Drainage Report

Salt River Valley Water Users' Association

1919

BOWER CO., PHOENIX

DRAINAGE REPORT

Salt River Valley Water Users' Association, 1919

Los Angeles, California, February 13, 1919.

To the Honorable President and Board of Governors,
Salt River Valley Water Users' Association,
Phoenix, Arizona.

GENTLEMEN:

We submit the following report on drainage of the Salt River Project, Arizona:

1.—AUTHORITY:

This report is made under the authority of the Board of Governors of the Salt River Valley Water Users' Association, who on May 20, 1918, directed that a drainage investigation be made and on August 5, 1918, created a Board of Engineers, consisting of the undersigned, to carry on such investigations and make report.

The report is supplemental to that of August 29, 1918, on location of wells and installation of pumping plants for increasing the water supply for the project.

2.—SCOPE OF REPORT:

The scope of this report is of necessity preliminary for the reason that complete data relative to some of the areas where drainage is necessary is not yet available, and cannot be obtained until wells have been constructed in these areas. We have, however, attempted to anticipate the needs of the Valley for drainage and to prepare a tentative plan and estimate of the work that will be required.

It is our understanding that there is a legal question whether the Association, under its present organization, is authorized to expend money for purely drainage purposes. The estimates are intended to give as definite an idea as is possible at this time, of the amount of money that will be required for drainage works, and enable the Board to take such action as will be advisable for providing funds for this purpose.

Attention is called to the rapid rate at which water has been rising on portions of the project during the past year, and the large area over which the ground waters are now sufficiently high to threaten the soils. We regard it of especial importance that consideration be given to relieving this condition at as early a date as is practicable.

3.—SOILS:

The surface soils of the Salt River Valley vary from coarse gravelly and sandy loams to very finely divided clays or adobes. In some instances they are of such fine texture that when compacted, water finds its way through them with difficulty. The soils generally have been formed by materials washed down from the hills and mountains adjacent to the valley, although on a few rather limited areas the materials have been brought in from long distances by streams. The underlying material or valley fill varies greatly in character. This has a marked effect upon the movement of ground water. The valley has been formed partly by materials brought in by the river, partly by wash from the adjacent hills, and partly by chemical precipitates from water. The river debris consists of water worn boulders, gravels, sand, silt and clays. The wash from the hills consists of irregular angular rock fragments and the chemical precipitates consist of hard, more or less tightly compacted materials of which the substance known as caliche is the most important and the most common. The various materials of which the valley fill is composed have been brought together in a very erratic manner. They apparently exist in the form of irregular shaped lenses which pinch out or terminate abruptly thus giving the diversified formation shown by well records. Generally, however, it may be said that gravel beds, more or less continuous, exist on the South side over the entire area south and east of Tempe, along and for some distance on either side of Salt and New Rivers, and on the Cave Creek delta. Wash from the hills is found quite generally on the upper portions of the valley proper. Caliche occurs throughout the entire valley. It is more or less continuous but sufficiently porous or broken to permit of water from below being carried through it and brought to the surface where the head or pressure of the ground water is sufficient to produce this amount of upward motion. Observations at various locations show, with few exceptions, that ground water stands at about the same elevation in deep wells as in shallow ones. This indicates a free communication between the lower water bearing strata and the surface soils, and shows also that the material is fully saturated below where free ground water is first encountered.

The character of the soils and valley fill has an important bearing upon the drainage of the valley. The deep water bearing strata of gravel and boulders, which are found over the greater portion of the area, give free movement of underground water. Drainage, as a result of this, becomes a general problem involving large areas rather than a local one that may be applied to individual tracts. On some of the upper areas where the valley fill is composed largely of relatively non-porous materials, the underground flow is interfered with and the slopes of ground water are less uniform. The fine textured soils which are found over a large part of the area have a high capillary power and result in bringing up water from considerable depths in sufficient quantities to damage surface soils through waterlogging and the concentration of harmful alkali salts in them. This condition makes it necessary that the ground water be kept, at all times, well below the surface.

4.—GROUND WATER CONDITIONS:

The elevations of ground water over the greater portion of the project have been observed from domestic and test wells since 1913. During that period there has been a general rise in the water table over the valley. The results of observations on 97 wells showing the rise for the entire project and for the North and South sides separately, are indicated graphically by the curves, Drawing No. 1.

During the present year extensive observations have been made to determine the rise of ground water and its average depth over the entire project. The results of observations made on 462 wells in May and October, 1918, are given by townships, on Drawing No. 2. A summary of these results shows an average rise of 1.6 feet on the North side and an average fall of 0.9 feet on the South side of the river. The fall was confined entirely to the eastern portion of the south side lands. In townships 1 North to 1 South and 4 to 5 East, an area of approximately 73,000 acres, the average fall was 1.9 feet.

The minimum depth to ground water that must be maintained to protect the tilth and irrigability of soils and prevent their becoming alkaline through capillary action and evaporation, varies for different types of soils. It also depends in a large degree upon the character of crops grown and the treatment which the soil receives. Cultivation tends to break up the soils and reduces capillary action through them. A higher ground water table, consequently, may be maintained upon thoroughly cultivated soils than upon non-cultivated ones, without increasing the danger due to alkali accumulations.

From observations in the Valley it has been found in some instances, that capillary action, from depths of from 6 to 8 feet is sufficient to bring perceptible quantities of alkali to the surface. In other instances, due to different character of soils and methods of cultivation, little or no surface accumulation of alkali is noted with the water table 6 feet or less below the surface. From a study of these various conditions it is believed, for complete protection of the soils, that a depth of not less than about 8 feet to ground water should be maintained. Areas where ground water is now 10 feet or less below the surface and still rising, are regarded as threatened and consideration should be given to their drainage in order to prevent a further rise beyond the danger limit. The area over which ground water was 10 feet deep or less in October, 1918, is estimated at about 67,000 acres, and is shown by the shaded area, Drawing No. 3.

5.—CAUSES OF RISE IN GROUND WATERS:

There are four principal sources which contribute to the filling up of the subsoils of the valley as follows:

Rainfall on the irrigable area;
Underground flow from streams;
Canal losses;
Irrigation.

The first two, rainfall and underground percolation from streams, are natural sources which have always existed. Waters falling as rain upon the valley which sink below the limit of capillary action and evaporation, and also waters which percolate from streams or that reach the valley as underground flow from the adjacent mountains, become a part of the underground supply. A series of wet years contributes more water to the valley than a series of dry years, and tends to cause a rise of ground water. A series of dry years, on the other hand, contributes a smaller amount to the underground storage and permits a portion of that already in the subsoils to be carried out by natural drainage and causes a lowering of the water table. Such changes, however, do not affect the average elevation of ground water taken over a long period of years, and it is probable that the amount of underground water contributed by these natural sources is practically the same now as before irrigation was begun. The water contributed to the subsoils through these natural sources is less than the natural drainage capacity. The result of this is that before irrigation ground water was generally well below the surface except on a few low lying areas immediately adjacent to the river.

When water was diverted into the valley for irrigation the source of underground supply was increased by canal and irrigation losses. Leakages from canals and laterals, unless held up by impervious strata, of which there are few in the valley, pass downward until they become a part of the general underground supply. So also all water applied to the soils in excess of what they can retain, if not carried off as surface waste, finds its way downward and contributes to the rise of the ground water. The irrigation supply which has been brought into the valley is primarily the cause of this rise. The losses from canals and irrigation, added to the natural underground supply is more than the natural drainage from the subsoils can carry away and the soils are slowly being filled. Since both canal losses and underground waste from irrigation contribute to the underground supply, it is not possible to say that either is wholly the cause of the rise in water table.

6.—CANAL LOSSES:

It is evident that seepage losses occur from all canals constructed in earth. The amount of these losses depends upon the character of materials which form the waterway. Observations made on various earthen canals throughout the irrigated sections of the country show losses varying from .25 acre feet or less to two acre feet or more, for 24 hours for each acre of wetted area. Canals which carry silt laden waters during all or a portion of the year tend to become more watertight with use due to the finer materials being carried into them. The disintegration and breaking up of materials forming the waterway also tend to close the openings through which water escapes.

There are but little accurate data available regarding losses from canals in the Salt River Valley. To measure such losses with certainty usually requires that the canal be put out of commission for carrying irrigation water while measurements are being made. This is difficult to do, especially in a climate where water is used practically continuously throughout the year.

During the past few months measurements have been made of losses by seepage and evaporation from sections of the Arizona, Grand and Western canals and on four main laterals. Some of the measurements were made above areas of high ground water for which it was believed the leakage from canals was largely the cause.

The results which show comparatively low losses are given in the following table:

	Length Miles	Wetted Area Acres	Loss Ac. Ft. in 24 Hrs.	Loss Ac. Ft. per Acre of Wetted Area in 24 Hrs.
Arizona, below Power House	1.19	6.95	1.65	0.24
Arizona, above Power House	2.25	17.47	1.88	0.11
Grand, from Lat. 10 to 14	4.58	21.57	9.76	0.45
Arizona Lat. No. 6	5.75	4.40	2.46	0.55
Arizona Lat. No. 10	2.50	1.58	1.17	0.74
Arizona Lat. No. 12	4.00	2.80	1.67	0.59
Arizona Lat. No. 16	6.00	6.18	2.00	0.32
Western	1.85	2.45	.89	0.37
Totals and Averages	28.12	63.40	21.48	0.34

It is probable that there are sections of canals where losses are less and other sections where they exceed those given above. Measurements on a larger number of canals are necessary in order to arrive at an accurate average of losses on the entire system. Some idea, however, may be obtained of the total amount of water lost from canals by using the above results.

There are on the project about 800 miles of canals and laterals. The total wetted area of these, it is estimated, is about 2000 acres. If the average loss as taken from above is 0.34 acre feet per acre of wetted area per day, the total loss is 680 acre feet per day. None of the canals carry water throughout the entire year, and many of the smaller laterals are dry for a considerable portion of the time. It is estimated that 250 days per year is a fair average time to consider for water in all of the canals of the system. Estimated on this basis, the loss over the entire system is 170,000 acre feet per year.

A small portion of this is carried off by evaporation. This probably does not exceed 10 per cent of the total loss, leaving a balance of 152,000 acre feet which may be regarded as passing into the soils.

As stated above, these results may be high or low, due to the fact that the average losses from canals as well as the other factors upon which the estimate is based, are not accurately known. The estimate, however, is the best that can be made with data available.

Practically all of the percolation losses from canals can be prevented and the water now lost in this manner saved for irrigation, by concrete lining the canals so as to render them water tight. Whether or not this plan is feasible and practicable is largely an economic question. The work would involve the placing of concrete lining over an area equal or nearly equal to the present wetted area of 2,000 acres, or 87,120,000 square feet. In some instances canal sections could be narrowed and the area reduced below that given above, but no material saving would be effected by this, on account of the cost of refilling a part of the canal section and shaping the banks to receive the concrete. On a basis of 10c per square foot, which we believe is less than the work can be done for under conditions which prevail on the project, the total cost would be $8,712,000.

Considering the amount of water that is lost from the canals, it is not believed that a general system of lining is feasible from an economic viewpoint. The cost of saving water in this manner is excessive, and it is not certain if the entire canal system of the project were lined, that the drainage problem would be solved. Underground losses from irrigation, which will be discussed later, might still be sufficient to cause a rise of ground water on portions of the project sufficient to do damage to the surface soils and drainage might still be required. It is possible, however, that there are sections of canals in particularly porous materials, where concrete lining is economically feasible and advisable for preventing seepage losses. In order to determine the location of these sections, it is necessary that careful measurements be made on portions of the various canals. The work of making measurements on sections of canals where conditions are favorable for high underground losses, has already been started and should be continued. Where abnormally high losses are found to occur, consideration should be given to concrete lining that portion of the canal. The lining of canals and laterals for other purposes than preventing seepage losses may be necessary and advisable in some instances; it may prevent erosion or the growth of weeds and thereby greatly reduce the cost of cleaning and maintaining canals. Requirements of this kind should be considered in connection with those of preventing loss of water.

7.—IRRIGATION:

Reference has already been made to underground waste from irrigation, which sinks into the soils and contributes to the rise in ground water. In order to form an idea of what these underground losses are, it is necessary to study the amount of water which is applied to the land. In studying the use of water it is necessary to consider not only the quantity applied to the lands as shown by the water duty records, based upon the deliveries to individual farms, but also the quantity of water delivered to canals less that wasted from the lower ends. All water which is delivered into the heads of main canals and laterals, unless carried away to the river as surface waste, sinks into the soils and becomes a part of the ground water of the valley.

A convenient method of expressing the quantity of water used is in terms of depth per month or per season over the area irrigated. The records of water delivered to the heads of main canals, exclusive of waste to the river, for the years 1912 to 1918, inclusive, are shown in this form on drawings Nos. 4, 5 and 6. Drawings Nos. 4 and 5 show results for four different groups of canals, while No. 6 shows the summary for all the canals. From the latter it is to be noted that the amount of water turned into the canals per year was sufficient to cover the total area irrigated under them from 3.8 to 5.4 feet deep.

There have been compiled also from the annual operation and maintenance reports, the quantities measured and charged for on the farms for the years 1913 to 1918. For convenienec of reference a summary of quantities delivered to canals and to farms, together with the percentage of the latter, is shown in the following table.

Quantities in Terms of Depths on Area Irrigated.

YEAR	Delivered to Canals.	Charged for at Farms.	Percent Charged for at Farms.
1912-13	4.60		
1913-14	3.80	2.39	62.9
1914-15	4.00	2.67	66.7
1915-16	4.70	2.94	62.5
1916-17	4.50	2.81	62.4
1917-18	5.40	3.22	59.6

It is to be noted, from the above, that there is a wide difference between the quantity delivered to the heads of canals and that charged for at the farms. In terms of quantity units this difference amounts to from 200,000 to 400,000 acre feet per year. This is important for the reason that the measurements to canals show a high or excess use of water while those at the farms show a moderate use. The methods of making measurements on the quantity of water delivered to the canals are such that we believe the results to be reasonably accurate.

The natural explanation of this discrepancy is that the difference was lost by seepage and evaporation from the canal and lateral system. We believe, however, that the difference is greater than actual canal losses and that the true explanation must be in the less accurate methods of making measurements of water deliveries to individual users on the farms,—in other words, that the water actually charged for to individual users, has been less than the quantities delivered. How much the measurements made at the farms may be in error, it is impossible to tell.

In the use of water in irrigation it frequently occurs that more is applied at a single time than the soils can retain. The excess above the soil capacity is wasted over the surface or carried downward until it becomes a part of the ground water below. The amount of water necessary to be applied at one time is the amount required to moisten the soil sufficient for plants to grow in it, to the depth the plant roots will penetrate. If we consider that the average depth of plant roots does not exceed five feet, which we believe to be a liberal estimate, and that the quantity of water necessary to moisten the soils to be 10% of the soil volume, which is also a liberal allowance, the amount necessary to be applied at one irrigation is 0.5 foot in depth. In many, and probably most instances, it would be less than this amount. On this basis it may be said that all water applied in excess of 0.5′ in depth at one irrigation is wasted through the soils and contributes to the raising of the ground water plane.

It is impossible to compute the amount of waste which occurs in this manner for the reason that no records are kept of the areas to which a given amount of water, delivered for irrigation, is applied. Some idea, however, may be obtained of this loss from a few specific examples. In these examples it has been assumed that the water delivered to an individual water user was applied to his entire irrigable area. This assumption undoubtedly gives a less depth than that actually applied since in most cases the entire area is not covered at one irrigation. The results therefore represent the minimum amounts wasted, and it is probable that the actual amounts exceed those shown. In these specific examples all water delivered at a single irrigation in excess of that necessary to cover the entire area to a depth of six inches, is computed as waste. The results are shown in the following table:

CANAL	No. Farms	Area Acres.	Water Delivered Acre Ft.	Underground Waste--Ac. Ft.	Percent Wasted.
Eastern	48	3,193	6,365	1,895	29.8
Consolidated	41	2,673	5,094	1,824	35.8
Maricopa	2	92	172	33	19.2
Western	33	2,266	4,183	1,368	32.7
Highline	7	309	259	42	16.2
Arizona	88	5,659	9,392	3,372	35.9
	219	14,192	25,465	8,534	33.5

These figures indicate that of the total amount of water delivered to the 219 farms, at least 33.5% was wasted. If it be assumed that the average waste in this manner over the entire project is one-half this percentage the total amount wasted during he season would amount to about 110,000 acre feet based upon the quantity actually charged for at farms.

From the studies of the irrigation figures we believe that the waste from irrigation through the excessive application of water at one time is an equally important factor in filling up subsoils as losses from canals and laterals. We believe, in order to curtail wastes of this kind, that a careful study should be made of irrigation practices to determine the quantity of water applied, and to reduce its use as nearly as possible to the amount that the soils will absorb and retain.

It is unnecessary for this Board to call attention to the effect of wasting irrigation water directly into the subsoils. The fact that the rise in ground water over the project is in part due to this cause has already been stated. A specific example, however, may be of interest. A waste of one foot in depth over the entire irrigable area of the project, amounting approximately to 200,000 acres, means a loss of 200,000 acre feet. This amounts to about 20% of the total quantity delivered to the heads of main canals during the season of 1917-18. Whatever amounts can be prevented from entering the subsoils through better irrigation practices, conserves the entire water supply by that amount, and also reduces the quantity which must be taken out of the soils in order to effect their drainage and protect them from the accumulation of alkali. It also reduces loss of soil fertility through leaching.

8.—QUANTITY OF WATER IN SOIL:

The amount of water which is stored in the subsoils of the valley, as is well known, is large. The rise in the water table as shown by the curves heretofore referred to, indicates also that this quantity has been greatly increased during the past few years. Some idea of the amount of increase in the volume of ground waters may be obtained from the following figures. The average rise over the entire valley from 1913 to 1918 is approximately 7.4 feet, or at the rate of about 1.5 feet per annum. If we consider the total area over which this rise has taken place as 250,000 acres, and that the water required to saturate the subsoils amounts to 30% of the volume of the soils, we have 112,500 acre feet per year. In addition to the water stored in the soils, there was pumped out of them from 1913 to 1918 an average of about 22,000 acre feet per year, which makes a total of 134,000 acre feet.

This quantity does not represent the entire amount of water which has been lost into the soils through irrigation and seepage from canals. A part of the losses has undoubtedly been carried away by natural drainage. It does, however, represent roughly the quantity of water which it is necessary to remove annually to maintain ground water at its present elevation. From the above figures, it may be roughly stated that to prevent a further rise in the ground water table from 125,000 to 150,000 acre feet per year must be removed, that is provided the loss from canals and waste from irrigation continue at the same rate as that of the past five years.

In order to lower the ground water to a safe depth, or in other words to drain the lands now seeped and threatened, it will be necessary to remove not only the annual accumulations from irrigation and canal losses, but also the water now stored in the soils above that depth. To lower the water table over an area of 250,000 acres one foot will require the removal of approximately 75,000 acre feet and the total quantity that must be pumped to produce a lowering of one foot per year, estimated on the above basis, will amount to from 200,000 to 225,000 acre feet per annum.

From the above it seems probable that not less than 200,000 acre feet per annum must be removed during the next few years in order to lower the water table and afford protection to the soils.

When the water table has once been lowered to a safe depth the amount of pumping that will be required each year may be reduced. It must be remembered, however, that with the ground water lower over the entire valley, natural underground drainage will be less.

9.—PLAN OF DRAINAGE:

In order to drain the valley in such manner as to protect all portions of it from seepage and the concentration of alkali on the surface, it is necessary to adopt a plan which will effect a general lowering of the water table. Any attempt at lowering ground water over individual areas or small portions of the project will not, as heretofore stated, prove satisfactory.

To effect a general lowering of the water table, it is necessary, in most instances at least, to tap the deep underlying gravel basins. Observations on areas now affected show that with but few exceptions seepage is due to the rise of ground water into the soils. The pore spaces in these materials form an underground reservoir which has become filled. When this water is taken out, space will be provided for excess water to move downward for a sufficient depth that it will no longer interfere with surface conditions. This applies to practically all of the lands of the project. There are, however, a few instances where water seems to be travelling down slopes and where it will be possible to intercept it before it reaches the lower areas where damage is now being done. Th greater part of the drainage, however, involves the taking of water out of the soils to a considerable depth and creating reservoir space sufficient to hold the accumulation of waste water below the surface.

10.—EFFECT OF PUMPING:

The effect of lowering the ground water through pumping is well shown by the experiments on the south side. Here the rise in ground water from 1913 to 1918 was 4.4 feet. On the north side, where no pumping was carried on, the rise for the same period was 10.0 feet. During the season of 1917-18, October 1 to September 20, the pumps on the south side were operated during a large portion of the time, and almost continuously for the last six months of this period. There were pumped a total of over 24,000 acre feet during the year, and about 16,000 acre feet during the period from April to September, inclusive. This is exclusive of the water pumped by the Tempe district and by the Southwest Cotton Company on the area south of the project lands. The former amounted to about 2,000 and the latter to about 23,000 acre feet during the period from February to September, 1918. The taking of this quantity of water out of the soil has undoubtedly been responsible, in a large degree, for the fall in ground water over that area heretofore referred to. On the north side, and also in the western portion of the south side, where no pumping was carried on, there was a steady rise in the water table during the same period. The entire area above referred to is underlaid by porous gravel.

On the north side an experiment has recently been tried on Central Avenue to determine the effect of pumping on the lowering of ground water. In the construction of this well, which is 285 feet deep, no gravel or sand was encountered, practically the entire well being in caliche. The well was pumped for a total period of 630 hours from November 26 to December 30 and yielded a total of 77.9 acre feet, or at the rate of approximately 2.93 acre feet per day of 24 hours for the time the pump was in actual operation. The maximum drawdown was 73 feet and the minimum discharge for any one day of continuous pumping 3.25 acre feet.

The effect of lowering ground water east, west, north and south of the well is shown on drawing No. 7. This shows a pronounced effect out to a distance of 1150 feet and a slight effect out to 2350 feet or over an area of nearly 400 acres. The average lowering of ground water over the inner area of 95 acres was 4.4 feet and over the outer 300 acres about 0.6 feet. The results obtained in the above location are, we believe, sufficiently encouraging to justify putting down additional wells for drainage on this and similar areas, that are not generally underlaid by porous sands or gravels. Pumping from wells similar to the one described above is not regarded as economically feasible for an additional water supply only, on account of the high lift and low yield of water. It may, however, be regarded as feasible for drainage purposes.

11.—DRAINAGE BY PUMPING.

Drainage throughout the valley, with few exceptions, can best be accomplished through pumping, first for the reason that the porous underground materials from which water must be removed, are too deep to be reached by ordinary drains, and second, for the reason that pumping provides a means whereby the ground water can be lowered to any required depth. Throughout the greater portion of the valley the sands and gravels or other porous materials through which a free water movement takes place, are found at depths of from 20 feet to 100 feet or more below the surface. The water as it exists in these porous underground strata, is under sufficient head to cause it to rise to near the surface. The wet condition of the soils is maintained largely by the upward motion of water into them. Drainage can be effected by pumping the water out of the porous strata below and permitting that in the soils to subside by a downward motion.

The areas where drainage by pumping is feasible and where it is believed that it offers the only satisfactory solution, include all of the affected lands on the south side, south and east of Tempe, nearly all of the lands on the north side of Salt River south and west of Phoenix, and along New River in the western portion of the project, and all, or nearly all of the lands north of Phoenix and extending eastward to the Arizona Canal near the Arizona Falls Power House. On a portion of the latter area pumping has not yet been tried. It is consequently impossible, with the data at hand, to state positively what results can be obtained from it. There are also two wet areas on the south side, as shown on the map, upon which pumping has not yet been tried, and where its feasibility for the relief of these areas has not been clearly established.

12.—DIRECT DRAINAGE:

Dirct drainage by means of open trenches, or covered drains is applicable where porous underground material through which water movement takes place, is sufficiently near to the surface to permit of it being tapped by drains. It is applicable also in relatively uniform materials, for intercepting water which is travelling down the slopes through the surface soils or over an impervious hardpan located at reasonable depths below the surface. The only places on the project where direct drainage may be necessary or applicable, is a small area under the Arizona Canal north and east of Phoenix, on the south side under the Western Canal, and on the bottom lands adjacent to the river south and west of Phoenix.

Pumping on these areas has not yet been tried and it is not certain that underground conditions are such that ground water can be effectively removed in this manner. It is our opinion, before drainage works are laid out and constructed on these areas, that test wells should be put down on each of them for the purpose of determining the feasibility of developing underground water and of lowering the water table by means of pumping. If pumping is feasible, drainage by it can be accomplished at a less cost than by the use of drainage ditches. It will be more effective also on account of the greater depth to which the water table can be lowered.

In connection with the estimate for the drainage of the project, it has seemed wise to provide for these areas on the basis of constructing drains over them. If further investigations should demonstrate that it is feasible to effect their drainage by pumping, the cost of the work may be somewhat reduced.

The estimates are based upon drains of the closed type in order to reduce property damages and future costs of maintenance to a minimum. On account of the high capillarity of the soils in all of the above areas, deep drainage is necessary in order to make it effective. The estimates are based upon drains approximately ten feet deep.

13.—DISPOSAL OF DRAINAGE WATER:

The disposal of drainage waters which are developed either by pumping or by direct drainage, is a question requiring careful consideration. These waters may be either carried off through surface channels and wasted into the river or they may be used for irrigation. Where waters have as high value as in the Salt River Valley, it follows from an economic viewpoint that the entire supply, if suitable for irrigation, should be used for that purpose. The only question in connection with the use of drainage waters for irrigation, is whether or not the quality of the water is satisfactory. It is impossible in advance of constructing wells or drains, to know the quality of the water that will be developed. It is necessary, on this account, to examine the character of water developed from each particular well or drain before it can be safely applied to lands.

In connection with the use of pumped or drainage water for irrigation, conditions are such in the Valley that this water ordinarily can be mixed with several times its volume of river water. By this process of mixing it is generally possible to produce a supply of unquestionable quality.

We have made provision in the estimate for the necessary works for the disposing of waters developed by pumping which are unfit for use, should the same be found. As previously stated, however, the construction of such works should be delayed until the need for them has been positively shown. An attempt has been made, in locating wells, to so place them that the pumped water can be delivered into irrigation canals and laterals. Conditions governing the use of pumped water has already been defined by resolution of the Water Users' Association referred to in our former report, and reading as follows:

"That as far as practicable, the pumped water be mixed with river water so as to give as large a percentage of river water to each shareholder as practicable, and that no shareholder shall be compelled, against his consent, to accept water containing a greater percentage of pumped water than is certified by the University of the State of Arizona, or any other recognized authority, not to be injurious in the percentage and of the quality delivered to said shareholder for the cultivation of lands or the growing of agricultural crops in the Salt River Valley."

14.—PUMPING INSTALLATION REQUIRED:

The quantity of water that must be removed from the soils during the next few years has been estimated at about 200,000 acre feet per annum. The capacity of wells and pumps—now installed on the project—when operated for a period of 300 days is about 30,000 acre feet per year. The wells now being put down for the purpose of increasing the water supply it is estimated will have a capacity of about 110,000 acre feet per year. This is based upon 60 wells having an average capacity of 6 acre feet per day, operated for a period of 300 days per year. The wells planned by the City of Phoenix, it is estimated, will have a capacity of about 200,000 acre feet per annum. Deducting the above amounts from the total of 200,000 there still remains 40,000 acre feet to be removed. This, on a basis of operating 300 days, is equivalent to 133 acre feet per day. The wells for removing this additional quantity must many of them be located in areas where conditions for large yields are not particularly satisfactory. It is our judgment that the average yield for these wells will not exceed 4 acre feet per day. On this basis and assuming that all of this water can be removed by pumping, 33 additional wells will be required.

15.—TENTATIVE PLAN:

On the map, drawing No. 8, are shown locations for wells to be first constructed, proposed locations for waste ditches, and areas where drains may be necessary.

In laying out the general plan for drainage an attempt has been made to provide for the future needs of the project so far as can be foreseen, and to determine the amount of funds that will be required to give drainage protection.

We do not deem it advisable to attempt to make exact locations for additional wells, or for drains at this time. This can be best done after the results of pumping on wells now under construction are available. It is possible that not all of the work included in the estimate will be required. For this reason, portions of the wells in each of the affected areas should be put down and their results determined before additional ones are built. By this plan or procedure only such works as are absolutely essential to the drainage of the valley need be constructed, and the cost reduced to a minimum.

The tentative plan provides for 33 wells to be equipped with the necessary pumps and motors, for twenty miles of deep drains intended for lowering and controlling ground water and for 60 miles of outlet drains intended for the disposal of drainage waters, should the same be found necessary.

16.—ESTIMATE OF COST:

The estimated cost of the works is as follows:

33 Wells with necessary motors and electrical equipment at $7,000. each	$231,000.00
60 Miles of waste ditches at $1,180. per mile	70,800.00
20 Miles of deep drains at $8,000. per mile	160,000.00
	$461,800.00

17.—SUMMARY:

Our principal conclusions may be summarized briefly as follows:

First:—The rise in ground water during the past few years, and its present proximity to the surface indicate clearly that drainage is needed to protect the surface soils, over large areas, from becoming water logged and alkaline and ultimately unfit for cultivation.

Second:—That drainage is feasible both from the economic and engineering viewpoints.

Third:—That pumping generally may be regarded as the most feasible means for drainage but there are some areas where the effectiveness of pumping has not been proven and where drains may be required.

Fourth:—The quantity of water which must be removed during the next few years, it is estimated will amount to about 200,000 acre feet per annum.

Fifth:—That to remove this quantity about 33 wells, in addition to those already provided for, will be required.

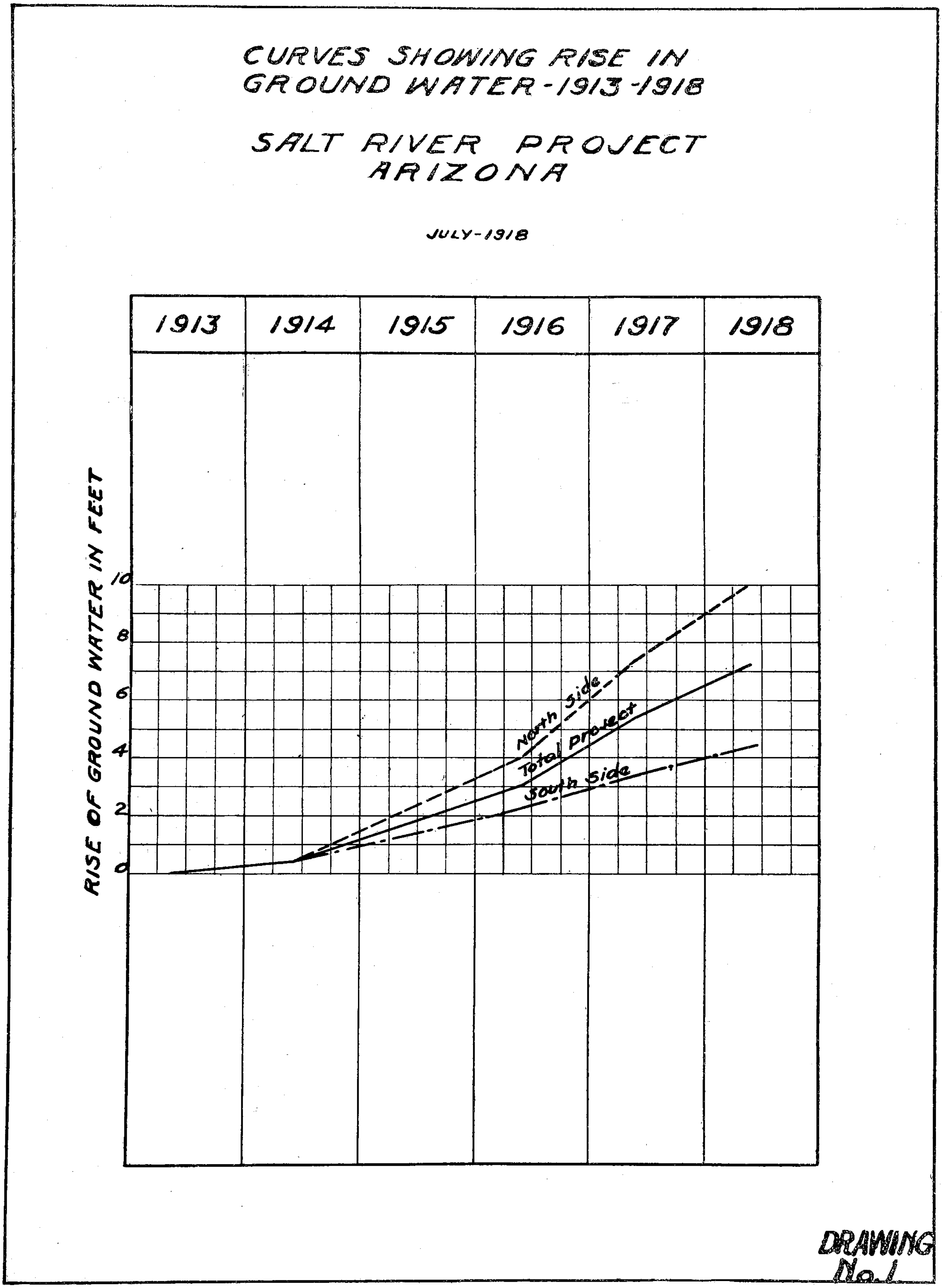
Sixth:—That a more economic use of water will reduce the amount of drainage that ultimately will be needed.

17.—RECOMMENDATION:

We recommend that provisions be made for drainage in accordance with plans herein outlined.

Respectfully submitted,

W. R. ELLIOTT,
D. W. MURPHY,
W. H. CODE,
Board of Engineers.

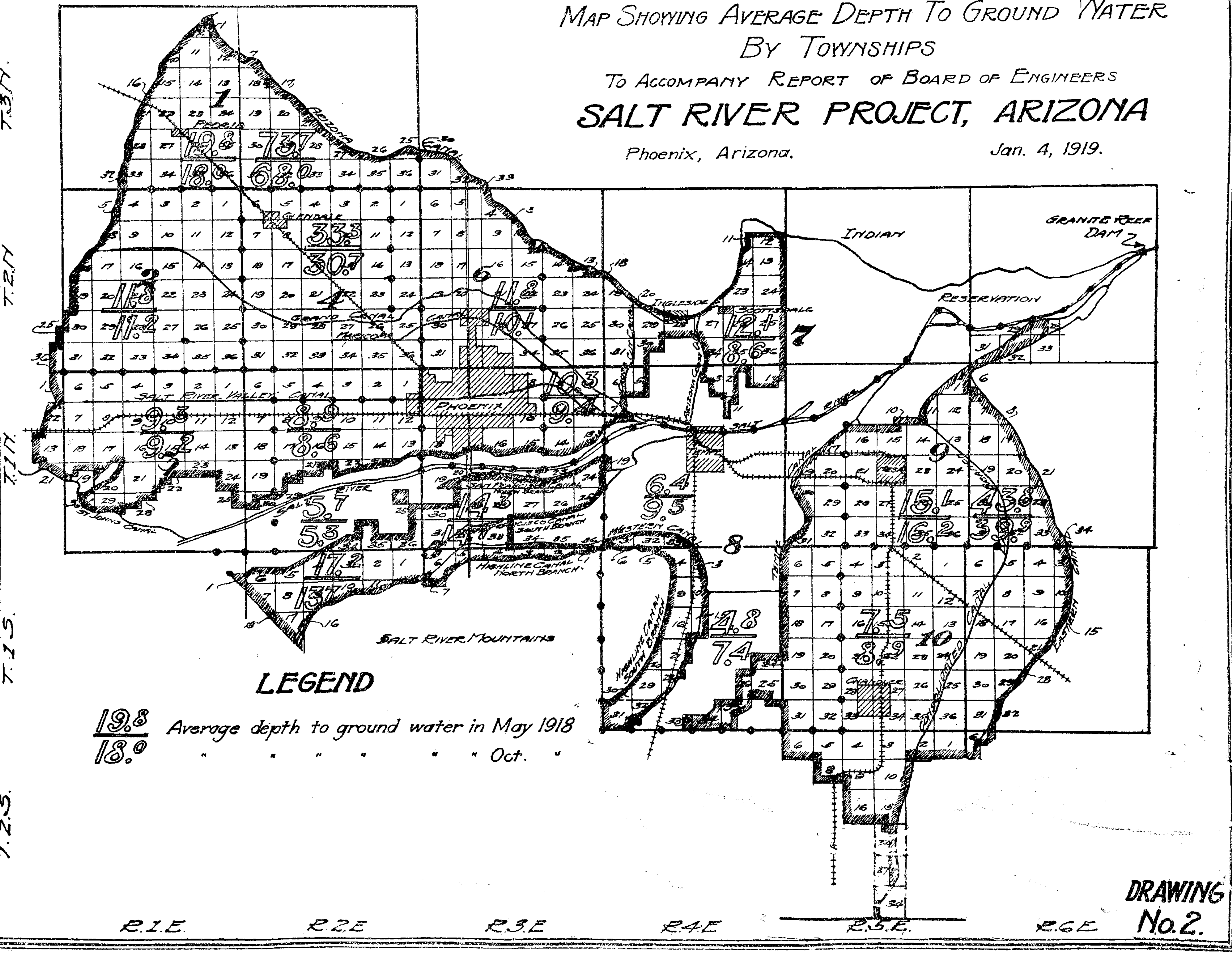

CURVES SHOWING RISE IN GROUND WATER-1913-1918
SALT RIVER PROJECT
ARIZONA
JULY-1918
1913
1914
1915
1916
1917
1918
RISE OF GROUND WATER IN FEET
10
8
6
4
2
0
North Side
Total project
South Side
DRAWING No. 1

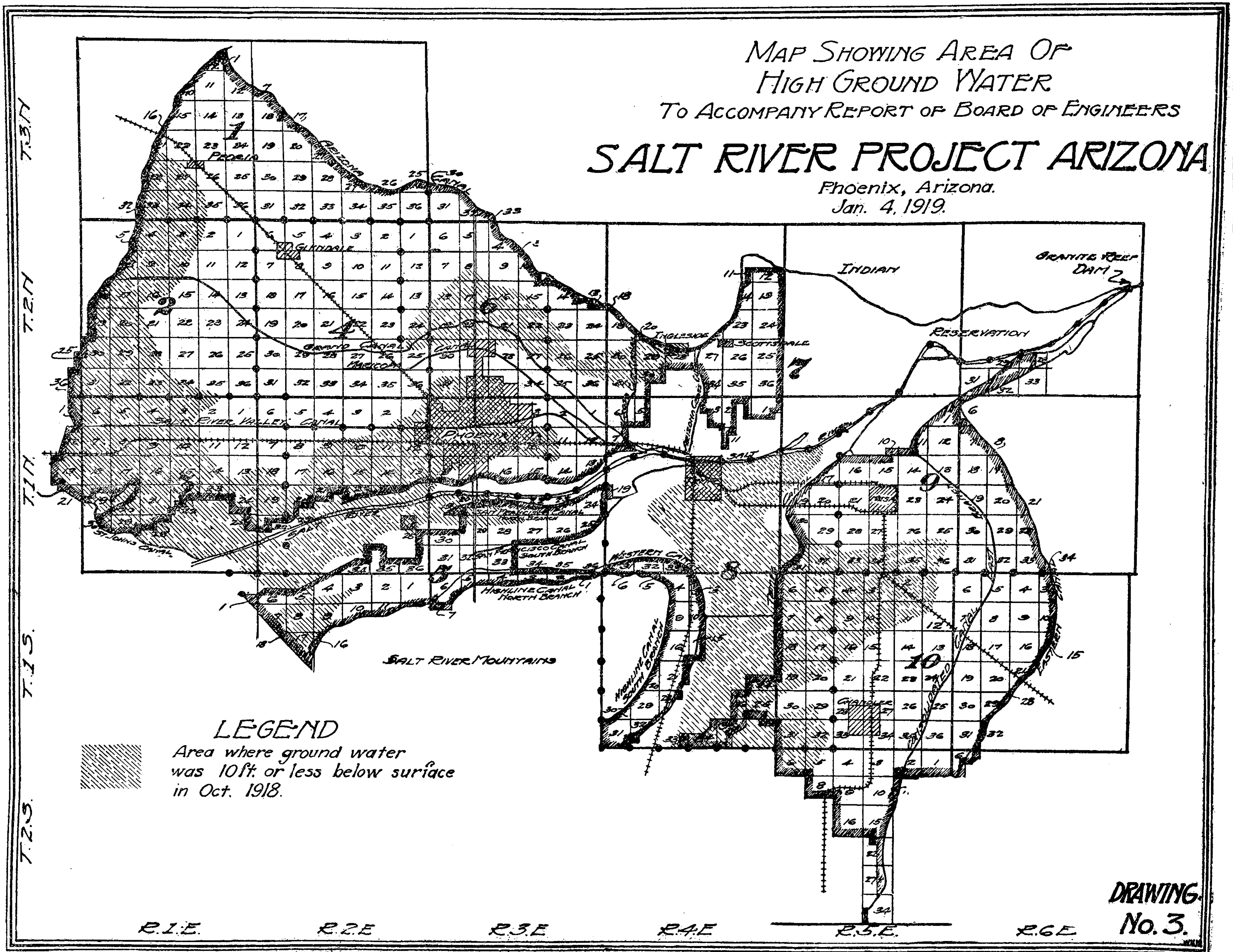
Map Showing Average Depth To Ground Water By Townships

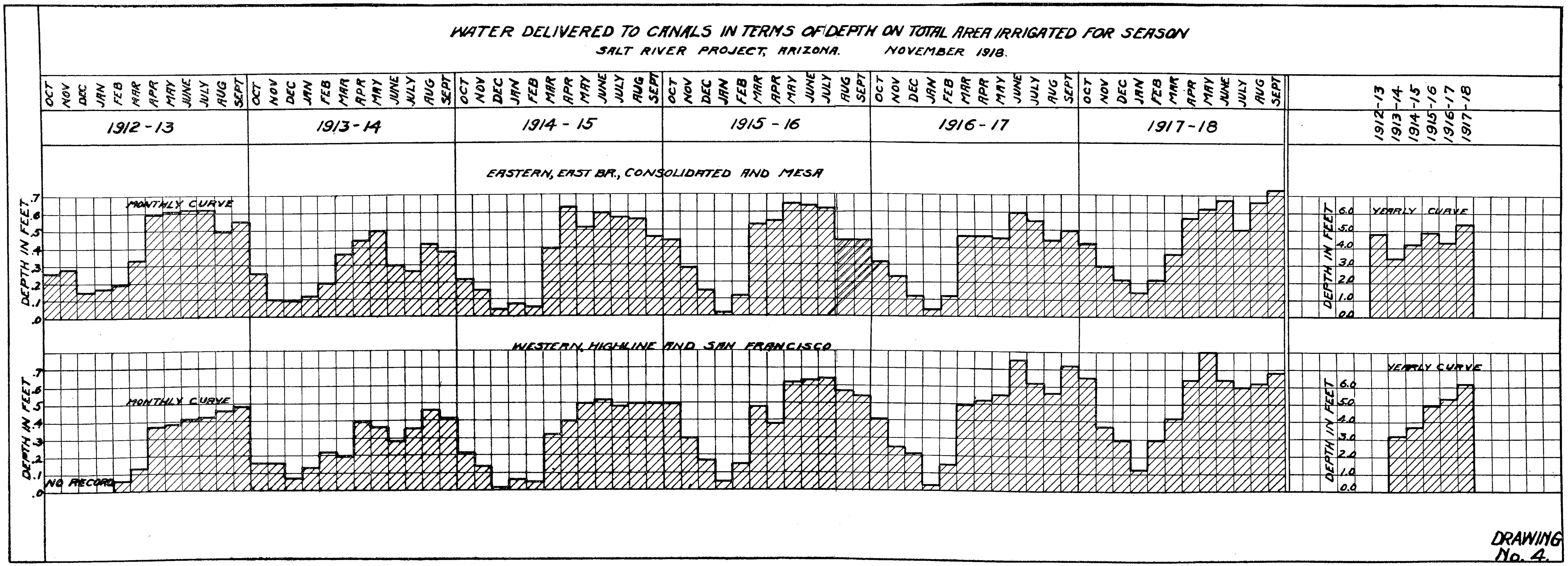
To Accompany Report of Board of Engineers

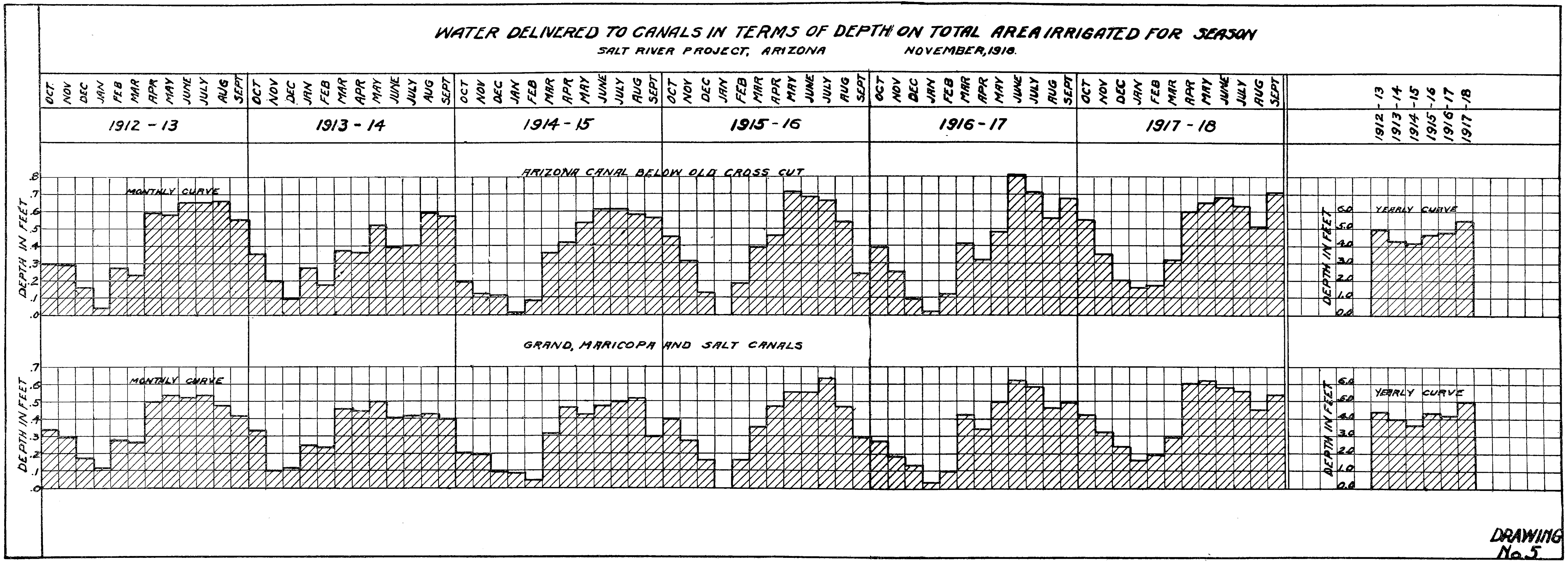
SALT RIVER PROJECT, ARIZONA

Phoenix, Arizona. Jan. 4, 1919.




MAP SHOWING AREA OF
HIGH GROUND WATER
TO ACCOMPANY REPORT OF BOARD OF ENGINEERS
SALT RIVER PROJECT ARIZONA
Phoenix, Arizona.
Jan. 4, 1919.
LEGEND
Area where ground water was 10 ft. or less below surface in Oct. 1918.
DRAWING No. 3.
T.3.N.
T.2.N.
T.1.N.
T.1.S.
T.2.S.
R.1.E.
R.2.E.
R.3.E.
R.4.E.
R.5.E.
R.6.E.
PEORIA
GLENDALE
PHOENIX
INGLESIDE
SCOTTSDALE
CHANDLER
GRAND CANAL
SALT RIVER VALLEY CANAL
ARIZONA CANAL
ST. JOHNS CANAL
WESTERN CANAL
HIGHLINE CANAL NORTH BRANCH
HIGHLINE CANAL SOUTH BRANCH
EASTERN CANAL
INDIAN RESERVATION
GRANITE REEF DAM
SALT RIVER MOUNTAINS


WATER DELIVERED TO CANALS IN TERMS OF DEPTH ON TOTAL AREA IRRIGATED FOR SEASON
SALT RIVER PROJECT, ARIZONA. NOVEMBER 1918.
OCT NOV DEC JAN FEB MAR APR MAY JUNE JULY AUG SEPT
1912-13
1913-14
1914-15
1915-16
1916-17
1917-18
EASTERN, EAST BR., CONSOLIDATED AND MESA
MONTHLY CURVE
YEARLY CURVE
DEPTH IN FEET
WESTERN, HIGHLINE AND SAN FRANCISCO
NO RECORD
DRAWING No. 4.

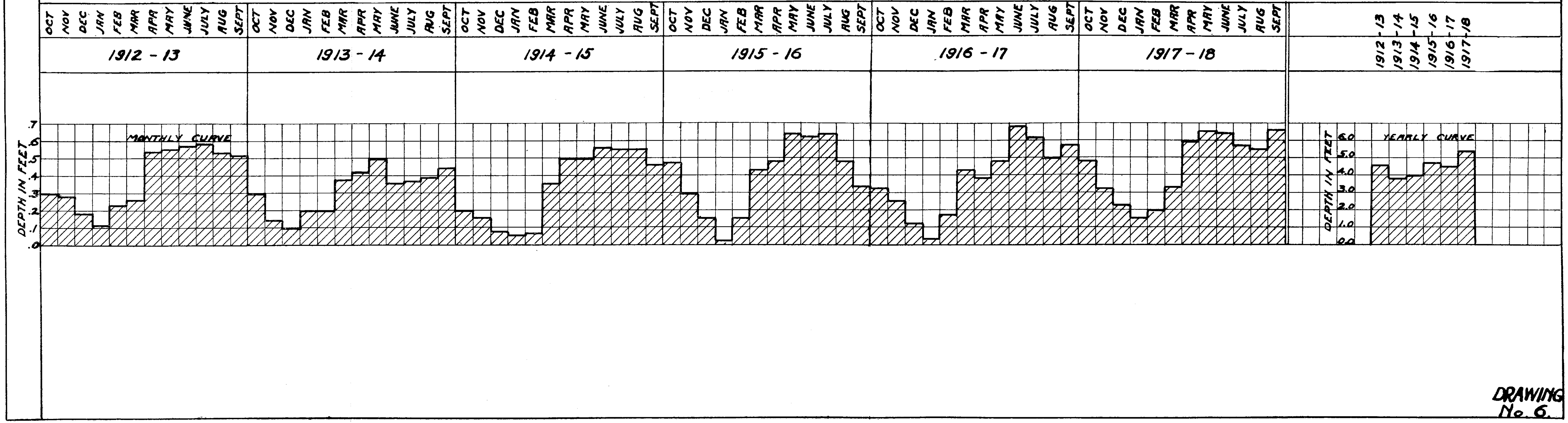


WATER DELIVERED TO CANALS IN TERMS OF DEPTH ON TOTAL AREA IRRIGATED FOR SEASON
SALT RIVER PROJECT, ARIZONA
NOVEMBER, 1918.
OCT NOV DEC JAN FEB MAR APR MAY JUNE JULY AUG SEPT
1912 - 13
1913 - 14
1914 - 15
1915 - 16
1916 - 17
1917 - 18
1912-13 1913-14 1914-15 1915-16 1916-17 1917-18
ARIZONA CANAL BELOW OLD CROSS CUT
MONTHLY CURVE
YEARLY CURVE
DEPTH IN FEET
GRAND, MARICOPA AND SALT CANALS
DRAWING No. 5

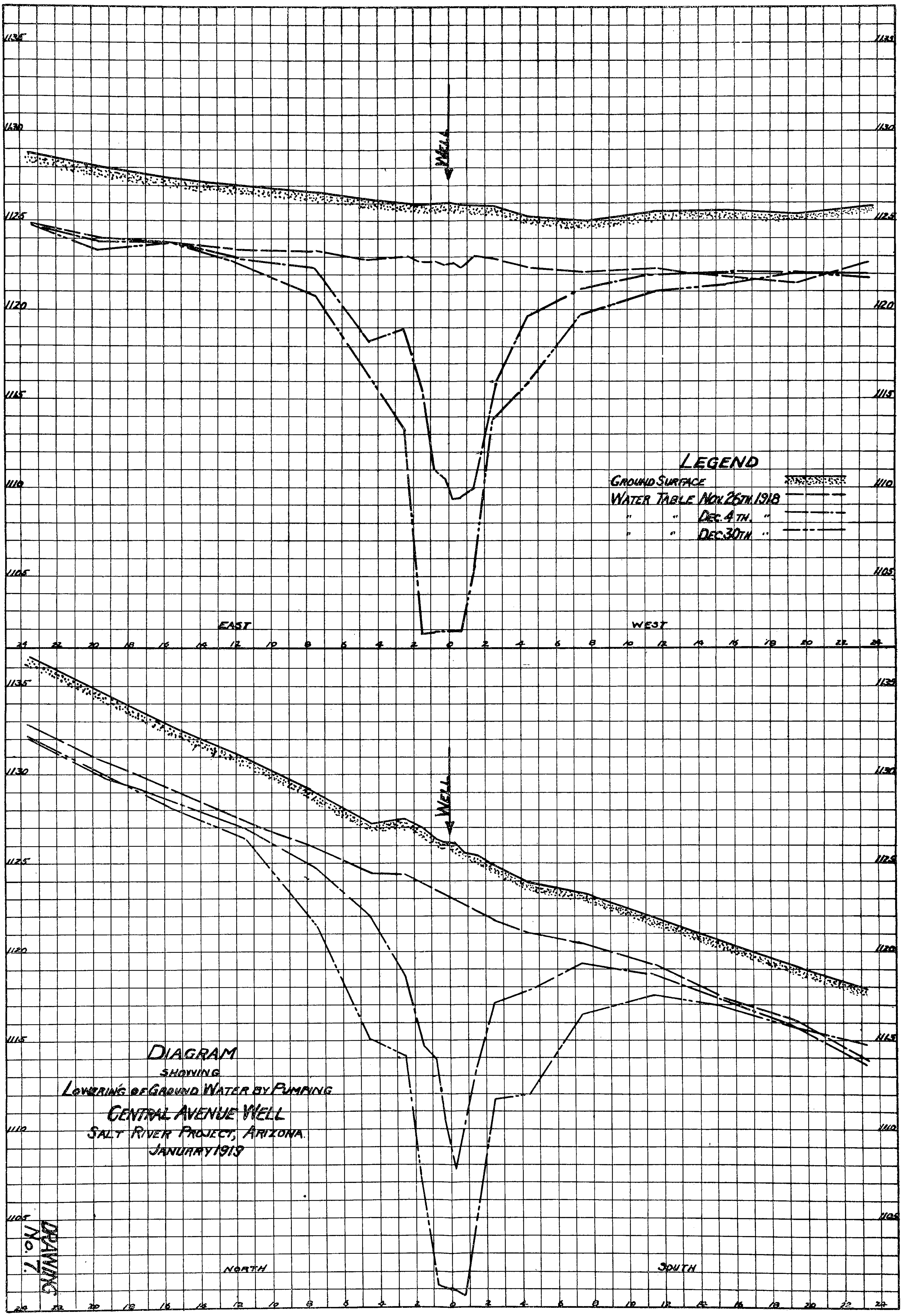
WATER DELIVERED TO CANALS IN TERMS OF DEPTH ON TOTAL AREA IRRIGATED FOR SEASON

EASTERN, E. BR., CONSOLIDATED, MESA WESTERN, HIGHLINE, SAN FRANCISCO, GRAND, MARICOPA, SALT, AND ARIZONA BELOW OLD CROSS CUT

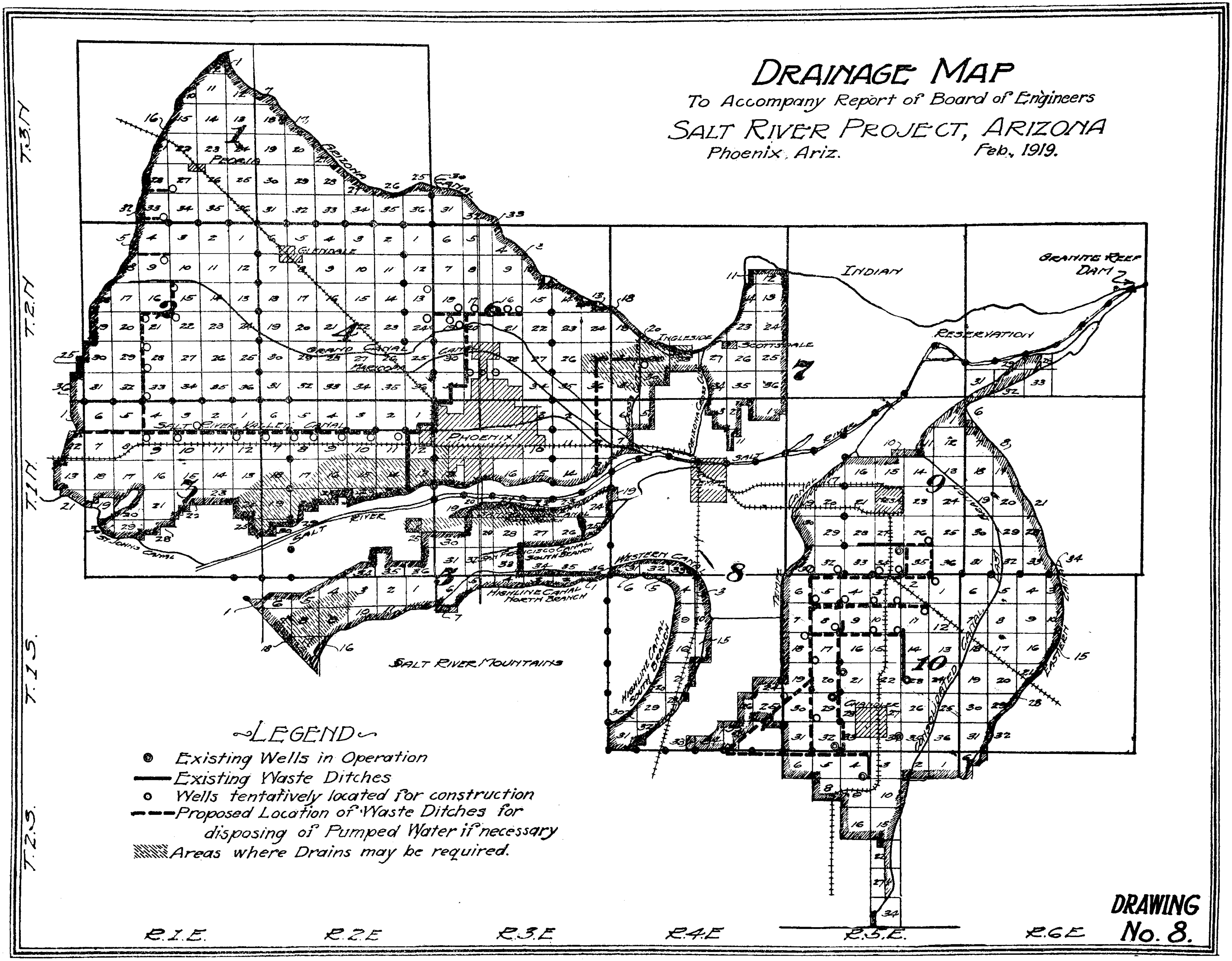
SALT RIVER PROJECT, ARIZONA NOVEMBER 1918.



DRAWING No. 6.



WELL
LEGEND
GROUND SURFACE
WATER TABLE NOV. 26TH 1918
" " DEC. 4TH. "
" " DEC. 30TH "
EAST
WEST
NORTH
SOUTH
DIAGRAM
SHOWING
LOWERING OF GROUND WATER BY PUMPING
CENTRAL AVENUE WELL
SALT RIVER PROJECT, ARIZONA.
JANUARY 1919
DRAWING No. 7.


DRAINAGE MAP
To Accompany Report of Board of Engineers
SALT RIVER PROJECT, ARIZONA
Phoenix, Ariz.
Feb., 1919.
LEGEND
Existing Wells in Operation
Existing Waste Ditches
Wells tentatively located for construction
Proposed Location of Waste Ditches for disposing of Pumped Water if necessary
Areas where Drains may be required.
T.3.N.
T.2.N.
T.1.N.
T.1.S.
T.2.S.
R.1.E.
R.2.E.
R.3.E.
R.4.E.
R.5.E.
R.6.E.
PEORIA
GLENDALE
ARIZONA CANAL
GRAND CANAL
MARICOPA
PHOENIX
SALT RIVER VALLEY CANAL
SALT RIVER
ST JOHNS CANAL
INGLESIDE
SCOTTSDALE
ARIZONA CANAL
INDIAN RESERVATION
GRANITE REEF DAM
SALT RIVER
TEMPE
SAN FRANCISCO CANAL SOUTH BRANCH
HIGHLINE CANAL NORTH BRANCH
WESTERN CANAL
HIGHLINE CANAL SOUTH BRANCH
SALT RIVER MOUNTAINS
CHANDLER
EASTERN CANAL
DRAWING
No. 8.