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# DRAINAGE OF THE LOGAN-HYDE PARK-BENSON AREA, UTAH

by

Gordon H. Flammer

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Irrigation and Drainage Engineering

UTAH STATE AGRICULTURAL COLLEGE
Logan, Utah

1953

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Appreciation is extended to Dr. O. W. Israelsen, my adviser and thesis director, for his encouragement, and most especially for the example he has set before his students as a teacher and research scientist.

G. H. F.

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## INTRODUCTION

B. A. Etcheverry (4) in his book, Land Drainage and Flood Protection, states that inadequate drainage causes: (1) a public health menace, (2) an animal health menace, (3) lower grade plant life, (4) inadequate soil aeration, (5) lower soil temperatures, (6) shallow root penetration and, therefore, plant suffering in late summer months from effects of drought, (7) poor soil texture and workability, (8) increased surface washing and erosion of land surface, and (9) alkali and saline conditions. Other factors such as poorer roads and highways, decreased tax revenues, etc., might be added to this list. The advantages of adequate drainage are absence of these disadvantages. Many public as well as private benefits are realized from land drainage.

The present world situation has brought about a great need for increased food production. Jones, in the July 1952 issue of Agricultural Engineering (13), writes:

> There is greater need for food and fiber production on United States farms today than ever before. U. S. population has increased 20 million in ten years...an appreciable part of our food supplies must go to feed men in the military service...our present exports require the production from approximately 50 million acres...as a result of these heavy demands, the agricultural surpluses we heard so much about a few years ago are now a myth.
>
> It appears that over the U. S. some 30-40 million acres of land are now under cultivation on which crop yields could be increased 50 per cent or more by farm drainage work, an increase which can be obtained without increased demands for machinery, labor, seed, or fertilizer. All that would be required would be a limited amount of construction equipment such as small draglines, bulldozers, and graders. In view of the urgent need for increasing our food supply, it would seem that every effort should be made to provide the necessary critical materials to furnish and maintain the small amount of equipment necessary to carry on an expanded program of farm drainage.

Conditions are more favorable economically for drainage than ever before. Land values and food values have both increased considerably.

## STATEMENT OF THE PROBLEM

### Location and extent of area

The Logan-Hyde Park-Benson drainage problem area is bounded on the south by Logan River and on the west by Cutler Lake and Bear River. On the east it is bounded roughly by U. S. Highway 89 running between Logan and Smithfield, except south and west of Hyde Park, where the boundary extends east to the center of section 10 T12NR1E. The north boundary extends up to the south edge of Smithfield City. The area is located in the center of Cache Valley. Map 8 shows the drainage area boundary. The valley itself is bounded on all sides by steep mountain ranges. The problem area is situated in the valley lowlands and has flat slopes and very fine textured soils. The higher lands between the lowlands and mountain ranges are of coarser texture and greater slope, and are therefore usually well drained.

The poorly drained land is economically well situated. It is near civic centers and good schools. It lies in a highly productive agricultural area with well-developed markets. The benefits of drainage of these lands would be widely felt by the citizens of the valley and state.

### Geological history

Cache Valley soils were formed by soil deposition in Lake Bonneville (see Figure 1). Streams flowing into the lake deposited coarse particles near the edge and the fine and very fine particles in the still water nearer the center of the lake. Thus the lowlands are composed of fine-textured soils and the higher border areas are of coarser material. Because the lake level fluctuated throughout the centuries, many sand

and gravel lenses (aquifers) were formed throughout the soil profile. The gravel aquifers do not extend to the valley center, but slowly pinch out east of the Salt Lake Base and Meridian (see Map No. 12). The 40-60 foot gravel aquifer forms such an aquiclude. The sand lenses continue to the valley center, but are very intermittent, as revealed by a study of well logs in the area (see figures 5, 6, 7, 8 and 9). These figures show underground profiles of the area. Such profiles are typical of lacustrine deposits.

Agricultural history

The Mormon Pioneers, following the colonization plans of Brigham Young, moved into Cache Valley in 1856 and settled Wellsville. They pushed their settlements slowly north and by 1859 had settled Logan. Since water for irrigation was the life blood of these colonies, the first settlers chose farms near the streams and along the valley bottoms. This afforded greater ease in getting irrigation water to the land. As the number of settlers increased, more extensive irrigation systems were developed and the higher lands were irrigated. Because these higher lands were of coarse texture, much of the irrigation water was lost by deep percolation. Excessive irrigations were necessary to supply plants' needs. The percolating waters found their way to the lower aquifers, causing greater artesian pressures. Gradually the lower farmed lands were forced out of production by rising water tables and resultant salt and alkali accumulations. A large portion of the area covered by this study was never used for anything but pasture, because of high water table conditions.

Today 20,000 acres of the lowlands are of very low productivity. The area is used almost entirely for pasture, and most of this pasture land is in very poor condition. Salt conditions have become increasingly

worse over the years, until most of the area will support only low grade pasture grasses. Visible accumulations of salt or alkali cover most of the area (Map 8). Apparently much of the land classed as water logged in 1913 is now saline and alkali. Conditions in general have become worse rather than better. One land owner recently estimated that much of his pasture land was capable of pasturing only one cow for every two acres. A large portion of the so-called "better" pasture is supporting only a fraction of its capabilities as well-drained land.

## REVIEW OF PAST STUDIES AND RECOMMENDATIONS

### 1913 soil survey (14)

In 1913 an extensive soil survey was made of Cache Valley by the U. S. Department of Agriculture (see Maps 1 and 2). This survey revealed that in the Logan-Hyde Park-Benson area, approximately 3840 acres of land were saline-alkali soils. (Note: The meaning of saline alkali has changed since this survey. Their notation did not indicate the difference between these conditions. "S" on their map meant spotty salt conditions and "A" indicated uniform salt coverage.) Ten thousand eight hundred and eighty acres were continuously waterlogged; and 5120 acres were injured by a fluctuating water table.

Map No. 2 shows the soil classification in 1913. Today's soil classifiers would break the soils down into more groups. However, the various soil type mechanical analysis will be of some value, especially in the absence of a recent soil survey covering the entire area.

### Trenton clay (TC)

Topsoil clay 56.3%, silt 37.2%, sand 6.6%
Subsoil clay 52.0%, silt 44.9%, sand 3.2%

### Trenton fine sandy loam (TS) light and heavy phase

Topsoil clay 10.3%, silt 18.4%, VF sand 28.2%, F sand 40.7%, sand 2.4%
Subsoil clay 10.0%, silt 10.6%, VF sand 32.4%, F sand 44.4%, sand 2.1%
Lower subsoil clay 3.9%, silt 5.5%, VF sand 27.3%, F sand 57.9%, sand 5.1%
Heavy phase soil clay 11.2%, silt 30.1%, VF sand 37.6%, F sand 19.9%, sand 1.2%
Subsoil clay 15.2%, silt 28.7%, VF sand 33.9%, F sand 20.4%, sand 1.4%

### Trenton loam (TL)

Topsoil clay 20.4%, silt 40.9%, VF sand 25.2%, sand 13.2%
Subsoil clay 32.1%, silt 40.2%, VF sand 24.6%, sand 3.1%

Salt Lake silty clay loam (SC)

Clay 26.1%, silt 62.3%, sand 11.6% topsoil
Clay 38.3%, silt 56.8%, sand 4.9% subsoil

Milville loam (M)

Clay 13.7%, silt 48.6%, VF sand 27.8%, sand 9.9% topsoil
Clay 15.7%, silt 38.6%, VF sand 33.4%, sand 12.1% subsoil

Cache County Drainage District No. 2 (7)

On August 8, 1921, the County Commissioners created Cache County Drainage District No. 2, which included some 8,422 acres of the 20,000 acres covered by this study. During the years 1921 and 1922 the Humphrey Brothers, engineers for the district, made a thorough study of ground water conditions and need for drainage. Their report, based on over 100 points of measurement, gives the following water table depths: (See Map 10)

| Date | Depth to Water Table (feet) | Acres | % of Total |
|---|---|---|---|
| October, 1921 | 0-4 | 7000 | 83.1 |
| | more than 4 | 422 | 16.9 |
| | | | 100.0 |
| April, 1922 | 0-4 | 7800 | 92.6 |
| | more than 4 | 622 | 7.4 |
| | | | 100.0 |

Drainage District officials made a careful study of costs and benefits and agreed upon the following estimates:

| | |
|---|---|
| Probable total cost of proposed drains | $294,000 |
| Probable damages | $ 18,600 |
| Probable annual maintenance | $ 2,410 |
| Aggregate benefits | $840,000 |

The district tax assessments were based on benefits received and ranged from $50-$150 per acre. Because of the high cost per acre of installing the drains and in spite of the benefits greatly outweighing the costs, many of the land owners objected strenuously. As a result the district was legally dissolved. In 1920 these undrained lands were

valued at $30, $40, $45, and $150 per acre. When the tax assessments were sent out amounting to $150 per acre on the very poor land, the owners revolted and submitted bitter letters of objection to the district officials. Map 3 shows the assessments by acreage for each section.

Excellent contour maps of the district lands plotted to a large scale (1" = 400') and a one-foot contour interval were made by the Humphrey Brothers. These maps are on file in the Irrigation and Drainage Department, Utah State Agricultural College. Because of size they are not attached to this study.

A map showing the location of the proposed drains for the district is in the appendix (see Map 4). The drains for most of the area run east and west with a spacing of 1/2 to 1 mile. These drains were designed to serve as outlets for the individual farms. The drains were all to be open drains except for a few hundred feet of short tile spurs in the coarse higher soils.

As already shown, the preliminary studies for Drainage District No. 2 indicated the drainage of this land to be economically feasible, with a ratio of costs to benefits of almost 1:3.

Permeability of soils low

As previously mentioned, most of the soils in the Logan-Hyde Park-Benson area are fine clays or silty clays of low permeability. A 6-foot deep auger hole was dug barely 14 feet from surface water which had stood for a long time, and no water table was encountered. When an auger hole 14 feet deep was dug, another instance of low permeability was shown. Although the water table at the time was more than four feet deep, yet water rose in the hole to the ground surface. Because the walls were so impermeable to water, the auger hole acted as a piezometer tube

measuring the pressure head of the water at the fourteen foot depth.

The estimated permeability of airport soils as computed by Israelsen et. al., (1934), from experimental data, was $1.71 \times 10^{-7}$ ft./sec. (9). The artesian aquifer underlying the clay has a permeability coefficient of approximately $1.71 \times 10^{-2}$ ft./sec. or 100,000 times that of the clay above it. Under the same conditions 274 years would be required to drain from the clay soil the same amount of water that could be drained from the gravel aquifer in 24 hours. By using the consumptive use of alfalfa to find the quantity of water flowing upward through the soil, Riley found the permeability of airport soils to be $2.70 \times 10^{-7}$ ft./sec. Justin, Hunds and Craeger quote $1.0 \times 10^{-7}$ ft./sec. as an average value for coarse clay (18).

Pumping experiments

There is little doubt that upward flow, especially from the 40- to 60-foot aquifer, is the major contributor to the drainage problem. Artesian pressures in this aquifer have been measured at 27 pounds per square inch or 60 feet of water head above the top of the aquifer and 20 feet above the ground surface. The gravel in this aquifer is highly permeable and therefore affords excellent pumping opportunity. It averages 10- to 20-feet or more in thickness and has a permeability of approximately $1.71 \times 10^{-2}$ ft./sec.

By O. W. Israelsen, et. al. (8 and 9). During the summer of 1929, 25 wells ranging from 2- to 5-inches were drilled into the 40 ft. aquifer. Twelve of these wells were drilled on a 20-acre tract south of the airport. Eleven were drilled along the Logan-Benson Canal (some of these wells are still discharging into the canal). The piezometric surface was appreciably lowered by the flowing of water from these artesian wells.

In 1930, a 14-inch well was drilled near Highway 91 at a point 2.5 miles north of Logan for a pumping experiment. On September 1, 1932, the lowering of the piezometric surface each hour after starting the pump was measured. In 10-3/4 hours the fall in piezometric surface ranged from 10.89 feet at a point 820 feet from the pump to 3.33 feet at a distance of 3680 feet. This shows how readily the pressure head in the aquifer may be reduced by pumping and how readily the upward flow of water toward the land surface may be decreased or entirely prevented. An interesting observation was taken on the rise of the piezometric surface after the well stopped pumping. The time-rate of rise showed a parabolic curve with the piezometric surface almost back to its original elevation in 8¼ hours. Israelsen and McLaughlin (9 p.24) concluded on the basis of their experiment that:

> It is physically feasible to pump water out of gravel in large enough streams ( and also large enough in total volume ) to prevent the flow of water upward and further to permit the flow of excess irrigation water and natural precipitation downward through the upper feet of soil as fast as the low permeability of the soil will permit.

They further concluded that extensive pumping from the aquifer would, over a large number of years tend to lower the water table to depths where further salt and alkali accumulation would cease, and where leaching out of the present salt could take place.

Economics of pumping. The quality of water in the 40' aquifer is excellent for irrigation use. In 14.9 days pumping the 14-inch well yielded 133.2 acre feet or 4.5 cubic feet per second. Israelsen (9) estimates that the aquifer could yield 20,000 acre feet per year. This is insufficient to irrigate the entire 20,000 acres, so additional irrigation water would be required. However, if water sells at $2.00 per acre foot then the annual value of the water would be $40,000. At 4

per cent interest, this represents a principal of $1,000,000.

And pumping has twin benefits (11). It not only drains the land, but at the same time furnishes irrigation water. Results of tests on the 1930 well indicate that a 14-inch well could provide drainage for an area of approximately 470 acres. The total cost of the well and pump was $3,200.00. This represents a cost of $6.80 per acre. Pumping is much cheaper than tile or open ditch methods of reclamation. In many instances the value of the water pumped more than equals the cost of pumping.

There is a general agreement that pumping is the ideal and cheapest way to drain these lands. There is a diversity of opinion as to the probable effectiveness of surface drainage systems as a present solution.

Legal difficulties encountered. Water laws for the State of Utah prevent the disturbance of flowing wells. The law states that underground waters are subject to appropriation. First in time is the first in right and an appropriator is entitled to have the original conditions at the time he drilled maintained or be compensated for increased costs of pumping (5).

Pumping would cause the artesian wells to cease to flow. This legal difficulty has prevented further pumping experimentation. The 1932 experiments were ceased because of court order.

Though this law does protect a few individual rights, yet the community progress has been at a standstill because of it. We might compare the situation to a surface reservoir. A surface reservoir may have very large capacity and yet be of no value if someone had the right to demand that it always be kept full and overflowing. Obviously a reservoir may be kept full at all times if the same amount of water flowing out is coming in. This is the situation of a full underground aquifer which must be kept full to provide flowing wells. The aquifer must be kept full and

has, therefore, little storage value for irrigation. If pumping were permitted it would open a huge 20,000 acre foot reservoir for irrigation purposes as well as alleviate a serious drainage problem (9).

Recommendations of Willard Gardner. Willard Gardner has done considerable research on the drainage of these soils. He has been especially interested in the possibilities and design of drainage well systems which would prevent upward flow and serve to irrigate the lands as well. He has been a strong advocate of relieving the upward pressure in the aquifer by pumping or siphoning as the best if not the only satisfactory means of reclamation.

Need for Farmer Education. It may be that this legal problem is largely one of education. The human problem in drainage is oftentimes bigger than the problem itself. Farmers need to be educated to the actual benefits of drainage to the land, crops and community; and likewise they must be educated to the economics of drainage. Though an initial outlay may seem high and the reaped benefits delayed, yet these benefits may represent one of the highest returns on a land investment possible for the farmer to make.

A further human problem exists in the Logan-Hyde Park-Benson area in that the land has lain unproductive for so long that a majority of land owners are highly skeptical of the possibility of drainage. Such a problem can best be overcome by actual projects in the problem area showing what can and what cannot be done. The Logan-Cache Airport already represents such a demonstration and it will be described on pages to follow.

It may be that by further demonstration of feasibility of drainage the land owners will gain sufficient interest to individually start to drain and to eventually organize a drainage district. From this point compensation of flowing well owners and removal of legal obstacles may

make pumping possible.

Siphon drainage

Frederick Bisal, graduate student, Department of Physics, designed a siphon drainage system for these lands (3). He proposed two wells approximately 8,448 feet apart. The eastern well was to drain into the Logan-Benson canal and the westernmost well was to drain into Hopkins Slough. A siphon tube from the aquifer drained into a 14-foot deep sump, which sump was siphoned by a 2-foot diameter pipe to Hopkin's Slough 3500 feet away. Head loss for a 6 cfs stream is 2.4 feet. Bisal estimated his design would drain 2560 acres.

Logan-Cache Airport drainage (18)-surface drainage

The question as to the feasibility and effectiveness of surface drainage methods is one of some dispute. A great deal of further study on surface methods of drainage is justified for two reasons: (1) because of the present legal restriction imposed on pumping, and (2) because there are actual instances in the problem area where surface drainage has improved or actually reclaimed the land. The most notable instance of the latter reason is the Logan-Cache Airport drainage system.

Original conditions of the soils and vegetation. Logan-Cache Airport is located in sections 9 and 16, T12NR1E of the Salt Lake Base Meridian line approximately 4 miles northwest of Logan City limits. It consists of approximately 400 acres of the old Cache County Drainage District No. 2. In 1913 its soils were mostly in the class of saline alkali, with a small part in the continuously waterlogged class. Soil conditions likely were worse in 1942 when the airport drainage system was installed than in 1913.

The vegetative growth covering these grounds was very low quality grasses with intermittent patches of tules. By way of comparison, such land is now worth about $80-90 per acre as compared to $500 per acre for

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high-class farm land. On a basis of pasture productivity, even $80 per acre could not be economically justified. All the effects of saline alkali soils were evident in the vegetative cover. Salt spots over the entire airport area are visible on aerial photos taken in 1939.

The tile drainage system installed by the Logan-Cache Airport represents the first major attempt to drain the lands overlying the artesian basin in the lower Cache Valley by other than pumping methods.

Description of the airport drainage system. The airport is made up of three landing strips in triangular shape and three taxiways as shown on Map 5. Each landing strip is drained by four longitudinal covered tile drains. The two inside drains are at the edge of the pavement strips and the outer drains are 255 feet from the centerline of the strips. Thus the inner and outer lines are spaced 176 feet apart. The tile trenches are backfilled with gravel to expedite rapid removal of surface water. Also, a shallow gutter enclosing the entire area intercepts waters running onto the field from adjoining lands.

Mr. Floyd Hansen, the airport manager, states that to survey the tile lines it was necessary to wade through swampy water. A general description of the main tile drains is as follows:

(a) Average length = 5500 ft.
(b) Spacing = 170 ft.
(c) Depth range = 4.5 to 10 ft.
(d) Size range = 12 to 36 in.
(e) Total length of drains = 18 miles (approx.)

Present conditions of soils and vegetation. In 1951, 175 acres of alfalfa and grasses were seeded at the airport. A fair stand of alfalfa is now growing on land which formerly would support only tules, cattails, or low grade grasses. About 100 acres of the area is classes as the best land by Mr. Floyd Hansen, airport manager. He said 3600 bales of alfalfa

were harvested from the acreage in 1952 as compared to 6000 bales in 1951. The cause for the marked reduction in stand in 1952 was due primarily to drought and in a small part to weed invasion of border areas. This makes a 1.5 to 2.5 ton per acre growth of alfalfa, which is a low yield for dry farming. On the other hand, it must be remembered that any growth at all of such a crop as alfalfa is significant on soils most of which were originally classified as saline alkali, and which were considered to be impossible to drain by any method other than pumping. The alfalfa was never irrigated and signs of drought were apparent. The upward movement of water was so slow that it was insufficient in quantity to supply the vegetative cover requirements.

In 1949 a soil survey was made of the airport, but the survey was made of just the texture and the depth to water table or inhibiting soil layers beneath the surface. A thorough study of saline alkali conditions would, no doubt, furnish useful information to a study of reclamation of these soils.

Study and conculsions made by J. P. Riley. J. P. Riley, research assistant and graduate student in civil engineering, made a study on the effectiveness of the airport drainage system. He installed sixty piezometers between tile lines to obtain a drawdown curve for the lines as well as to make a study of hydraulic gradient characteristics in the soils above the 40 ft. aquifer.

A soil profile was made to the artesian aquifer. In general this profile indicated that the upper ten feet were more permeable than the deeper soils. A 5 ft. layer immediately above the aquifer is also less permeable than the clay soil from 10-35 ft. depth. Sand lenses are struck occasionally, but these lenses appear to be so intermittent as to be of little value for drainage purposes.

On April 28 a well drilled near the buildings at the airport broke a mud seal around the casing and flowed a substantial stream. Almost immediately piezometer readings 1600 ft. away dropped 2 ft. and continued to drop slowly until July 10 when they were 4 ft. below their April 27 reading. Thus pressure changes are readily transmitted through the highly permeable aquifer.

The airport drains act only to remove surface waters; no water is removed from the soil. During the entire period of investigation from December 1951 to July 1952 the water table remained below the level of the tile drains. Of course no drawdown curve existed. It appears, at least for part of the area in which the airport is located, that surface drainage may be adequate.

The artesian pressure, after even such a wet winter as that of 1951-52, was not able to raise the water table above 6.5 ft. from the surface. It would appear that adequate drainage of surface waters such as the spring melt may be part of the answer to drainage of a large section of the Logan-Hyde Park-Benson area. This is especially true of areas which are classed as continuously waterlogged or fluctuating water table lands, yet not classed as saline alkali. Saline alkali lands present the leaching problem.

## SOURCES OF EXCESS WATER

Average monthly and annual diversions by canals above the problem area

One of the basic questions to be answered in a drainage study of this area is the amount of water supplied to the artesian aquifers by excess irrigation on the higher lands. This is especially true since upward flow from the 40- to 60-foot aquifer is the principal source of difficulty for almost half of the area and upward gradients exist beyond the limits of this aquifer.

Logan-Hyde Park-Smithfield Canal. The only canal with any record of flow measurement is the Logan-Hyde Park-Smithfield Canal. Since this canal is diverted above the Geological Survey gaging station, it must be measured daily by the Geological Survey to obtain the total stage of Logan River. The records on this canal extend back to 1920.

The average monthly flow of the Logan-Hyde Park-Smithfield Canal is shown on figure 2. A study of the records indicates a slight decline in total annual use during the more recent years. The average annual use for the 30 years is 20,820 acre feet. The area under the canal has probably changed very little in the 30 years and is given by the Utah Irrigation Company Survey (see reference 10) as 3060 acres. This represents an annual use of 6.81 acre feet per acre. Little comment need be made about the excessiveness of this use.

Several reasons might be given for the high water use. First, the foothill areas and higher lands are of coarse-textured soils. The 1913 soil survey gives the following mechanical analysis for the major soil type (Trenton gravelly loam) of this area: 4.4% gravel, 31.7% sand,

48.9% silt, and 15.2% clay. In order to satisfy plant needs, more water is required on these highly permeable soils than on the finer textured soils. Secondly, there is a natural tendency for farmers to over-irrigate rather than to under-irrigate. This tendency is emphasized by the failure of most farmers and irrigation companies to measure water; and also by the lack of knowledge on the part of farmers about the water requirements of various crops.

Two of the five irrigation companies watering the upper lands, have stated needs for additional water requirements.

Total diversions by the five canal companies. As stated above, only one of the five canals is closely measured throughout the year. However, it is still possible to approximate rather closely the total diversions by the canals for an average year. When the stage of Logan River reaches 400 cfs, the Kimball Decree of 1922 takes effect and the various irrigation diversions are carefully measured to equitably distribute the flow. For the past 30 years, the average date when the river has reached this stage has been June 30. Anderson (1) in a B. S. Thesis, 1938, studies the characteristics of the recession curve for Logan River. He found this curve followed very closely the curve shown in figure 3. This fact is very useful in determining the total diversion of the five canals for an average year. The average stage of the river on September 30 has been 155 cfs. Knowing the average date the 400 cfs stage is reached, the characteristic regression curve, and also the average stage on September 30, makes possible the drawing of an average annual recession curve.

The Kimball decree divides the flow according to the river stage from 400 cfs down to 90 cfs (see Table 1). By use of the average recession curve, it is possible to accurately compute the average

diversions by the upland canals (see Table 2) from June 30 to September 30. Water rights held by Anderson Bros. Lumber Co. have been transferred to the Logan Northwest Field and Benson Canal Co. In order to obtain the May and June diversions, it was necessary to call the irrigation company officials of each canal. The general practice is to run the ditches nearly full through both May and June. As much water is diverted during May and June as during the remaining three months of the irrigation season. Irrigation company officials maintained that there was little waste water leaving the end of the canal during May and June. Sometimes during April or early May a week is taken for ditch cleaning. Total ditch capacity for the 5 contributing canals is 348 cfs. During May, a flow of 250 cfs was assumed and during June a flow of 300 cfs. The Logan and Northern Canal uses only 44.6 per cent of its water south of Smithfield.

Total diversions by the upland canals for five growing season months are 53,995 acre feet for 10,150 acres or 4.66 acre feet per acre.

Consumptive use estimate. A great deal of time was spent trying to find acreages by crops of the Logan-Hyde Park-Smithfield area. Surveys, some of which have cost great sums of money, have been made of crop acreages. One of these surveys had 83 three-man crews making statewide plane table surveys of crop layouts and over 100 men doing the office work for the survey crews. The work took an entire summer. Today this information cannot be found in local or state offices. The government agencies concerned had "thrown out these maps or had lost them."

The only information to be found was one PMA report for 1940 giving the crop acreages by areas (such as the Hyde Park area, North Logan area, etc) for 80% of the farmers. From this report, crop divisions

appear to be about 50% alfalfa, 20% grain crops, and 30% sugar beets, vegetable crops, corn, orchards, etc. Figures on consumptive use of these crops as taken from Reference 19 indicate: 25 inches for alfalfa, 15 inches for grain, and 20 inches for corn, sugar beets, etc.

| | | |
|---|---|---|
| Alfalfa 5079 acres @ 25 inches = | 10,600 | acre feet |
| Grains 2032 acres @ 15 inches = | 2,705 | |
| Corn, sugar beets, etc. 3047 acres @ 20 inches = | 5,080 | |
| Total use by plants | 18,385 | acre feet |

Of 53,995 acre feet diverted only 18,385 acre feet is used by the plants. The remainder of this water (35,610 acre feet) is lost primarily to deep percolation.

Artesian aquifer pressure head variations. Riley found that the 40- to 60-foot aquifer pressure head at the airport varies according to the time of year (see figure 4). The pressure head is highest during the fall and early winter, and lowest during the late winter and early spring. Its highest peak was recorded in November and its lowest in May. Dr. Willard Gardner has found the same to be true for an open well in North Logan. The water level in the well varied as a sine curve. The depth varied from 104 feet from ground surface to water level on April 1, 1952 to 96 feet on August 15, 1952. On November 3, 1952, the water level was 96.5 feet below the ground surface compared to 105 feet on April 1, 1953.

It is significant to note that the aquifer receives its recharge during the irrigation season. The pressure head in the aquifer is lowest during May and June and highest from August to November. This would appear to indicate that excess irrigation might well be a major water contributor to the 40- to 60-foot artesian aquifer. There has been a diversity of opinion on the major source of supply for the aquifer. Further studies on pressure head variation should be made not only on the 40- to 60-foot aquifer but on other significant aquifers as shown on the

well log profile sheets (figures 5, 6, 7, 8 and 9).

Canal losses and suggested repairs

Huang (6) made a study on "Problems of Seepage Losses and Lining of Logan and Northern Canal," and found the average permeability of the canal top soils to be k = 1.06 ft./day, which was close to those obtained by permeameters (k = 0.98 ft./day). The maximum seepage loss measured was 4.83 $ft^3/ft^2/day$ at a water depth in the canal of 2.5 feet. The minimum measurement was 1.01 $ft^3/ft^2/day$ at a water depth of 0.5 feet; a value of 2.0 $ft^3/ft^2/day$ water loss was assumed for the entire canal. This represents a loss of 6000 acre feet for the 13-mile canal over a 150-day irrigation period. The irrigation company has stated a need for 1480 acre feet of additional water. Huang concludes that the value of the water saved by lining would economically justify lining of the entire canal either with bentonite or soil and cement. Six thousand acre feet of water ($12,000) would be saved annually by lining.

Suggested improvements on other canals (10) are as follows: The Logan and Northern Canal needs 1 mile of canal lining and several outlets replaced; the Logan-Hyde Park and Smithfield Canal has seepage loss troubles over its entire length; and the lower canals need headgate replacements. Without doubt, canal losses from the upper two canals more than account for the shortage of water claimed by these two irrigation companies.

Also, flow during the winter months in these canals, however small, increases canal losses to the aquifer. As seen from figure 2, the average flow during the winter months is several second feet in the Logan-Hyde Park and Smithfield Canal. Even though the diversion headgates of the lower canals were closed during the winter of 52-53, these canals still had flows varying from 2 to 7 second feet a few miles downstream. This flow represents mostly ground water seeping into the canals.

Excess surface waters

Canal waste ditches for three of the canals cut across the drainage area. The Hyde Park Canal waste ditch runs due west of Hyde Park. It is used partially to irrigate some of the pasture lands, and it ends in Hopkins slough. The Logan Northfield Canal outlet enters the drainage area just east of the airport. It crosses under the airport in a concrete pipeline and terminates in the Benson Canal.

Much of the problem area is very uneven with numerous depressions, mounds, and irregular topography. The valley slopes more and more gradually toward its center. Because of the uneven topography and the comparatively level slope of the valley bottom, poor surface drainage for the spring snow melt and spring precipitation is afforded. This poor surface drainage considerably aggravates the drainage problem. When the water moves very slowly or stands on the land surface, it has much greater opportunity to infiltrate into the soil. Thus, the water table rises and the lands remain wet late in the spring and early summer. An axiom of drainage, especially when pertaining to fine textured soils, is that it's much easier, more economical and satisfactory to arrange for rapid drainage of surface waters, than it is to drain these soils after the surface water has seeped into the soils and become ground water.

In Cache Valley the major precipitation occurs during the winter and spring months. The winter precipitation is generally in the form of snow, most of which remains on the land until the spring snow melt. Adequate surface drainage to carry off the spring snowmelt and precipitation would without doubt be a substantial contribution to the overall problem.

Throughout the area there are numerous flowing wells and a few springs. The flow from any one artesian well isn't significant, but the aggregate flow is. Several springs which are located toward the eastern

boundary of the area, yield significant flows. The total flow, comprised of artesian well discharge, spring flow and waste irrigation water, inundates many acres of pasture land in the central area for the entire year. Needless to say, such areas are in extremely poor condition.

## ARTESIAN AQUIFER STUDY

In 1935 legislation was passed requiring the filing with the State Engineer's Office on all wells (artesian and non-artesian) drilled prior to that date. The law also required all those desiring to drill to file an application with the State Engineer. When the well was completed its log was to be sent in by the well driller. Good well-log information is available on early all wells drilled since 1939, but logs of wells prior to that time generally do not exist. Most of the information on well logs contained in this report was obtained at the State Engineer's office at Salt Lake City, Utah. In 1946, William Peterson, Extension Director Emeritus at the USAC, published a bulletin entitled "Ground Water Supply in Cache Valley Utah" (15). This bulletin contains valuable information on artesian wells and artesian conditions throughout Cache Valley. The careful investigation of the artesian aquifers underlying the area is of vital importance to this study, since the drainage problem of a large portion of the area is due primarily to upward flow from these aquifers.

### Aquifer boundaries

Map 12 shows the approximate boundaries of wells of various depths. The 30- to 80-foot well boundary probably represents fairly closely the approximate line where the 40- to 60-foot aquifer pinches out. The 80- to 200-foot well boundary lines appears to be the zone where the first major aquifer below the 40- to 60-foot aquifer pinches out. The 200- to 300-foot wells have no general location but are widely scattered over the entire area. The 300- to 400-foot wells are localized around the

Benson area, as are the 400-foot and deeper wells. The boundary lines are nicely defined except for the 200-300 ft. group.

Upward hydraulic gradient problem

Fourteen batteries of piezometers were driven throughout the area as shown on Map 8. The primary purpose of these piezometers was to determine the extent of the upward hydraulic gradient over the area. Each battery consists of a 7 and 14 foot piezometer, except for No. 8 where an additional 21 foot length was used. Battery No's. 1 to 6 are located above the 40- to 60-foot aquifer. Numbers 7, 8 and 9 are located along the Salt Lake Base Meridian. Numbers 10, 13 and 14 are located along the Benson Road running south to the Valley View Highway and No's. 11 and 12 are located in the Benson area.

A problem exists in the readings of these piezometers. On March 31st significant upward pressure was found at 5 batteries; whereas, on April 15th only 2 batteries showed upward pressure. Dr. Willard Gardner drove 3 sets of piezometers during September, 1952. Readings were taken frequently on these batteries. A difference of 2.5 feet upward head was read between a 14 and 9 foot battery in December, as compared to a difference of 25 feet in March. This battery was located near the W½ of Sec. 19 T12 N. R 1 W. Another battery, located near the W½ of Sec. 14 T12 N. R 1 W, varied from an upward pressure difference of 4.0 feet in November to a downward pressure of 0.25 feet in March. The third battery, located near the W½ of Sec. 13 T12 N R 1 W, varied from 0.5 feet upward head in October to 3.75 feet upward pressure head in March.

Because of the variations in the hydraulic gradient indicated by Dr. Gardner's studies, it would be difficult to draw accurate conclusions from the short time period covered by this piezometer study. It is recommended that these piezometers be read weekly over a years period to

obtain useful information on hydraulic gradients and hydraulic gradient variations at various times of the year. The shallow aquifers tend to pinch out before the valley bottom is reached. These aquifers are gravel lenses, and have much higher yield than the bottom land sand lenses. No gravel lenses extend west of the 80- to 200-foot lense.

First gravel aquifer

The yield of ninety-nine 30- to 80-foot flowing wells is 2070 gallons per minute (4.6 cfs) or an average discharge per well of 20.9 gpm. Israelsen pumped 4.5 cfs from a 14-inch well in 1930. He concluded from his experiments that such a well would drain approximately 470 acres. Thus the specific yield of pumped wells from this aquifer is very promising.

The quality of water in the aquifer is excellent for irrigation purposes. Israelsen (9, p.14) found this to be true in 1930. Samples taken from the 1930 well during January of 1953 showed a conductivity of 580 micromhos per centimeter. As far as total dissolved solids are concerned, this water is first class for irrigation use.

Computations on the quantity of water flowing upward through the soils from the 40-foot aquifer near the airport, indicate an average value of 2.82 acre-inches per acre per month. This value is obtained by using the average hydraulic gradient found by Riley (18). The permeability was assumed to be $1.71 \times 10^{-7}$ feet per second (9). The alfalfa growing on the airport suffers from lack of water during the summer months.

The yearly addition of salt to the soil each year is found to be about 1.54 tons per acre. This value is found by using the water conductivity found in January, 1953, and the quantity of water flowing up through the soil given above. Figure 10 shows the head loss of several east-west 30- to 80-foot well lines.

Second gravel aquifer

The aquifer underlying the 40- to 60-foot aquifer is a gravel lense also. It yields 6036 gallons per minute (13.5 cfs) from 97 wells--an average of 62.2 gpm per well. Several wells are pumped and have comparatively high yields. One 13-inch pump well yields 639 gpm.

The deep sand lenses in the valley center have low yields. Nineteen 300- to 400-foot wells yield 75.4 gpm (.17 cfs) with an average of 4.0 gpm per well. Fifty-eight wells deeper than 400 feet yield 169.1 gpm (.38 cfs) with an average of 2.9 gpm.

## NATURAL SURFACE DRAINAGE

As indicated in a previous section, natural drainage of the area is aggravated by uneven topography and rather flat slopes. There are only two main natural drainage channels for the area, viz: Hopkin's Slough and Swift's Slough (see Map 6). These sloughs vary in depth from 2 to 8 feet. The depths are far too shallow, considering the distances on each side of the sloughs from which any surface drains would have to be brought. Even if they were deeper, a more comprehensive system of surface drainage mains is needed. Cache County Drainage District No. 2 design spaced the open ditch mains approximately one-half mile apart. Hopkin's slough and Swift's slough are two miles apart at closest; and Swift's slough drains land three miles south and east of it. The channels of laterals coming into the sloughs are shallow and often indistinct.

A map showing the areas where water stands or moves very slowly during the spring season, would be very desirable. Because of the unusually mild winter, it was not possible to obtain that information this year. Poor surface drainage appears to be general over most of the area.

## SOIL SURVEYS OF THE AREA

The only soil survey to date which has covered the entire problem area is the 1913 Cache County Soil Survey (14). This survey is very old, and methods and classification procedures have since changed. The U. S. Bureau of Reclamation "preliminary" surveys today are more thorough and comprehensive than the 1913 survey. And it is general practice for the Bureau to also make a "detailed" survey during the final stages of study of a drainage project. In 1949 a preliminary soils survey following U. S. Bureau of Reclamation standards was made which covered the area north of a line running east and west through the south boundary of the airport (see Map 11).

Arrangements have been made with Professor LeMoyne Wilson of the Agronomy Department at the Utah State Agricultural College to have his soil classification class take the Logan-Hyde Park-Benson area as their classification project. Ten sections will be classified this spring by the class. This survey will be available at the end of May.

The 1913 survey has information on soil classes, saline conditions and drainage conditions. The 1949 survey contains information on land use, slope, water table depth, salt percentage, Ph, and soil types (table No. 3).

Saline conditions

The 1913 soil survey map shows 3840 acres of the 20,000 acres needing drainage as saline or alkali. A map was traced from 1946 aerial photos outlining visible salt accumulations. A comparison of these two maps (see Map 7) shows that conditions have gotten worse since 1913. The

saline area in 1946 is nearly double that in 1913.

As would be expected, salt has accumulated over the lower fringe area above the 40- to 60-foot artesian aquifer. However, the "visible salt" area is by no means confined to the boundary of this aquifer. It extends from one to three miles west. High water table and upward flow are not confined to the 40- to 60-foot aquifer area either.

A study of the 1949 survey (Map 11) indicates a sizeable portion of the area is very low-class land. Class 1 land must have a pH below 9.0 with no evidence of black alkali present and total salts not to exceed 0.2%. Class 3 land, the lowest class of arable land, must have a pH of 9.0 or less, no evidence of black alkali, and total salts not to exceed 0.5%. An alkali condition automatically places land in Class 6. U.S.B.R. stand

Map 8 shows the boundary of the saline area and the boundary of cultivated crops. Most of the boundary crops appear to be grains. The boundaries generally coincide.

Water table conditions

In 1913, 20,000 acres in the problem area were seriously affected by a high water table (Map 1). Seventy-four per cent of the 20,000 acres was classified as continuously waterlogged and 19.2% was saline. Investigation for Cache County Drainage District No. 2 revealed that in October, 1921, 83.1% of the district lands had a water table less than 4 feet from the ground surface (Map 10). In April, 1922, 92.6% of the area had water tables less than 4 feet deep. Map 9 shows the water-table conditions for the northern three-eights of the overall area. Most of these readings were taken during the fall of 1949. Additional water table information on the southern and western parts of the area will be available at the end of May from the 10 sections now being surveyed by the soil classification students. These portions have not had water

table studies made on them since 1913.

For Class 1 lands the water table should be predominantly below six feet throughout the growing season. Class 2 requires it to be below 36 inches and Class 3 requires a predominant depth of 18 inches for the growing season.

Land classification specifications (Map 11)

Class 1 soils. The texture may vary from sandy loam to friable clay loam with a 36-inch depth of good workable topsoil. The pH should be less than 9.0 and the total salt not over 0.2%. Slopes should not exceed 4% and should be smooth and even. Only minor leveling should be required. The soil and topography should be such that no specific farm drainage requirement is anticipated. The water table should be predominantly below 6 feet during the growing season.

Class 2 soils. The texture may vary from loamy sand to very permeable clay with a 24-inch depth of good free working topsoil. The pH should be not in excess of 9.0 and total salts should be less than 0.5%. Slopes may be as high as eight per cent, but they should be smooth and even. Only moderate grading should be required. Drainage will probably be required but the cost should be moderate; water table depth below 36 inches.

Class 3 soils. Texture is loamy sand to permeable clay with 18 inches plus of good free working topsoil. The pH should be less than 9.0 and total salts should not exceed 0.5%. Smooth slopes up to 12% are allowable. Heavy expensive grading may be required in spots. Drainage generally is a necessity; it is feasible, though rather expensive.

Class 4. Land which has excessive deficiencies or restricted utility, but which special economic and engineering studies have shown to be irrigable. Classified as limited arable.

Classes 4, 5, and 6 are classed as non-arable lands. These lands are considered to be economically unfeasible to drain.

Suggested further soil studies

Twenty sections remain to be classified south and west of the 1949 soil survey. Ten of these will receive a preliminary survey this spring. It would be very desirable to have the Soil Classification class complete the remaining ten sections next year. A complete preliminary survey of the area would be of great value.

Preliminary soil surveys are used as indicators of the feasibility of a project. If the project appears to be economically sound, then a detailed survey should be made.

Permeability determinations

Permeability determinations were made on disturbed soil from six locations over the area.

| Depth | Location | Type Sample | k(ft/sec) |
|---|---|---|---|
| 1'-0 | Piezometer 1 | disturbed | $55.0 \times 10^{-7}$ |
| 3'-0 | Piezometer 1 | disturbed | $11.3 \times 10^{-7}$ |
| 5'-0 | Piezometer 1 | disturbed | $1.71 \times 10^{-7}$ |
| 1'-0 | Piezometer 2 | disturbed | $1.58 \times 10^{-7}$ |
| 3'-0 | Piezometer 2 | disturbed | $151 \times 10^{-7}$ |
| 5'-0 | Piezometer 2 | disturbed | $6.38 \times 10^{-7}$ |
| 3'-0 | Piezometer 4 | disturbed | $45.5 \times 10^{-7}$ |
| 5'-0 | Piezometer 4 | disturbed | $44.7 \times 10^{-7}$ |
| 2'-6 | Piezometer 8 | disturbed | $.01 \times 10^{-7}$ |
| 5'-0 | Piezometer 8 | disturbed | $.47 \times 10^{-7}$ |
| 6'-0 | Piezometer 8 | disturbed | $.41 \times 10^{-7}$ |
| **1'-0 | Piezometer 10 | disturbed | $1.403 \times 10^{-7}$ |
| *1'-0 | Piezometer 13 | disturbed | $.292 \times 10^{-7}$ |

* The permeability of this sample decreased with time, varying from $.89 \times 10^{-7}$ feet per sec. to $.23 \times 10^{-7}$ feet per second 12 days later.

** The permeability of this sample increased with time, varying from $.98 \times 10^{-7}$ feet per sec. during the first 15 hours to $3.33 \times 10^{-7}$ feet per sec. to $.23 \times 10^{-7}$ feet per second 12 days later.

These permeabilities are very low and indicate the low rate of movement of water through the fine-textured bottom land soils. Results shown here are somewhat lower than the permeabilities computed by Israelsen ($1.71 \times 10^{-7}$ ft/sec.). One undisturbed sample was taken which gave a much lower permeability value than the disturbed samples. See Map 8 for locations of piezometers where permeability samples were taken.

## DRAINAGE PROJECTS IN THE AREA

### Logan-Cache Airport (18)

The most successful drainage project in the area is the Logan-Cache Airport. Land which originally showed salt spots over its entirety, now shows very few salt spots. And most important, this land now grows fair crops of dry farm alfalfa. The airport drainage system is tile backfilled with gravel. The cost of the system would be prohibitive to farmers; but, on the other hand, the fact remains demonstrated that these lands may be successfully drained. It appears too, that these lands could be drained much cheaper, since the airport gravel covered tile drains serve only to remove surface waters (18).

### Riggs' drain

During the fall of 1952, the Soil Conservation Service investigated and surveyed a proposed drain for Lewis B. Riggs of Benson. The drain consisted of 600 feet of tile forming a "T" with 3,300 feet of open drain. The tile is 6.5 feet deep and is 125 feet south of the Benson Canal. The open drain varies from 6.5 to 8 feet deep. S.C.S. workers and research specialists were skeptical of the success of the drain because of the low permeability clay soils. Water table depths during the investigation are shown on Map 14.

Mr. Riggs was very much interested in the success of the drain, and therefore dug seven-foot-deep auger holes on a grid pattern as shown on Map 14. He has read the water table depths several times each month since November 27, 1952. The results of these readings until April 11, 1953 are shown in Table 8. Draw down curves for this drain (the open portion) are shown on figure 11. These curves show a drop in water table of 2.6

feet and 2.0 feet for a distance of 240 feet. There has been no water in the canal since September of 1952 and the winter of 52-53 has been very mild. Therefore the readings taken up until April lack the influence of the canal and of very wet winter weather. However, water is soon to be turned into the canal and Mr. Riggs intends to continue taking readings. The final results of two or three years of study on this drain should be of great value in answering the question of whether open and tile drains are economically feasible for draining these clay soils.

With a mild winter and no water in the canal the open drain appears to have a drawdown effect for at least 480 feet.

Reese open drain

P. A. Reese of Benson states that he dug a ditch barely 3 feet deep across the upper end of a very low grade pasture. It is not possible to get greater depth because of outlet restrictions. This drain did little more than regulate irrigation, which previously had continuously flowed onto the pasture as waste water from the upper lands. The season after digging the drain, Mr. Reese planted improved grasses on the pasture, and now the pasture which previously grazed only one cow for every two acres, is easily grazing two cows per acre.

There have been very few attempts to drain any of the clay pasture lands. The airport affords an interesting study of reclamation of the area. Also the Riggs' drain should, with careful study, give much needed information on this drainage problem.

## ECONOMIC STUDY OF DRAINAGE

The question of whether the Logan-Hyde Park-Benson area can be drained or not is largely economical. Almost any land can be drained, but the costs of drainage of some land would be excessive. The airport drainage system affords strong evidence that much of the large area can be drained. The question of cost is not answered by the airport system, since its cost per acre is far beyond a farmer's means. The economics of drainage of this area is subject to debate. In 1921 the ratio of benefits to cost as given by the investigating engineers was about 3:1. However, the Bureau of Reclamation place a large portion of the lands of the area in Classes 4 and 6 (Map 11). According to their classification, lands in these classes are not economically feasible to drain.

Lands in this area now sell for $100 to $200 per acre. If these lands were reclaimed, their value would be increased many fold. Good grade pasture land sells from $250 to $400. The land value should easily double itself with adequate drainage.

If the lands were drained by pumping, and by shallow surface ditches, drainage might well prove economically feasible. The water pumped should pay the cost of pumping. Land-leveling and a network of satisfactory outlet drainage ditches would be the most costly. There is little doubt that pumping and surface drainage would improve the general area greatly. The land value could be easily doubled, and its productivity increased many fold. These facts should justify a substantial drainage outlay.

The Cache County Assessor's Office use the following land classification as a basis of taxation assessments:

Crop land (irrigated land)

| | | |
|---|---|---|
| Class 1 | (60 or more bu. of barley) | $90 |
| Class 2 | (48-60 bu. of barley) | 72 |
| Class 3 | (36-48 bu. of barley) | 54 |
| Class 4 | (24-36 bu. of barley) | 36 |

Pasture land (land too wet to plow)

| | | |
|---|---|---|
| Class 1 | (bluegrass & clover) | $45 |
| Class 2 | (broadleaf and wiregrass) | 36 |
| Class 3 | (salt grass) | 18 |
| Class 4 | (grease wood) | 8 |

These valuations given by the assessors office are about 20% of the actual value of land. However, these figures give a much better basis for the comparative producing value of land than current selling prices. Class 1 cropland is worth 11 times Class 4 pasture land. Class 1 cropland is worth 2 times Class 1 pasture land. The best grade of pasture, which is still too wet to plow, is worth almost 6 times Class 4 pasture and 2½ times Class 3.

Acreages for these various land classifications are not available.

## DRAINAGE METHODS FOR THE AREA

### Pumping for drainage and irrigation

Any reclamation design of the area should include as its backbone, pumping of the two gravel aquifers. Pumping from the 40- to 60-foot aquifer would relieve the upward pressure in that aquifer and at the same time supply irrigation water for the drained land. The 80- to 200-foot aquifer, too, is promising as a source of irrigation water. If these lands are drained, provision must be made for their irrigation. Few landowners in the area have water rights. Most of them depend on waste waters and sub-irrigation.

Israelsen estimates the quantity of water available yearly in the 40- to 60-foot aquifer to be about 20,000 acre feet (9). The amount of water in the next lower gravel aquifer has not been estimated; but flowing well yields indicate it should be significant. The question as to whether the valley bottom sand lenses can be profitable pumped is not known. The low average yield per flowing well in the Benson area and the thinness of the artesian sand lenses do not appear encouraging for pumping. However, if 40,000 acre feet were available from the two gravel aquifers, the irrigation problem for 13,000 acres or more would be solved.

### Surface drainage

Surface drainage appears desirable as part of the reclamation program to accompany pumping. It should consist of land levelling and shallow-surface drains. Surface drainage is desirable for several reasons: (1) the land should be levelled to facilitate irrigation, and (2) because of the slow permeability of the clay soils, the spring runoff and

irrigation waters should move off the land rapidly. The part surface drainage has played in reclamation of the airport soils is significant.

Surface drainage of low permeability soils of the midwest (2). In the Midwest whenever fine-textured soils of low permeability have been encountered, it has been found that adequate drainage of gently sloping to flat areas can be accomplished by using a complete surface drainage system. To accomplish removal of excess surface water the drainage system must be so planned and installed that the surface water will not be allowed to collect or stand on any area of the field. The key to surface drainage is to keep the runoff water running - moving off the field as rapidly as possible without causing erosion.

There are four general surface drainage systems used: (1) The bedding system, (2) Random ditch system, (3) Cross slope ditch system, and (4) The parallel ditch system. All of these systems are adaptable to regular farm operations, though the design of spacing etc. might be influenced by the type of crop to be grown.

The "Bedding system" is generally used on lands that are practically flat (0-1.5%) where the soils are slowly permeable, and where the tile drain is not economically feasible. The system is designed, constructed, and maintained so that the surface water drains laterally from beds similar to plow lands, into dead furrows. The dead furrows carry the water to an outlet ditch. Where land is flat and of low permeability the recommended spacing is about 300 feet, wider spacings allowed for more permeable soils. Width of the beds from center to center of the dead furrows is from 23 to 27 feet. The number of $3\frac{1}{3}$ foot corn rows with two allowed per dead furrow is generally 6 to 10. The number of rounds using two 14-inch plows is from 5 to 8.

The "Random Ditch System" is adaptable to depression type farm topography where holes are too deep for filling by land smoothing. The ditch should meander from one low spot to another.

"The Cross Slope Ditch System" is adapted to field of 4 per cent slope or less, where internal drainage is poor from the plow soil downward. The ditches run along contour lines through the field to a common outlet. For ease of farming operations the side slopes should be very gentle.

The "Parallel Ditch System" is adapted to flat, poorly drained soils in which there are many small shallow depressions. The field ditches should be parallel but not equidistant.

Network of large waste ditches. If any surface drainage projects for the area were to be successful, they would need a thorough network of large waste ditches. These ditches should have sufficient depth and capacity; and should be spaced close enough together. Perhaps the drains of Cache County Drainage District No. 2 might serve as a guide for such a network covering the entire 20,000 acres. The ditches should be spaced about ½ mile apart - seldom farther.

Land levelling and surface drainage of individual farms. The major portion of the area is uneven. In order to irrigate properly as well as to drain properly, the land should be levelled. In the midwest where there is sufficient rainfall, surface drainage designs need not be concerned with level land; however, here where irrigation is a necessity, land leveling too is very necessary. It appears, therefore, that the bedding system (2) after land leveling would be best adapted to surface drainage in this area.

Tile and open drains

Experts in drainage give the spacing of tile lines in clay soils as from 30 to 40 feet (4). Computations using $k = 1.71 \times 10^{-7}$ ft/sec.

give a spacing for tile drains of less than 25 feet. The spacing of open drains is approximately the same. Upward flow of water makes the problem more severe than a simple high water table situation. The general opinion of writers on drainage is that tile and open drains are not economically feasible for drainage of clay soils.

The Riggs drain should give valuable information on the effectiveness of deep open drains.

Soil ammendments, leaching, salt tolerant crops, etc.

Leaching of saline and alkali salts is a real problem because of the very low permeability of the clay soils. Saline soils low enough in salt content to allow salt tolerant crops to grow, will have crop roots to help make the top soil more permeable. Especially where deep rooted legumes may be grown, will this be ture. The airport soils were once covered with salt spots, but now have alfalfa growing on them. With proper drainage and good irrigation practice, the production of improved grasses, will certainly be made possible. Forage crops which are the most tolerant to salinity are alkali sacaton, salt grass, Nutall alkali grass, Bermuda grass and western wheat grass. Alfalfa, yellow and white sweet clover, and Hubam clover are all moderately tolerant of salt (18).

The alkali areas will require soil ammendments. Table 5 shows the analysis of soils in Sec. 8 T 12 N R 1 E where black alkali covered much of the ground surface. These samples were taken near piezometer battery No. 5. The clay complex had a sodium percentage of 47. To replace this amount of exchangeable sodium, 11 tons of gypsum would be required and 2.05 tons of sulphur (20).

Leaching of the soils would probably require several years. Improved grasses mixed with deep-rooted salt-tolerant legumes would increase the productivity of the land for pasture or hay cropping.

Positive education program

By all means an active research program should be continued in the Logan-Hyde Park-Benson area. The surface has just been scratched. In order that farmers may know of the work being done and the interest of the College in the area, progress reports should be published periodically. These reports could well be in the form of bulletins especially written for the farmer. Such bulletins should be written so any farmer could understand and be interested in them. Most of our present literature on drainage is for the technical man and not the farmer.

A very desirable project would be the purchase and management of a farm in the area, on which drainage and reclamation experiments could be carried out. This farm could serve two purposes:

(1) various reclamation experiments for the area could be carefully planned and supervised by experts from the college in agronomy and drainage;

(2) the farm could serve as a demonstration to farmers.

If reclamation experiments proved successful, such a demonstration would be very effective as an educational measure.

Individual drainage projects by farmers should be encouraged; and where ever possible, data should be collected on the project effectiveness. Such a project is the Riggs drain previously mentioned. Interest shown by College experts in individual projects may encourage others to drain. As the soil becomes less saline, and the soil structure improves, higher cropping practices might be used. County Agents from Holland, while visiting the area, said we should be farming these potentially fertile lowlands in preference to much of the upper land area.

## SUMMARY AND CONCLUSIONS

1. The water-logged area. Twenty thousand acres of lowlands lying in the center of Cache Valley are seriously in need of drainage. Most of this land has never been cultivated, but has served only as pasture since the first settlers moved into the valley. The drainage problem is complicated by several factors: first, the bottom land soils are fine textured lacustrine clays of very low permeability; second, over half of the area is seriously affected by upward flow from artesian aquifers; and third, the major part of the soils of the area have become saline, with some alkali areas.

2. Surveys and investigations. Some important surveys and investigations have been made in the area. A soil survey made by U.S.D.A. in 1913 gives an account of drainage needs and saline conditions at that time. The results of the investigations made for Cache County Drainage District No. 2 give water table depth information for 1922 as well as excellent contour maps of over 8000 acres. From 1930 to 1932 O. W. Israelsen and associates drilled many wells to the 40- to 60-foot aquifer; the most important of which was a 14-inch pump well. Their experiments indicated this aquifer to offer excellent pumping possibilites. Willard Gardner, D. S. Jennings and others have spent considerable time investigating artesian conditions. Frederick Bisal has prepared an M.S. Thesis on siphon drainage of the area. J. Paul Riley has recently concluded a study on the Logan-Cache Airport drainage system. He concludes that the gravel-backfilled tile drains served as surface water drains only.

3. Irrigation water sources. A study of the water use by five upper

land canal companies, indicates a use of 53,995 acre feet for 10,158 acres. Consumptive use estimates indicated than only about one-third of the water diverted (18,385 acre-feet) is used by plants and the two-thirds (35,610 acre-feet) is lost principally by deep percolation into the artesian aquifers. One canal company diverted 6.81 acre feet per acre and yet stated a need for 2,910 acre feet additional water. From these figures and from artesian pressure head variations, it would appear that excessive irrigation is a substantial contributor to aquifer recharge. These figures are on the conservative side.

4. Other water sources. Other sources of excess waters are: the snowmelt in the mountains, some of which undoubtedly finds its way into the aquifers; the snow melt and spring precipitation of the problem area itself, which because of uneven topography and level slopes moves very slowly off the land; springs and artesian wells, which flow the year around often innundating wide areas of land; and canal waste ditches which cut across the area.

5. Well logs. A study of well logs in the Logan-Hyde Park-Benson area gives approximate boundaries to some of the principal artesian aquifers. Wells ranging in depth from 30 to 80 feet, 80 to 200 feet, 300 to 400 feet, and 400 feet or more, show these definite boundaries. Piezometer studies have indicated artesian pressures not only above the 40- to 60-foot aquifer, but also west of this aquifer. These studies indicate, too, a wide seasonal variation in hydraulic gardient.

6. Pumping. The first gravel aquifer appears very promising for pumping. A 14-inch well yielded 4.5 cfs in 1930. This well lowered the piezometric surface effectively over 470 acres. The quality of water is class 1 for irrigation purposes.

7. Natural drainage inadequate. Natural surface drainage for the

area is completely inadequate. First, there are only two main drainage channels for the entire area, vix: Swifts' Slough and Hopkins' Slough. These sloughs are too shallow and too far apart. Second, surface drainage for much of the area is poor due to depressions, uneven topography and overall flat slopes.

8. More soil surveys needed. Soil survey information for the entire area is very inadequate. The 1913 survey furnishes little useful information. A soil survey of the north half of the area was made in 1949. This survey gives water table depth, total salts, pH, slope, land use, soil texture, etc. A large part of the area was placed in class 4 (limited arable) and class 6 (non-arable). Lands lower than class 3 are generally considered uneconomical to drain by the Bureau of Reclamation. No recent survey has been made on the south half of the area.

9. Salinity, water tables and premeabilities. Saline conditions have gotten steadily worse. The area showing salt spots has nearly doubled between 1913 and 1946. Water table conditions are given for 1913, 1922, and 1950. Permeability determinations were made at five locations over the area. Results indicated widely variable permeabilities.

10. Airport drainage. The Logan-Cache Airport is the most notable drainage project in the area. Land originally showing salt spots, now grows healthy dry farm alfalfa. Most of this reclamation has been the result of speedy removal of surface waters. Lewis B. Riggs of Benson installed a tile and open drain in the fall of 1952 in clay soil. Mr. Riggs is taking depths to water table weekly in a grid of auger holes. The effectiveness of this drain is yet to be determined, but the results should be of considerable interest. One farmer just by regulation of surface water pouring onto his land and by planting improved grasses quadrupled the productivity of his pasture land.

11. Land values. According to the county assessors valuation the poorest grade pasture land is worth 1/11 of class 1 irrigated crop land. It is worth 1/6 of class 1 pasture land. Much of the problem area could be improved several classes by improved surface drainage and regulated irrigation. By reclamation these lands should increase in value $100 to $300, to say nothing of the increase in productivity. The entire area is economically well situated. It appears that a substantial outlay for drainage costs would be justified economically.

12. Reclamation favored. A survey taken on ten of the more prominent farmers indicated that in general they were in favor of group action toward reclamation of the 20,000 acres. However, assessments for a drainage district would probably be high and without doubt many farmers would object strenuously. There is still a spirit of resignation to the condition of the land. Before any major effort is made to organize a group project, a thorough educational program should be undertaken. Newspaper articles, bulletins, progress reports, radio programs could all help. A tract of land purchased for experimental and demonstrative purposes would go far to "show" what could be done.

13. Research needed. A great deal of experimental work remains to be done before a conclusive design of a reclamation program for the area can be given. However, after preliminary studies a design can be suggested. Pumping of the gravel aquifers is necessary for two reasons: (1) the upward pressure head and hence flow from the aquifer would be relieved, and (2) the problem of irrigation water for a large part of the drained land would be solved. Certain legal difficulties will have to be overcome to allow pumping. Land leveling and a network of outlet waste ditches should be an integral part of the drainage design. Rapid surface drainage of snowmelt and spring precipitation is necessary in order to

let the land dry out in the spring time. Tile and open drains would theoretically have to be spaced too close together. A study of the Riggs drain should furnish some answer to the spacing question. In some locations soil amendments may be necessary. Leaching of salts by wise irrigation practices in conjunction with a good cropping procedure should hasten the reclamation period. At best the period required will be long. Even if the lands could be reclaimed only to first class pasture, the project seems desirable.

## SUGGESTED STUDIES

1. Further studies should be made on canal losses and irrigation efficiencies. If the maps prepared by AAA under the supervision of J. R. Barker in 1938-39 can be located, a good consumptive use study could be made to accurately determine excessive use.
2. Yearly pressure head variations should be studied on the 40-to 60-foot gravel aquifer, the 90- to 200-foot gravel aquifer, and on wells in the Benson area varying in depth from 300 to 600 feet. Such a study should help indicate the sources of recharge of the various aquifers.
3. The question of why upward pressures exist west of the boundary line of the 40- to 60-foot gravel aquifer should be studied.
4. Existing piezometer batteries and perhaps new installations should be read weekly or bi-weekly for several years to help answer the seasonal hydraulic gradient variation problem.
5. A soils survey of the southern half of the area is urgently needed.
6. An infiltrometer study of the area using U. S. Bureau of Reclamation filtrometers is needed.
7. A study of the cause of the mounds located in the E½ of sec. 19 T12NR1E could be made.
8. A graduate agronomy student could contribute substantially in a study of the area from an agronomist's viewpoint. Continued studies by irrigation and drainage students should be planned for.

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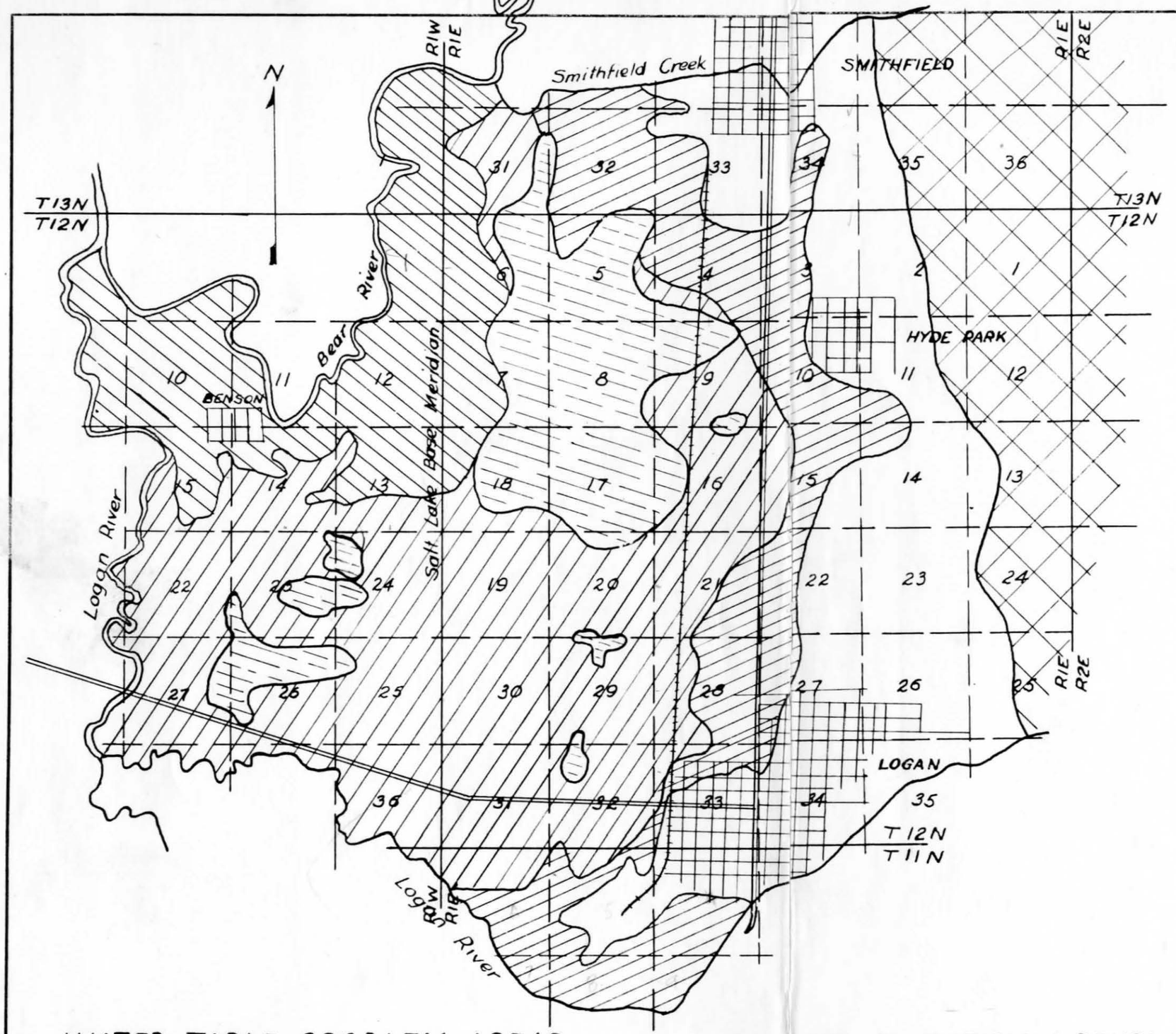



1 - Saline Alkali

2 - Continuously Waterlogged

3 - Fluctuating Water Table

4 - High ground bordering Bear R.

5 - Well drained

| Type | No Secs | Acres | Per cent | | |
|---|---|---|---|---|---|
| 1 | 6 | 3840 | 12 | 48% | 64% |
| 2 | 17 | 10880 | 36 | | |
| 3 | 8 | 5120 | 16 | | |
| 4 | 7 | 4480 | 14 | | |
| 5 | 11 | 7040 | 22 | | |
| | 49 | 31360 | 100 | | |

BASED ON 1913 SOIL SURVEY

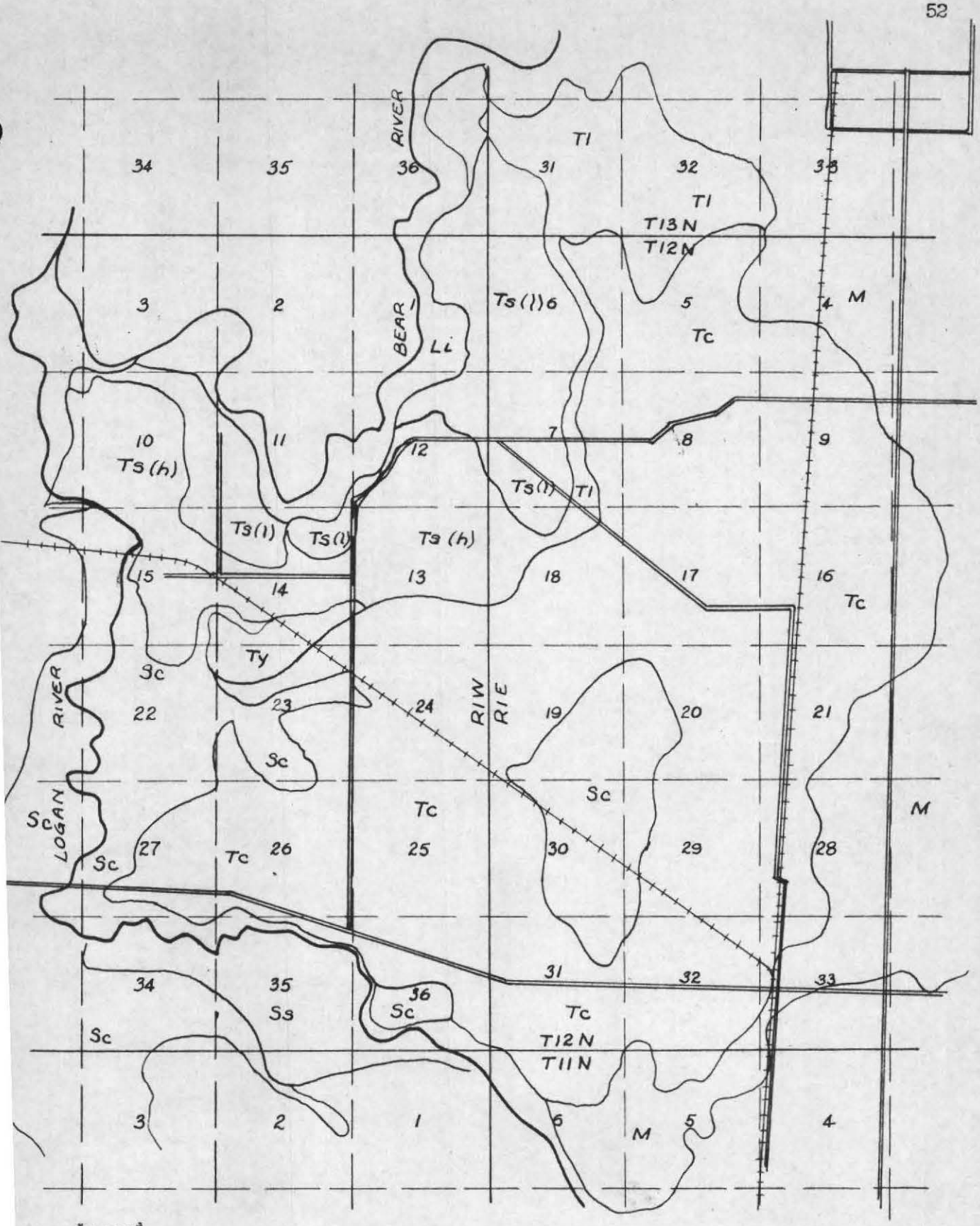
Map No. 1 Drainage needs as of 1913

**UTAH STATE AGRICULTURAL COLLEGE**
ENGINEERING DRAWING

DRW. BY G.H.B. DATE Feb 28 1952
SCALE 1" = 1 MI DRW. NO.

WATER TABLE PROBLEM AREAS - LOGAN, HYDE PARK, SMITHFIELD & BENSON

DIETZGEN 198M AGEPROOF

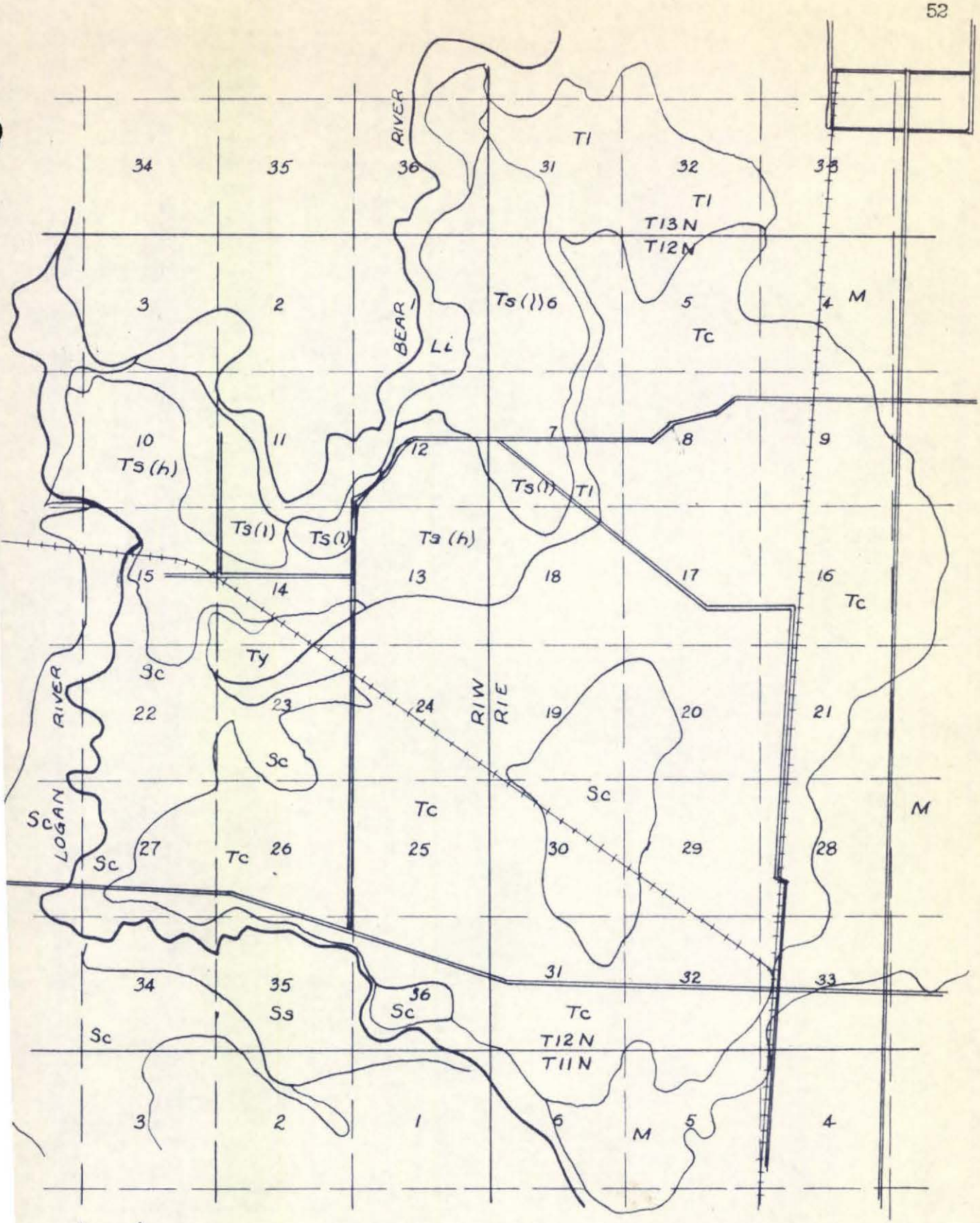



Legend

M Millville loam
Tc Trenton clay
Tl Trenton loam

Ts(h) Trenton sandy loam (heavy phase)
Ts(l) Trenton sandy loam (light phase)
Sc Salt Lake City clay loam
Ss Salt Lake City sandy loam

Map No. 2. 1913 soil classification.

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Ts(h) Trenton sandy loam (heavy phase)
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Sc Salt Lake City clay loam
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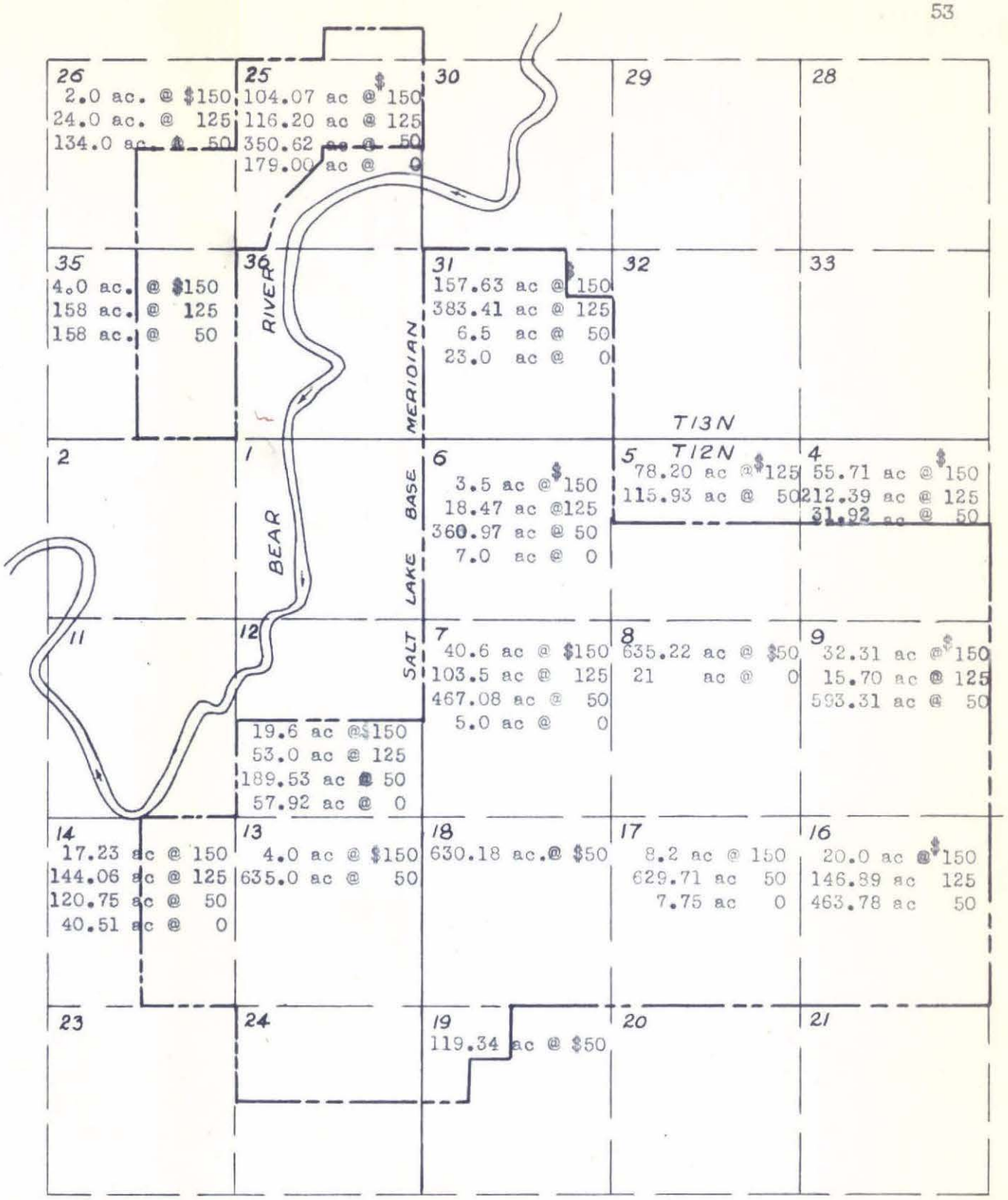
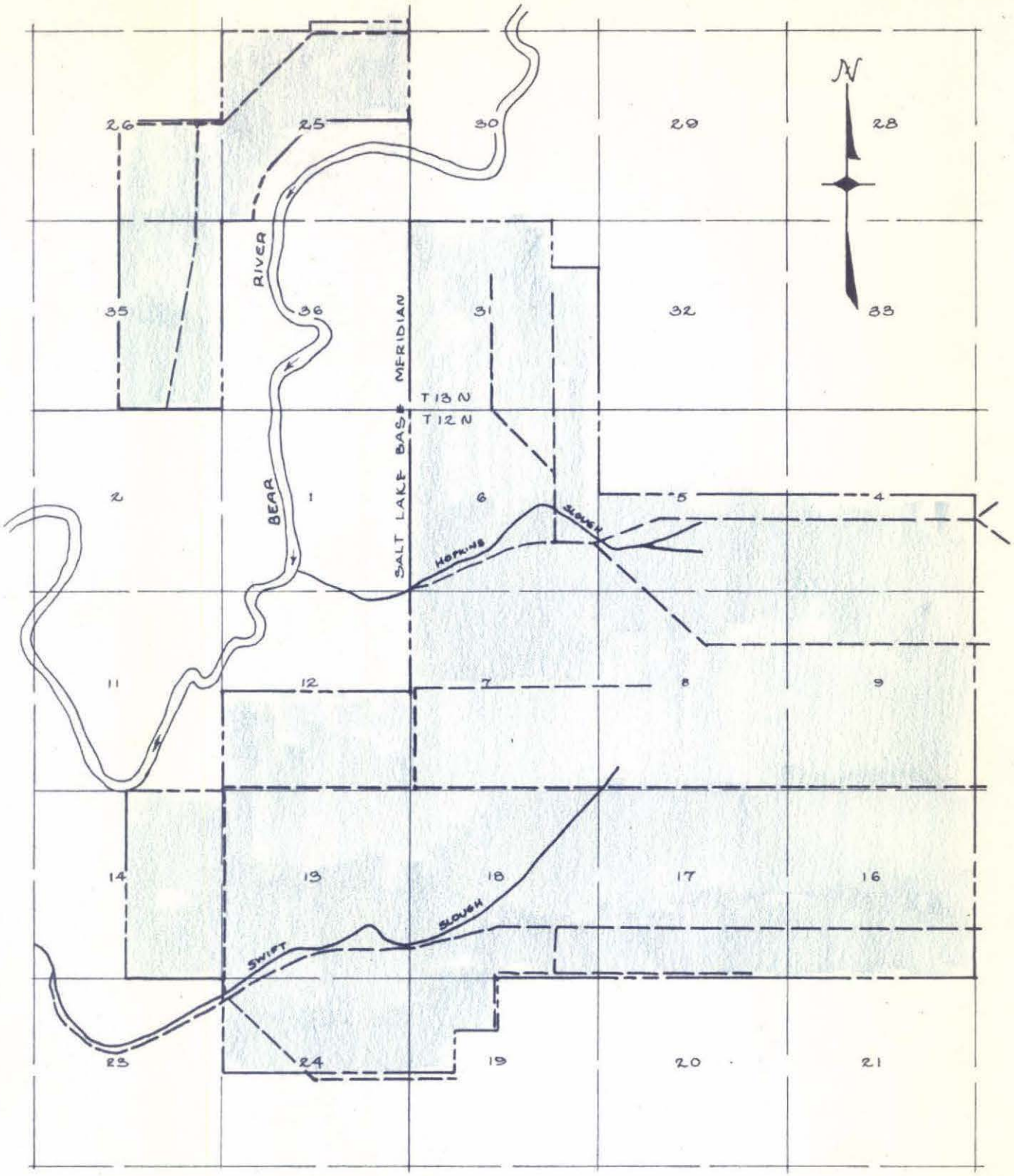
Map No. 2. 1913 soil classification.



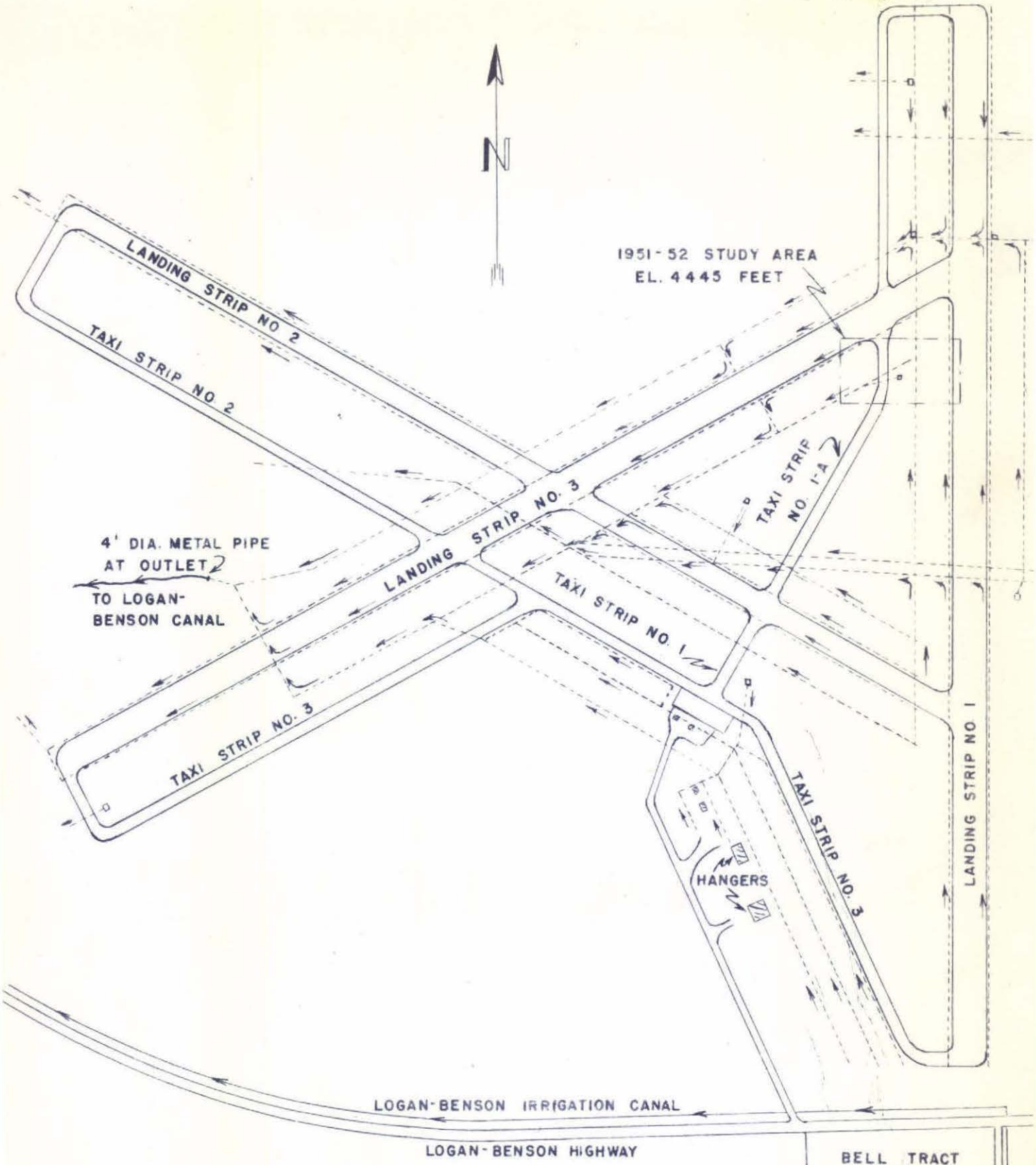

Map No. 3. Cache County Drainage District No. 2 (1922) Areas and assessments of benefits by Cache County Drainage District No. 2 obtained from Cache County Clerk's Record




District boundary

Open drains

Map No. 4. Cache County Drainage District No. 2 Proposed open drains.

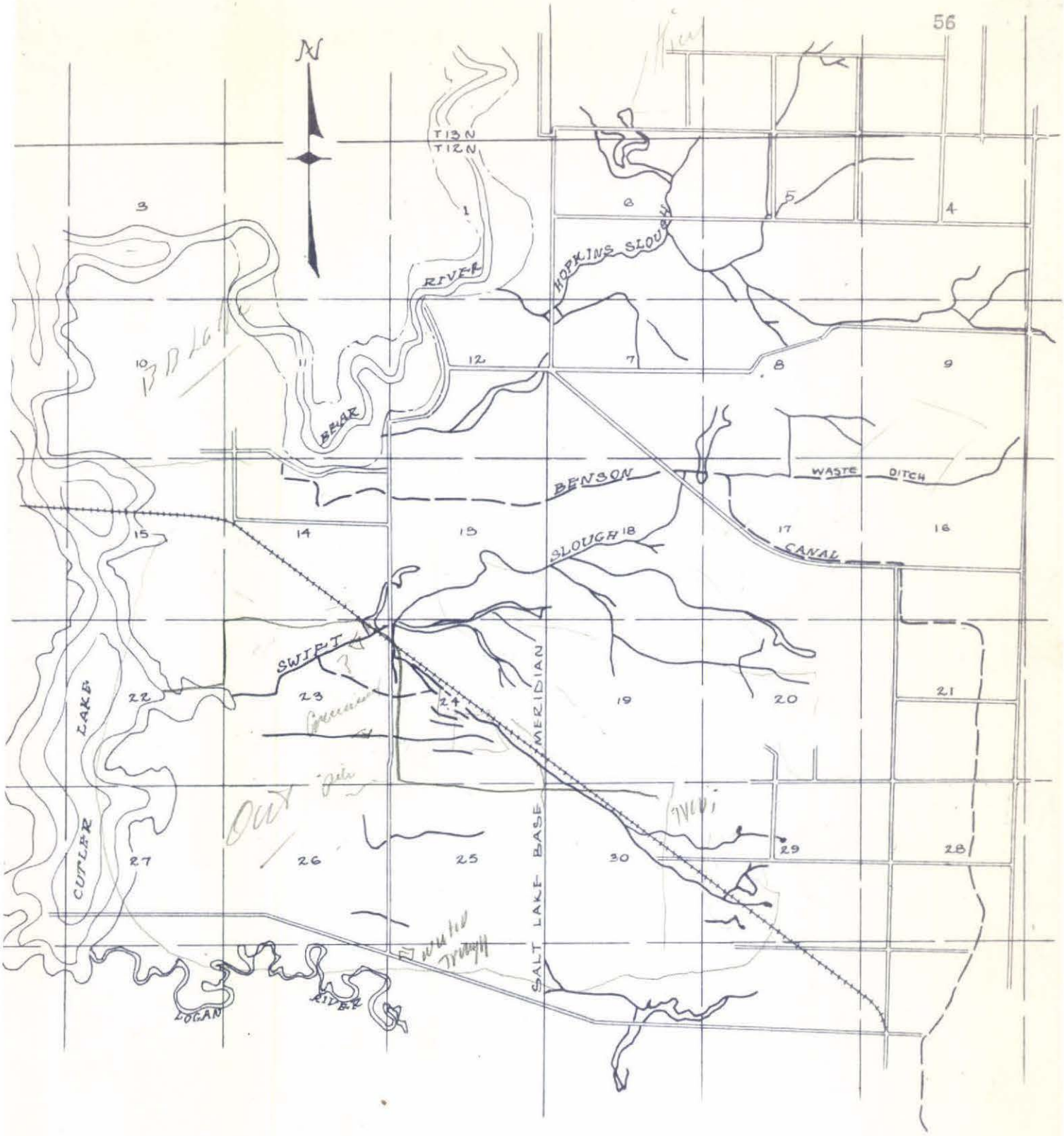



BELL TRACT
WATER-TABLE
MEASUREMENTS BY
ISRAELSEN, McLAUGHLIN,
GARDNER, & JENNINGS
IN 1930-32
EL. 4450 FEET

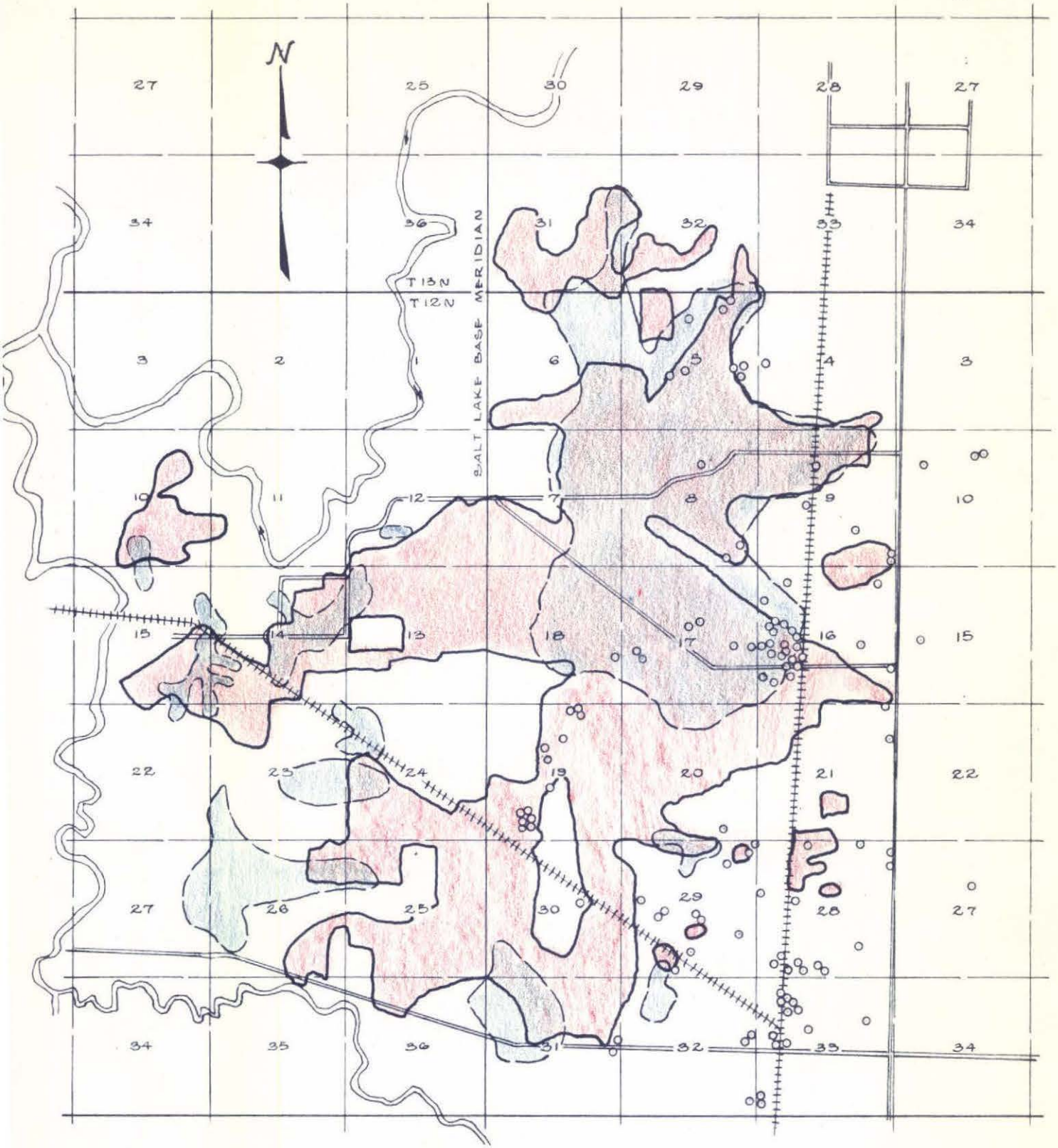
SCALE: 8" = 1 MILE

LEGEND: ---- TILE DRAINS
□ CATCH BASINS

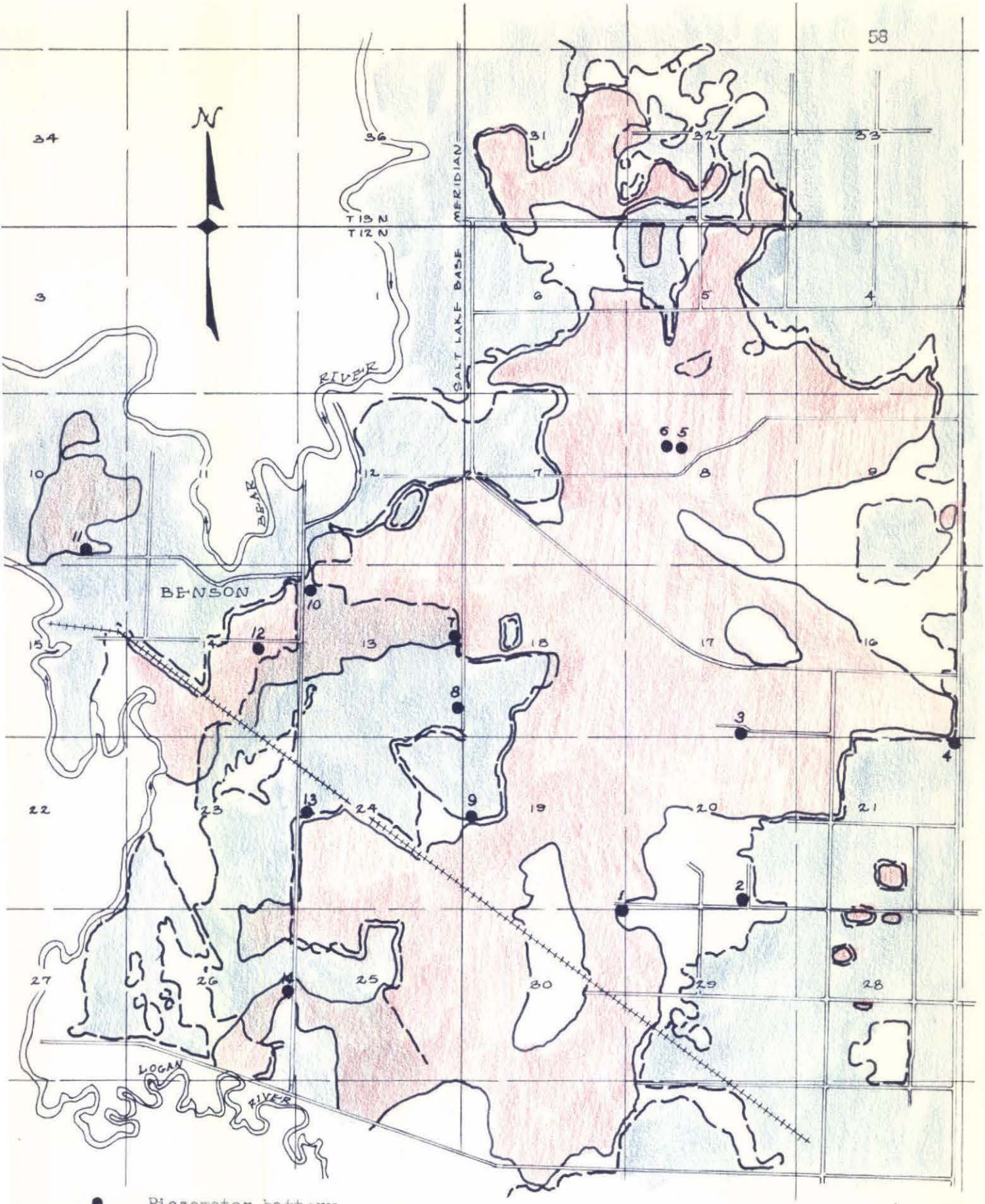
Map No. 5. The location of buried tile drains at Logan-Cache Airport




Map No. 6. Showing the natural drainage of the Logan-Hyde Park-Benson area surface waters. Taken from Aerial Photos.

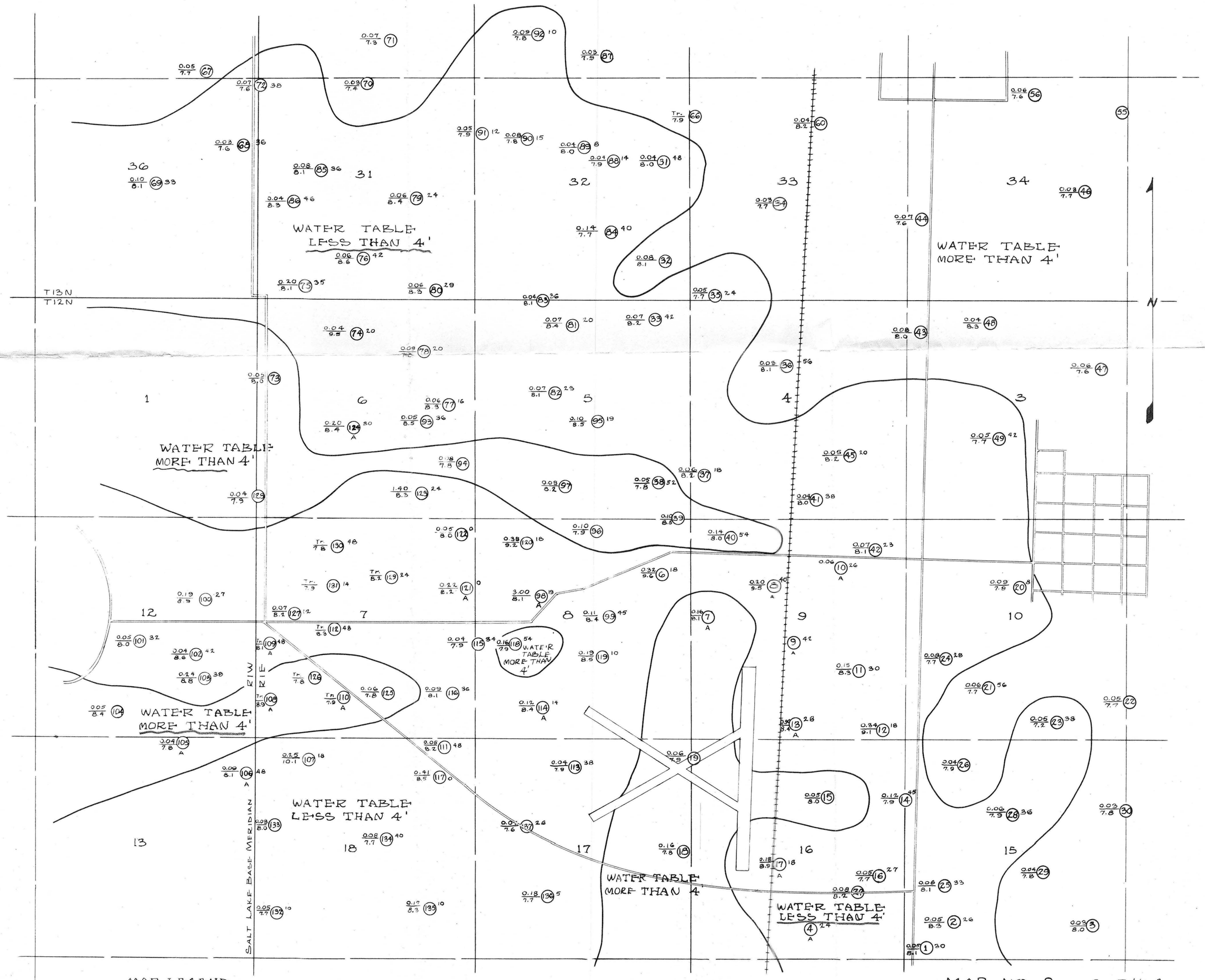



Map No. 7. Showing the boundary of salty soil in 1946 as compared to the boundary in 1913. Taken from 1913 soil survey and aerial photos.




Piezometer battery
Saline soil boundaries
Cultivated crop boundary

Map No. 8. Showing the approximate boundary of saline surface spots and the cultivated crop boundary. (Taken from aerial photos.)




MAP LEGEND

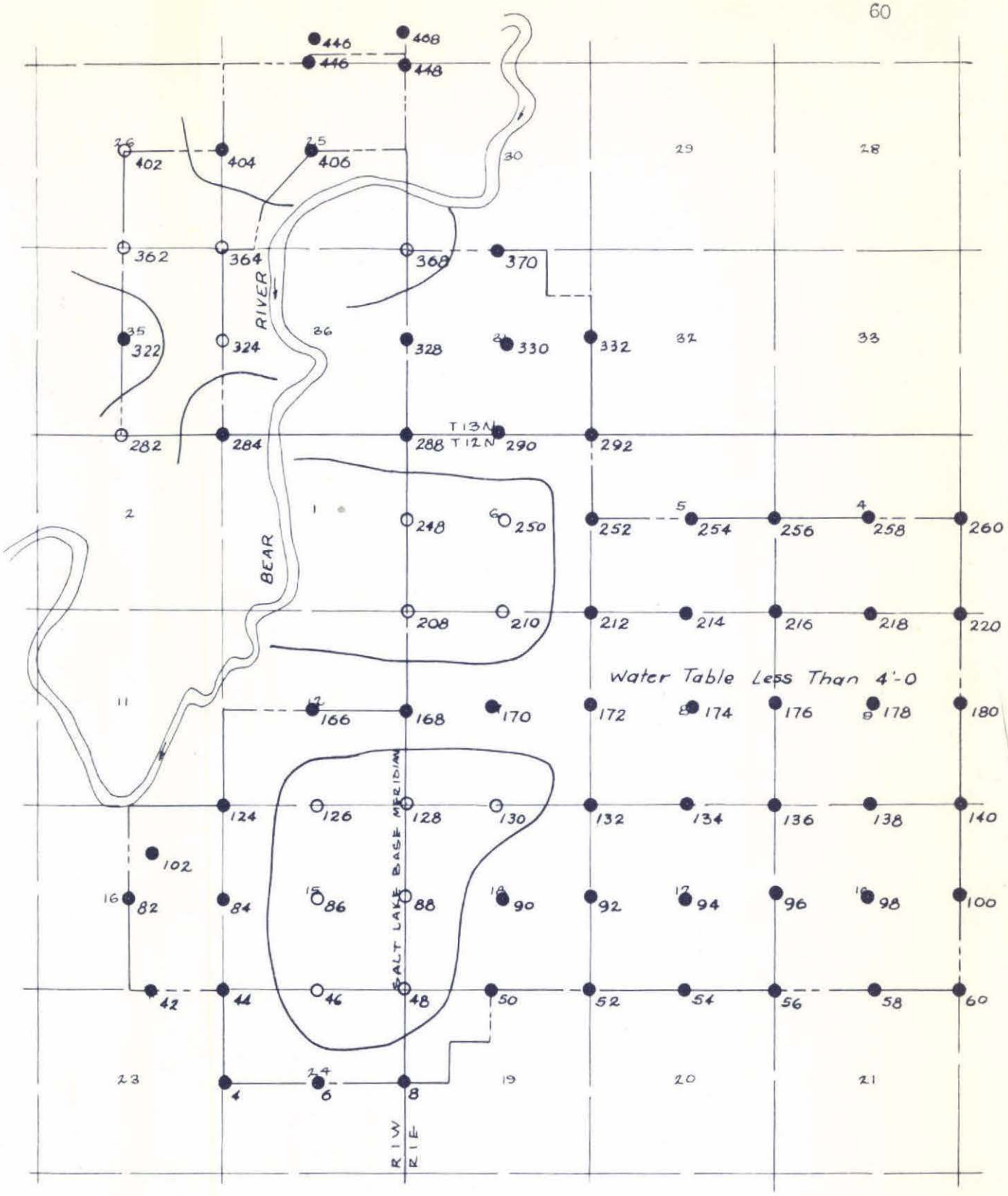
0.05 / 8.1 (1) 30 — HOLE NO. 1; WATER TABLE DEPTH = 30"; % TOTAL SALTS = 0.05; $P_H$ = 8.1

OCT. 1949

MAP NO 9 See Table 3

# 1949 SOIL SURVEY

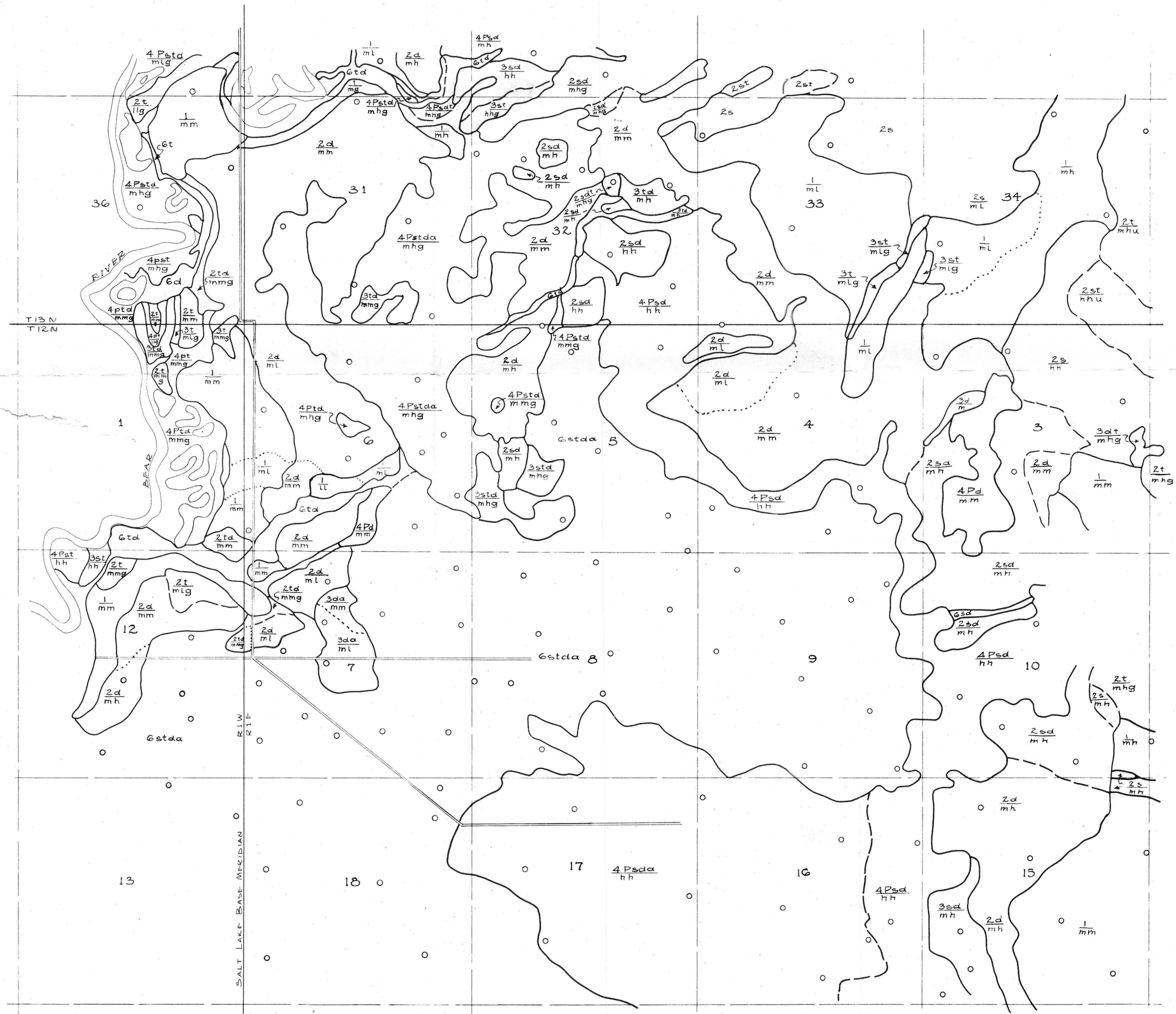
SALT PER CENT, $P_H$, AND WATER TABLE DEPTHS




● Water table less than 4'-0

○ Water table more than 4'-0

Map No. 10. Auger hole pattern used in 1921 and 1922 to measure water table depths. (October 1921) Cache County Drainage District No. 2




BUREAU OF RECLAMATION SYMBOLS

ABOVE LINE

- t - TOPOGRAPHY
- s - SOIL
- d - DRAINAGE
- a - ALKALI
- 4P - PASTURE

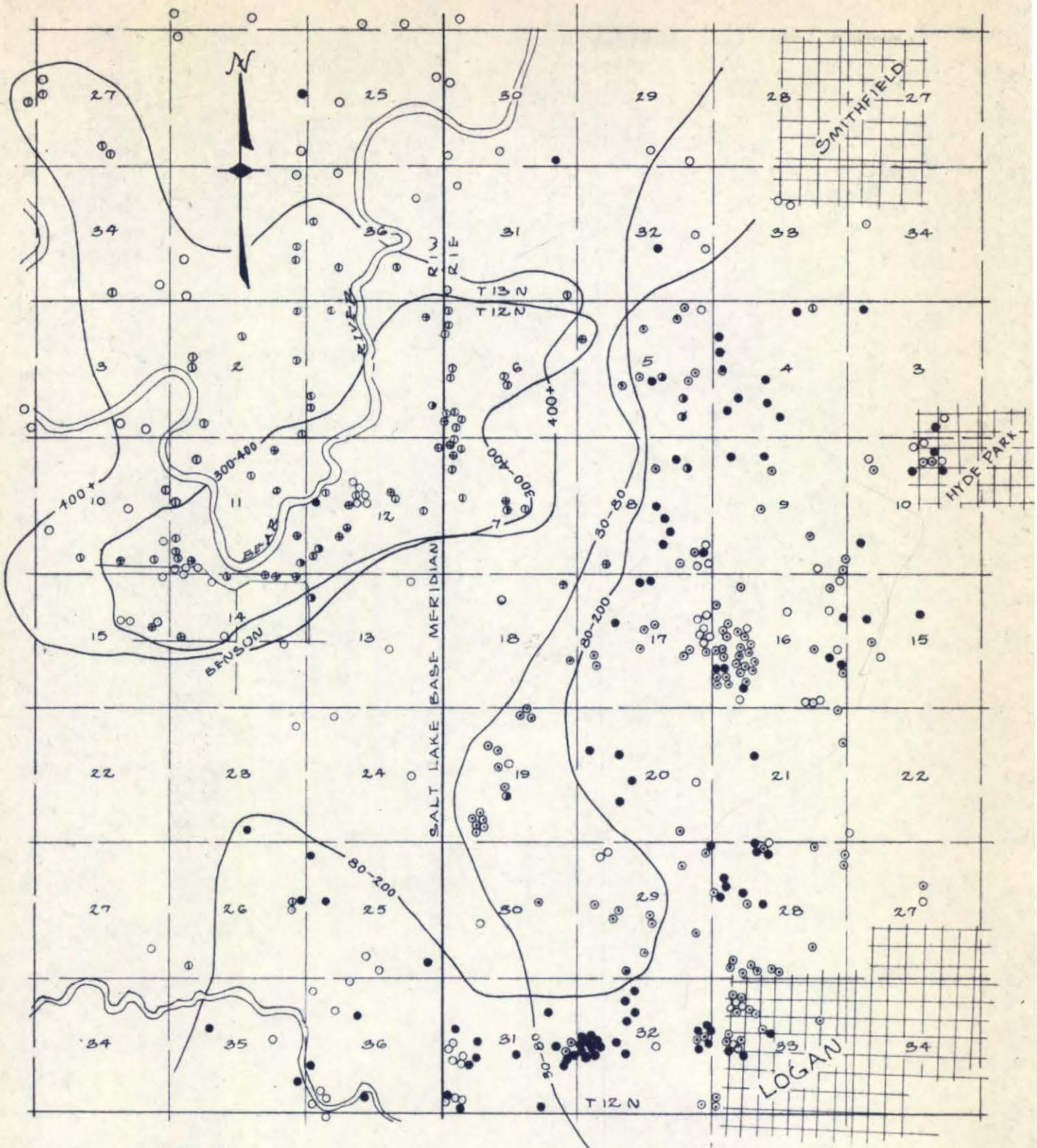
BELOW LINE

- l - SANDS TO SANDY LOAMS
- m - LOAMS TO CLAY LOAMS
- h - VERY PERMEABLE TO SLOWLY PERMEABLE CLAYS
- g - GRADIENT SLOPE (LAND LEVELING)

MAP NO. 11 Based on U.S.B.R. survey. See Table 3

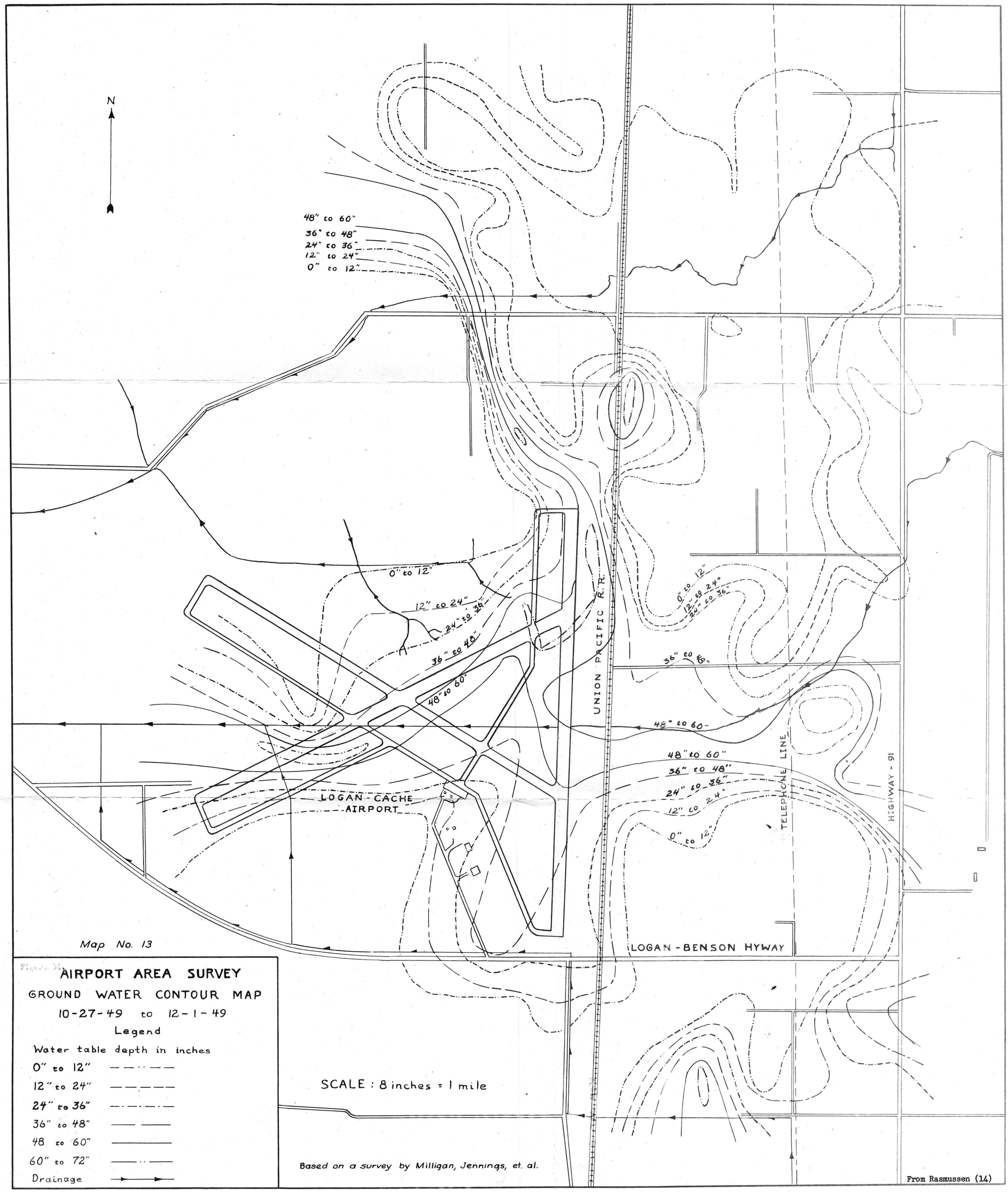
# 1949 SOIL SURVEY

PRELIMINARY SURVEY

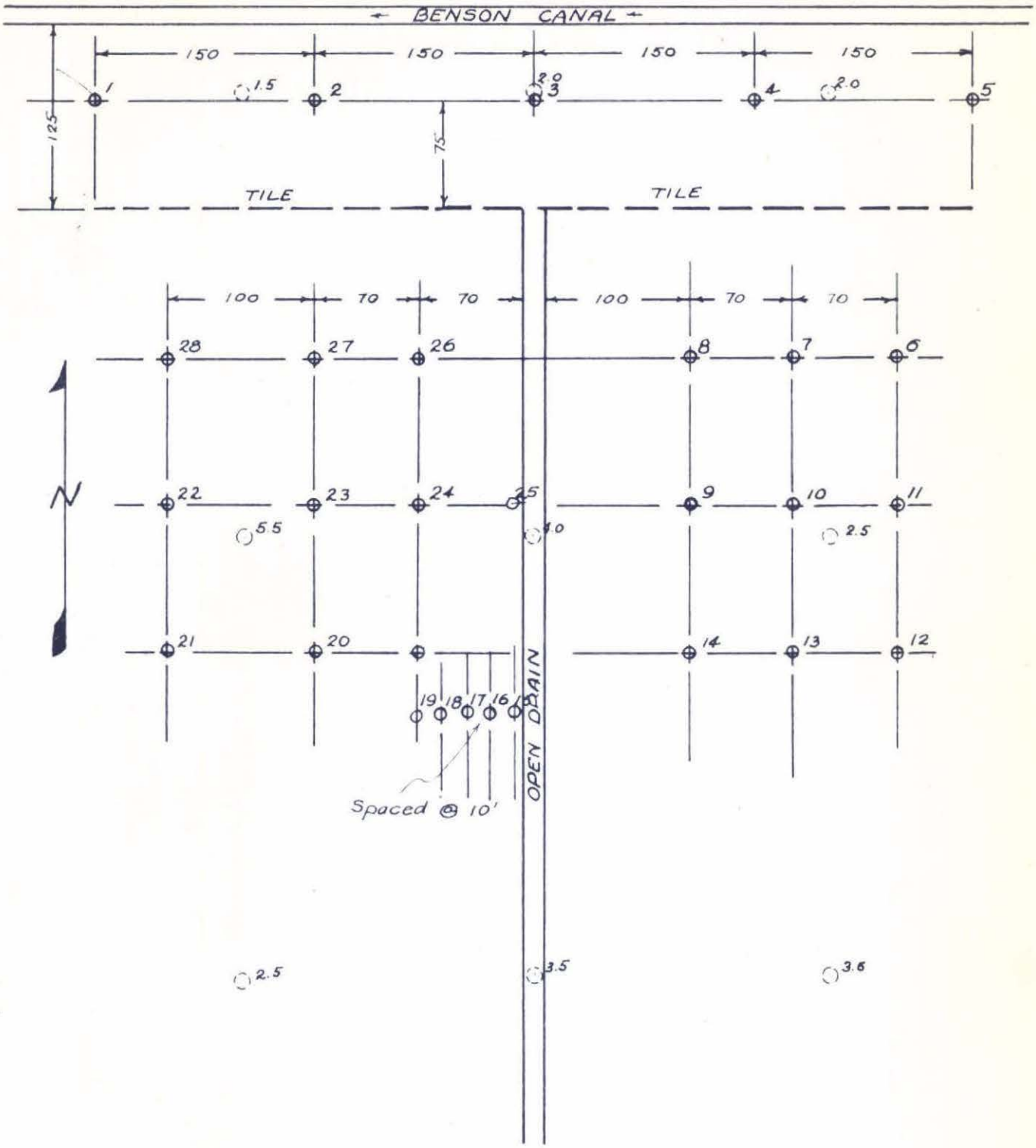



- 30-80 ft.
- 80-200 ft.
- 200-300 ft.
- 300-400 ft.
- 400 + ft.
- not known

Map No. 12. Showing well locations, depths and various aquifer boundaries.




From Rasmussen (14)




2.0 Grid of investigation auger holes 200' x 300' and water table depths, Fall, 1952.

O Present grid of augur holes.

Map No. 14. Drain layout and auger hole pattern for determining drain effectiveness on Lewis B. Riggs farm, Benson Ward.

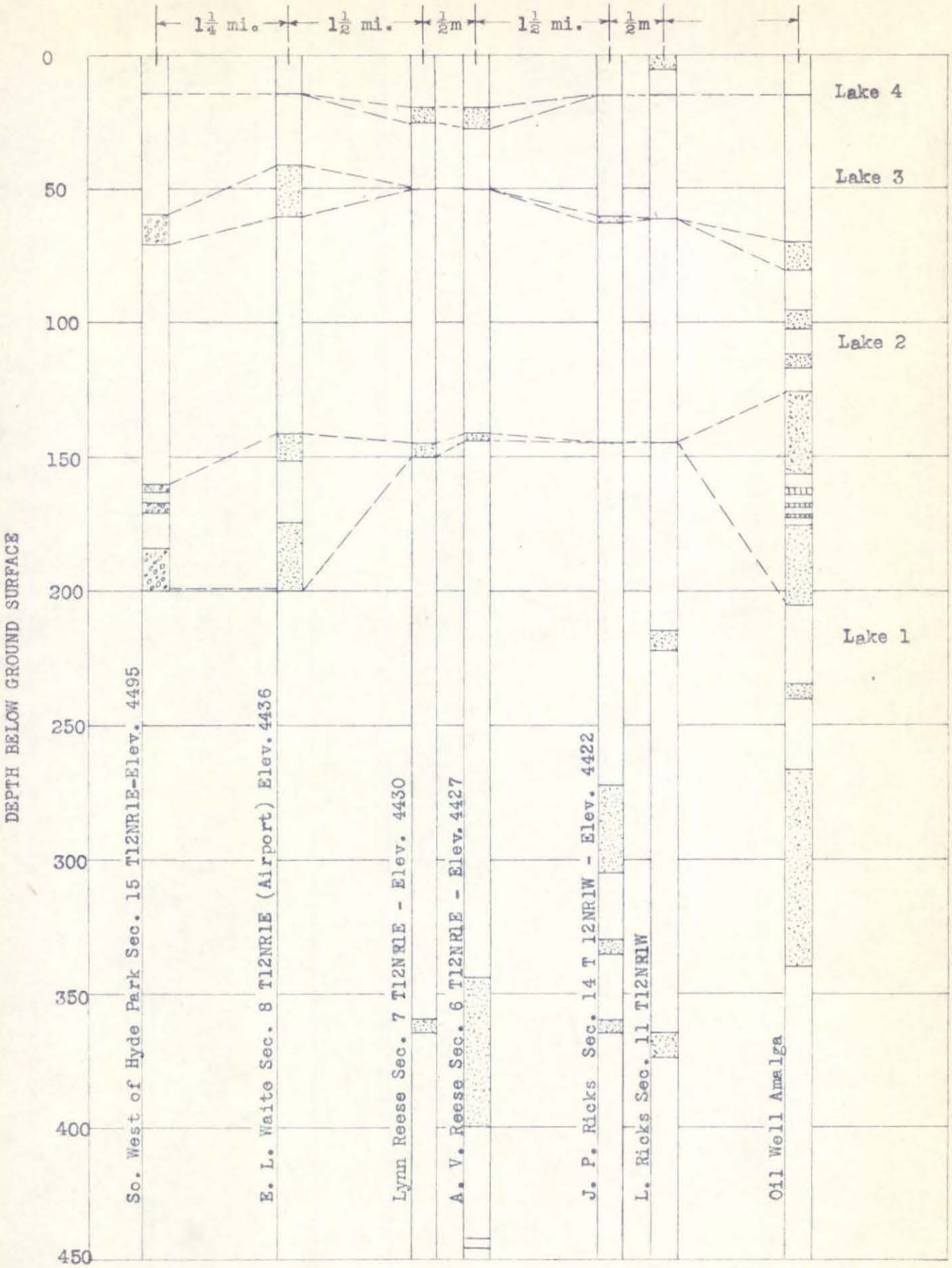



Figure No. 1 Ground profile of well logs on east-west section through the drainage area showing various aquifers. (USAC Geology Dept.) (See fig. 9)

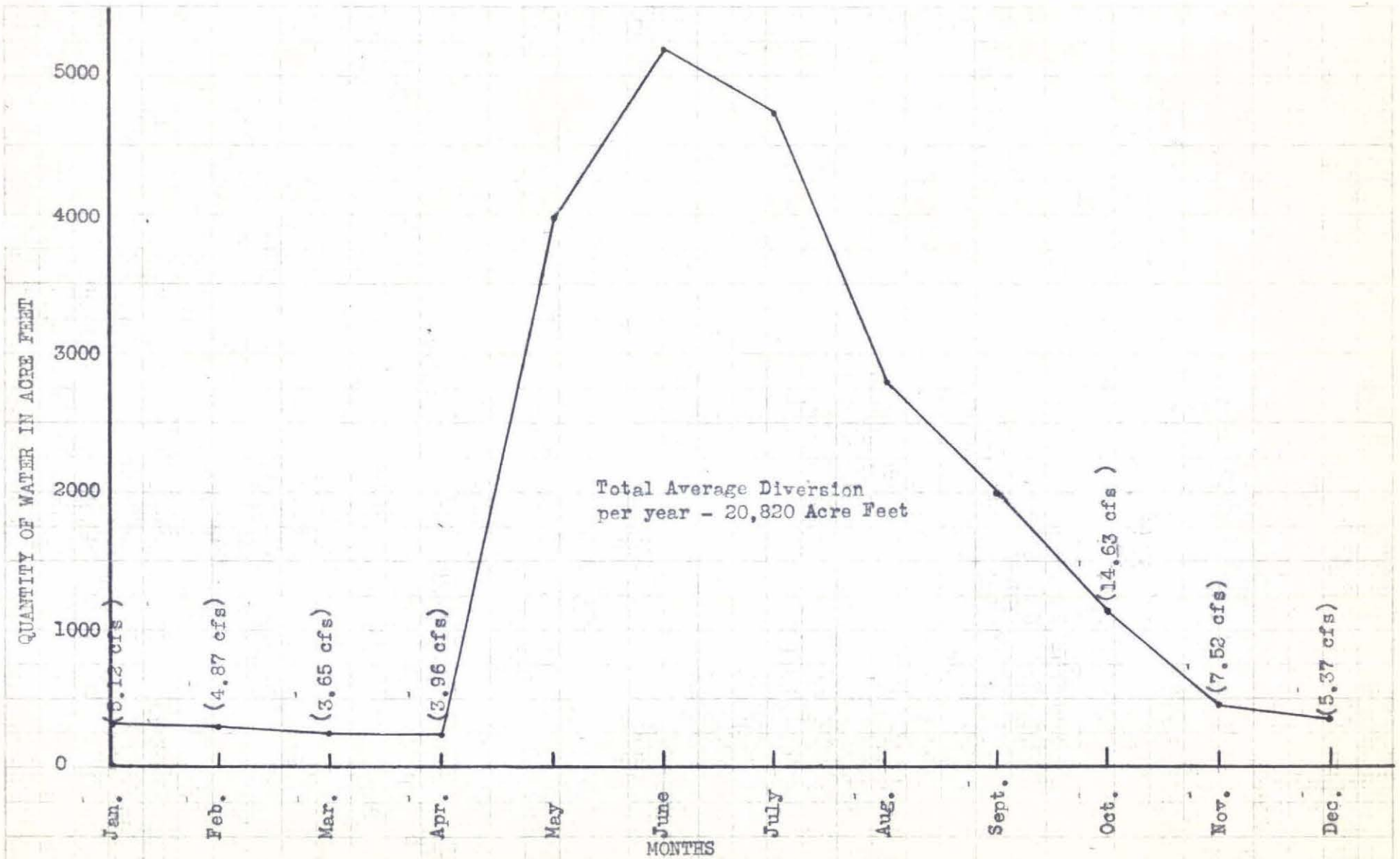



Figure No. 2 Average Diversion for the Logan-Hyde Park-Smithfield Canal by months.
(32 years of record)

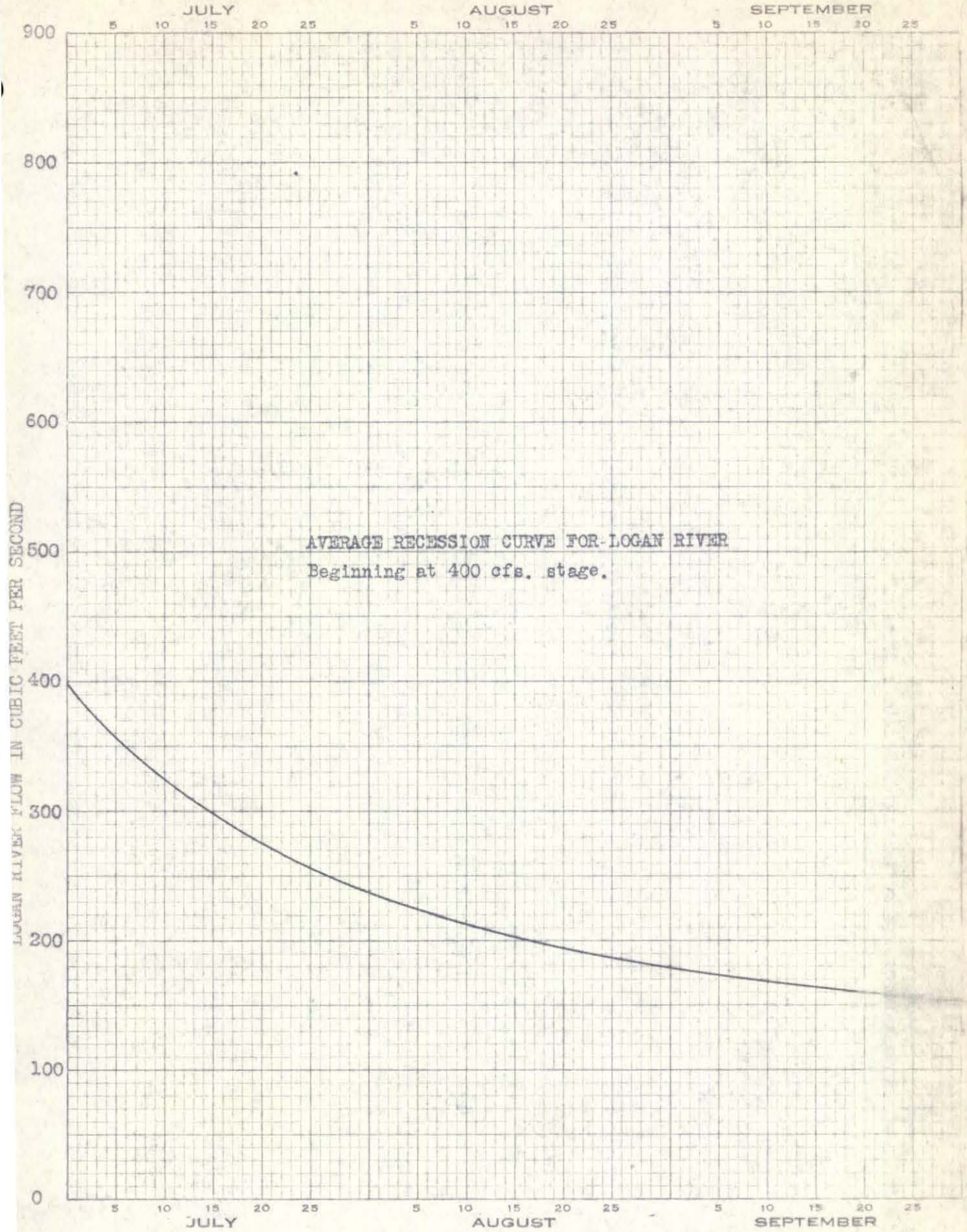
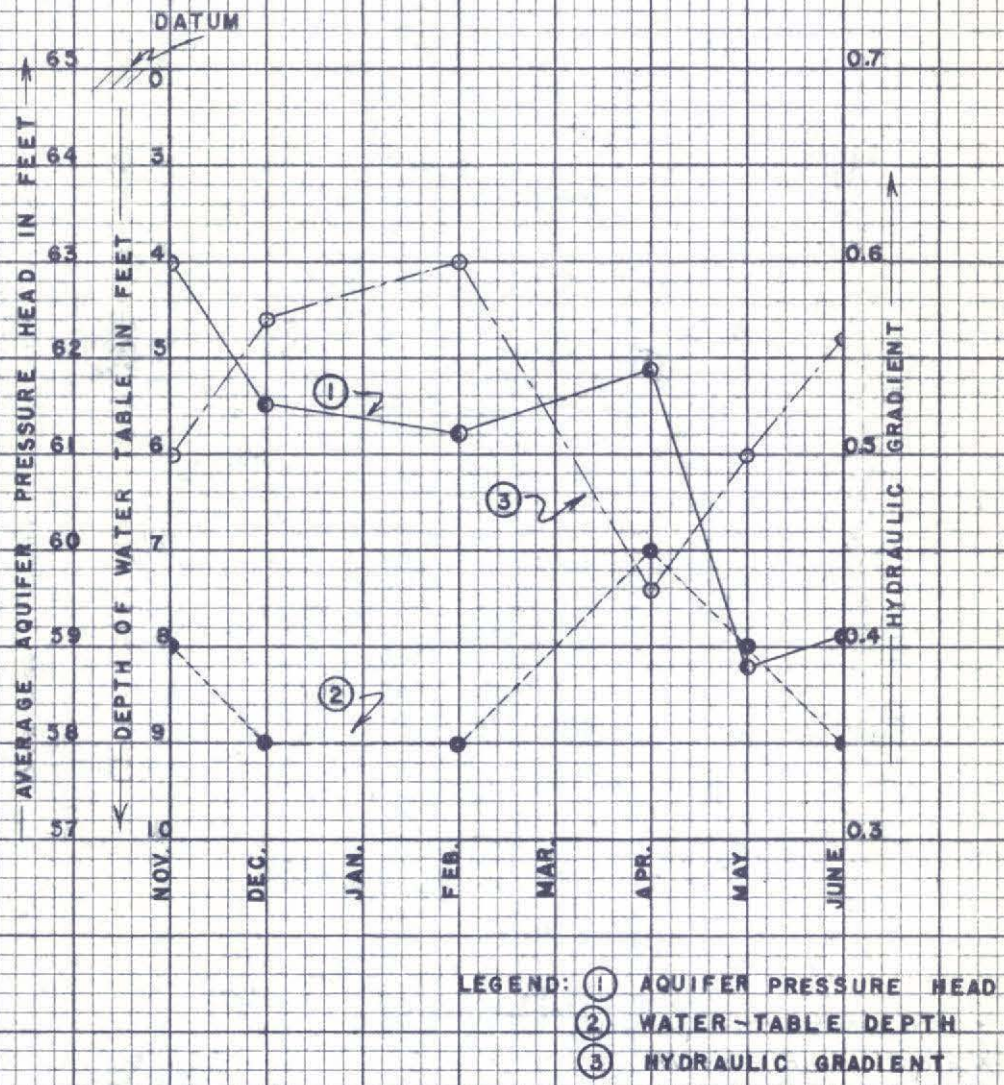



Figure No. 3 Normal recession curve for Logan River.




LEGEND: (1) AQUIFER PRESSURE HEAD
(2) WATER-TABLE DEPTH
(3) HYDRAULIC GRADIENT

Figure ~~18~~ 4. The relation between the artesian aquifer pressure head, the water-table depth, and the hydraulic gradient

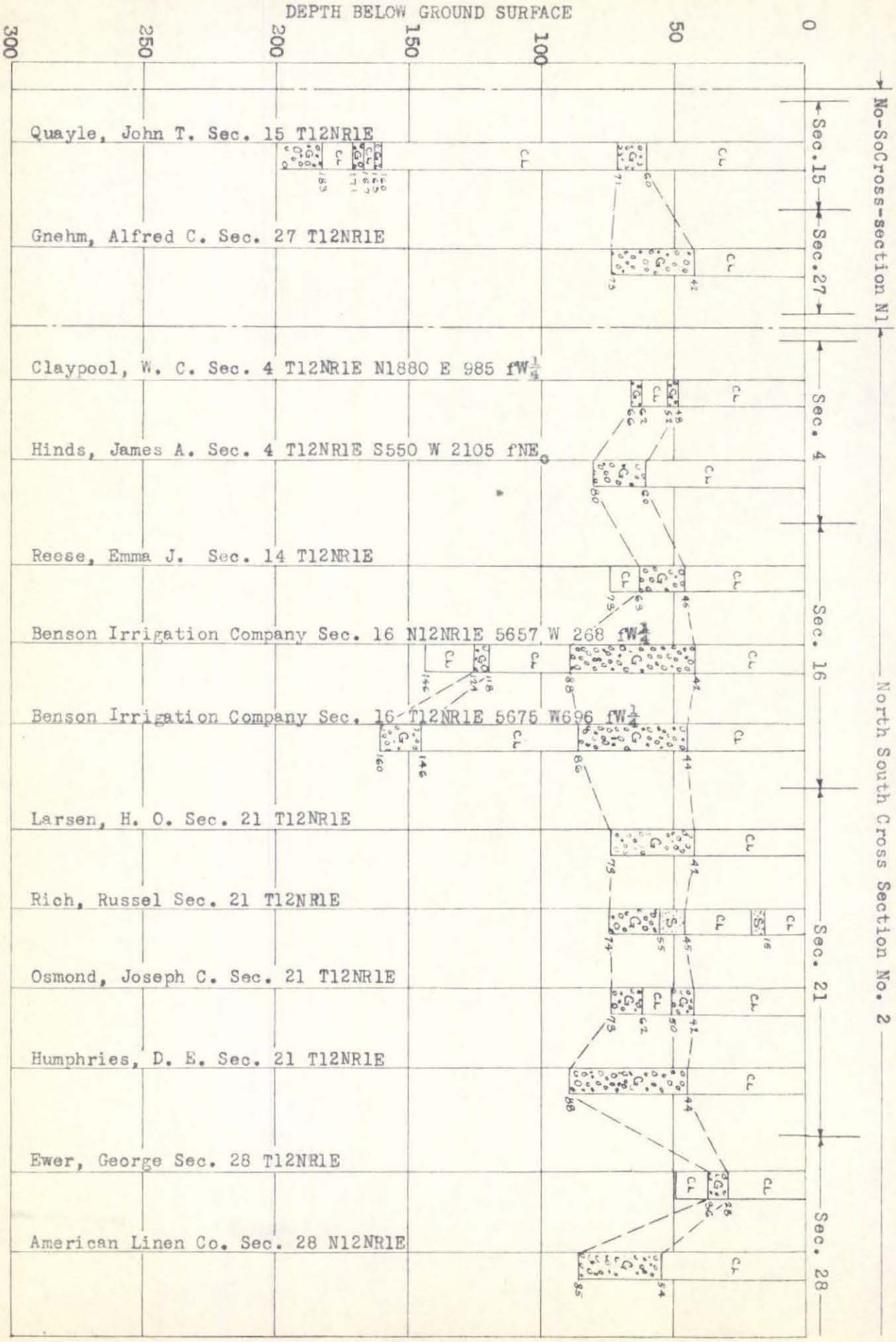



Fig. No. 5 Well logs along north-south sections showing various aquifers and strata.

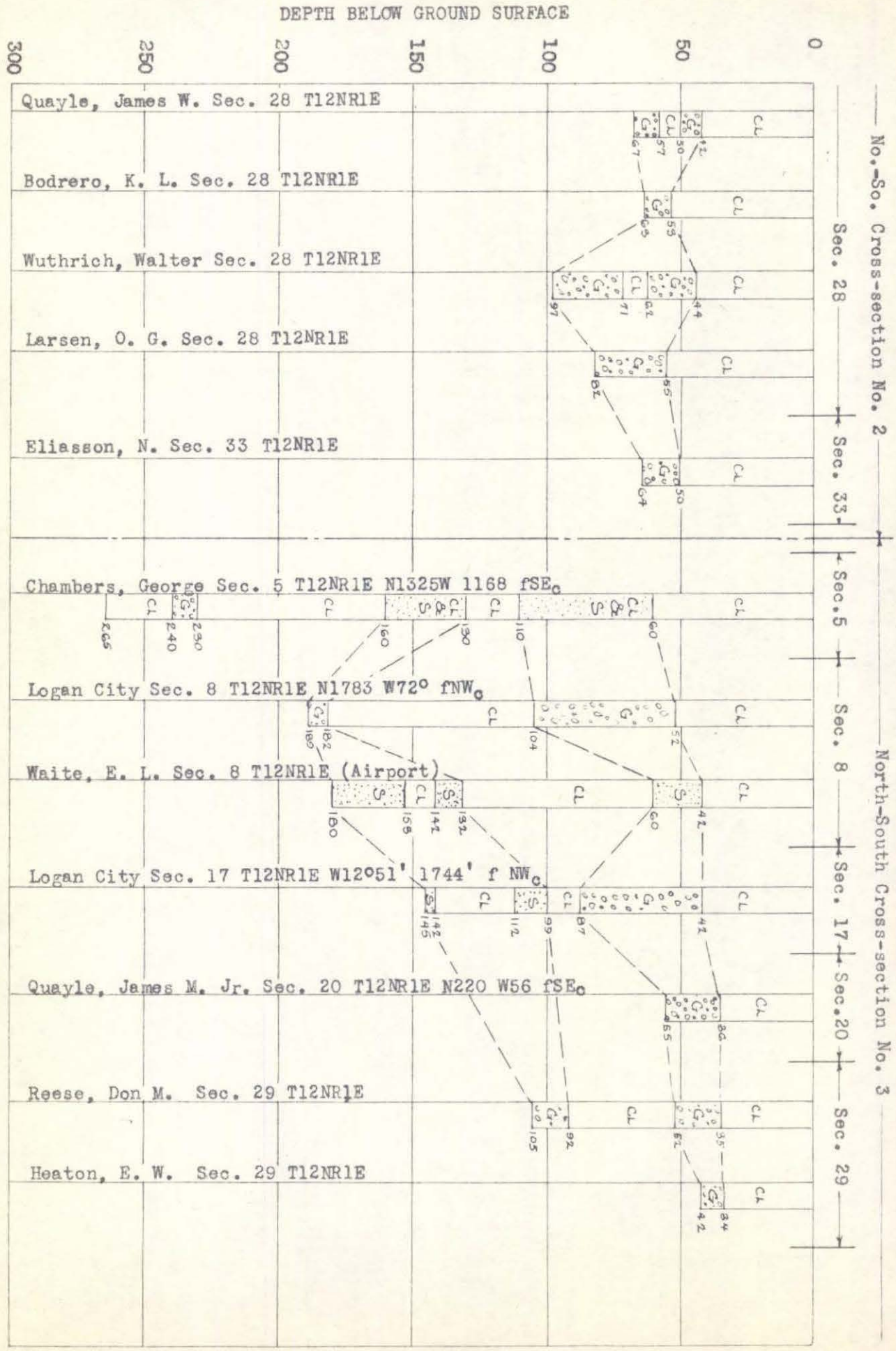



Fig. No. 6 Well logs along north-south sections showing various aquifers and strata.

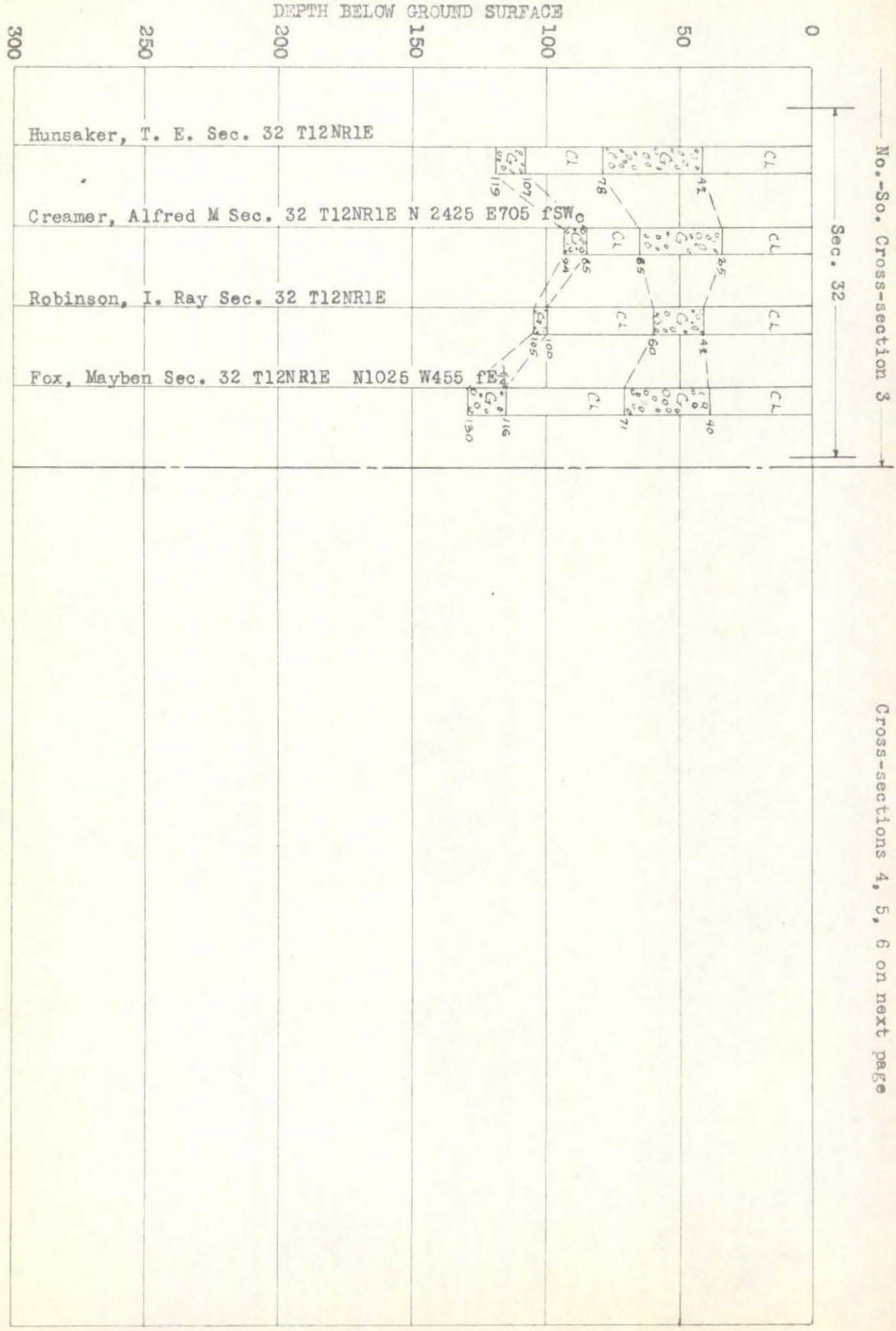



Fig. No. 7 Well logs along north-south sections showing various aquifers and strata.

Cross-sections 4, 5, 6 on next page

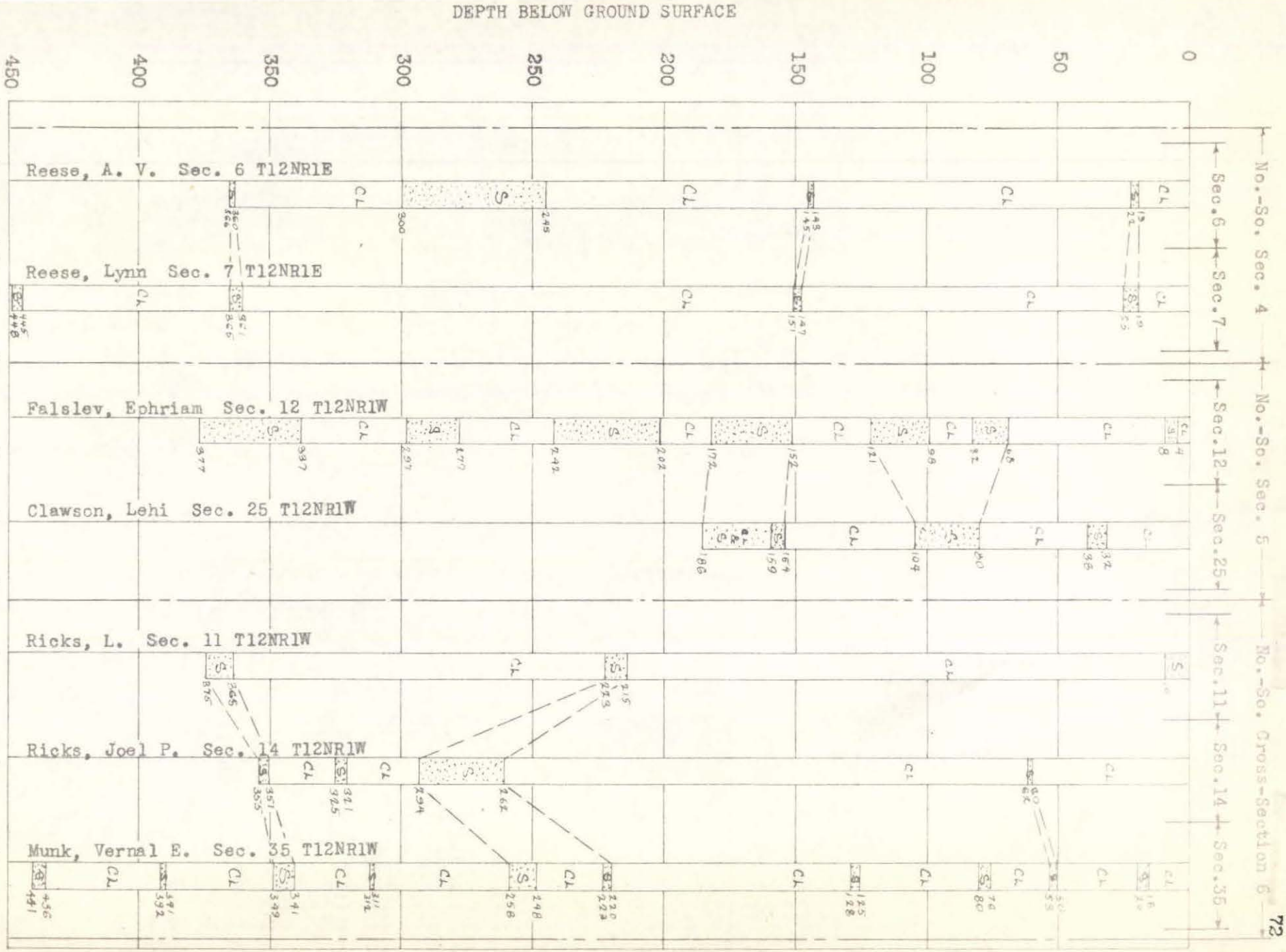



Fig. No. 8 Well logs along north-south sections showing various aquifers and strata.

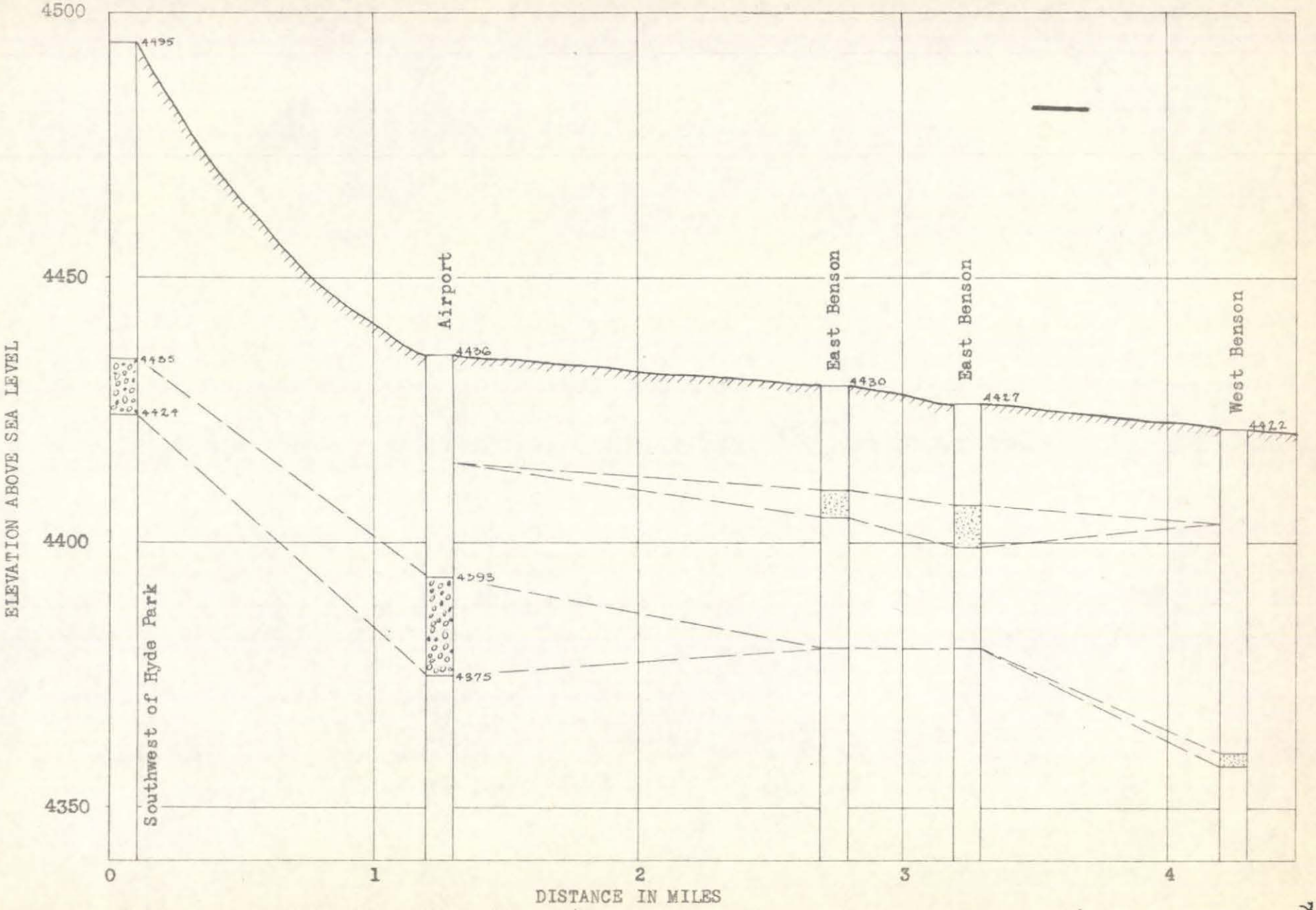



Fig. No. 9 Profile of 40'-60' aquifer - (Prepared from well logs by Geology Department)

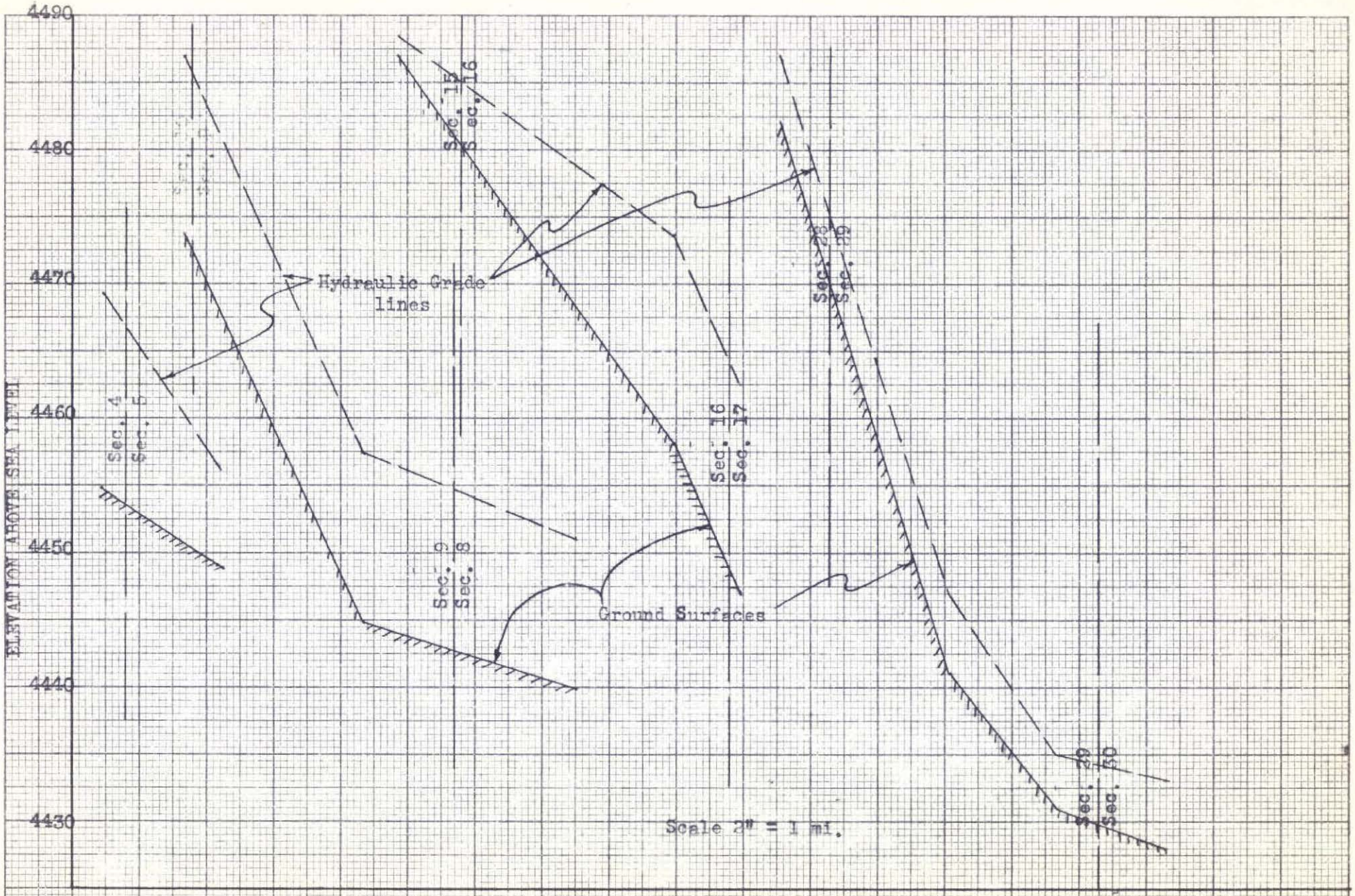



Figure No. 10 Diagrams showing Head Loss in the 40' aquifer and the ground surface slope.

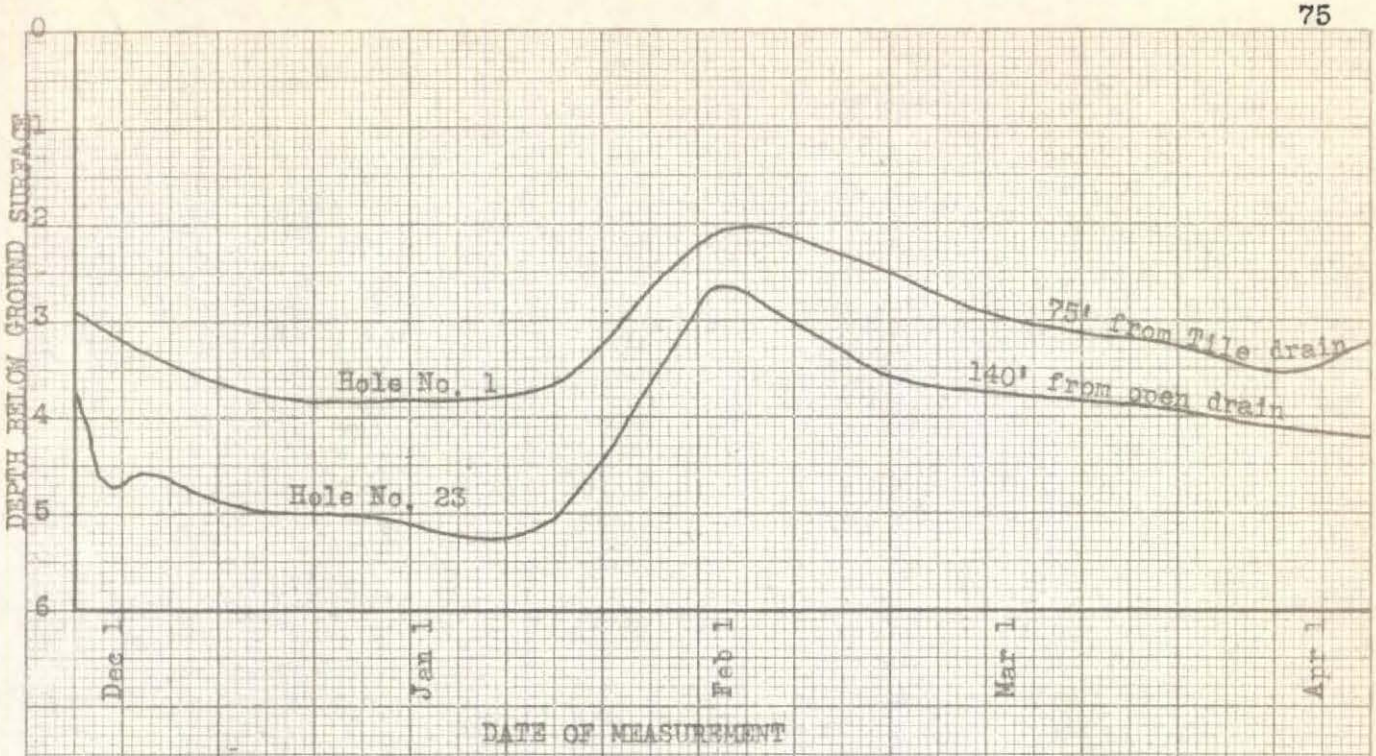



Figure No. 11 Variation of Water Table with time at Rigg's Drain (See Map No. 14)

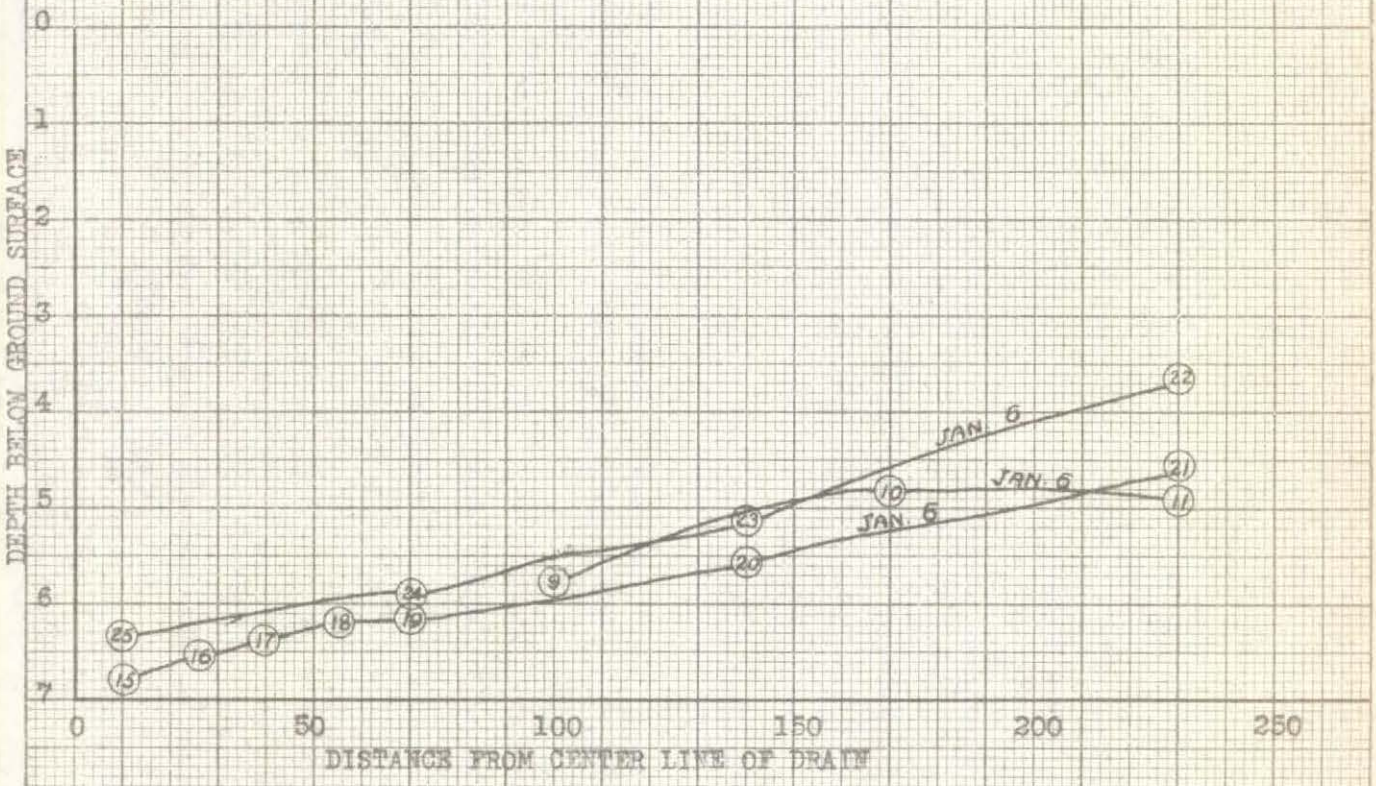



Figure No. 11 Draw down curves for Rigg's drain

| Stage of Logan River | Logan, Hyde Park And Smithfield Canal | *Logan And Northern Irrig. Co. (44.6% of Total Flow) | Hyde Park Irrig. Co. )Twin Logan Northern ) | Logan Northwest Field | Total Flow for the Four Irrigation Companies |
|---|---|---|---|---|---|
| Cap. | 130 | 115 | 43 | 60 | 348 |
| 400 | | | | | |
| 360 | 87.3 | 38.8 | 43.7 | 48.0 | 217.8 |
| 350 | 83.5 | 37.2 | 42.0 | 48.0 | 210.7 |
| 340 | 79.7 | 35.5 | 41.3 | 48.0 | 204.5 |
| 330 | 76.0 | 33.8 | 40.6 | 48.0 | 198.4 |
| 320 | 72.2 | 32.2 | 39.9 | 48.0 | 192.3 |
| 310 | 56.9 | 31.3 | 39.2 | 48.0 | 184.4 |
| 300 | 60.0 | 30.3 | 38.5 | 48.0 | 176.8 |
| 290 | 54.0 | 29.3 | 37.9 | 48.0 | 169.2 |
| 280 | 51.2 | 28.3 | 37.2 | 48.0 | 164.7 |
| 270 | 48.3 | 27.3 | 36.5 | 44.6 | 156.7 |
| 260 | 46.8 | 26.3 | 35.9 | 43.6 | 152.6 |
| 250 | 44.6 | 35.6 | 34.5 | 41.9 | 146.6 |
| 240 | 42.4 | 24.6 | 33.1 | 40.3 | 140.4 |
| 230 | 40.2 | 23.6 | 31.7 | 38.6 | 134.1 |
| 220 | 39.6 | 22.3 | 30.3 | 36.9 | 129.1 |
| 210 | 37.8 | 21.5 | 29.0 | 35.2 | 123.5 |
| 200 | 36.0 | 20.5 | 27.6 | 33.5 | 117.6 |
| 190 | 34.2 | 19.5 | 26.2 | 31.9 | 111.8 |
| 180 | 32.4 | 184 | 24.8 | 30.2 | 105.8 |
| 170 | 30.6 | 17.4 | 23.4 | 28.5 | 99.9 |
| 160 | 28.8 | 16.4 | 22.1 | 26.8 | 94.1 |
| 150 | 27.0 | 15.4 | 20.7 | 25.2 | 88.3 |
| 140 | 25.2 | 14.4 | 19.3 | 23.5 | 82.4 |
| 130 | 23.4 | 13.3 | 17.9 | 21.8 | 76.4 |
| 120 | 21.6 | 12.3 | 16.5 | 20.1 | 70.5 |
| 110 | 19.8 | 11.3 | 15.1 | 18.4 | 64.6 |
| 100 | 18.0 | 10.3 | 13.7 | 16.7 | 58.7 |
| 90 | 16.2 | 9.2 | 12.3 | 15.0 | 52.7 |

* 1648 acres or 44.6% of the area under this canal lies south of Smithfield and contributes to the drainage problem

Table No. 1. The allocation of water to the six irrigation companies serving between Logan, Smithfield, and Benson as outlined by the Kimball Decree. (Allocations in cubic feet per second)

| Time Period | Logan River Av. Dschg.(cfs) | Total Diversions For The Four Canals (A.F.) |
|---|---|---|
| May 10-14 | Over 400 | 2500 |
| May 15-19 | Over 400 | 2500 |
| May 20-24 | Over 400 | 2500 |
| May 25-29 | Over 400 | 2500 |
| May 30-June 4 | Over 400 | 3600 |
| June 5-9 | Over 400 | 3000 |
| June 10-14 | Over 400 | 3000 |
| June 15-19 | Over 400 | 3000 |
| June 20-24 | Over 400 | 3000 |
| June 25-30 | Over 400 | 3600 |
| July 1-4 | 380 | 2178 |
| July 5-9 | 345 | 2045 |
| July 10-14 | 315 | 1844 |
| July 15-19 | 290 | 1692 |
| July 20-24 | 267 | 1526 |
| July 25-31 | 253 | 2050 |
| Aug 1-4 | 235 | 1341 |
| Aug 5-9 | 222 | 1291 |
| Aug 10-14 | 210 | 1235 |
| Aug 15-19 | 201 | 1176 |
| Aug 20-24 | 193 | 1118 |
| Aug 25-31 | 185 | 1481 |
| Sept 1-4 | 177 | 1058 |
| Sept 5-9 | 172 | 999 |
| Sept 10-14 | 166 | 941 |
| Sept 15-19 | 162 | 941 |
| Sept 20-24 | 158 | 883 |
| Sept 25-30 | 155 | 996 |
| TOTAL | | 53,995 |

Table No. 2. Computation of total diversions for the four canals between Logan and Smithfield (5 canal companies represented - not taking into consideration the Benson Irrigation Company.) See figure 3 for Logan River stage after June 30 and table 1 for diversions to the four canals.

| Hole No. | Land Use | Slope Percent | Depth To Water Table | Salt Percentage | | Ph | | Soil Type & Permeab. | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Topsoil | Subsoil | Topsoil | Subsoil | Topsoil | Subsoil |
| 1 | P | 0-1 | 30 | .05 | .03 | 8.1 | 8.1 | VPC | PC |
| 2 | P | 1-2 | 26 | .05 | .03 | 8.3 | 8.1 | SL | CL |
| 3 | A | 1-3 | | .03 | Tr. | 8.0 | 8.2 | SL | SL |
| 4 | P | 0-1 | 24 | (A) | | | | CL | SL |
| 5 | P | 0-5 | 14 | | | | | SL | PC |
| 6 | P | 0-1 | 18 | .32 | .17 | 9.6 | 8.8 | CL | SPC |
| 7 | P | 0-1 | | .16(A) | .23 | 8.1 | 8.4 | CL | SPC |
| 8 | P | 0-1 | 40 | .20(A) | .20 | 9.5 | 8.9 | CL | SPC |
| 9 | P | 1-2 | 42 | (A) | | | | CL | SPC |
| 10 | P | 1-2 | 26 | .06(A) | .06 | 8.2 | 8.1 | CL | SPC |
| 11 | P | 1-2 | 30 | .15 | .34 | 8.3 | 9.1 | VPC | SPC |
| 12 | P | 0-1 | 18 | .34 | .24 | 9.1 | 9.4 | CL | SPC |
| 13 | P | 0-1 | 28 | .90(A) | .33 | 8.4 | 8.7 | CL | SPC |
| 14 | P | 1-2 | 45 | .12 | .05 | 7.9 | 8.2 | CL | PC |
| 15 | P | 0-1 | | .05 | .05 | 8.0 | 8.3 | CL | SPC |
| 16 | P | 0-1 | 27 | .05 | .04 | 7.7 | 8.0 | CL | SPC |
| 17 | P | 0-1 | 18 | .18(A) | .11 | 8.9 | 8.8 | CL | SPC |
| 18 | P | 0-1 | | .16 | .12 | 7.8 | 8.5 | VPC | CL |
| 19 | P | 0-1 | | .06 | .16 | 7.9 | 8.6 | VPC | CL |
| 20 | P | 1-2 | 8 | .09 | .08 | 7.9 | 7.9 | CL | SPC |
| 21 | A | 0-2 | 56 | .06 | .07 | 7.7 | 8.0 | CL | SPC |
| 22 | G(W) | 1-3 | | .05 | .05 | 7.7 | 7.8 | SL | CL |
| 23 | G(W) | 0-1 | 38 | .05 | .06 | 7.2 | 7.9 | SL | CL |
| 24 | P | 0-2 | 28 | .08 | .06 | 7.7 | 7.9 | SL | VPC |
| 25 | G(W) | 0-1 | 33 | .06 | .05 | 8.1 | 8.0 | SL-CL | VPC |
| 26 | A | 0-1 | | .04 | .05 | 7.9 | 7.9 | CL | SPC |
| 27 | P | 1-2 | | .08 | .18 | 8.2 | 8.5 | | |
| 28 | G | 1-2 | 36 | .06 | .26 | 7.9 | 6.3 | SL | CL |
| 29 | A | 0-1 | | .04 | .03 | 7.8 | 8.2 | SL | SPC |
| 30 | S.B. | 0-1 | | .03 | .03 | 7.8 | 8.0 | SL | CL |
| 31 | S.B. | 1-2 | 48 | .04 | .04 | 8.0 | 8.2 | SL | CL |
| 32 | P | 1 | | .08 | .09 | 8.1 | 8.3 | SL | SPC |
| 33 | P | 1 | 42 | .07 | .06 | 8.2 | 8.2 | CL | SPC |

P-pasture; A-alfalfa; G-grain; (W)-wheat; S.B.-sugar beets; C-corn; B-beans; (A) indicates visible alkali on surface
SL-silty loam; S-sand; L-loam; CL-clay loam; VPC-very permeable clay; PC-permeable clay; SPC-slowly permeable clay.

Table No. 3 Soil survey data to accompany maps Nos. 9 and 11.

| Hole No. | Land Use | Slope Percent | Depth To Water Table | Salt Percentage | | Ph | | Soil Type & Permeab. | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Topsoil | Subsoil | Topsoil | Subsoil | Topsoil | Subsoil |
| 34 | S.B. | 1-2 | | .03 | .02 | 7.7 | 8.0 | SL | S |
| 35 | P | 1-2 | 24 | .05 | .04 | 7.7 | 8.0 | CL | PC |
| 36 | S.B. | 1-2 | 56 | .03 | .02 | 8.1 | 8.3 | SL | CL |
| 37 | P | 3-4 | 18 | .06 | .04 | 8.2 | 8.5 | SL | CL |
| 38 | P | 2-3 | 52 | .05 | .07 | 7.8 | 8.3 | CL | SPC |
| 39 | P | 0-1 | | .10 | .57 | 8.5 | 9.0 | SL | CL |
| 40 | P | 0-1 | 54 | .14 | .12 | 8.0 | 8.8 | SL | SPC |
| 41 | P | 1-2 | 38 | .04 | .03 | 8.0 | 8.2 | CL | VPC |
| 42 | P | 1 | 23 | .07 | .06 | 8.1 | 8.2 | CL | PC |
| 43 | S.B. | 0-1 | | .03 | .02 | 8.0 | 8.2 | SL | S |
| 44 | P | 1-2 | | .07 | Tr. | 7.6 | 8.1 | SL | S |
| 45 | P | 1-2(U) | 20 | .05 | .03 | 8.2 | 8.3 | SL | VPC |
| 46 | A | 2 | | .03 | .03 | 7.7 | 7.9 | SL | CL |
| 47 | S.B. | 3 | | .06 | .05 | 7.6 | 7.7 | SL | PC |
| 48 | G(O) | 2 | | .04 | .04 | 8.3 | 8.1 | SL | VPC |
| 49 | A | 2 | 42 | .05 | .07 | 7.7 | 7.8 | SL | VPC |
| 50 | A | 0-1 | | .05 | .05 | 8.0 | 8.2 | SL | PC |
| 51 | P | 1-3 | | | | | | | |
| 52 | G | 1-5(U) | | | | | | | |
| 53 | P | 1-3(U) | | .03 | | 8.2 | | | |
| 54 | A | 1-3(U) | | .06 | Tr. | 7.9 | 8.2 | | |
| 55 | G | 3-4(U) | | | | | | | |
| 56 | S.B. | 1 | | .06 | .05 | 7.6 | 7.7 | | |
| 57 | A | 2 | | .06 | .06 | 7.4 | 7.6 | | |
| 58 | W | 2 | .04 | .06 | 7.7 | 7.9 | | | |
| 59 | S.B. | 3 | | .03 | Tr. | 8.3 | 8.1 | | |
| 60 | Peas | 1 | | .04 | Tr. | 8.2 | 8.4 | | |
| 61 | A | 1 | | Tr. | Tr. | 8.2 | 8.1 | | |
| 62 | A- | 1 | | Tr. | Tr. | 8.3 | 8.3 | | |
| 63 | C | 1-4(U) | | .03 | Tr. | 7.9 | 8.0 | | |
| 64 | A | 2-4 | | | | | | | |
| 65 | Peas | 1 | | .03 | Tr. | 7.8 | 8.0 | | |
| 66 | Pot. | 2 | | Tr. | -- | 7.9 | | | |
| 67 | C | 0-1 | | .05 | .04 | 7.7 | 7.9 | SL | SL |
| 68 | P | 1 | 36 | .03 | .03 | 7.6 | 8.0 | SC | SC |

Table No. 3 (Continued)

| Hole No. | Land Use | Slope Percent | Depth To Water Table | Salt Percentage | | Ph | | Soil Type & Permeab. | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Topsoil | Subsoil | Topsoil | Subsoil | Topsoil | Subsoil |
| 69 | P | 1-3 | 33 | .10 | .12 | 8.1 | 8.9 | SL | S |
| 70 | V | 0-1 | 50 | .03 | .02 | 7.4 | 7.9 | SL | SL |
| 71 | A | 0-1 | | .03 | .02 | 7.3 | 7.9 | SL | S |
| 72 | P | 2-3 | 38 | .09 | .09 | 7.6 | 7.8 | CL | SL |
| 73 | A | 1 | | .05 | .06 | 8.0 | 8.0 | S | S |
| 74 | P | | 20 | .04 | .11 | 9.5 | 8.8 | VPC | CL |
| 75 | P | 1-3 | 85 | .20 | .07 | 8.1 | 8.2 | SL | VPC |
| 76 | B | 3 | 42 | .06 | .04 | 8.6 | 8.1 | SL | SL |
| 77 | P | 1-3 | 16 | .06 | .05 | 8.3 | 8.1 | SL | CL |
| 78 | P | 1-3 | 20 | .09 | .07 | 7.8 | 7.9 | SL | PC |
| 79 | P | 1-2 | 24 | .06 | .04 | 8.4 | 8.3 | SL | CL |
| 80 | P | 1-2 | 29 | .06 | .15 | 8.3 | 8.7 | CL | SPC |
| 81 | P | 1-3 | 20 | .07 | .18 | 8.4 | 8.7 | SL | SPC |
| 82 | P | 0-2 | 23 | .07 | .25 | 8.1 | 8.8 | SL | SPC |
| 83 | A | 1-2 | 36 | .04 | .06 | 8.1 | 7.9 | SL | CL- |
| 84 | Pot. | 1-2 | 40 | .14 | .06 | 7.7 | 7.9 | SCL | VPC |
| 85 | P | 1-2 | 36 | .08 | .03 | 8.1 | 8.1 | CL | S |
| 86 | P | 1-2 | 46 | .04 | .02 | 8.3 | 8.2 | SL | CL |
| 87 | Peas | 1-2 | | .03 | .02 | 7.9 | 8.1 | SL | CPC |
| 88 | P | 1-4 | 14 | .04 | .07 | 7.9 | 7.7 | SL | PC |
| 89 | P | 1-3 | 8 | .04 | .09 | 8.0 | 7.9 | SL | SPC |
| 90 | P | 1-2 | 15 | .08 | .06 | 7.8 | 7.8 | VPC | PC |
| 91 | P | 1-3 | 12 | .05 | .06 | 7.9 | 7.9 | SL | CL |
| 92 | P | 2-3 | 10 | .09 | .10 | 7.8 | 7.8 | PC | PC |
| 93 | P | 1-3 | 36 | .05 | .04 | 8.5 | 8.4 | SL | SL |
| 94 | P | 2-3 | | .08 | .45 | 7.8 | 8.0 | SL | SL |
| 95 | P | 2-3 | 19 | .10 | .08 | 8.5 | 7.8 | VPC | VPC |
| 96 | P | 1-3 | | .0 | .35 | 7.9 | 8.8 | VPC | VPC |
| 97 | G(W) | 0-1 | | .08 | .39 | 8.2 | 9.0 | PC | PC |
| 98 | Alkali | 0-1 | 19 | 3.00 | .18 | 8.1 | 8.7 | SL | SL |
| 99 | P | 0-1 | 45 | .11 | .29 | 8.4 | 8.6 | SL | SL |
| 100 | P | 0-1 | 27 | .19 | .20 | 8.9 | 8.5 | SL | SL |
| 101 | P | 0-1 | 32 | .05 | .06 | 8.0 | 8.4 | SL | SL |
| 102 | G(B) | 1-2 | 42 | .04 | .06 | 8.6 | 9.1 | SL | SL |
| 103 | G(B) | 0-1 | 38 | .24 | .25 | 8.8 | 9.0 | SL | C |

Table No. 3 (Continued)

| Hole No. | Land Use | Slope Percent | Depth To Water Table | Salt Percentage | | Ph | | Soil Type & Permeab. | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Topsoil | Subsoil | Topsoil | Subsoil | Topsoil | Subsoil |
| 104 | A | 0-1 | | .05 | .17 | 8.4 | 9.3 | SL | SPC |
| 105 | A- | 1-4(U) | | .04(A) | .27 | 7.8 | 9.6 | SL | SL |
| 106 | Weeds | 1-3 | 48(A) | .09 | .80 | 8.1 | 8.3 | SL | SL |
| 107 | Alkali | 0-1 | 18 | .25 | .32 | 10.1 | 9.6 | SL | C |
| 108 | G(W) | 1-3 | (A) | Tr. | .10 | 8.9 | 9.0 | S | S |
| 109 | G(W) | 1-3 | 48(A) | Tr. | .12 | 8.1 | 8.9 | SC | S |
| 110 | A | 103 | (A) | Tr. | .12 | 7.9 | 9.1 | SC | C |
| 111 | Alkali | 0-2 | 48 | .05 | .62 | 8.2 | 7.5 | SC | SPC |
| 112 | C | 2 | 48 | Tr. | .03 | 8.3 | 8.2 | SC | S |
| 113 | Alkali | 1 | (38 M) | .04 | .12 | 7.9 | 8.7 | SC | C |
| 114 | Alkali | 1 | 40(A) | .12 | .34 | 8.4 | 9.0 | VPC | VPC |
| 115 | Alkali | 1 | (34M) | .04 | 1.25 | 7.9 | 7.8 | SC | PC |
| 116 | Alkali | 1-4(U) | (36M) | .09 | 1.15 | 8.1 | 8.1 | SC | CL |
| 117 | Alkali | 1 | 0 | .41 | .24 | 8.5 | 8.3 | CL | VPC |
| 118 | Alkali | 1 | 54 | .16 | .24 | 7.9 | 8.8 | VPC | PC |
| 119 | Alkali | 0-1 | (10M) | .19 | .30 | 8.5 | 8.9 | PC | SPC |
| 120 | Alkali | 1-3(H) | (18M) | .38 | .25 | 9.2 | 8.7 | PC | SPC |
| 121 | Alkali | 1-3(H) | 0(A) | .22 | .10 | 8.2 | 8.2 | CL | PC |
| 122 | P | 1-3(H) | 0 | .05 | .25 | 8.0 | 8.2 | SL | PC |
| 123 | P | 1-3(H) | 24 | 1.40 | .07 | 8.3 | 7.8 | PC | PC |
| 124 | Alkali | 1-2 | 30(A) | .20 | .16 | 8.4 | 8.5 | SL | CL |
| 125 | A | 1-2 | | .06 | .50 | 7.8 | 8.9 | SL | S |
| 126 | Idle | 0-2(U) | | Tr. | .14 | 7.8 | 9.1 | SL | S |
| 127 | P | 0-1 | 12 | .07 | .04 | 8.2 | 7.8 | SL | S |
| 128 | A | 1-2 | | .04 | .01 | 7.9 | 7.8 | SL | SL |
| 129 | A | 1 | 24 | Tr. | .04 | 8.2 | 8.1 | SL | S |
| 130 | A | 0-1 | 48 | Tr. | Tr. | 7.8 | 8.2 | SL | S |
| 131 | A | 1-2 | 14 | Tr. | .30 | 7.9 | 8.1 | SL | S |
| 132 | G(W) | 0-1 | 10- | .05 | .55 | 7.7 | 8.4 | CL | PC |
| 133 | P | 1-3(U) | | .03 | .20 | 8.0 | 8.6 | L | PC |
| 134 | G(W) | 1-3(U) | 40 | .08 | 1.00 | 7.7 | 7.9 | L | PC |
| 135 | P | 0-1 | 10 | .17 | .66 | 8.3 | 8.4 | PC | SPC |
| 136 | P | 0-1 | 5 | .18 | .27 | 7.7 | 8.3 | VPC | SPC |
| 137 | P | 0-1 | 26 | .07 | .21 | 7.6 | 8.4 | PC | SPC |

Table No. 3 (Continued)

Table No. 4. Showing the depths to water table in 81 auger holes for a late fall and early spring measurement. Taken during investigations for Cache County Drainage District No. 2.

| Well Number | Dist. to Water Table Date Observed '21&'22 | | Well Number | Dist. to Water Table Date Observed '21&'22 | |
|---|---|---|---|---|---|
| | 10/23-11/10 | 4/18 | | 10/23-11/10 | 4/18 |
| 4 | 2.6 | 0.6 | 210 | 4.5 | 3.2 |
| 6 | 0.6 | 0.6 | 212 | 1.0 | 0.8 |
| 8 | 0.0 | 0.5 | 214 | 0.0 | 0.8 |
| 43 | 4.5 | 3.5 | 216 | 0.0 | 0.0 |
| 44 | 1.5 | 2.8 | 218 | 0.5 | 0.8 |
| 46 | 8.0 | 7.8 | 220 | 2.0 | 1.4 |
| 48 | 6.8 | 0.2 | 220B | 5.5 | 7.2 |
| 50 | 0.0 | --- | 248 | 4.5 | 2.6 |
| 50A | 9.0 | 0.0 | 250 | 4.5 | 1.5 |
| 52 | 3.0 | 0.7 | 252 | 1.2 | 2.8 |
| 53 | 3.5 | --- | 254 | 1.5 | 1.5 |
| 54 | 1.0 | 0.9 | 256 | 1.6 | 1.8 |
| 56 | 2.0 | 2.9 | 258 | 0.5 | 0.3 |
| 58 | 2.0 | 1.0 | 260 | 2.0 | 2.4 |
| 60 | 0.5 | 0.7 | 283 | 1.0 | 0.4 |
| 82 | 1.6 | 1.0 | 284 | 4.0 | 1.8 |
| 84 | 2.3 | 1.0 | 288 | 3.5 | 0.0 |
| 86 | 5.5 | 1.0 | 290 | 0.6 | 1.2 |
| 87 | --- | 0.8 | 292 | 2.8 | 2.8 |
| 88 | 6.5 | 4.5 | 322 | 4.0 | 4.0 |
| 90 | 2.0 | 0.7 | 324 | 6.0 | 1.8 |
| 92 | 3.5 | 0.2 | 328 | 4.0 | 0.9 |
| 94 | 1.2 | 3.5 | 330 | 2.0 | 1.6 |
| 96 | 1.0 | 0.4 | 332 | 1.0 | 1.2 |
| 98 | 1.3 | 1.2 | 363 | 6.0 | 0.0 |
| 100 | 1.3 | 0.4 | 364 | 4.0 | 0.8 |
| 102 | 2.0 | 2.8 | 370 | 9.0 | 6.0 |
| 124 | 1.0 | 4.0 | 402 | 7.0 | --- |
| 126 | 4.5 | 3.9 | 404 | 0.0 | 1.0 |
| 127 | 3.0 | 0.5 | 406 | 3.5 | 0.9 |
| 128 | 7.0 | 4.8 | 425 | 3.5 | 1.5 |
| 130 | 5.5 | 3.2 | 446 | 3.0 | 1.6 |
| 132 | 2.0 | 1.6 | 448 | 3.0 | 1.8 |
| 134 | 0.8 | 12. | 466 | 4.0 | 3.8 |
| 136 | 0.5 | 2.0 | 468 | 4.5 | 1.4 |
| 138 | 2.0 | 2.4 | | | |
| 140 | 0.0 | 0.0 | | | |
| 140B | 2.0 | 2.4 | | | |
| 166 | 1.5 | 1.3 | | | |
| 168 | 1.6 | 1.3 | | | |
| 170 | 2.0 | 4.0 | | | |
| 172 | 2.0 | 0.3 | | | |
| 174 | 1.3 | 0.8 | | | |
| 176 | 0.0 | 1.0 | | | |
| 178 | 1.5 | 1.3 | | | |
| 180 | 0.0 | 0.1 | | | |

Form R6-205
(4/1/49)

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
Soils Laboratory

Work Group Engineering Dept., Irrigation Division District or Survey
Collected by W. W. Rasmussen Date 10/30/52 Analyzed by James Thorne Date 12/5/52

| Lab. No. | Sample No. | Location Photo No. | Cons. Survey Symbol | Depth | pH Paste | pH 1:5 | Total Soluble Salts % | Sat. Cond. | B.E.C. | Ex. Na | Na % | N as $NO_3$ PPM | Avail. K PPM | Mech. Composition Sand % | Silt % | Clay .002 % | Clay .005 % | Dispersion % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U 19386 | 1 | Robert Reese | | 0-12 | 7.5 | 8.8 | .17 | | | | | | | 11 | 49 | 40 | 54 | |
| U19387 | | Leon Reese | | 12-60 | 8.2 | 9.2 | .40 | | | | | | | 6 | 34 | 60 | 83 | |
| | | Oliver Thurston | | | | | | | | | | | | | | | | |
| U19388 | W2 | " | | 0-12 | 7.9 | 9.5 | .63 | | | | | | | 13 | 57 | 40 | 55 | |
| U19389 | | " | | 12-36 | 8.2 | 9.6 | .79 | | | | | | | 5 | 46 | 49 | 69 | |
| U19390 | | " | | 36-60 | 8.3 | 9.8 | .69 | | | | | | | 0 | 42 | 58 | 84 | |
| U19391 | W3 | " | | 0-12 | 7.7 | 9.3 | .16 | | | | | | | 5 | 60 | 35 | 53 | |
| U19392 | | " | | 12-60 | 8.6 | 10.1 | .43 | | | | | | | 6 | 39 | 55 | 78 | |
| U19393 | W4 | " | | 0-18 | 9.2 | 10.1 | .22 | 3.2 | 17.0 | 8.0 | 47 | | | 8 | 59 | 33 | 46 | |
| U19394 | | " | | 18-36 | 8.9 | 9.8 | .09 | | | | | | | 14 | 57 | 29 | 42 | |
| U19395 | | " | | 36-60 | 8.3 | 9.6 | .08 | | | | | | | 6 | 62 | 32 | 46 | |
| U19396 | 3 | " | | 0-12 | 8.2 | 9.3 | .10 | | | | | | | 6 | 54 | 40 | 57 | |
| U19397 | | " | | 12-60 | 8.7 | 9.9 | .30 | | | | | | | 6 | 40 | 54 | 76 | |
| U19398 | 4 | " | | 0-12 | 8.2 | 9.3 | .13 | | | | | | | 18 | 46 | 36 | 51 | |
| U19399 | | " | | 12-60 | 9.1 | 10.0 | .31 | | | | | | | 16 | 39 | 45 | 64 | |
| U19400 | 7 | " | | 0-12 | 8.4 | 9.4 | .17 | 2.6 | 21.5 | 5.0 | 23 | | | 4 | 56 | 40 | 57 | |
| U19401 | | " | | 12-60 | 8.8 | 10.0 | .47 | | | | | | | 5 | 42 | 53 | 76 | |

CS-5 Table 5 Soil Analysis - section 8 T12N R1E



SOIL CONSERVATION SERVICE, ALBUQUERQUE, NEW MEXICO
APRIL 1949 M-173

Form D6-205
(4/1/49)

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
Soils Laboratory

Work Group Experiment Station — District or Survey Cache County
Collected by Wilson & Hugie — Date 10/ /53 — Analyzed by James Thorne — Date 10/ /53

| Lab. No. | Sample No. | Location Photo No. | Conn. Survey Symbol | Depth | pH Paste | pH 1:5 | Total Soluble Salts % | Total Grav. Salts % | Org. Mat. % | $CaCO_3$ (Lime) % | Avail. ($PO_4$) PPM | N as $NO_3$ PPM | ~~XXXXXX~~ Gypsum | Mech. Composition Sand % | Silt % | Clay .002 % | Clay .005 % | Disper-sion % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U19321 | 1 | Parley Reese | | 0-6 | 8.2 | 9.0 | .12 | | | | | | .00 | 7 | 38 | 55 | 74 | |
| U19322 | 1 | meadows, Benson | | 6-18 | 8.2 | 9.1 | .23 | | | | | | .00 | 0 | 35 | 65 | 85 | |
| U19323 | 1 | " | | 18-36 | 8.1 | 8.3 | .39 | | | | | | 3.53 | flocculated | | | | |
| U19324 | 1 | " | | 36-60 | 8.0 | 8.2 | .61 | | | | | | 4.55 | flocculated | | | | |
| U19325 | 2 | " | | 0-6 | 8.3 | 9.4 | .83 | | | | | | | 13 | 55 | 32 | 46 | |
| U19326 | 2 | " | | 6-18 | 8.5 | 9.3 | .40 | | | | | | | 13 | 50 | 37 | 51 | |
| U19327 | 2 | " | | 18-36 | 8.7 | 9.6 | .34 | | | | | | | 6 | 40 | 54 | 74 | |
| U19328 | 2 | " | | 36-60 | 8.6 | 9.6 | .41 | | | | | | | 0 | 34 | 66 | 91 | |
| U19329 | 3 | " | | 0-6 | 7.8 | 8.5 | .18 | | | | | | | 3 | 57 | 40 | 64 | |
| U19330 | 3 | " | | 6-18 | 7.8 | 9.0 | .10 | | | | | | | 4 | 40 | 56 | 74 | |
| U19331 | 3 | " | | 18-36 | 8.5 | 9.7 | .19 | | | | | | | 4 | 37 | 59 | 84 | |
| U19332 | 3 | " | | 36-60 | 8.8 | 9.9 | .31 | | | | | | | 1 | 44 | 55 | 80 | |

CS-5

Table 6 Soil Analysis - section 10 T12N R1E



SOIL CONSERVATION SERVICE, ALBUQUERQUE, NEW MEXICO
APR. 1949 M-122

| Battery No. And Depth | | Depth Below Ground Surface March 31 | April 11 | April 15 |
|---|---|---|---|---|
| 1 | 7'-0 | 1.1 | 0.4 | 0.3 |
| | 14'-0 | 0.7 | 0.2 | 0.2 |
| 2 | 7'-0 | 1.1 | 0.5 | 0.4 |
| | 14'-0- | 0.9 | 0.3 | 0.4 |
| 3 | 7'-0 | 0.3 | 1.8 | 1.9 |
| | 14'-0 | 2.5 | 2.1 | 2.0 |
| 4 | 7'-0 | 1.8 | 1.8 | 1.9 |
| | 14'-0 | 1.7 | 1.7 | 1.9 |
| 5 | 7'-0 | 3.8 | 3.6 | 3.7 |
| | 14'-0 | --- | 6.5 | 7.1 |
| 6 | 2'-6" | 0.5 | 0,7 | 0.7 |
| | 7'-0 | 1.2 | 0.3 | 0.3 |
| | 14'-0 | --- | --- | |
| 7 | 7'-0 | 5.4 | 7.2 | 7.2 |
| | 14'-0 | 9.5 | 9.4 | 9.6 |
| 8 | 7'-0 | 3.2 | 2.6 | 2.0 |
| | 14'-0 | 2.6 | 2.6 | 2.3 |
| | 21'-0 | 2.2 | 2.7 | 2.5 |
| 9 | 7'-0 | --- | Under | --- |
| | 14'-0 | --- | Water | --- |
| 10 | 7'-0 | 1.5 | 1.0 | 1.1 |
| | 14'-0 | 1.5 | 1.0 | 1.0 |
| 11 | 7'-0 | 1.6 | 1.2 | 1.0 |
| | 14'-0 | 0.6 | 1.0 | 1.0 |
| 12 | 7'-0 | 2.2 | 2.2 | 2.2 |
| | 14'-0 | 2.5 | 2.1 | 2.1 |
| 13 | 7'-0 | 0.8 | 2.3 | 2.2 |
| | 14'-0 | 3.3 | 0.5 | 0.5 |
| 14 | 7'-0 | 2.0 | 1.5 | 1.2 |
| | 14'-0 | 1.8 | 1.5 | 1.2 |

Table No. 7. Piezometer readings in Logan-Hyde Park-Benson Area. (For peizometer locations see Map 13.)

| Hole No. | 11/27 ft-in | 12/1 ft-in | 12/5 ft-in | 12/9 ft-in | 12/14 ft-in | 12/17 ft-in | 12/29 ft-in | 1/6 ft-in | 1/15 ft-in | 1/31 ft-in | 2/14 ft-in | 2/28 ft-in | 3/15 ft-in | 3/30 ft-in | 4/11 ft-in |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2-11 | 3-2 | 3-5 | 3-7 | 3-9 | 3-9 | 3-10 | 3-11 | 3-9 | 2-0 | 2-4 | 3-0 | 3-2 | 3-6 | 3-1 |
| 2 | 2-3 | 2-10 | 2-1 | 3-4 | 3-5 | 3-5 | 3-6 | 3-8 | 3-4 | 1-8 | 2-0 | 2-8 | 2-10 | 3-4 | 2-9 |
| 3 | 2-0 | 3-0 | 3-1 | 3-1 | 3-2 | 3-3 | 3-5 | 3-6 | 3-4 | 0-9 | 1-5 | 2-1 | 2-4 | 2-10 | 2-8 |
| 4 | 2-10 | 3-1 | 3-6 | 3-8 | 3-8 | 3-8 | 3-10 | 3-11 | 3-8 | 1-11 | 2-3 | 2-11 | 2-11 | 3-3 | 2-9 |
| 5 | --- | --- | --- | --- | 3-5 | 3-6 | 3-9 | 4-9 | 3-10 | 1-3 | 1-7 | 2-3 | 2-5 | 2-10 | 2-6 |
| 6 | --- | --- | --- | --- | 4-6 | 4-8 | 4-9 | 4-10 | 4-0 | 2-8 | 3-0 | 3-8 | 3-10 | 4-1 | 3-4 |
| 7 | 3-9 | 4-0 | 4-2 | 4-3 | 4-4 | 4-5 | 4-5 | 4-6 | 4-5 | 2-8 | 3-0 | 3-8 | 3-10 | 4-1 | 3-5 |
| 8 | --- | --- | --- | --- | 4-8 | 4-10 | 5-0 | 5-1 | 5-0 | 3-9 | 4-2 | 4-9 | 4-11 | 5-2 | 4-6 |
| 9 | --- | --- | --- | --- | 5-5 | 5-6 | 5-9 | 5-9 | 5-8 | 4-6 | 4-10 | 5-4 | 5-6 | 5-8 | 4-11 |
| 10 | 4-0 | 4-2 | 4-4 | 4-5 | 4-6 | 4-6 | 4-9 | 4-11 | 4-9 | 3-2 | 3-4 | 4-8 | 4-11 | 5-2 | 3-9 |
| 11 | --- | --- | --- | --- | 4-6 | 4-7 | 4-9 | 4-10 | 4-8 | 2-8 | 3-0 | 3-8 | 3-10 | 4-3 | 3-3 |
| 12 | --- | --- | --- | --- | 5-7 | 5-9 | 6-0 | 6-2 | 6-0 | 3-10 | 4-1 | 4-6 | 4-7 | 4-10 | 4-6 |
| 13 | 4-7 | 4-9 | 4-10 | 5-0 | 5-2 | 5-5 | 5-8 | 5-9 | 5-7 | 3-6 | 3-10 | 4-4 | 4-6 | 4-9 | 5-8 |
| 14 | --- | --- | --- | --- | 5-8 | 5-10 | 6-0 | 6-2 | 6-1 | 4-1 | 4-5 | 4-1 | 5-1 | 5-6 | 5-3 |
| 15 | 5-10 | 6-4 | 6-7 | 6-9 | 6-10 | 6-10 | 6-7 | 6-9 | 6-6 | 3-3 | 5-6 | 6-0 | 6-1 | 6-0 | 6-0 |
| 16 | 5-9 | 6-2 | 6-3 | 6-4 | 6-5 | 6-5 | 6-4 | 6-6 | 6-3 | 3-8 | 5-5 | 5-1 | 6-0 | 6-0 | 6-0 |
| 17 | 5-8 | 5-10 | 6-0 | 6-2 | 6-3 | 6-4 | 6-3 | 6-4 | 6-3 | 3-3 | 5-2 | 5-8 | 5-9 | 5-10 | 5-11 |
| 18 | 5-3 | 5-6 | 5-8 | 5-10 | 6-0 | 6-1 | 5-0 | 6-2 | 6-0 | 4-6 | 4-10 | 5-1 | 5-2 | 5-5 | 5-2 |
| 19 | 5-0 | 5-1 | 5-7 | 5-0 | 5-10 | 5-11 | 5-11 | 6-2 | 6-0 | 4-3 | 4-8 | 4-10 | 5-11 | 5-1 | 4-0 |
| 20 | --- | --- | --- | --- | 5-0 | 5-2 | 5-5 | 5-6 | 5-4 | 3-0 | 4-0 | 4-3 | 4-5 | 4-8 | 4-11 |
| 21 | --- | --- | 4-1 | 4-2 | 4-3 | 4-3 | 4-6 | 4-8 | 4-6 | 1-11 | 2-10 | 3-6 | 3-10 | 4-3 | 3-9 |
| 22 | 3-8 | 3-6 | 3-7 | 3-7 | 3-7 | 3-8 | 3-9 | 3-10 | 3-8 | 1-2 | 2-3 | 2-9 | 2-11 | 3-0 | 2-9 |
| 23 | 3-8 | 4-9 | 4-7 | 4-9 | 4-11 | 5-0 | 5-1 | 5-3 | 5-1 | 2-8 | 3-6 | 3-9 | 3-11 | 4-2 | 4-3 |
| 24 | --- | 4-4 | 5-1 | 5-4 | 5-6 | 5-9 | 5-10 | 6-0 | 5-10 | 3-0 | 4-2 | 4-4 | 4-5 | 4-8 | 5-3 |
| 25 | 5-7 | 5-10 | 5-1 | 6-3 | 6-4 | 6-5 | 6-3 | 6-6 | 6-4 | 2-0 | 6-4 | 6-2 | 6-0 | 6-3 | 6-1 |
| 26 | --- | --- | 3-8 | 3-8 | 3-9 | 3-10 | 3-11 | 4-0 | 5-5 | 3-11 | 5-0 | 5-4 | 5-6 | 5-7 | 5-0 |
| 27 | --- | --- | --- | --- | 4-2 | 4-4 | 4-6 | 4-7 | 4-5 | 2-5 | 3-8 | 4-0 | 4-2 | 4-6 | 3-10 |
| 28 | --- | --- | --- | --- | 5-3 | 5-4 | 5-6 | 5-7 | 3-10 | 1-5 | 2-1 | 2-9 | 2-10 | 3-0 | 2-9 |

Table No. 8. Depth to water table and drawdown curve for Louis B. Riggs' open and tile drain. For location and layout see Map 16 and Figure 11.