (no test data for these wells have been found). About 1941 these wells were obtained by the City of Delta. Since then they have provided the Delta domestic water supply (table 1). A log of the well of 703-foot depth drilled by the Union Pacific Railroad at Delta in 1923 is also shown in fig. 13. At the time of completion, this well was reported to flow at the rate of 25 gallons per minute, or 36,000 gallons per day. The flow has since decreased and the well is now pumped. The log of a 239-foot flowing well in the Delta Area is also shown.

EXPERIMENTAL PUMPING FOR DRAINAGE

A STUDY OF DRAINAGE by pumping in the Delta Area was started in 1946 and continued until December 1948. Two wells were drilled, one in 1946 and one in 1947. Pumping tests were made to determine the discharge and hydraulic characteristics of the wells, and the effect of pumping on the water table was determined by the use of piezometers placed at many points in the vicinity of the well.

LOCATION AND INSTALLATION OF EXPERIMENTAL WELLS

In order to locate advantageously the proposed drainage test well, available information on the sedimentary formation was compiled.

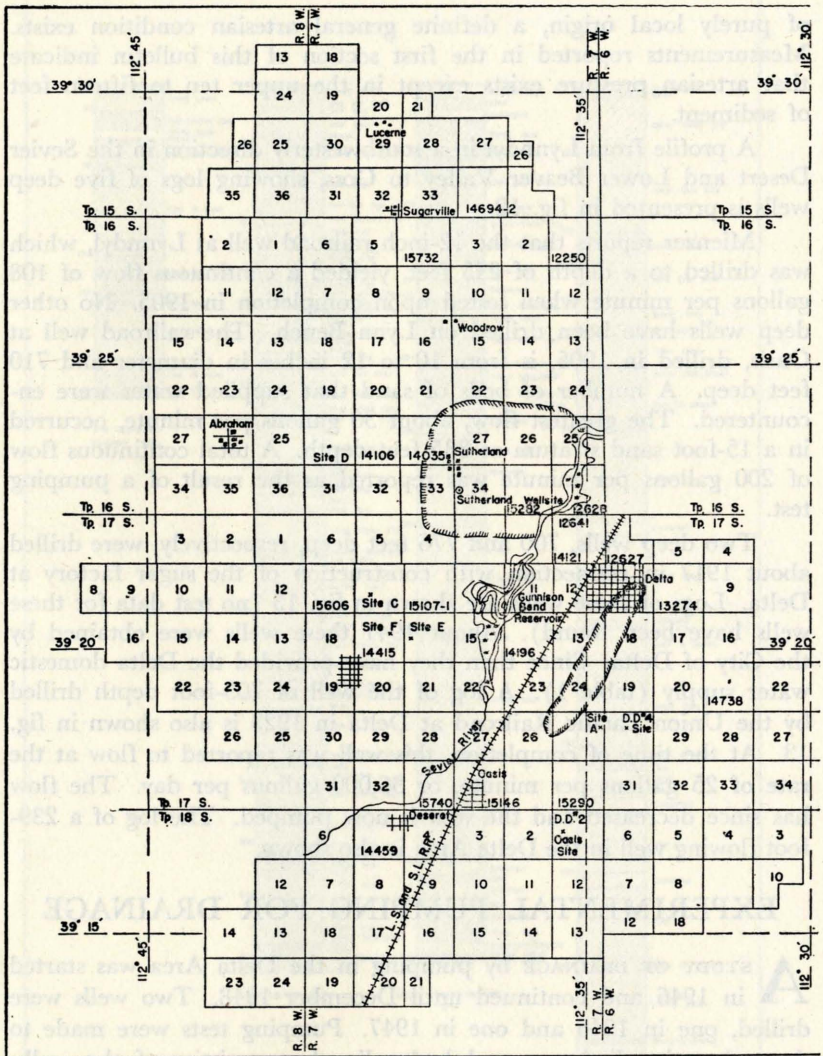
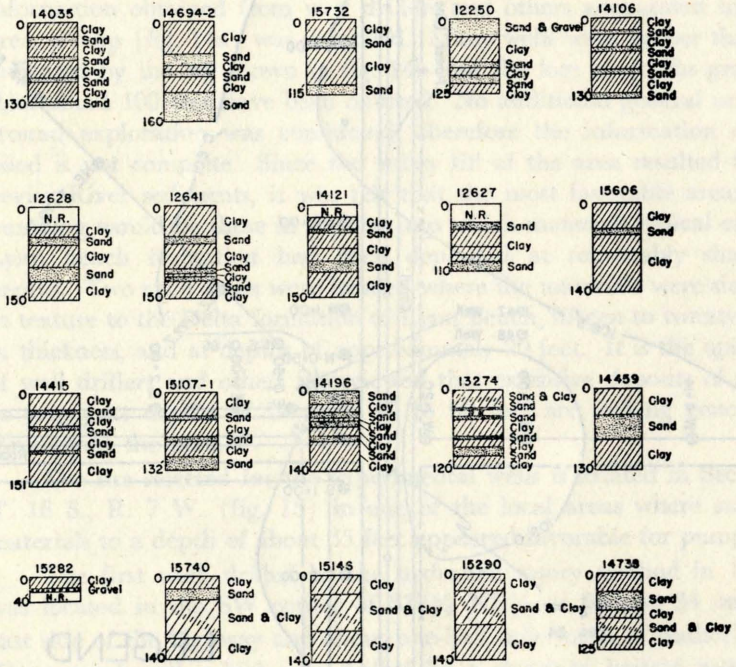


Fig. 14a. Locations of 20 shallow wells in the Delta Area



NOTE: WELL LOCATIONS ARE WITHIN THE INDICATED SECTIONS INFORMATION FROM WELL LOGS RECORDED IN STATE ENGINEER'S OFFICE.

AREAS WHERE CONDITIONS FAVORABLE TO DRAINAGE BY SHALLOW WELLS ARE INDICATED BOUNDARY APPROXIMATE ONLY



Fig. 14b. Logs of 20 shallow wells in the Delta Area

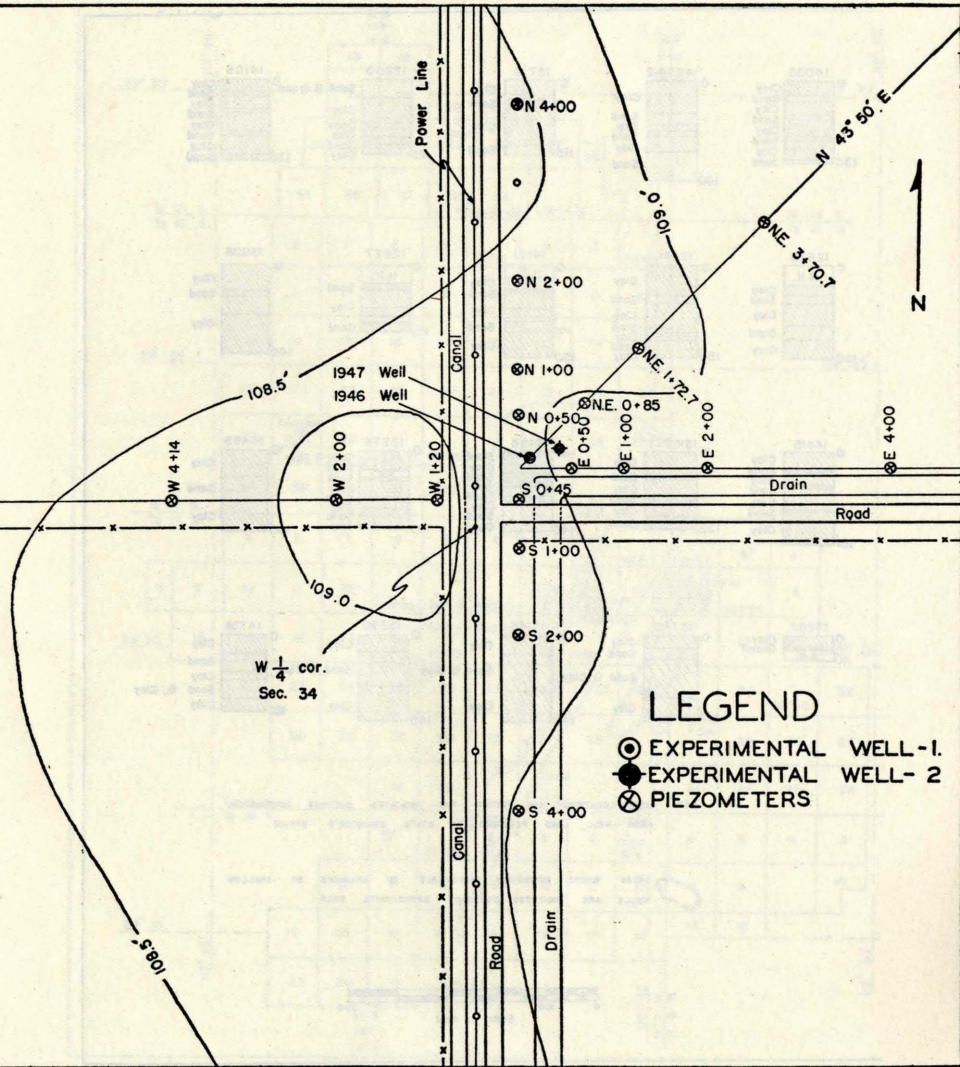


Fig 15. The locations of two drainage experimental wells and of piezometers for ground water hydraulic head and flow studies

Utah well drillers since 1935 have been required to furnish well logs to the state engineer. On the basis of a study of these well logs, and information obtained from well drillers and others acquainted in the area, a map (fig. 14a) was compiled. Many wells were deeper than is indicated by the log shown in fig. 14b and the logs of depths greater than about 100 feet have been omitted. No additional general underground exploration was conducted; therefore the information compiled is not complete. Since the valley fill of the area resulted from Sevier River sediments, it was felt that the most favorable areas for pumping would be those in the flat into which materials typical of the Lynn bench formation had been deposited at reasonably shallow depths. Two such areas were located where the materials were similar in texture to the Delta formation of Lynn Bench, fifteen to twenty feet in thickness, and at depths of approximately 20 feet. It is the opinion of well drillers and others interviewed that extensive deposits of sand or gravel at depths of between 40 to 90 feet are lacking generally throughout the area.

The site selected for the experimental wells is located in Sec. 34, T. 16 S., R. 7 W. (fig. 15) in one of the local areas where subsoil materials to a depth of about 35 feet appeared favorable for pumping.

The first well, drilled by the hydraulic rotary method in 1946, was located in the SW corner of SW $\frac{1}{4}$ NE $\frac{1}{4}$ of Section 34 on the east side of the highway and about one-half mile south of Sutherland. The second well, which was drilled by a standard bailing method, was approximately 50 feet east of the first well (fig. 15).

Methods of installation of piezometers have been described in recent publications (5, 26) and are not repeated here.

Well 1, drilled in 1946, consisted of a 16-inch diameter casing placed in a 25-inch diameter hydraulic rotary drilled hole to a depth of 35 feet. A gravel pack was placed in the annular space around the outside of the casing.

Well 2, drilled by a standard bailing method in 1947, consisted of a 12-inch diameter casing to a depth of 39 feet, within a 26-inch diameter casing which extended to the top of the water-bearing gravel, a depth of 15 feet. The details of this well, including perforations, gravel pack, and the stratum profile, are shown in fig. 16. The gravel pack was placed in the annular space between the two casings and flowed down around the casing as sand and fine gravel were bailed from the well in the development process.

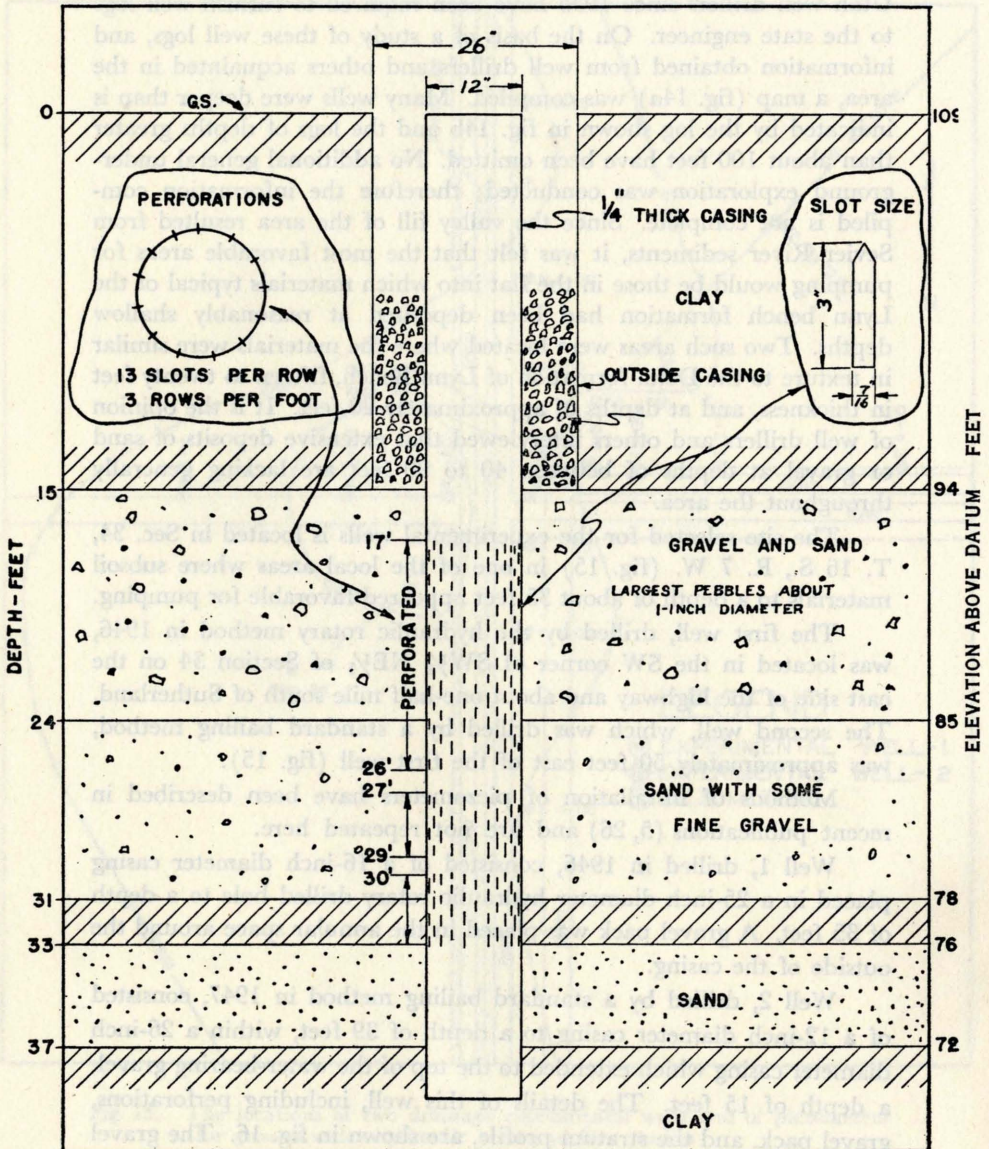


Fig. 16. The 1947 experimental well stratum and profile

EXPERIMENTAL PROCEDURE

Piezometer Installations

Piezometers were installed in 1946 on lines radiating from the well in 5 directions, at distances up to 800 feet from the well, as shown in fig. 15. At each location two piezometers of different lengths were placed to measure the water levels in the upper confining fine-textured soil and in the water-bearing stratum. Several additional piezometers were installed near the well as an aid in determining its hydraulic characteristics. In addition, control piezometers to register the natural changes of the water table (outside the probable radius of influence of the well) were placed during December 1947 at the following locations:

1. East piezometer—one-half mile east of well.
2. South piezometer—one-half mile south and one-eighth mile east of the well.
3. West piezometer—one-fourth mile west of the well.
4. North piezometer—one-half mile north and 100 yards west of the well.

All control piezometers were 10 feet long with the tops extending about one foot above the ground surface.

Readings of water levels in all piezometers were made periodically, before, during, and after pumping tests to determine the effect of pumping on the water table.

Development of Wells

Soon after installation, the wells were developed to some extent by the pumping process. A considerable amount of sand was pumped from the 1946 well, which is essential in the development process, but difficulty was encountered in placing the gravel pack. Because of this, and the fact that the drilled hole did not stand up, the well was probably not developed to its full capacity.

The 1947 well showed little development by pumping as indicated by the small amount of sand removed. Development of the well by the surge block method was therefore undertaken during the period June 30 to July 5, 1948. By this method a considerable amount of sand from the water-bearing stratum was bailed out and approximately 3 cubic yards of gravel was placed around the perforated casing.

The clay overlaying the water-bearing aquifer exhibited a fractured, loose structure, and during the development process a large

amount of clay flowed through the coarse gravel pack and was pumped from the well, leaving a large cavity. This cavity, which was about 12 feet in diameter and about 6 feet in depth, was filled with gravel.

The gravel used in the gravel envelope of the 1946 well was obtained from a local pit near Delta and contained a large proportion of plate-like rocks which are objectionable for such use. The gravel used for the 1947 well was obtained from a pit near Santaquin, Utah, and consisted of well graded angular and spherical particles ranging from $\frac{1}{4}$ to $1\frac{1}{2}$ inches in diameter.

Pumping Tests

Pumping tests were made on both the 1946 and 1947 wells. The test for the 1946 well was conducted intermittently over a period of about two months. The quantity of water pumped and the lowering of the water table in the vicinity of the well were measured.

Pumping tests on the 1947 well were begun in August 1947 and continued uninterrupted until March 1948 when pumping was stopped because of pump failure. Thereafter tests were continued intermittently until December 22 when pumping was discontinued.

The quantity of water pumped from the well was measured by use of a V-notch weir. The quality of the pumped water was determined several times throughout the test. Lowering of the water table from continued pumping was measured by means of piezometers. At various stages in the development and testing of the well the relation of the quantity of water pumped to the drawdown in the well was determined for the complete drawdown range. The data thus assembled provide the means for evaluating the effectiveness of the well in lowering the water table for drainage.

RESULTS OF EXPERIMENTAL PUMPING

Evaluation of the effectiveness of experimental pumping for drainage is difficult because of many influencing factors. The seasonal fluctuation of the water table and the influence of local irrigations tend to mask or enhance the effect of pumping depending upon whether the tests are made on an upward or downward cycle. In addition, the variations of texture and permeability of the water-bearing aquifer cause changes in the functioning of the well as the water table rises and falls. Because of these and other similar factors it is necessary to make long-time pumping tests to evaluate properly the effectiveness of a well.

The 1946 well produced a flow of about 100 gallons per minute and the specific capacity was 5 gallons per minute per foot of draw-down. The pumping test for this well was of relatively short duration, being conducted for only about 1½ months. The water table was

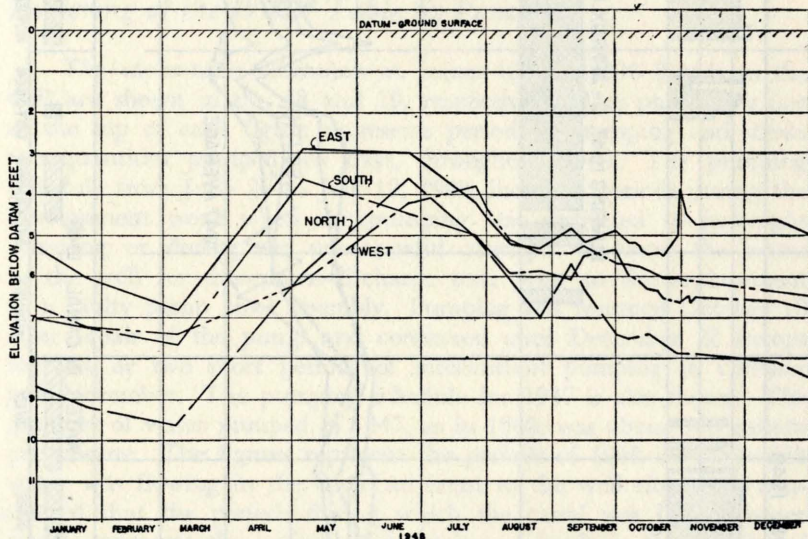


Fig. 17. Water-table elevations at control piezometers for experimental well

lowered an average of about 1.5 feet at the five measuring stations, 800 feet from the well. This lowering occurred during the time of the year when the water table is normally receding so that the measured drop did not all result from pumping. However, there was a significant change in the rate of lowering at the beginning of the pumping test, indicating that pumping had some effect at a distance of 800 feet from the well.

The pumping test for the 1947 well, although intermittent, was continued over a much longer period of time than that at the 1946 well, and records of water-table levels at the control piezometers at radial distances varying from 1320 feet to more than 2640 feet from the well were available to help evaluate the results of pumping. The water-table elevations in the control piezometers during 1948 are shown in fig. 17. Irrigation in this area is usually started near the first of April each year indicated by the rapid rise in ground-water levels shortly after this time.

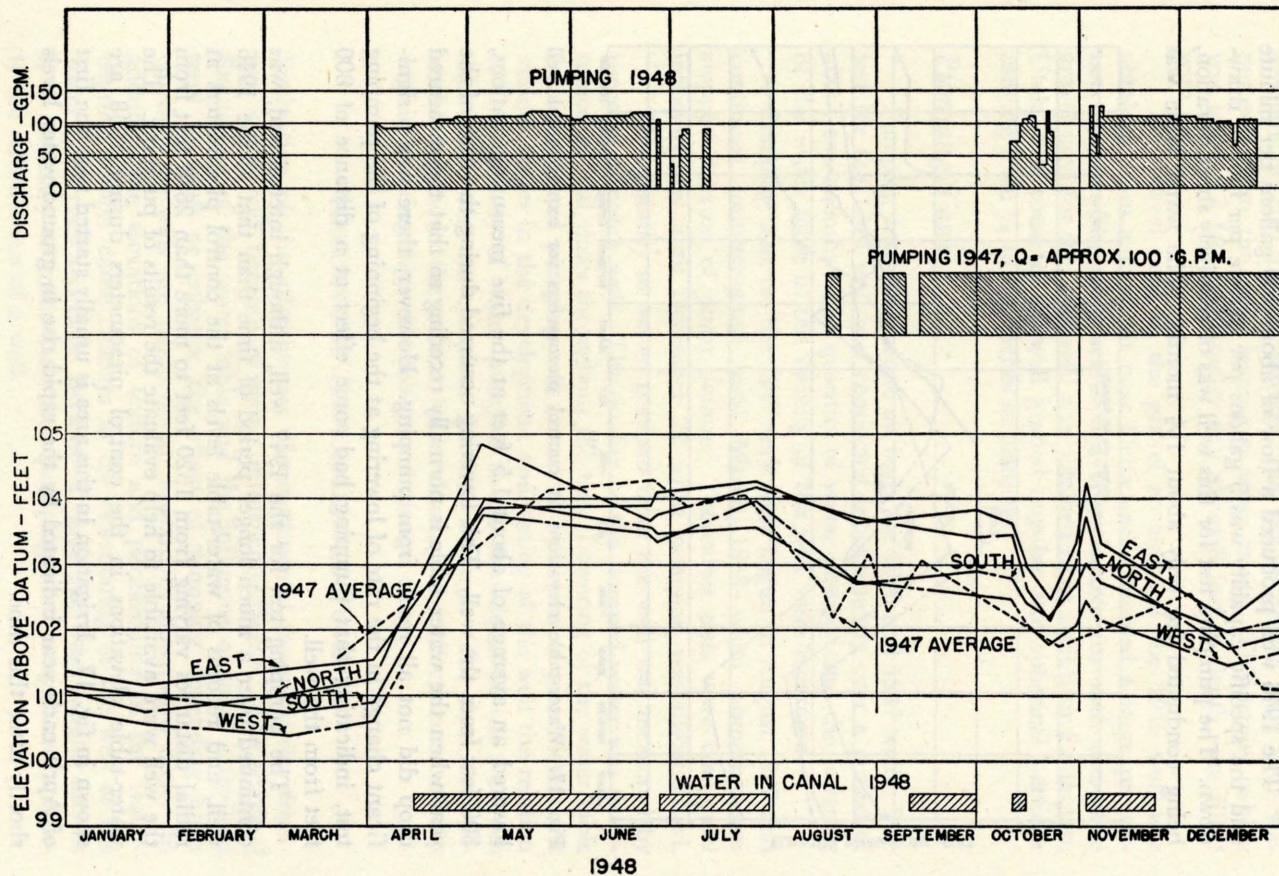


Fig. 18. Water-table elevations at points 400 feet from well during 1948

The highest water-table elevations of the season are reached in the latter part of May or first of June, and after that the water-table slowly recedes to a minimum level about March of the next year.

Lowering of the Water Table by Pumping

The water-table elevations at points 400 and 800 feet from the well are shown in fig. 18 and 19, respectively. The pumping chart at the top of each figure represents periods of pumping and shows the quantities pumped, by days, throughout 1948. The pumping schedule from June 26 to July 12, 1948, indicates periods during the development work when the pumping was restricted to overnight pumping or during the unsuccessful attempts to lower the water in the well for drawdown-discharge tests prior to the replacement of a faulty pump bowl assembly. Pumping was resumed October 10 after repair of the pump and continued until December 22 except for one or two short periods of intermittent pumping in October and November. The pumping schedule for 1947 is also shown. The quantity of water pumped in 1947, as in 1948, was about 100 gallons per minute. The figures represent the periods of 1948 during which water was flowing in the canal adjacent to the well site. It is considered that the periods during which the canal was full of water closely represent the periods of irrigation of lands in the vicinity of the well. The solid lines show the fluctuation of the water table at the respective piezometers.

In comparing the fluctuation of the water table with the periods during which water was flowing in the canals, a close correlation may be observed, i.e., the ground-water table rose as the water flowed in the canal. The water table at all piezometers did not always fluctuate in the same direction when the canal was full of water. This indicates that the percolation of water from the root zone soils during and soon after irrigation in the various local areas near the well site is the dominant factor causing a rise, or lowering, of the water table rather than canal seepage losses. The figures also show that the radius of influence of the well is greater than 800 feet inasmuch as the resumption of pumping October 10 caused a marked lowering of the water table in all piezometers. This is further substantiated by the fact that the period of non-pumping, during October 23 to November 3, was accompanied by a rise in the ground-water table at all stations at 800 feet. The seasonal lowering of the water table during this period was small.

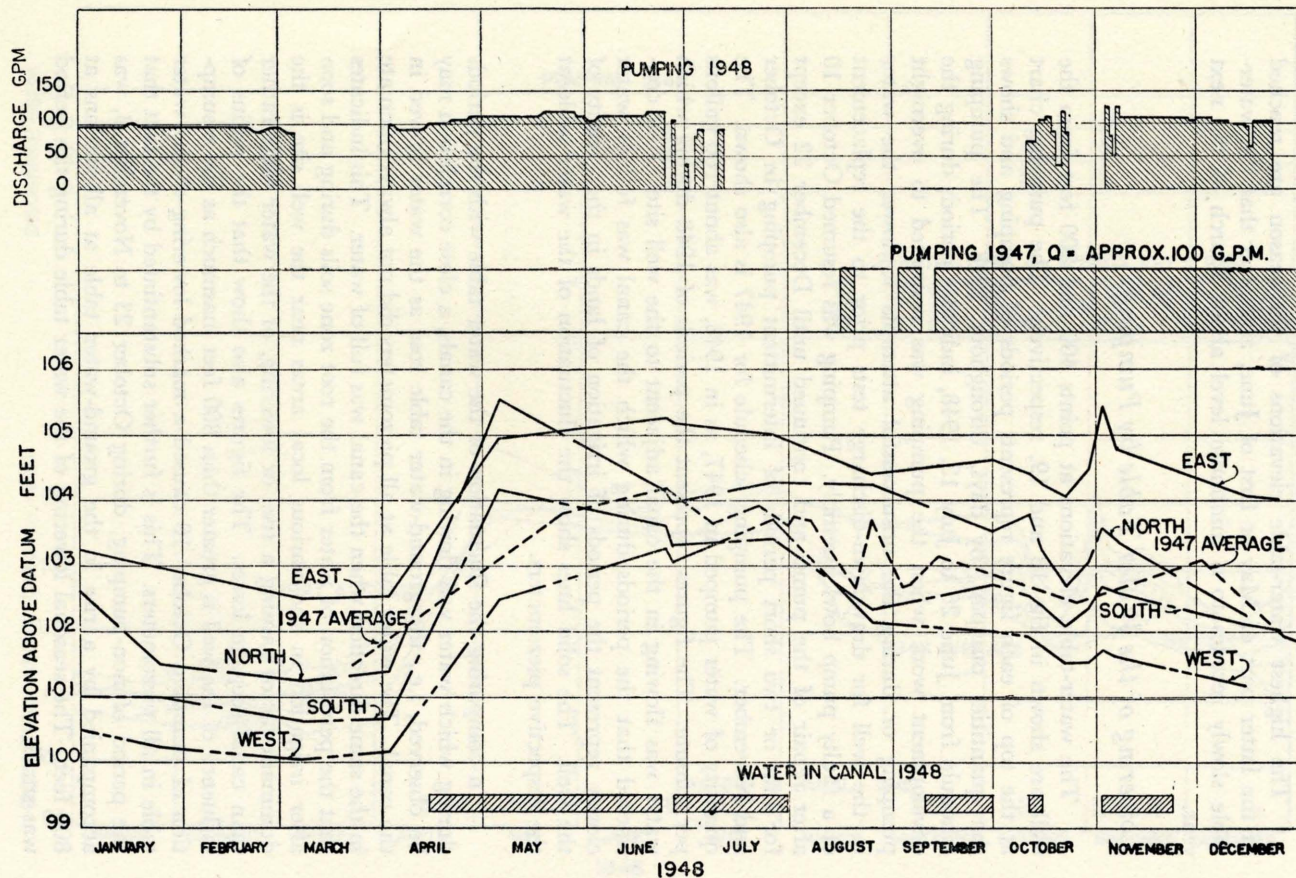


Fig. 19. Water-table elevations at points 800 feet from well during 1948

The curves of fig. 18 and 19 show that the water-surface elevations rose at points 400 and 800 feet from the well from April to June in 1947 and also in 1948 (after long time pumping). The average water-table elevation from April to June in 1948 was even higher than in 1947. This may be attributed to the general higher elevation of the water-table in the Delta Area in 1948 than in 1947. It is important to note that in experimental pumping as reported here the total irrigated area readily supplying ground water to the pump is probably many times larger than the area that should be assigned to one well for effective drainage by use of a number of pumps.

A rapid and wide variation in the elevation of the water table in the area caused by changes in the water supplies may obscure the effect of pumping from only one well on the water table within the radius of influence. However, by comparing the average lowering or rising of the water table at locations 400 feet and 800 feet during pumping, to those at the controls, the effect of pumping is evident and appreciable.

PUMPING TEST DATA

The advisability of pumping ground water for drainage and irrigation depends on many factors that can be measured at reasonable cost. The quantity of water pumped in relation to the drawdown, an important factor, is designated the specific capacity of the well. A preliminary measurement of specific capacity was made in June 1947, and 16 additional tests were made during the period October 12 to December 17.

The length of the time period of each test, together with drawdown, specific capacity, permeability, and other factors, are presented in table 2.

The time period for each test ranged from 16 to 78 hours and averaged nearly 30 hours. The actual drawdown ranged from 3.27 feet up to 25.79 feet, as shown in column 4, and averaged 14.7. Column 5 shows that the average calculated or theoretical drawdown was 7.67 feet, thus making the efficiency or effectiveness of the well, as defined by Wenzel (33), only 60 percent. The average specific capacity was 7.2 gallons per minute per foot of drawdown.

The permeability tests of the water-bearing sand ranged from 86 to 132 inches per hour and averaged 117 inches per hour (or 84,240 feet per year) as shown in column 11.

Table 2. *The drawdown, efficiency, quantity, specific capacity, and soil permeability obtained in 17 well tests, 1948*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|----------|---------------------|-------------------|--------------------|-------------|------|--------------------------|---------|------------------------------------|-------------------|----------------------|------|
| Test no. | Date completed 1948 | Time | Drawdown | | Eff. | Quantity of water pumped | | Specific capacity per ft. drawdown | Soil permeability | Ratio to the average | |
| | | | Observed or actual | Theoretical | | | | | | | |
| | | | hours | feet | | feet | percent | | | | |
| 1A | 6-24 | 78 | 8.95 | 8.21 | 91.8 | 101 | .225 | 11.28 | 2.6 | 112 | .95 |
| 1 | 10-12 | 24 | 8.81 | 5.52 | 62.7 | 71 | .158 | 8.05 | 2.7 | 117 | 1.01 |
| 2 | 10-13 | 31 | 12.60 | 7.31 | 58.0 | 98 | .218 | 7.78 | 3.0 | 130 | 1.11 |
| 3 | 10-15 | 48 | 25.79 | 8.70 | 33.8 | 104 | .232 | 4.04 | 2.7 | 117 | 1.00 |
| 4 | 10-16 | 19 | 24.19 | 9.50 | 39.3 | 111 | .247 | 4.60 | 2.6 | 112 | .95 |
| 5 | 10-17 | 24 | 16.27 | 9.40 | 57.8 | 111 | .247 | 6.84 | 2.7 | 117 | 1.00 |
| 6 | 10-18 | 24 | 11.07 | 7.48 | 67.6 | 86 | .191 | 7.78 | 2.7 | 117 | 1.00 |
| 7 | 10-20 | 44 | 3.27 | 3.03 | 92.7 | 33 | .073 | 10.10 | 2.9 | 125 | 1.08 |
| 8 | 10-21 | 24 | 24.88 | 9.90 | 39.7 | 118 | .263 | 4.74 | 2.7 | 117 | 1.00 |
| 9 | 10-22 | 22 | 10.38 | 7.69 | 74.0 | 85.7 | .191 | 5.26 | 2.5 | 108 | .92 |
| 10 | 11-3 | 24 | 24.10 | 9.10 | 37.7 | 126 | .281 | 5.24 | 3.0 | 130 | 1.12 |
| 11 | 11-4 | 24 | 9.60 | 6.40 | 66.7 | 82.6 | .184 | 8.61 | 2.9 | 125 | 1.08 |
| 12 | 11-5 | 16 | 4.95 | 3.71 | 75.0 | 49.2 | .109 | 9.95 | 3.1 | 132 | 1.13 |
| 13 | 11-6 | 24 | 18.60 | 9.71 | 52.2 | 126 | .281 | 6.78 | 2.9 | 125 | 1.08 |
| 14 | 12-15 | long time pumping | 15.42 | 8.80 | 57.0 | 98 | .218 | 6.35 | 2.5 | 108 | .92 |
| 15 | 12-16 | 21 | 8.24 | 6.55 | 79.5 | 65.8 | .146 | 8.00 | 2.1 | 86 | .74 |
| 16 | 12-17 | 24 | 23.10 | 9.30 | 40.3 | 103 | .229 | 4.46 | 2.4 | 105 | .90 |
| Averages | | 29.4 | 14.7 | 7.67 | 60.3 | 92.3 | 0.206 | 7.22 | 2.70 | 117 | |

The sum of the theoretical or computed drawdown under pumping, plus the hydraulic head required to make water flow through the well casing, equals the observed drawdown in the well.

The theoretical drawdown for each test, as shown in column 5 of table 2, was obtained as follows:

The observed drawdowns in the soil at various distances in the influence region of the well are plotted on semi-logarithmic paper. The straight line best fitting the data of the test shows the theoretical depth of the water table in the vicinity of the well. The point where the line intersects the perforated casing of the well gives the position of the water table immediately outside of the well casing. The theoretical drawdown was thus obtained. With the theoretical drawdown and the slope of the line, the effectiveness of the well, the specific capacity, and the permeability of the aquifer were calculated.

More than 600 tests of about 200 wells in the Madera Irrigation District in California showed that 95 percent of them had a specific capacity exceeding 7 gallons per minute per foot of drawdown. The 1947 Sutherland well has a low specific capacity. This may be explained by conditions at the well which lowered the effectiveness to 50 percent, and by the relatively low permeability of the strata being drained by the well. The average permeability of these strata was only about 84,000 feet per year. For comparison, the permeability of the artesian aquifer in Cache Valley, Utah, near Logan, averages about 535,000 feet per year (13) or is over six times that of the material at the Sutherland well.

In the Draper area, Utah, under typical water-logged lands, the saturated sandy soils from 10 to 100 feet below the land surface have an average permeability of only 1/25 that of the Sutherland well materials.

Data Analysis

The relation of the drawdown in feet to the well discharge in gallons per minute after development work was completed in 1947 and 1948 is shown in fig. 20. The plotted and numbered points are for the tests made in 1948. The curves show the average condition only. They seem to be influenced by water-table depths in the vicinity of the well, probably being affected by irrigation. Point 1A represents a preliminary test before the 1948 well development. At the time of test 1A in June, the general ground-water level in the area was comparatively high. However, tests 14, 15, and 16, which represent a drawdown-discharge relation less favorable than the average, were made during non-irrigation season when the water table was

relatively low. The average curve of 1948 represents results under more favorable conditions than that of 1947. This may be influenced by the higher water table in 1948.

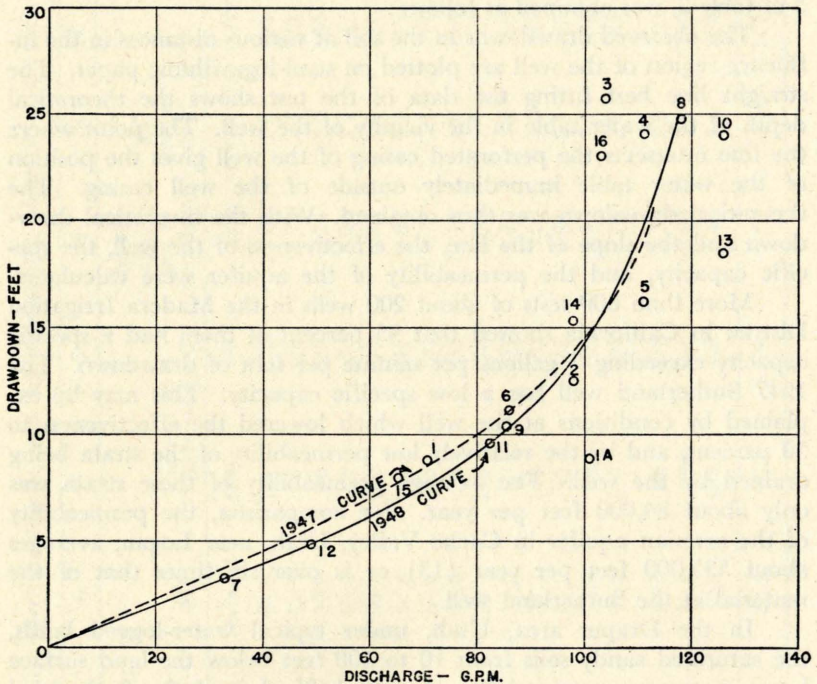


Fig. 20. Drawdown-discharge curves for the 1947 experimental well

The relation of the pumped and non-pumped ground-water tables is shown in fig. 21. Only the results of tests made on the most significant dates are presented. Comparing the ground-water table during the pumping periods with the non-pumped periods on the nearest date, it is evident that the deviation of the water surface during pumping periods from that of the non-pumped periods increases as the water table lowers.

Backwashing by starting and stopping the pump intermittently was employed in developing the well for one hour after each of the first 13 tests. By inspection of the degree of turbidness of the pumped water it may be concluded that the benefits would be confined to the upper part of the aquifer. Comparing tests 3, 4, and 5 with tests 10 and 13 in fig. 20 indicates that this type of development was bene-

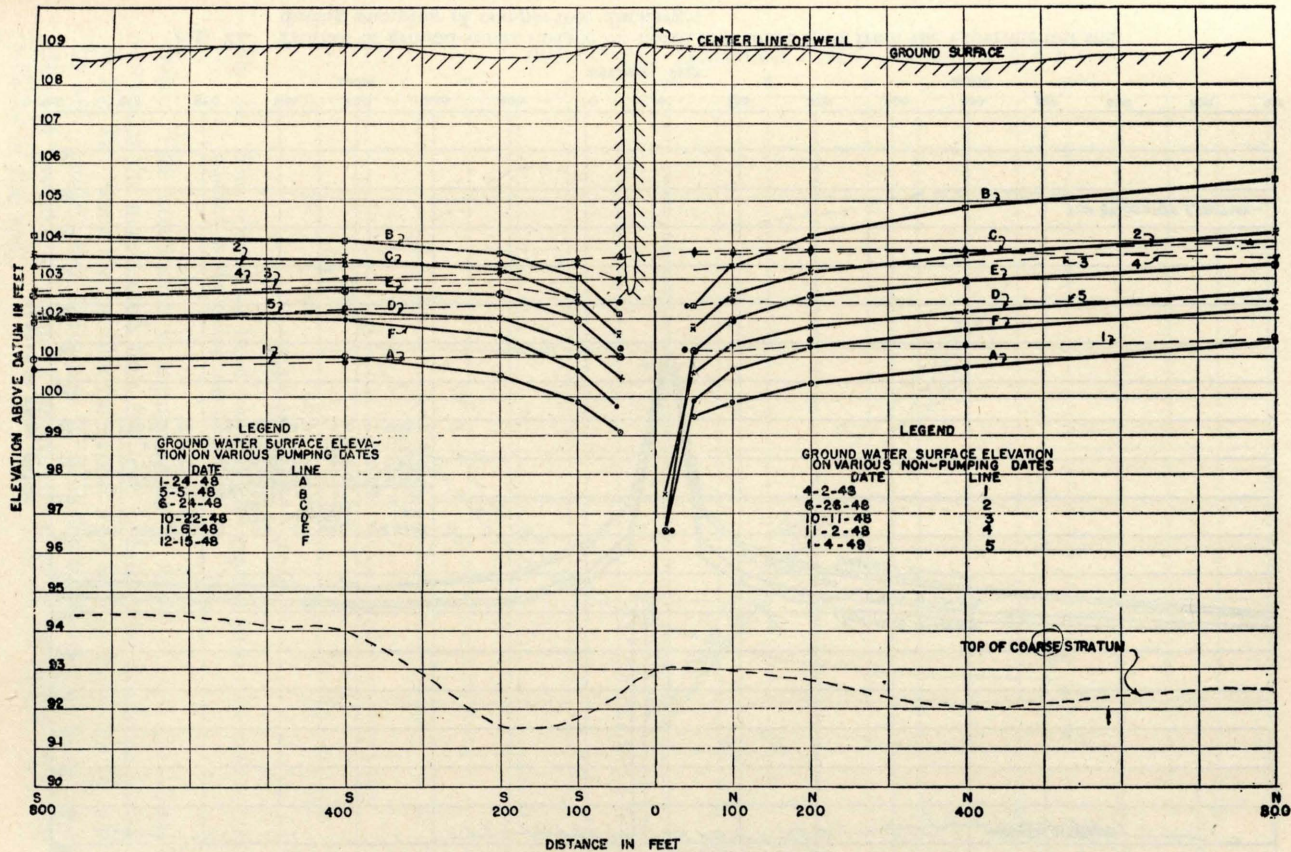


Fig. 21. Profiles of ground-water surface north and south lines from the experimental well on pumping and non-pumping dates

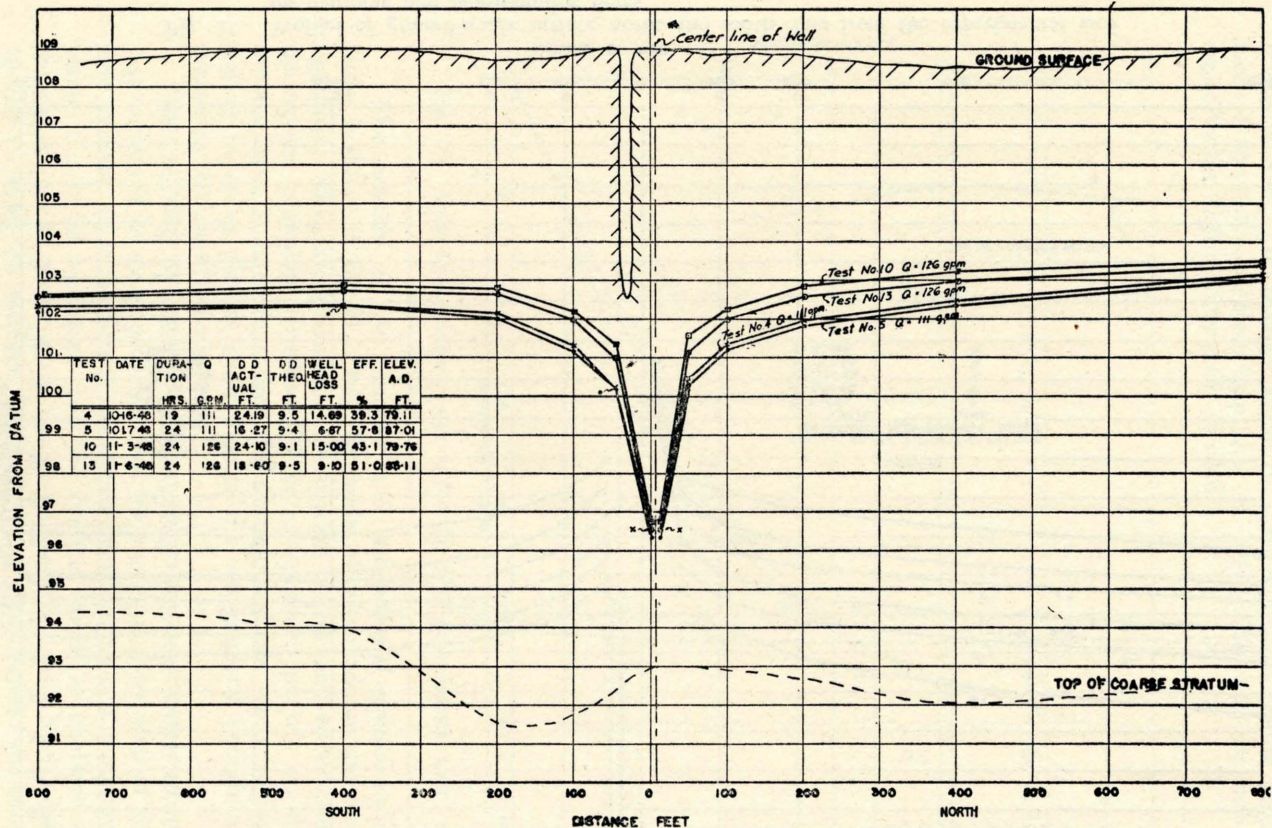


Fig. 22. Profiles of ground-water surface on north and south lines from the experimental well during pumping of comparable discharges

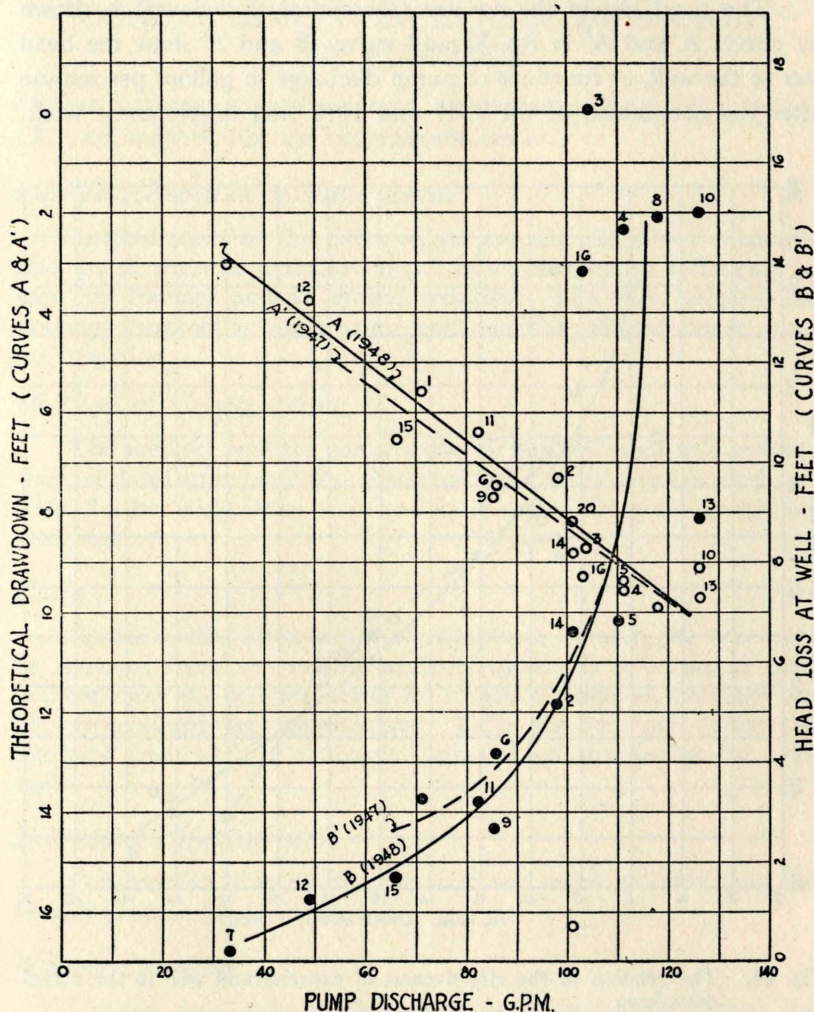


Fig. 23. The relation of head losses at the experimental well and in the aquifer to the pump discharge

ficial. This conclusion is supported by a study of the drawdown curves in the north-south lines for tests 4, 5, 10, and 13, as presented in fig. 22. Since the profiles for 4 and 5 as well as those for 10 and 13 are parallel, the difference in drawdown between tests in each group is probably a result of improvement from development in the vicinity of the well.

The head loss in the aquifer (theoretical drawdown) is shown by curves A and A' in fig. 23 and curves B and B' show the head loss at the well, as functions of pump discharge in gallons per minute after the completion of the 1947 and 1948 well development work.

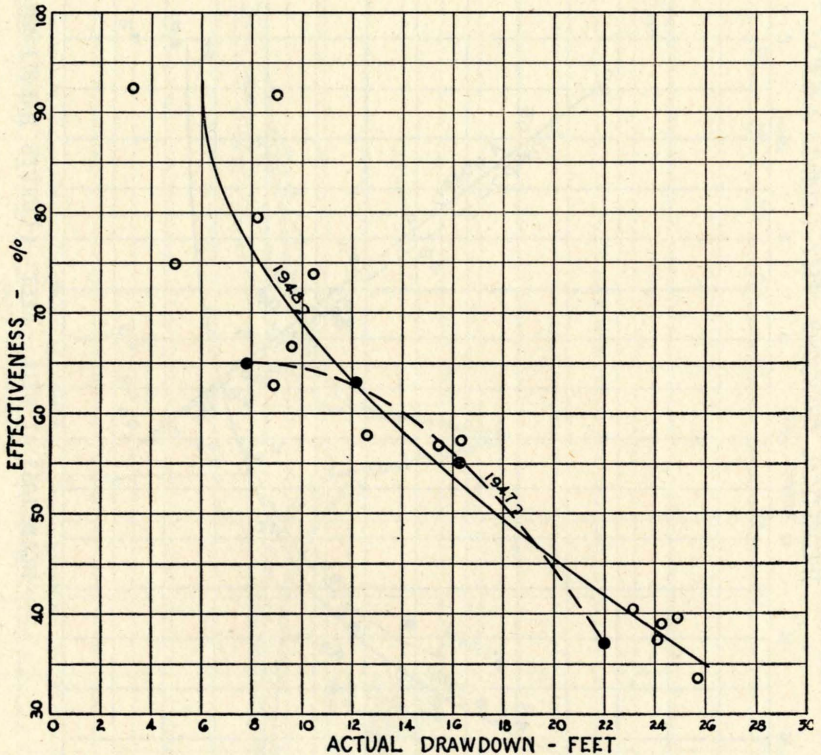


Fig. 24. The relation of the effectiveness of experimental well to the actual drawdown

The improvement in gravel envelope during 1948 is confined mainly to discharges of less than 100 gallons per minute. Again the benefit of development can be seen from the large difference in head losses at the well for tests of same discharge such as 4 and 5 and 10 and 13.

The effectiveness of the well, plotted with the actual drawdown as shown in fig. 24 decreases sharply as the drawdown increases.

CONCLUSIONS CONCERNING DRAINAGE BY PUMPING

THE FOLLOWING CONCLUSIONS concerning drainage by pumping are supported by the experimental work:

Pumping Feasible in Some Areas

Limited areas of the Delta region are underlain by a relatively thin gravel stratum at shallow depth in which pumped wells may be used for drainage and for limited irrigation. The water pumped for drainage purposes is highly saline and should be diluted before using for irrigation.

Method of Construction

The method used for construction of the 1947 well will produce wells of satisfactory stability. More effective wells may be produced when further experience is gained in pumping from the particular formation.

Costs

Assuming that eight inches average depth of water per year must be removed from the soil by artificial means, it is estimated that, without using the pumped water for irrigation purposes, drainage can be accomplished for approximately \$0.90 per acre per annum by pumping from wells of the same degree of effectiveness as the 1947 well.

Increased Effectiveness

Construction of more effective wells will result in lowering of the annual expense for drainage.

Winter Pumping

Limited data indicate that pumping a single well during the winter season does not produce a rapid lowering of the water table beyond a certain depth. However, general pumping throughout the area would be considerably more effective.

Well Screens

If further test wells are to be constructed, particular consideration should be given to using properly designed well screens, especially in the more sandy formations.

Further Exploration

Consideration should be given to constructing test wells in other favorable areas and especially small-diameter exploratory wells in areas where available information indicates favorable formations.

Local Gravels Not Suitable

Local gravels are flat-shaped and platelike and not suitable for the gravel envelope. Importation of gravels in which particles are not flat for use as envelope material is desirable.

Careful Planning Recommended

Any extensive program of drainage by pumping should be undertaken cautiously since the areas where pumping is feasible are limited. Slow, well-planned progress would provide the opportunity to apply the experience gained from previous drilling and pumping as the development progresses. Careful observations and complete records of all work done, performances, and costs should be maintained in order to evaluate the effectiveness of variations in technique.

PUMPING GROUND WATER

GREAT ADVANCES have been made since 1900 in the drilling and development of wells, the design, construction, and maintenance of pumps, and the development and utilization of hydroelectrical and other forms of mechanical energy for pumping ground water (1, 2, 3) for many purposes. Ground water reservoirs, when properly used, have been found to be of great value (23, 24).

Pumping ground water for irrigation and drainage has been well developed in California (4, 29, 32) and the Southwest (14) but has not been developed adequately in Utah.

If physically feasible, there are many advantages in drainage by pumping from wells. Drainage is seldom, if ever, a problem in arid-regions where an appreciable part of the irrigation water is pumped from wells.

EXPERIENCES IN PUMPING FOR IRRIGATION AND DRAINAGE

The experience of the Modesto Irrigation District, California, is typical of the benefits resulting from pumping for irrigation and drainage. This district uses both gravity drains and pumped wells. In 1939

Cecil reported that only 1,900 acres out of 50,000 in the district had water tables less than 4 feet in depth and that on more than 76 percent of the area the depth to the water table exceeded 6 feet (4).

Four years after irrigation began, construction of drains was begun, and 20 years after the beginning of irrigation 53 miles of gravity drains, including 30 miles of open drains, had been constructed. In 1922 the drainage situation had become acute and the first drainage well was drilled. In this year, 16 percent of the area had a water table within 4-foot depth, and 73 percent within 6 feet. The gravity drains had dried up most of the swamps and open lakes, and the areas adjacent to the drains had been improved, but no relief was afforded to lands at greater distances from the drains and extensive manifestations of the high water table were evident, especially in the form of decreased crop production. Since 1922 several drainage wells have been drilled each year, and by 1939 there were 77 wells in the valley. By then, 7.1 miles of gravity drains had been abandoned and 57.7 miles remained in operation. The great improvement in the drainage situation during the years 1922 to 1939 is attributed to pumping. The experience of the Modesto District with drainage leads to the conclusion that as far as they were concerned the operation of deep well pumps is the most satisfactory method of drainage. The cost is reasonable and the results most gratifying. Cecil summarizes the situation as follows:

The total cost of construction for wells, pumps, and discharge pipe lines, up to and including 1939, was \$159,000 as compared with \$308,000 previously cited as cost of gravity drains. The cost of operation and maintenance for the pump system totaled \$60,050, and similar cost for gravity drains equaled \$148,700. The power cost for operating pumps totaled \$393,100.

On the basis of 50,000 acres, which is the area subject to a high water table, the cost per acre, including \$4.38 for construction, maintenance, and operation, and \$7.86 for power cost, is \$12.24 for drainage pumps as compared with \$9.13 per acre expended for gravity drains. During the period in which the District has operated the pumps, a total of 602,000 acre-feet of water has been pumped, equivalent to more than twice the capacity of Don Pedro Reservoir. Approximately 75 percent of all pumped water has been used for irrigation. At the rate of \$1.36 per acre-foot, the pumped water which was used instead of gravity water for irrigation would have a potential value of \$612,150, which would entirely offset all drainage pump costs.

The Modesto experience leads to the conclusion that the operation of deep-well pumps is not only a most satisfactory method of sub-surface drainage, but also a self-liquidating project.

In the Salt River Valley, Arizona, drainage became a problem about 1918, seven years after the construction and use of Roosevelt

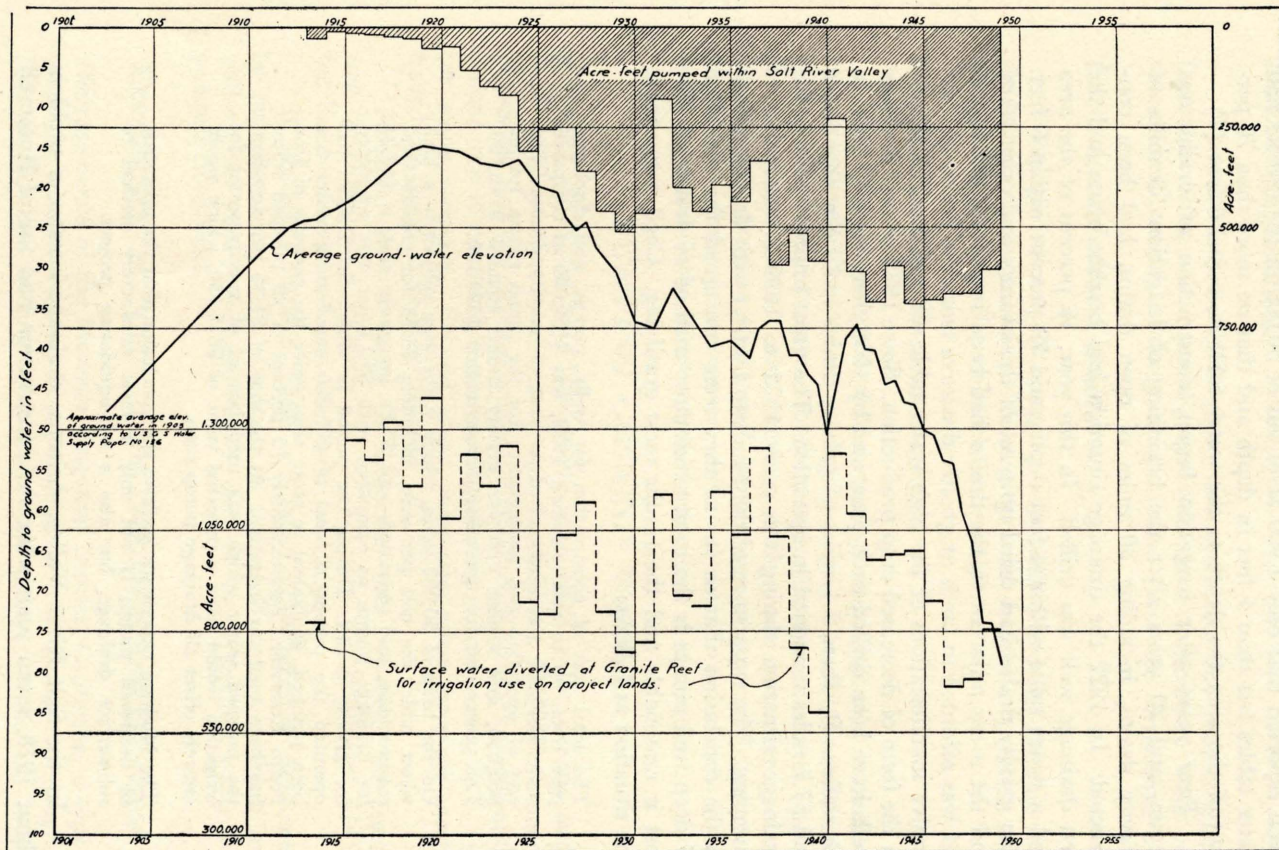


Fig. 25. Depth to ground water in relation to the acre-feet of water pumped in the Salt River project, Arizona, each year from 1913 to 1948. (Courtesy Salt River Valley Water Users Association)

Dam greatly expanded irrigation. In that year the Salt River Valley Water Users Association began pumping ground water to improve land drainage. How the water-table elevation in the Salt River Valley has declined as a result of pumping since 1920, when it was at its highest elevation, is shown from records of the Salt River Valley Water Users Association in fig. 25. In 1946, one-third of the water provided to irrigators by the Salt River Valley Water Users Association was pumped water, and the average depth to ground water was greater than 50 feet. The drainage problem has long been solved and the present concern is not drainage but recharge of the ground-water reservoir.

The above examples are typical of experiences in other areas where geological conditions are favorable for pumping and where water can be re-used for irrigation.

Pumping of ground water for irrigation and drainage has lagged in Utah. In 1940 there were 48,568 pumped wells in California; 2,878 in Colorado; 1,858 in Arizona; 309 in Idaho; and 286 in Utah. California's installed pumping capacity exceeded Utah's by 50 times. Arizona pumped 35 times as much water as Utah during this year.

DRAINAGE BY PUMPING COMPARED WITH GRAVITY DRAINAGE

One of the great disadvantages of open drains is the wide strips and large areas of land required for rights-of-way. In addition open drains are unsightly and clog with weeds. The slopes, made unstable by seepage, tend to sluff and slide so that constant and expensive maintenance must be provided. In general the difficulty of maintaining open drains at depths greater than 5 or 6 feet has not been solved on a practical basis with the result that the depths to which open drains successfully lower ground water in adjacent fields is nearly always insufficient. The depth to which tile drains may be placed is also limited practically to around 7 feet with the result that water tables may not be adequately lowered by them. Although land over tile drains may be farmed, many problems of maintenance arise.

Gravity-type drains appear to be even more inefficient where artesian conditions prevail (13, 18), a common condition in irrigated valleys. A study of flow patterns into tile drains indicates that artesian conditions tend to steepen the water surface back from the drain and to require a closer spacing of drains for relief (15). Reduction of artesian pressure by wells appears to be a highly logical approach to this problem. Measurements by Israelsen and McLaugh-

lin in Cache Valley (13), definitely show that waterlogging of large areas of land in that valley may be attributed to upward flow of water from an artesian aquifer. A strong argument for removing the water from the more permeable underground soils rather than from the less permeable upper soils is made by Israelsen and McLaughlin in the following statement about conditions in Cache Valley:

Remembering that the permeability of the artesian ground-water reservoir is 100,000 times that of the surface foot of clay soil, it follows that if the same conditions were maintained it would require 274 years to drain from the clay the same volume of water that could be drained from the sands and gravels of the ground-water reservoir in one 24-hour day.

The following advantages of pumping to provide drainage should be carefully considered by drainage district supervisors and land owners:

1. If the water is of such a quality that it can be used for irrigation, its value for that purpose materially offsets the cost of drainage. Furthermore, such underground water is a valuable natural resource that should be fully utilized.
2. The elevation of the water table can be closely controlled.
3. Maintenance costs are lower with pumping than with gravity drains.
4. The cost of mechanical energy, which is the principal annual pumping cost, has decreased over the years and this trend promises to continue.
5. Experience in areas where ground water has been pumped extensively indicates that capital costs for draining by pumping are materially less than for any other method.
6. Almost no land is withdrawn from cultivation for pumping plants, whereas wide strips are made non-productive in the construction of deep open drains.

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The genuine interest and financial backing of the Delta Area Irrigation and Drainage Investigation Committee has been gratifying. This committee is comprised of representatives of the four Millard County drainage districts, the four Delta Area irrigation companies, and other prominent businessmen in the area. D. D. Crafts has been especially active in supporting this research.

DEEP WELL RECENTLY DRILLED

ADDITIONAL information concerning the water-bearing materials near Delta is now available from drilling a deep well in Sec. 3, T. 17 S., R. 6 W., during August and September 1950. The log of the well was filed in the State Engineer's office in January 1951. When examining this log presented herewith, the reader will find it interesting to compare with the logs of the 3 deep wells presented in fig. 13 on page 34. The first water-bearing stratum was found at 176 feet depth. Before pumping the ground-water surface was at a depth of 68 feet, and during the test pumping of 5 cubic feet per second the ground-water-surface depth was 154 feet.

A steel casing of 16-inch diameter was used at the top of the well and 10-inch diameter near the bottom.

LOG OF WELL

| <u>Depths, feet</u> | <u>Soil formation</u> |
|---------------------|------------------------------|
| 0 - 0.5 | Top soil of sandy loam |
| 6 - 70 | Sandy clay |
| 70 - 130 | Blue clay with silt |
| 130 - 136 | Blue to brown clay |
| 136 - 176 | Brown clay |
| 176 - 181 | Fine to coarse sand |
| 181 - 206 | Pea gravel with clay streaks |
| 206 - 236 | Yellow stiff clay |
| 236 - 247 | Fine to coarse sand |
| 247 - 256 | Fine sand, some clay |
| 256 - 290 | Fine sand |
| 290 - 296 | Yellow clay |
| 296 - 311 | Fine sand |
| 311 - 346 | Brown clay with sand streaks |
| 346 - 356 | Fine to coarse sand |
| 356 - 386 | Yellow clay |
| 386 - 409 | Sand and fine gravel |
| 409 - 427 | Clay and gypsum |
| 427 - 439 | Clean gravel |
| 439 - 448 | Gravel with clay streaks |
| 448 - 458 | Brown stiff clay |
| 458 - 479 | Fine quicksand |
| 479 - 518 | Gravel with clay streaks |
| 518 - 550 | Brown clay with grit |
| 550 - 567 | Gravel with some clay |
| 567 - 580 | Brown clay |