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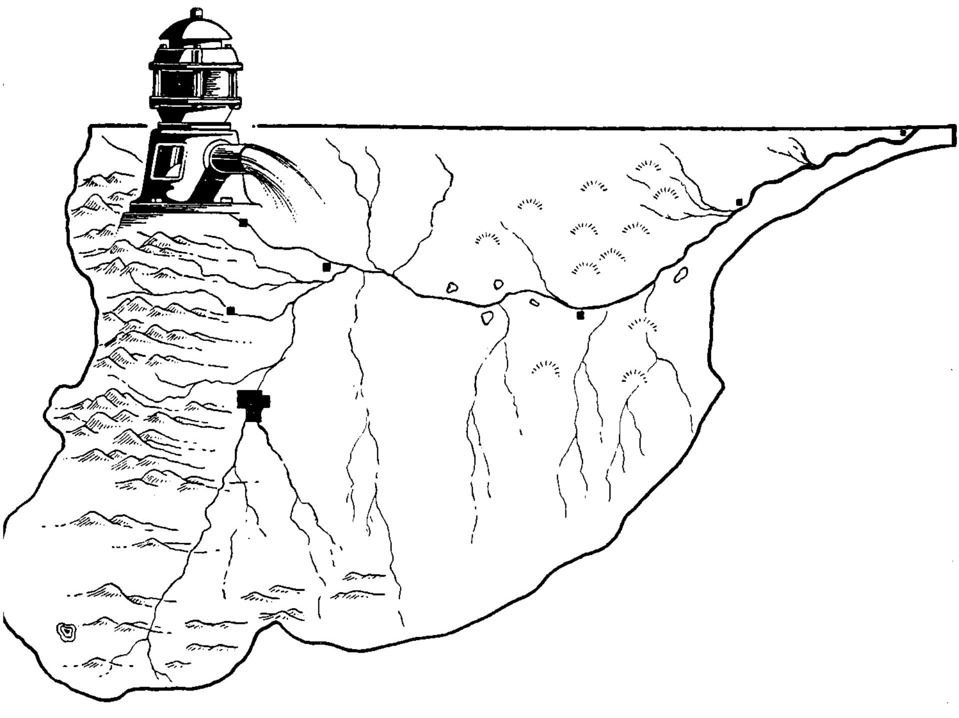
USE OF GROUND WATER FOR IRRIGATION in the SOUTH PLATTE VALLEY OF COLORADO

W. E. CODE



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Use of Ground Water for Irrigation In the South Platte Valley of Colorado[1]

W. E. Code[2]

Contents

AGRICULTURE has imposed increasing demands upon ground water as surface irrigation water supplies dwindled during recent drought periods and as new land has been brought into intensive production where ground water could be developed. A lowering of the water table has occurred in varying degrees because of the increased demand and deficient stream flow in many places. In some places this lowering has been rather serious and has been attended by a necessary change in equipment, an increase in cost of power, and a decrease in well capacity and pump efficiency. Also, many stock and domestic wells have had to be deepened.

Extent and Importance of Ground-Water Use

Of the 3,220,000 acres under irrigation in Colorado, 1,113,000 acres, or about one-third of the total, are in the South Platte Valley.

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[1]The work on which this report is based was done in cooperation with the Division of Irrigation, Soil Conservation Service, U. S. D. A. Acknowledgement is due to Carl Rohwer of that agency for his help in planning the work; to the various power utilities which generously made available their records on annual consumption of electric current, which were vital in the determination of the amount of water pumped; and to the Colorado Water Conservation Board, which prepared the survey map of the area from data obtained by the Experiment Station and provided as assistants R. E. Kennedy in the field season of 1940 and W. R. Judd in the field season of 1941.

[2]Associate irrigation engineer, Colorado Agricultural Experiment Station.

Conditions for obtaining irrigation wells are not favorable over a large proportion of this area; however, approximately 165,000 acres receive water in part or wholly from wells. As of January 1, 1940, according to the United States Census, there were about 2,670 pumping plants in Colorado, including those pumping surface-water supplies, and about 1,860 in the South Platte Valley. In the Experiment Station survey of 1940 there were found in the South Platte Valley 1,957 pumping plants pumping from wells. A discrepancy is to be expected since the Census count was made in 1939 and, further, it included all irrigation pumps. In 1930 the Census reported about 500 pumps for the State and 325 for the South Platte Valley. The Experiment Station estimate for the South Platte Valley was 530 irrigation-well plants for 1930.

There are other important uses of ground water besides irrigation. More than half the State's total population of 1,123,000 is located in the South Platte Valley. The water supply of many towns and practically all rural stock and domestic supplies in the area are derived from wells. The water requirements of some of the sugar factories and those of the railroads are met in part by this source of supply.

Character of Equipment

Well irrigation in the South Platte Valley has passed through all the phases of well construction and power application that have attended development of ground water in western United States.

The first wells were hand dug, of very large diameter, and curbed with lumber. Because of the difficulties attending such construction, these wells seldom extended more than 15 feet into the water, and many were failures. Later these large wells were curbed with concrete blocks or solid concrete. Although concrete casing 36 to 48 inches in diameter is still used, most wells put down within the last 25 years have been cased with 16- to 10-gage riveted galvanized steel ranging between 12 and 48 inches in diameter. The larger sizes are usually reinforced with heavy iron bands. The most generally used sizes range between 16 and 24 inches. Perhaps the greatest criticism on metal-cased wells in this area is that a tendency prevails to use metal too thin for safety in sinking and for permanence.

Since the water-bearing depth is frequently limited to 20 or 30 feet by shale or sandstone, wells 48 inches in diameter have been of definite advantage in obtaining reasonable capacities in such locations. Another method often used to obtain maximum capacity in shallow water-depth areas is that of drilling several small wells spaced 40 to 70 feet apart and operating them as a unit. If a horizontal centrifugal pump is used in such cases, the header pipe connecting

Figure 1.—Final stages of construction of an irrigation well. Applying gravel to outside of casing after removing larger outside blank casing and during test of well for capacity.

the wells is attached directly to the suction inlet, but should the pump be of the turbine type the water is conducted to the pumped well by means of siphon pipes.

The pump type most commonly found is the turbine, which lends itself to nearly any pumping condition. Horizontal centrifugal pumps are used extensively where the depth to water is less than 20 feet and the drawdown is moderate. The vertical centrifugal pump in common use 20 years ago has been almost completely replaced by the turbine.

The very earliest pumps were driven by steam tractor engines. The use of electricity and gasoline engines extended the possibilities of pumping greatly, but the high price of electricity and the uncertainty of performance of early gasoline engines prevented any widespread activity. The early gasoline engine was followed by the slow-speed oil-burning engine, then by the multiple-cylinder high-speed gasoline engine. The high-speed diesel engine first used in 1932 further opened up fields where heavy-duty power units were required. Electricity has become increasingly available and at lower rates, and electric motors have replaced engines in a majority of cases. At present there are about 1,170 pumps or 60 percent of the total operated by electric motors.

Quality of Water

The following statement on the quality of ground water in the South Platte Valley is provided by J. W. Tobiska:[3]

[3]Chemist, Colorado Agricultural Experiment Station.

"Surface waters in streams on leaving the mountains contain less than 100 parts per million of minerals; these minerals are largely bicarbonates and sulfates of sodium, potassium, magnesium, and calcium. This water, when applied for irrigation, is lost in part by deep percolation from ditches, reservoirs, and fields to become part of the ground-water supply. In the process other salts in the soil are dissolved so that mineralization of ground waters in such areas is greater than water in surface streams. Some of this water returns to the rivers from seepage and is used a second or even a third time for irrigation. Increased mineralization of both surface and underground water, therefore, occurs as distance downstream from the mountains increases.

"No systematic investigation on the character of shallow ground waters has been made, but from the available scattered data taken from samples of water submitted for analysis by farmers and a few selected samples, the conditions are approximately as follows:

Location	Mineralization parts per million
Fort Collins west to foothills	200-800
Wellington and southeast of Fort Collins	1,500-7,800
Greeley vicinity	1,000-9,000
Fort Morgan vicinity	2,000-7,400
Sterling vicinity	2,000-3,500
Julesburg vicinity	2,000-3,000

"The mineral content of the waters consists largely of sulfates and bicarbonates of lime and magnesia. Sodium sulfate and sodium chloride also occur but usually in much smaller quantities. In a very few places there are waters which carry so much magnesium sulfate that they are unfit for livestock. Typical of shallow waters in the northeastern plains section of the State is the presence of nitrate nitrogen which may vary in amount from traces to as much as 750 parts per million.

"Since it is the presence of the sodium salts in water that makes for harmful effects on soils, it is the present opinion that the waters on which information is now available are, in general, safe for irrigation use. Whether this situation will continue cannot be foretold."

Causes for Increasing Use of Ground Water

A number of causes may be cited for the increase in pumping plants, principal among them being the drought period starting in 1931. The climatological and stream-flow data presented in figure 2 show this water-supply condition clearly. During that period the

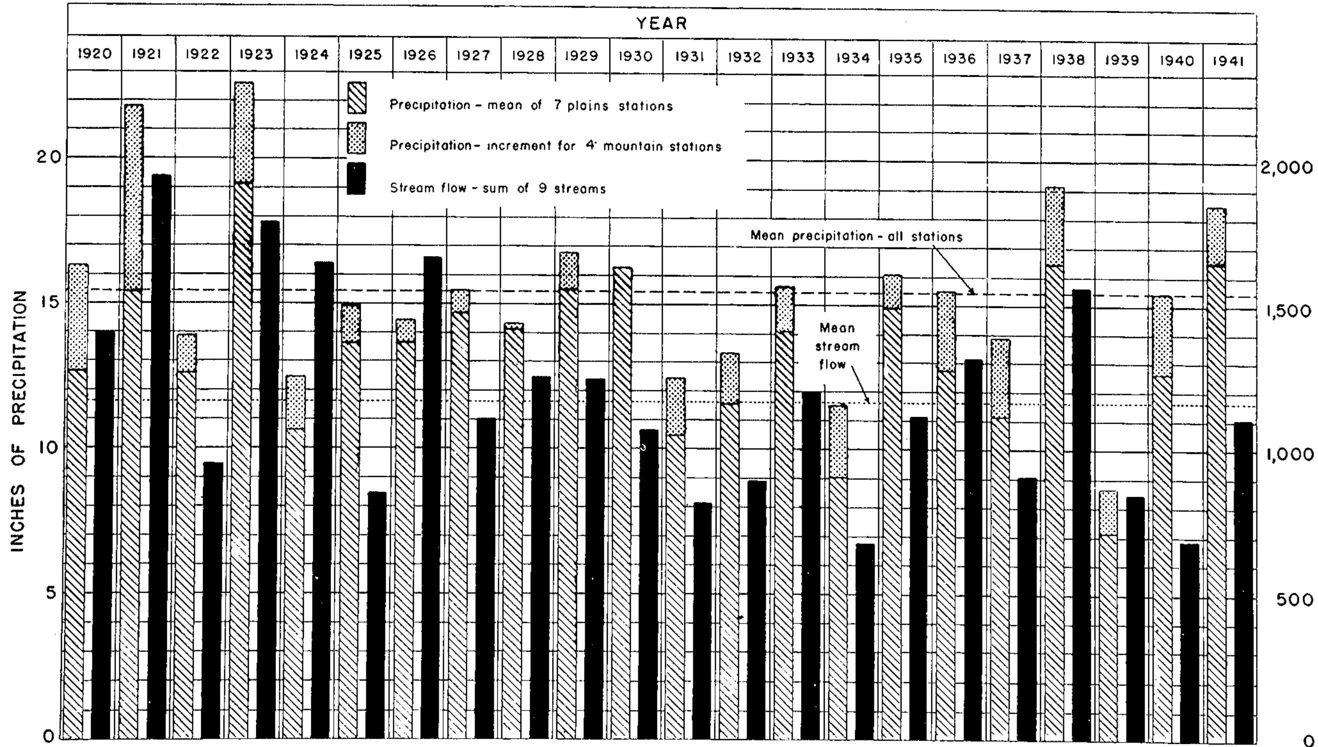

Figure 2.—Precipitation and stream-flow data for the South Platte Valley. The precipitation data are for the following U. S. Weather Bureau stations: Idaho Springs, elev. 7,543; Longs Peak, elev. 8,600; Hartsel, elev. 8,900; Silver Lakes, elev. 10,500; Cheeseman, elev. 6,890; Denver, elev. 5,280; Fort Collins, elev. 4,985; Greeley, elev. 4,649; Grover, elev. 5,076; Fort Morgan, elev. 4,319; and Sterling, elev. 3,900. The stream-flow data are for the following designated stations maintained by the State Engineer: South Platte at South Platte, Bear Creek at Starbuck, Clear Creek near Golden, St. Vrain at Lyons, Boulder Creek near Orodell, South Boulder Creek at Eldorado Springs, Left Hand Creek near Boulder (estimated), Big Thompson River near Drake, Poudre River at canon mouth and North Poudre and Poudre Valley canals (partly estimated).

high-speed diesel engine came into general use and found application on the newer developments involving high lifts and large quantities of water. Electric rates [4] were reduced twice by the power companies operating in the Valley, and the Morgan County Rural Electrification Association, serving a large pumping territory, came into being in 1938.

The removel of underground water continued at an accelerated pace from 1931 through 1940, especially in 1934 and 1940. This increase in pumping, combined with subnormal river flow, was attended by a general lowering of the water table. There were places, however, where the lowering was only temporary during the pumping season, there being no definite trend over the drought period. The conditions are shown graphically in figures 10 to 16, where the fluctuation of the water table in observation wells [5] in the various districts has been plotted.

Utility of Survey of Use of Ground Water

The increasing use of ground water and the probable effect on the water table were the principal reasons for conducting a survey for ascertaining the extent of use for the single year of 1940. The condition of the water table in pumping districts has been under observation since 1929 in some instances. At that time regular measurements were begun in representative wells, and, as pumping areas expanded or new districts were developed, the number of observation wells was increased to a total of 140 in 1940. These wells have been visited each spring and fall, with a few exceptions, and the observations have yielded reliable data on the general condition.

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[4]The electric rate for pumping of nearly all public utility companies operating in the Valley in 1940 was:

First	100 kw.-hr. per horsepower per season	5.0c per kw.-hr.
Next	200 kw.-hr. per horsepower per season	3.0c per kw.-hr.
Next	200 kw.-hr. per horsepower per season	2.0c per kw.-hr.
Next	1,000 kw.-hr. per horsepower per season	1.5c per kw.-hr.
Over	1,500 kw.-hr. per horsepower per season	1.0c per kw.-hr.

Where this schedule was used, the horsepower demand was based on the nameplate rating of the motor.

The Morgan County R. E. A. rate for pumping in 1940 was:

First	100 kw.-hr. per horsepower per season	5.0c per kw.-hr.
Next	100 kw.-hr. per horsepower per season	3.0c per kw.-hr.
Next	100 kw.-hr. per horsepower per season	2.0c per kw.-hr.
Next	200 kw.-hr. per horsepower per season	1.5c per kw.-hr.
Over	500 kw.-hr. per horsepower per season	1.0c per kw.-hr.

In this case the horsepower demand was measured.

[5]The location of these wells is shown on the map attached inside the back cover of this bulletin.

Besides the effect of pumping on the water table, there are other uses to which the data gathered may be put. Since a large proportion of the pumped area is adjacent to the South Platte River, or reasonably so, there may be some influence upon return flow. This return flow is so large and of such great economic importance that any extensive interference would produce far-reaching effects on agriculture in the lower part of the Valley. A determination of return flow of even ordinary accuracy, however, is most difficult to make with the character of data now existing. Only an elaborate and comprehensive survey such as was made by this office in 1920 (*1*)[6] would yield truly satisfactory results. A quantitative evaluation of the influence of pumping, therefore, would be doubly difficult because, in addition to the uncertainty mentioned, there is a time element involved as well as a masking effect of unusual stream flow. However, it may be possible that the data gathered may be of value in such a study.

Another possible use of the data lies in the formulation of legislation affecting the use of irrigation wells or in court litigation either as between users, or between users of wells and those diverting water from streams.

The tremendous value of water from wells in this Valley is universally admitted even by those whose river rights might possibly be affected. The tendency in late years is to recognize that wells are a source of immediate relief in case of water shortage and that, even if return flow is affected, the injury so engendered is probably of less importance than the total economic benefits derived. The significance of this attitude will be recognized from the fact that 80 percent of the pumping plants are operated in conjunction with surface water rights. It has the effect of diminishing the probability of litigation. Such litigation could have far-reaching results of undesirable character unless it was properly presented in court and was of rather broad scope. No legislation should be attempted which is directed at the control of pumping without having at hand competent statewide data on the subject. The data gathered in the survey of 1940-41 are but a part of the information required for a full understanding of the problem. Other surveys are required to complete the picture, which include detailed examination of the geology of the regions, and the source, the slope, and the direction of flow of the underground waters. The collection of such data is beyond the scope of work of the Experiment Station independently and will not be attempted, but the data now collected can and may be used in any future, more comprehensive survey.

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[6]Italic numbers in parentheses refer to references cited, page 44.

Ground-Water Considerations

Ground water occurs under all the plains areas of the State and may be divided into two classes for the purpose of this report: That confined in consolidated formations such as sandstone and often under pressure, and that occurring in unconsolidated formations such as sands and gravels and having a free water table. The latter is the only type under consideration here since nearly all irrigation supplies are developed in such formations and are not so widely distributed. By referring to the location of irrigation wells on the map attached to the back cover, it will be seen that generally the favorable conditions are confined to the proximity of the major stream courses—often to the immediate valley.

Except in tightly closed basins ground water is continually moving toward an outlet at lower elevations. All the ground-water tables in the South Platte Valley are sloping, usually with the land slopes. The rate at which the ground water travels is dependent on the permeability of the material and the steepness of slope. Permeability varies between wide limits. Clay, for instance, may have a permeability coefficient of less than 1, whereas coarse gravel may have a coefficient of 20,000. Some miscellaneous tests on well drillings have been made by the Experiment Station which have given results ranging from 4 to 468, and a test hole drilled for the Experiment Station near Peckham in 1941 yielded materials which gave permeability coefficients ranging from 26 to 1,150.

Sand, gravel, and soil formations will transmit water directly in proportion to their permeability. This permeability may vary considerably in short distances because of the rapidly changing character of alluvial formations. Not only does the gravel change in texture, but the gravel strata vary greatly in thickness and are often separated by irregular clay masses. The velocity of water moving underground is also proportional to the slope; that is, doubling the slope doubles the velocity of water provided the character of the formation remains constant. Ground-water velocities are always surprisingly low, ranging from a few to 200 or 300 feet per day.

Permeability of material can be ascertained by laboratory methods from drillers' samples (*5, 6*). Because a true sample is difficult to obtain and, further, because a complete rearrangement of the particles takes place, the permeability as determined in the laboratory on such samples can be considered only an approximation of the permeability of the material in place. Other methods of testing the materials in place and as a group have been developed from observations made on the water table in the vicinity of a well being pumped (*7*).

Under favorable conditions the velocity of the underflow at a point may be determined by an electrical method developed by C. S. Slichter (*4*). Since it can be expected that velocities will vary at different levels as the permeability varies, this method does not usually yield true average velocities in deep sections.

Not all the water contained in a material can be removed. Part of it will always be held by capillary attraction of the soil particles, and a part of the remaining moisture can be removed only by evaporation or by plant roots. The proportion that can be removed by draining under pumping conditions is known as its specific yield. Specific yield is always less than the porosity and has no relation to it. It may be as much as 40 percent in poorly sorted sands and gravels where porosity is usually low and as little as 1 percent for very fine materials such as silts and clays which may have a very high porosity. Specific yield is important in evaluating water supplies in that it permits the calculation of the amount of water in storage in the ground available for pumping.

It can be seen from the foregoing that there are methods by which it is possible to estimate, within certain limitations, the quantity of water moving underground. The accuracy of such estimates will vary considerably according to the extent of information available and the detail in which a survey may be made. The personal factor of the investigator is important in that experience, training, and judgment enter into the evaluation of the results.

Ground-Water Inventories

In any study of ground-water inventory of an area there are certain basic conditions of supply and withdrawal (discharge) that require evaluation either by direct measurement, controlled estimate, or assumptions. Water-table fluctuations are very important in a study of this character.

Free ground water has its source in direct percolation from the surface and losses from stream flow. Only when the surface soil is porous and the water table exists at shallow depths is there any substantial contribution to ground water by immediate penetration from precipitation on the area. Losses from irrigation canals and frequent heavy applications of irrigation water to crops contribute greatly to ground-water supplies. All irrigation projects have a history of rising ground waters and, if natural underdrainage is inadequate, seep conditions arise which must be corrected by artificial drainage. When the water table is lower than the beds of streams, then during periods of flow water passes from the stream to join the ground water. Replenishment also may occur by escape of water from outcroppings of deep water-bearing strata, the sources of which may be at a great distance.

Discharge of ground water occurs in numerous ways. Moving to places of lower elevation, it normally appears as surface flow at some point. Frequently ground water is forced to the surface in a stream channel because of geological constrictions such as rock outcroppings and as frequently disappears again below it. Usually this is a continuous flow with little variation. When within reach, trees and other vegetation transpire substantial quantities of water drawn from the ground. Artificial discharge is effected by means of constructed drains or by pumping.

When recharge takes place in a limited area or zone, the water builds up in the form of a ground-water mound under such places. In time this mound levels off as it flows out into the surrounding area. Pumping an irrigation well produces a local lowering and, if pumping plants are numerous, the local depressions coalesce into a general depression. Water then flows in from the sides of such an area and, if the total supply is adequate, there will be no residual annual depression. During the pumping period water is usually withdrawn at a greater rate than that of inflow; the pumps then are supplied with water in storage. Continued withdrawal from storage always produces a lowering of the water table.

Since specific yield does not vary greatly for gravels, it is possible to make reasonable assumptions of this factor and calculate the amount of water in storage. To calculate the permanent yield of a limited body of ground water, it is necessary to have the following data: The pumping draft, change in the water-table elevation, specific yield, replenishment factors, and, if possible, the normal natural inflow and outflow from the area. Sometimes the outflow factor is determinable as stream flow.

Behavior of Wells

Permeability has a direct bearing on the capacity of wells. Other factors remaining the same, well capacity increases in the same ratio as permeability increases. When a well is pumped, the water level recedes in the casing and the water table adjacent assumes an inverted cone shape with the original water table as its base (see figure 3). The shape and size of the cone will depend upon the quantity of water pumped and the permeability. For materials of low permeability the cone will be steep and have a small base or circle of influence, while for highly permeable materials the cone will have less steep sides and a greater base.

As pumping continues, the depression increases both in depth and extent. Water approaches this depression from all directions because of the greatly increased slope of the water table towards the well. The fact that water approaches from all directions makes un-

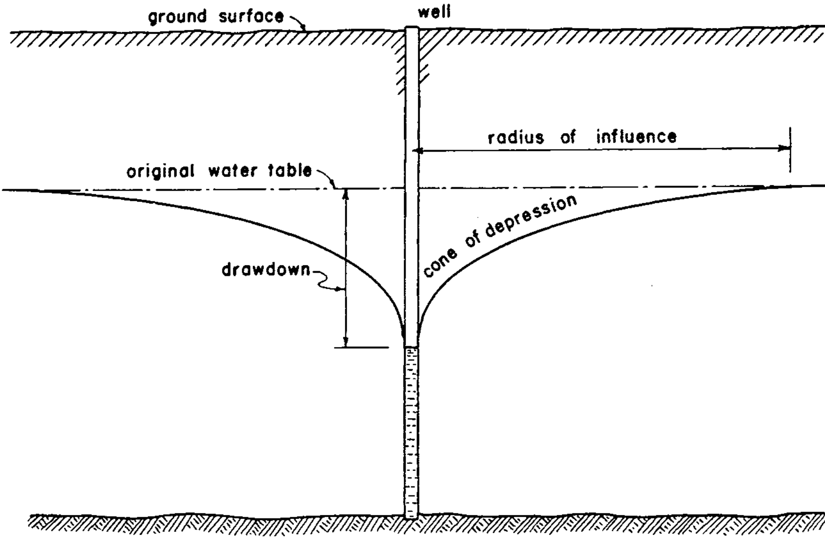

Figure 3.—Diagram showing generalized hydraulic conditions near a well being pumped and use of terms employed.

important, in most cases, the direction that the group of wells forming a battery take with respect to the direction of underflow. After pumping ceases, the water level in the well rises very rapidly in the first few minutes, then slowly for a long period, and may not reach equilibrium for several days or weeks, depending on the total supply conditions.

In a given well the relationship between drawdown and discharge is constant, provided there are no changes in the conditions. A change will occur because of change in elevation of the water table, shifting of materials in the water-yielding formations, and deterioration of screen openings in the well casing. Well capacity will increase or decrease in about direct proportion to the percentage increase or decrease in the water-bearing depth of the well if the formations are uniform throughout. The first pumping on a well produces an alteration of arrangement and withdrawal of fine sand from the vicinity of the casing, resulting in a gradual increase in capacity. If a well continues to produce fine sand to such an extent that cavities are formed which allow extensive soil movements, the productive capacity of a well is usually reduced and in many cases the well casing becomes separated, constituting a complete loss of the well. Screen deterioration may occur through simple rusting shut of the openings. However, as usually found in Colorado, the rusting involves the materials next to the metal and is often accompanied with a lime deposit. Specimens of this coating have been recovered which are half an inch thick and several square feet in area.

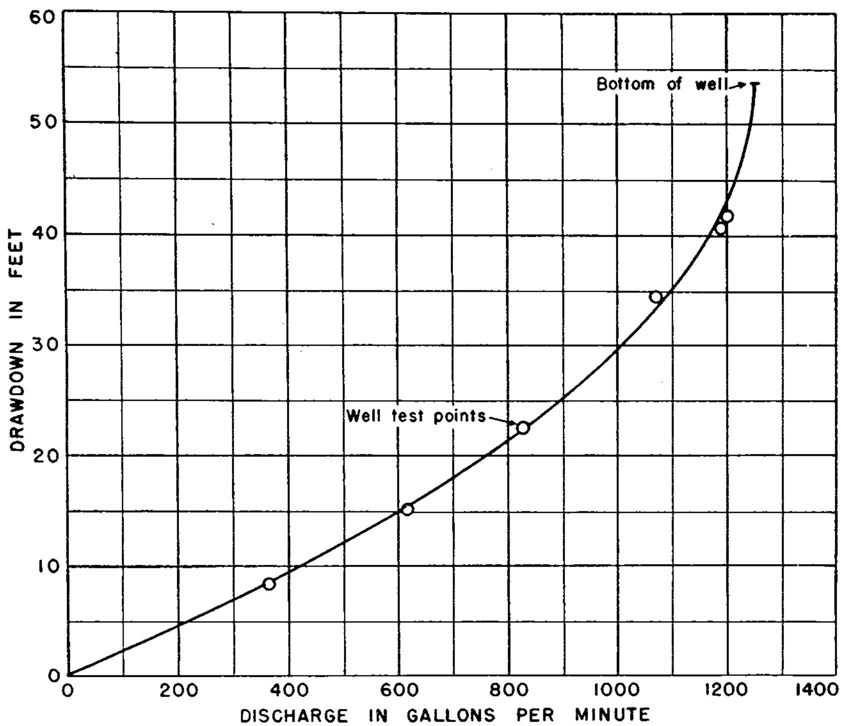

Figure 4.—Theoretical well discharge-drawdown curve based on a test point at 825 gallons per minute capacity and a maximum depth of 54 feet. Circles indicate points actually observed in the test of a South Platte Valley well. The log of this well showed several gravel strata separated by clay.

If a well is pumped at various rates and the drawdown noted in each case, the resultant data will plot in a curve such as is shown in figure 4. The curve indicates that the yield becomes less per foot of drawdown as more and more water is pumped; this curve is very useful in determining correct pump requirements. In uniform materials its shape is definite and determinable from one point obtained by testing. The curve will follow the points shown in table 1 and may be used in determining the capacity for a permanent pumping installation.[7] Because of head loss at the well screen, the table is not reliable for drawdowns in excess of about 60 percent.

Since each well has its own individual characteristics, its capacity for a certain drawdown can be determined only by test pumping. It it important that this be done in advance of the purchase of a permanent pump in order to obtain the greatest possible efficiency.

[7]As an illustration, should a field test indicate a 40-percent drawdown and a discharge of 768 gallons per minute, then the theoretical ultimate capacity is 768 ÷ 0.64 = 1,200 g.p.m. The yield at a drawdown of 50 percent is found by multiplying 1,200 by 0.75, which is 900 g.p.m.

TABLE 1.—*Characteristics of a well in uniform materials under water-table conditions**

Percent drawdown	Percent yield	Percent drawdown	Percent yield	Percent drawdown	Percent yield
10	19	40	64	65	88
20	36	45	70	70	91
25	44	50	75	80	96
30	51	55	80	90	99
35	58	60	84	100	100

*Taken from the water-table or nonartesian well formula

$$Q = K \frac{H^2 - h^2}{\log \frac{R}{r}}$$

in which K is a quantity depending on the characteristics of the water-bearing material and units of flow; H is the original water depth in the well; h is the distance from the point where the water surface stands just outside the casing to the well bottom while being pumped; R is the radius of the circle of influence; and r is the well radius. All dimensions are in feet.

Also, since the character of underground strata varies rapidly in most sections, it is advisable and sometimes absolutely necessary to drill test holes to locate the favorable sands and gravels.

The 1940 Survey

Previous to the beginning of field work, a 3 by 5 inch form filing card was devised that would permit the recording of pertinent data on pumping plants. As many of these data were obtained as were conveniently available from owners, tenants, well drillers, and pump dealers. The location of wells was greatly facilitated by data furnished by the agricultural statistician of the Colorado Cooperative Crop Reporting Service and by well drillers, pump dealers, and power companies, and by previous work done by the writer. Names and possible locations of pumping plants were transferred to the form cards and used in the field for finding and locating each plant. Every effort was made to supplement this information by local inquiry so that practically all plants were ultimately found.

The plan of work was that of obtaining the quantity of water pumped by the most accurate method conveniently available. It was recognized that it would be impossible to obtain accurate records of pumping time and that it would be impossible to find all plants operating at the time of visit. The limited personnel and large area of territory prevented revisiting plants except to a very limited extent. If the plant was found in operation or the owner volunteered to put it in operation, a measurement of the water was made. If no measurement could be made, inquiry was made at the end of the season as to the number of irrigations applied to each crop on the area

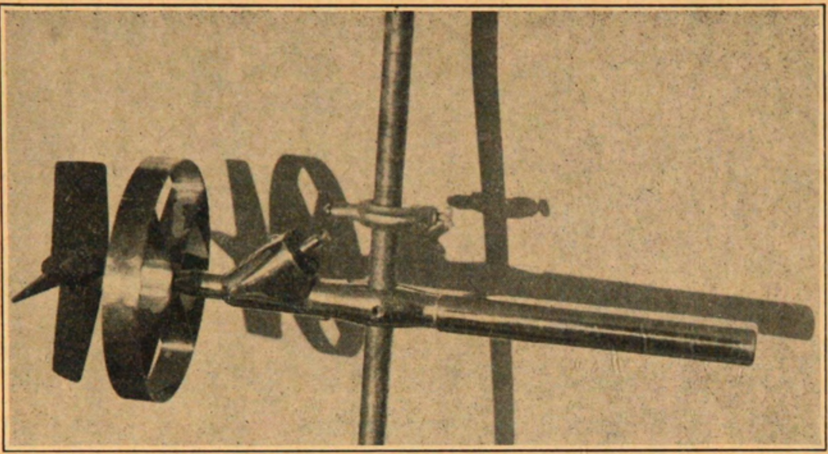

Figure 5.—Hoff current meter with guard for measuring flow in pipes.

involved, together with an assumption as to the water requirement. In some cases it was necessary to guess at the quantity of water pumped from fragmentary data and superficial observation. If the plant was electrically operated, the service meter was observed with a stop watch to obtain the power consumption. The approximate operating time then was obtained by dividing the total kilowatt power consumption[8] by the hourly rate. Since so very few farmers keep a record of operating time, the data on engine-driven plants had to be based on fuel consumption or estimates. Refusal to permit any data to be taken or yield any information was encountered in perhaps 30 instances. During the two survey seasons 665 measurements of flow were made, of which nearly two-thirds were made in 1940 when, because of the extreme shortage of water, many more plants were found in operation. In addition there were about 30 measurements furnished by other agencies and on 285 pumps controlled estimates were made by measuring the depth of flow in part-full pipes.

The number of measurements made may appear to be a rather low proportion of the total of 1,955 existing plants, but from the standpoint of total pumpage the proportion is much greater. Toward the end of the 1941 season very few plants were found in operation. They were mainly on garden tracts and, although rather numerous, were of relatively small capacity. Work was continued into 1942 because of information acquired of the existence of a number of plants

[8]All except one of the seven power companies operating in this area generously made available the annual consumption of electric current for each of its customers. Because of the failure to obtain cooperation in the one case, the data on the amount of water pumped in Morgan County is of much lower accuracy than that in the remainder of the basin.

in remote places and because of missing data on plants where previously contact with the owner had been unsuccessful.

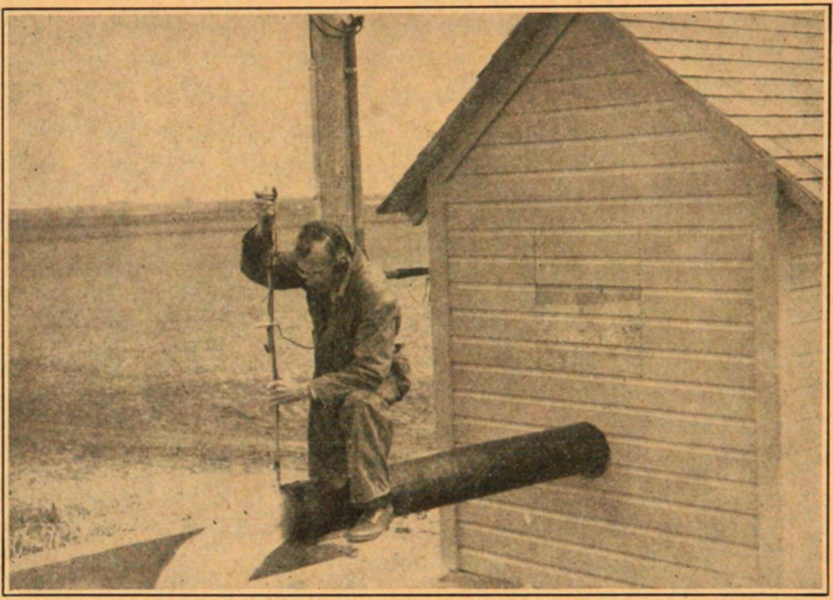

Figure 6.—Making discharge measurement with Hoff current meter. Pump is the turbine type in a shelter typical of the region.

Method of Measuring Water

The subject of methods of measuring discharges from pumps was given considerable attention before final decision was made. A wide range of conditions was known to exist, but mainly discharges free or submerged through pipes of many types predominated. It was known that some flows would be in very long pipes, others in very short pipes, and that there would be both very high and very low velocities. It was also known that some pipes would not be flowing full and that measurements in open channels might be necessary. The Hoff current meter equipped with a rubber propeller was suggested by Mr. Carl Rohwer[9] as best fitted for the various conditions anticipated. This meter, shown in figure 5, has a horizontal axis and its propeller with the added guard can be inserted into a pipe end which has a diameter of 4½ inches or more. It was rated in the laboratory under many conditions in pipes of various sizes for use in this particular work and was found very satisfactory (*3*). Figure 6 shows the meter being used in making a discharge measurement.

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[9]Engineer, Division of Irrigation, Soil Conservation Service, U. S. Department of Agriculture, stationed with the Colorado Agricultural Experiment Station in Fort Collins.

Investigations also were made on the discharge of level pipes flowing part-full and from 6 to 14 feet long. The plotted results indicated that it would be possible to form a reasonable estimate of discharge if the depth of flow at the pipe end did not exceed one-half the diameter. For depths greater than half the diameter, the curve was irregular and unreliable.

In the field every sort of flow condition was encountered, from the ideal to pipes only a foot long attached to an elbow. In some cases the flow was measured in an open channel with the current meter, while in others a crude weir was hastily built with materials carried for such emergencies. Part-full pipes were sometimes made to flow full by partly obstructing the lower part of the opening. Some small flows were measured in a 6-gallon bucket.

The lift was not regularly observed but, where desired, this was obtained by means of a float on a steel tape or with an electrical sounding device.

All the data, regardless of year in which they were gathered, were related to the quantities pumped in 1940. Because of the higher water table in 1941 in the Gilcrest area, measurements made there

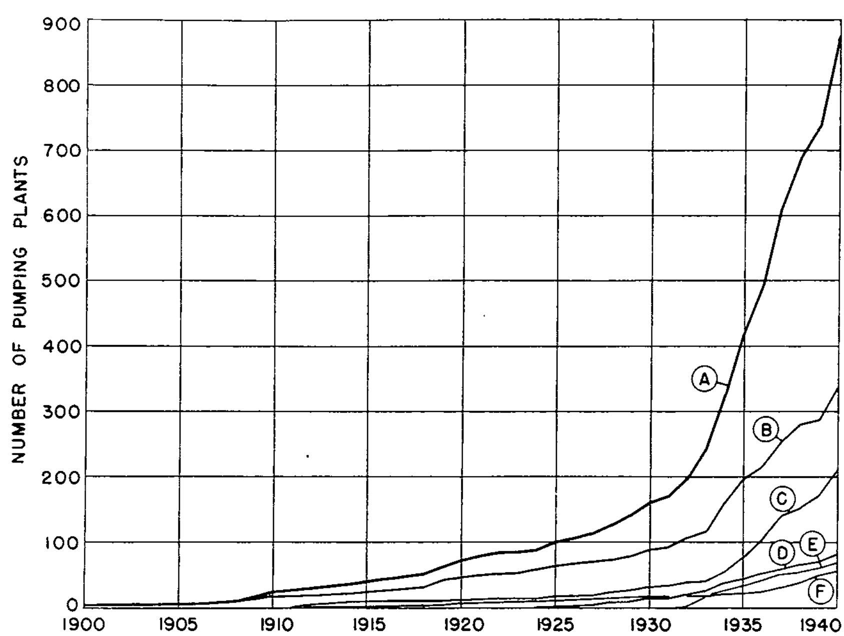

Figure 7.—Rate of growth in number of pumping plants in Water District No. 1: A, district total; B, Lone Tree Area; C, area adjacent to South Platte; D, Box Elder area; E, Prospect Valley; F, Beaver Creek area.

in the middle and late summer of that year were arbitrarily discounted about 10 percent so as to make them more nearly comparable with conditions in 1940. The quantities determined for this year may be used as a base for estimates of use in other years. The consumption of electricity is a fair index of extent of pumping, and, knowing the quantities for any one year, a clue is provided for other years. It is not entirely trustworthy because of the steady conversion of engine-driven plants to electricity.

The dates of first use of plants were obtained where available; however, many were not obtained for various causes and many were estimated. This lack of complete data prevents accurate indication of the rate of growth as shown in figures 7, 8, and 9. These charts are compiled for water districts 1, 2, 3, 7, and 64, as shown on the insert map and for the entire valley. The number of pumps in the

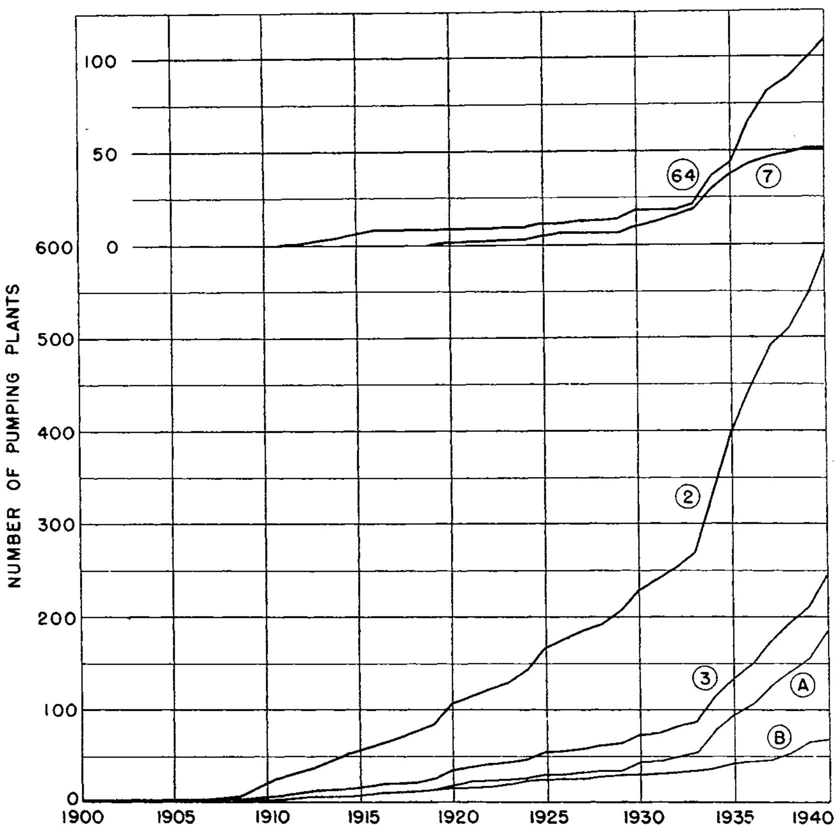

Figure 8.—Rate of growth in number of pumping plants in Water Districts 2, 3, 7, and 64. A and B graphs are for the Poudre and Box Elder areas in District No. 3.

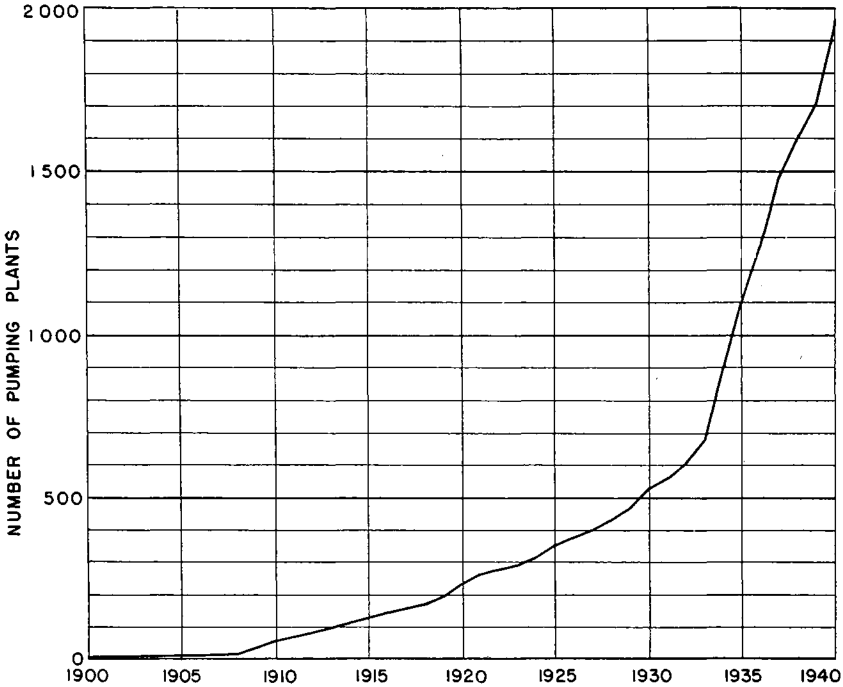

Figure 9.—Rate of growth in number of pumping plants in the South Platte Valley.

other districts is very small in comparison and is not shown. The State Engineer's report for 1912 includes a statement of historical interest on the number of irrigation wells by counties in operation at that time as follows: Weld, 47; Larimer, 5; Adams, 5; Morgan, 14; and Logan, 2; totaling 73. He states also that most of these plants were installed in 1910 and 1911, one in 1890, one in 1902, one in 1903, and two in 1904.

Amount of Water Pumped

Tables 2, 3, and 4 show by irrigation water district,[10] county, and drainage the amount of water pumped for irrigation in 1940; this totaled about 220,000 acre-feet. The use by cities and towns was approximately 9,000 acre-feet and that by sugar factories and railroads

[10]Shown by red boundary lines and numbers on map. Unfortunately these boundary lines were taken from a map other than the one used for the purpose of tabulation and are in error in several locations. The east boundary of District 3 should pass through Eaton and 2 miles west of Ault. The east boundary of District 5 should begin near Milliken and continue on the west side of the South Platte River. District 7 should extend to the mouth of Clear Creek. Other deviations are of a minor character.

TABLE 2.—*Use of ground water for irrigation in 1940 by water district.*

District No.	Acre-feet	District No.	Acre-feet
1	137,810	7	650
2	45,800	8	1,170
3	22,600	9	50
4	1,740	64	10,100
5	190		
6	30	Total	220,140

TABLE 3.—*Use of ground water for irrigation in 1940 by counties.*

County	Acre-feet	County	Acre-feet
Adams	12,800	Larimer	8,620
Arapahoe	1,160	Logan	8,260
Boulder	100	Morgan	61,600
Denver	220	Sedgwick	980
Douglas	70	Washington	4,340
Elbert	10	Weld	121,800
Jefferson	180		
		Total	220,140

TABLE 4.—*Use of ground water for irrigation in 1940 by drainage area.*

Drainage	Acre-feet	Acres supplemental	Acres independent
South Platte, direct	103,400	67,650	8,470
Bear Creek	50	180	
Cherry Creek	1,170	1,600	150
Clear Creek	650	300	290
St. Vrain Creek	220	500	
Thompson River	1,360	1,360	10
Box Elder Creek (Water District 3)	6,210	5,290	120
Cache la Poudre River, direct	16,400	12,730	750
Lone Tree Creek	39,400	26,580	1,340
Crow Creek	4,920	3,320	380
Box Elder Creek (Water District 1)	10,400	6,940	1,980
Prospect Valley	12,700	9,300	550
Kiowa Creek	7,570		5,020
Bijou Creek	7,980	60	5,480
Beaver Creek	7,710	260	4,920
Totals	220,140	136,070	29,460

about 4,000 acre-feet. The grand total of 233,000 acre-feet is equivalent to more than two-thirds the average annual flow of the Cache la Poudre River or more than three-fourths the proposed capacity of the Colorado-Big Thompson diversion tunnel and about 20 percent of the total average river inflow into the valley. It is also of interest to note that the pumped water equalled about one-third the mountain stream flow in 1940. The pumpage in that year greatly exceeded that of any previous year; for comparison with other recent years reference is made to table 5, which is based on the assumption that

TABLE 5.—*Use of electric power by irrigation wells in South Platte Valley, with corresponding assumptions of water pumped.*

Year	Kilowatt-hours used	Acre-feet pumped
1930	1,500,000	*
1931	2,200,000	*
1932	2,100,000	*
1933	1,760,000	*
1934	3,730,000	56,000
1935	3,610,000	51,000
1936	5,710,000	81,000
1937	7,870,000	112,000
1938	5,170,000	73,000
1939	11,690,000	166,000
1940	15,340,000	220,000
1941	10,570,000	150,000

* Not computed because relationship becomes less valid for the earlier years.

there is a direct relation between power used and water pumped. The tabulation, although showing steady growth, also shows the effect of moisture conditions. The considerable falling off in load for 1938 was due to heavy September rains.

General Conditions in Specific Areas

An attempt was made in several pumping areas having reasonable natural boundaries to evaluate factors of replenishment, discharge, and withdrawal from storage with a view to determining conditions for a stable water table. Although some relationships were discovered, it was found that the water-table records were too meager and the canal diversions too complicated to make satisfactory conclusions possible. This work did indicate, however, what data were lacking and resulted in the selection of more wells for observing water-table fluctuations. The following discussions, therefore, are based on the information collected and are necessarily of a general nature only.

In order to understand the causes of water-table fluctuations, it is necessary to compare the diagrams in figures 10 to 16 with the water supply from precipitation and stream flow as shown in figure 2. Stream flow is the more important, and comparisons clearly indicate its association with ground water. During years of subnormal stream flow the natural water-table lowering is accelerated by increased pumping. It will be noticed that in nearly all cases the low points follow years of low stream flow and that the lowest point was reached in the spring of 1941. Precipitation as shown in figure 2 seems to bear but limited relation to stream flow and water-table conditions.

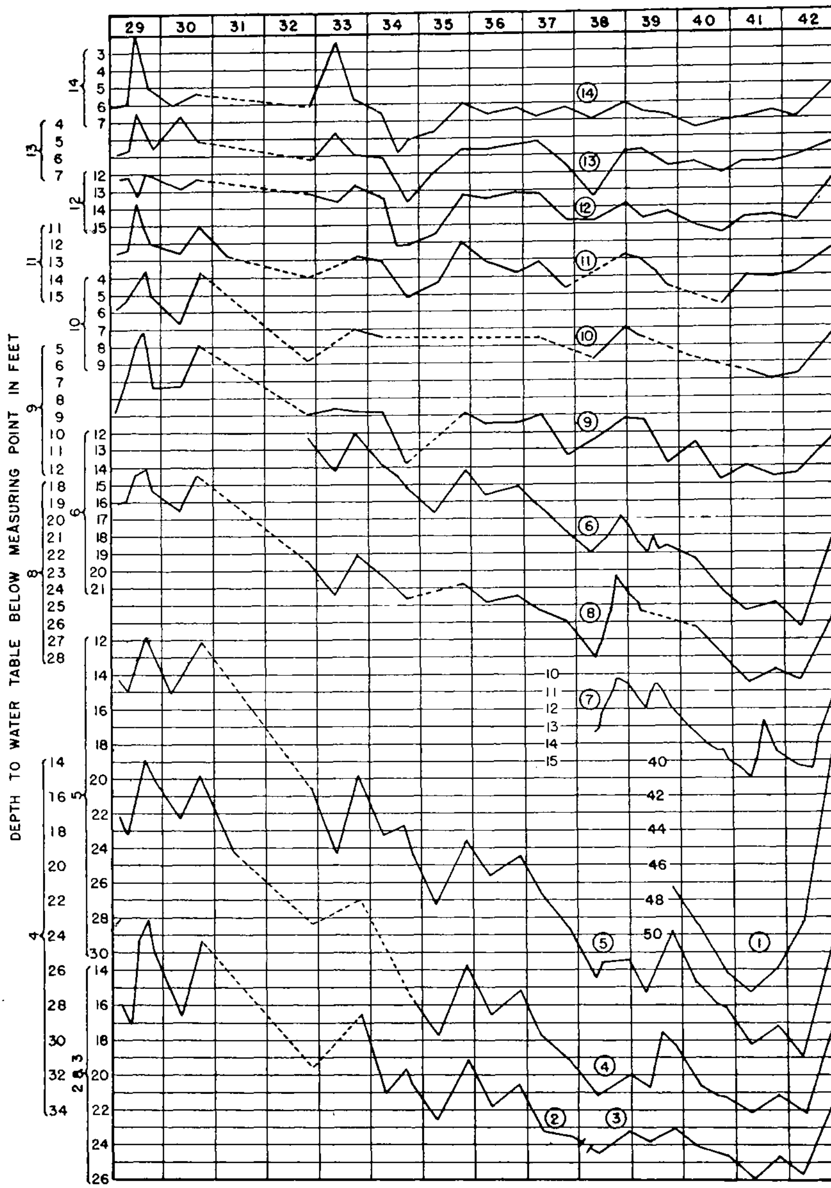

Figure 10.—Fluctuations in observation wells at following locations: No. 1 Sec. 17, No. 2 Sec. 29, No. 3 Sec. 28, No. 4 Sec. 33, T. 9 N., R. 68 W. No. 5 Sec. 4, No. 6 Sec. 10, No. 7 Sec. 15, No. 8 Sec. 16, No. 9 Sec. 22, No. 10 Sec. 28, No. 11 Sec. 27, No. 12 Sec. 33, T. 8 N., R. 68 W. No. 13 Sec. 10, No. 14 Sec. 22, T. 7 N., R. 68 W.

Box Elder Area (Water District No. 3)

Box Elder Creek rises in a low mountain area wholly within Colorado, flows in a somewhat southeasterly direction, and emerges into the valley about 10 miles above the upper end of the pumping area. The main canal of the North Poudre system crosses the valley about the location of the first wells. The valley is also crossed by the Poudre Valley canal just north of Wellington, the Larimer County canal about 3 miles south of Wellington, and the Eaton canal near the lower end. Recharge to the underflow from the creek begins at the point where it leaves the solid rock of its canyon. Here there is a small continuous flow which is lost soon after entering the valley. The principal source of the creek flow is heavy rains occurring between April and September, and losses from these flows and tributary gulches provide part of the ground-water supply. Heavy contributions to the ground water are made by losses from the irrigation ditches and some from reservoirs. Losses from reservoirs probably do not contribute a very large share since they are located principally to the west of the area. The southern boundary was arbitrarily set at about 2 miles north of the Cache la Poudre River.

The deposit of alluvium on top of the shale or sandstone varies from about 35 feet in depth at the south end to 65 feet at the north end except for a recently discovered strip hardly one-fourth mile wide on the west side where the deposit is from 40 to 50 feet deeper than in other portions of the valley. The water-bearing gravels are highly permeable but, since they are shallow in depth over most of the area, single wells are not of high capacity. Many of the irrigation pumping systems are composed of from two to six wells which are connected by means of siphons or are pumped directly through a suction-header pipe tapping the group. The capacities of the various plants vary from as little as 100 gallons per minute to as much as 1,300 gallons per minute. New single wells in the deep western channel yield as high as 1,500 gallons per minute with reasonable drawdowns.

Fifty-nine irrigation pumping plants were operated in this area in 1940, which had a total output of 6,210 acre-feet. Fluctuations in the water table at observation wells since 1929 are shown in figure 10. It will be noted that a very considerable decline occurred in the vicinity of Wellington, amounting to about 22 feet. As the Cache la Poudre River is approached, the decline becomes negligible. The effects of dry years accompanied by heavy pumping, such as 1934, 1937, 1939, and 1940, are apparent. Approximate equilibrium obtained under the conditions of pumping and canal flow in the years 1938 and 1941. How rapidly recovery may occur is shown in the record for 1942, a year of excess precipitation and stream flow.

The lowering of the water table near Wellington has resulted in the abandonment of several pumping plants and a severe reduction in capacity of many others. It is of interest to note that previous to the establishment of the North Poudre and Poudre Valley canal systems, the water table near Wellington stood at from 10 to 15 feet lower than in 1941.

Cache la Poudre River Area

The boundary of the Cache la Poudre River area is taken as that of Water District No. 3 not including Box Elder (see map) and encloses many quite unrelated conditions. For the most part the wells are located in territory directly tributary to the Poudre.

Favorable sands and gravels lie in the immediate river valley only and, since the river channel lies to the south side, practically all the irrigation wells are on the north side. The possibilities of obtaining even a reasonably good well west of Fort Collins are poor because the valley fill is shallow and composed largely of boulders and fine sand. Outside the valley bottom, scattered local deposits of gravel occur in which small-capacity wells may be obtained. A few miles east of Fort Collins and below the confluence with Box Elder Creek, conditions are fairly good for wells up to 900 gallons per minute capacity. The maximum depth of fill here is about 60 feet. The valley is narrowest at Timnath, below which it widens to several miles. Just east of Windsor fair conditions for wells exist in a local drainage as far north as Severance. Conditions vary greatly in the Windsor area and eastward. The maximum well depth is about 65 feet and the maximum pump capacity about 900 gallons per minute, but most of the wells are between 18 and 40 feet in depth and yield less than 500 gallons per minute.

There are perhaps half a dozen plants now operating that are more than 30 years old, but most of 188 found have been installed since 1933. The calculated output from these wells in 1940 was approximately 16,400 acre-feet. Observations of water-table fluctuations in this area were not begun until 1940 except for one discontinuous record near Windsor, which is shown in figure 12, No. 42. No serious lowering of the water table has occurred and apparently there was a complete recovery in 1942.

Lone Tree Creek Area

The Lone Tree Creek pumping area north of Greeley is confined to the Lone Tree Creek Valley as indicated by the well locations on the map. Outside the boundaries of this area gravels do not exist or the water depth above the shale is too meager to support an adequate well flow. This latter condition is especially true above the highest canal, the Pierce Lateral. A number of attempts were made to ob-

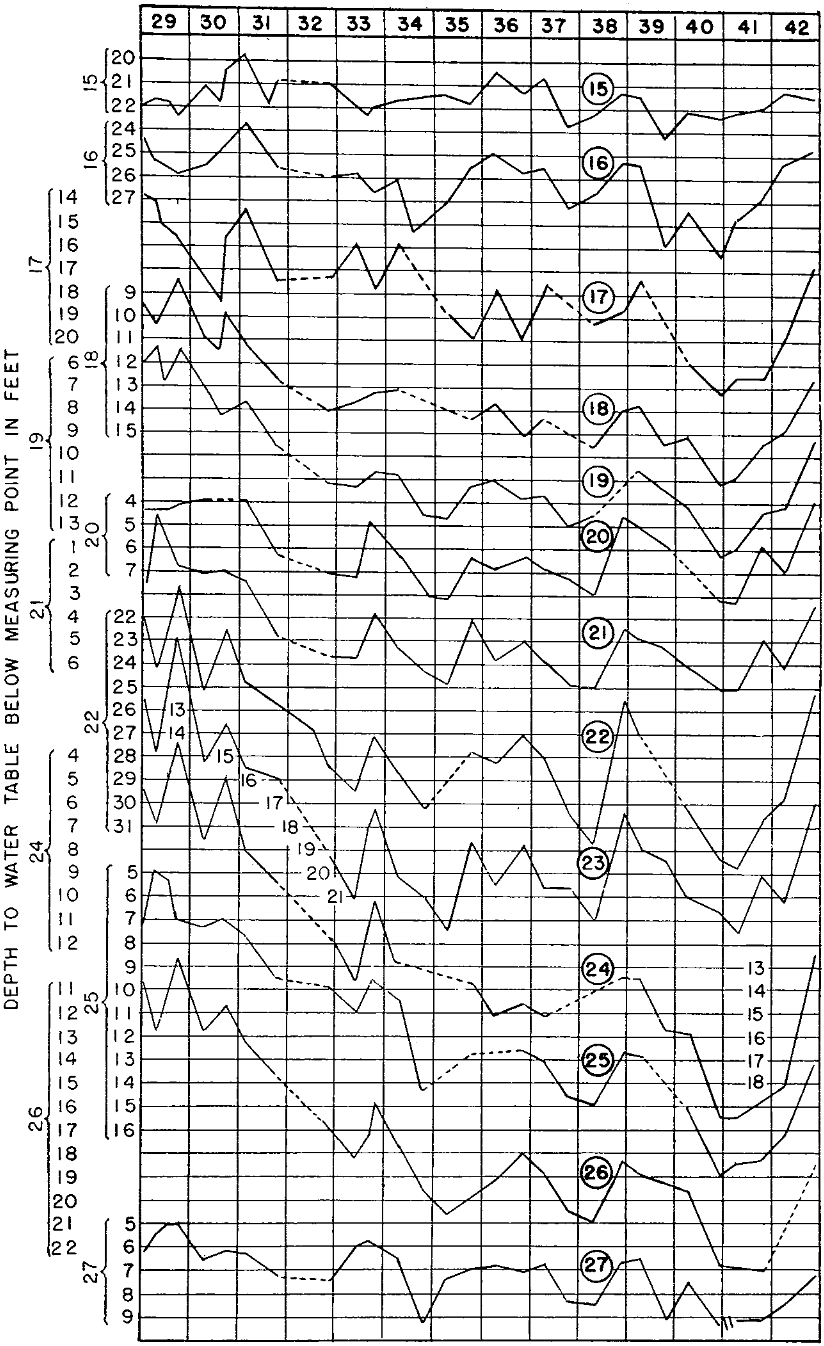

Figure 11.—Fluctuations in observation wells at following locations: No. 15 Sec. 22, No. 16 Sec. 26, T. 8 N., R. 66 W. No. 17 Sec. 20, No. 18 N. W. Sec. 28, No. 19 S. E. Sec. 28, No. 20 N. E. Sec. 34, No. 21 S. E. Sec. 34, T. 8 N., R. 65 W. No. 22 Sec. 2, No. 23 Sec. 1, T. 7 N., R. 66 W. No. 24 Sec. 6, No. 25 Sec. 10, No. 27 Sec. 21, T. 7 N., R. 65 W. No. 26 Sec. 14, T. 7 N., R. 66 W.

tain wells north of the Pierce Lateral and below the Laramie-Poudre Canal about 4 miles north of it. Water ran through this canal discontinuously for a few years previous to 1928 but none has run since. The plants were operated a few years and then abandoned when the water table dropped 5 to 10 feet.

Wells east from Ault and Pierce are from 30 to 40 feet deep and have a water depth seldom exceeding 20 feet and capacities ranging from 50 to 400 gallons per minute. South from Ault the thickness of the alluvium increases, especially on the west side, to about 70 feet near Eaton. South from Eaton the valley fans out into the Poudre. Wells in the southern half of the area average much higher in capacity than in the northern half because of the greater water-bearing depth of gravel. The total number of plants operating in the entire area in 1940 was found to be 336, with a discharge of about 39,400 acre-feet.

Lone Tree Creek receives drainage only from the plains area in Colorado, which to the north is broken up by many low ridges. Except in the vicinity of Carr, water flows in it only during storms, and discharges may reach as high as 1,000 second-feet, overflowing its narrow, shallow channel. In the irrigated area, when the water table is high, as in 1929, seepage water appears in a small continuous stream. The ground water in the area derives some benefit from losses during these floods. Four irrigation canals, Pierce Lateral, Larimer County, Larimer and Weld, and Greeley No. 2, cross the area in a west-to-east direction. Losses from these canals and deep percolation from irrigated fields are the principal sources of ground-water supply and the water table responds quickly to the irrigation season, which begins about the middle of May. Previous to irrigation it was difficult to obtain even small-capacity domestic wells near Eaton. Many dug by hand in this period were 60 to 90 feet deep and indicate the approximate position of the water table. The Eaton canal was built in 1880, and in the 20 years following the water table rose to within 16 feet of the surface.

Most of the wells south of Eaton, where water shortage was felt much later than in the Ault-Pierce district, have been drilled since 1932. The older plants are mostly near Lone Tree Creek on the east side of the valley. It is generally supposed that the oldest irrigation well in the State was on this creek 3 miles east of Eaton. It was dug in 1888 and abandoned in 1939 because of failure of the curbing. The water table near Eaton dropped nearly 20 feet between 1929, when the present program of observations began, and 1941. The drop has been less north of Eaton except for some heavily pumped local areas where a drop of as much as 30 feet was observed. The fluctuations in the water table at observation wells are shown in figures 11 and 12, Nos. 15 to 38. They clearly show the influences of the ap-

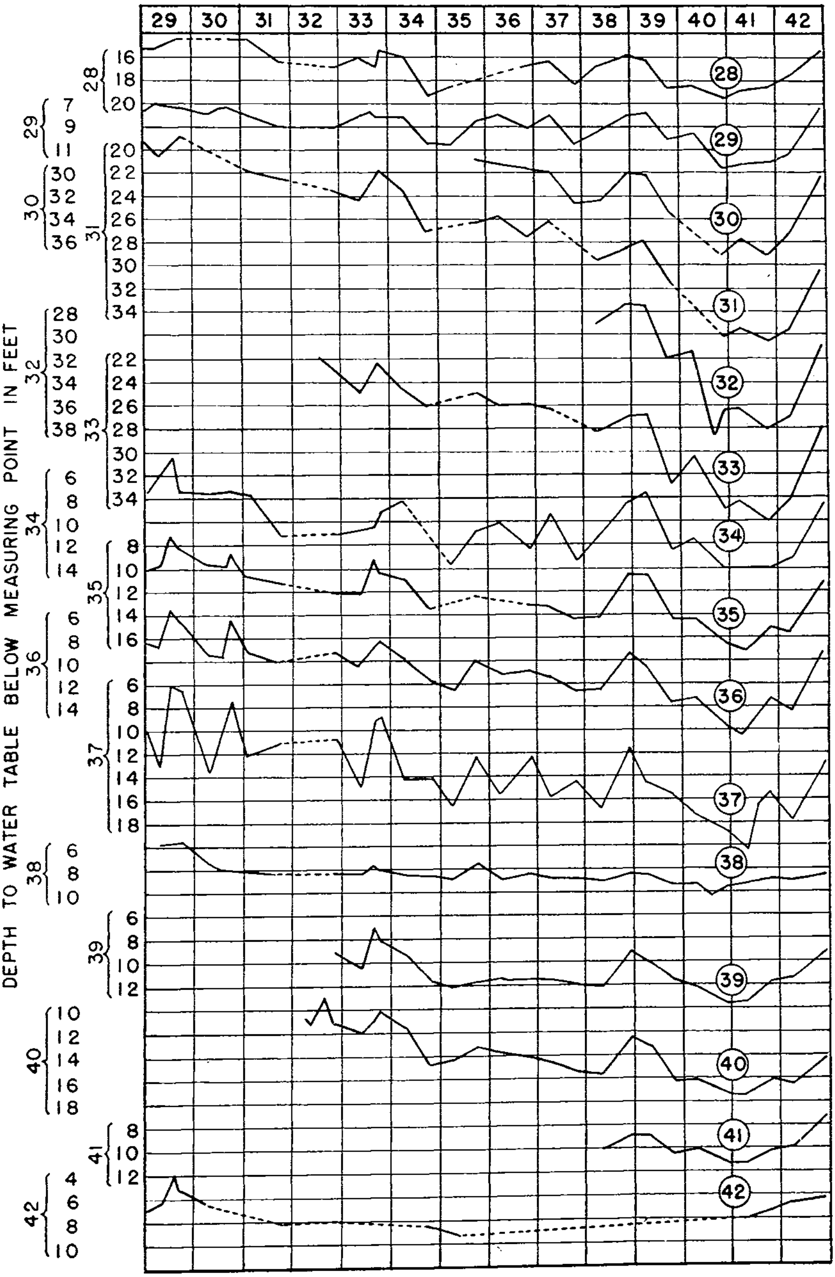

Figure 12.—Fluctuations in observation wells at following locations: No. 28 Sec. 28, T. 7 N., R. 65 W. No. 30 Sec. 25, T. 7 N., R. 66 W. No. 31 Sec. 1, T. 6 N., R. 66 W. No. 29 Sec. 3, No. 32 Sec. 18, No. 33 Sec. 17, No. 34 Sec. 10, No. 35 Sec. 15, No. 36 Sec. 21, No. 37 Sec. 34, T. 6 N., R. 65 W. No. 38 Sec. 19, No. 39 Sec. 24, No. 41 Sec. 26, T. 6 N., R. 64 W. No. 40 Sec. 29, T. 6 N., R. 63 W. No. 42 Sec. 17, T. 6 N., R. 67 W.

plication of irrigation water, being usually higher in the fall than in the spring.

From a study of the data on pumping and canal water supplies in this area from 1936 to 1941 inclusive, it would appear that conditions similar to those obtaining in 1936 and 1941 are necessary to maintain equilibrium generally in the water table. In 1936 total water supply in the ditches serving the area was about 240,000 acre-feet, and it is estimated from the power consumption that 31,000 acre-feet were pumped. The year 1938, with 305,000 acre-feet in ditches and 24,500 acre-feet pumped, produced a general rise of 2 feet in the water table.

Crow Creek Area

Crow Creek has its headwaters in the Sherman Mountains west of Cheyenne, Wyo., but very little water from these mountains appears as stream flow in Colorado. It joins the South Platte about 10 miles east of Greeley. A peculiar water-bearing formation known as Brule clay extends from Wyoming into Colorado along Crow Creek and then bears southeasterly along the foot of some high bluffs. Several wells north of Keota are in this formation. The Brule clay, impervious in some places, yields water for irrigation wells in this area from interconnecting crevices. Wells in the vicinity of Hereford are found in both Brule clay and gravel and may be as deep as 150 feet. The water table along the creek is encountered at very shallow depths, while a few miles from the creek the depth may be 30 feet or more. Well capacities of 900 gallons per minute are possible, but yields vary greatly in very short distances because of rapidly changing conditions. Although attempts at well irrigation date back 25 years or more in the Grover-Hereford area, these early wells were either abandoned or little used. Recently interest has been revived by the introduction of electric power, and a number of good-capacity wells have been drilled. No proof of the adequacy of the underground supply has as yet been possible because of the newness of the development.

Pumping in the area east of Gill dates back to about 1918, but not until about 1930 was there any considerable activity in well development. In 1940 there were 43 plants operating in this drainage with a calculated output of 4,920 acre-feet. Water-table fluctuations in three observation wells are shown in figure 12, Nos. 39, 40, and 41. They show a decline in the water table beginning in 1933, except for 1938, 1939, and 1942, of 5 or 6 feet. Replenishment occurs here from flood flows in Crow Creek, from losses from the Larimer and Weld Canal and Greeley Canal No. 2, principally the latter, and from such water applied to the land. Conditions during the last

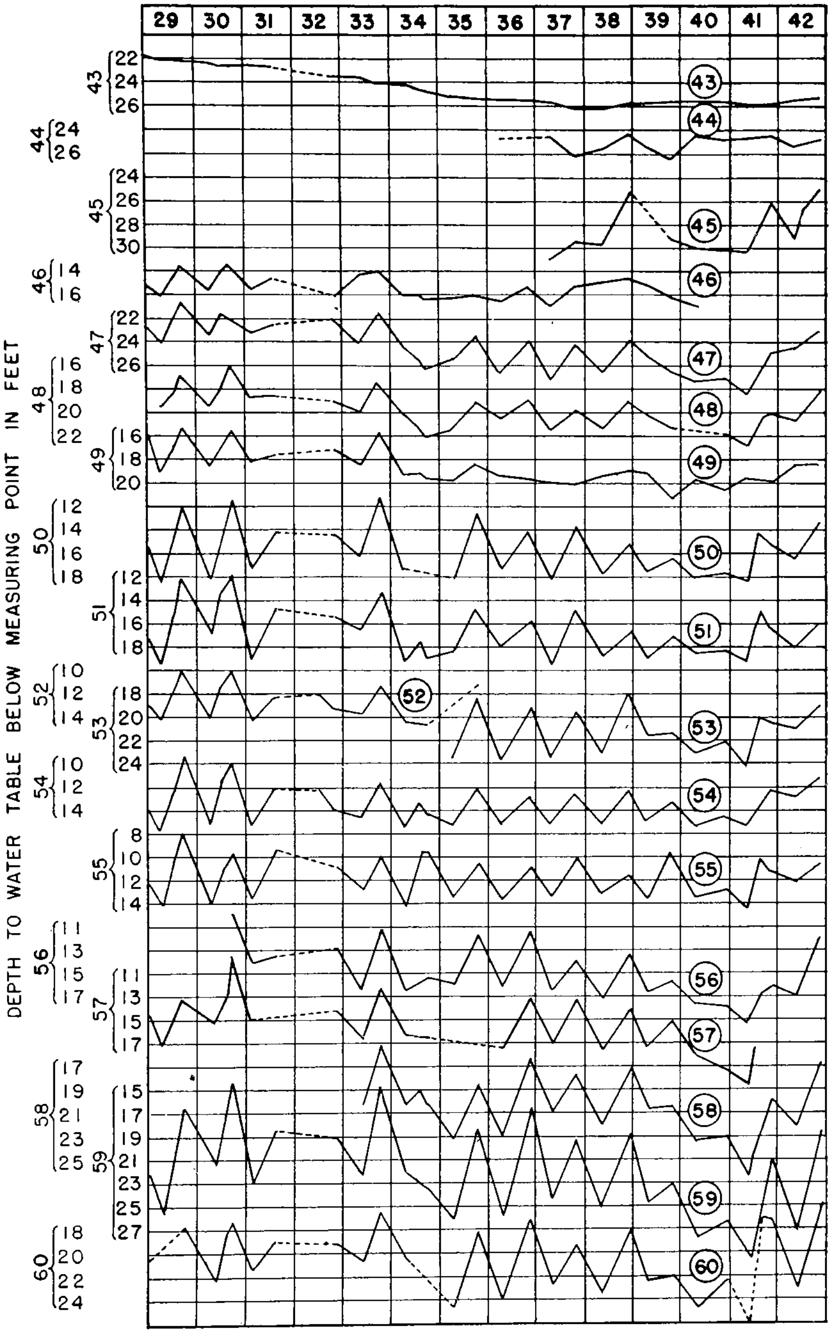

Figure 13.—Fluctuations in observation wells at following locations: No. 43 Sec. 31, No. 44 Sec. 20, No. 45 Sec. 10, T. 2 S., R. 67 W. No. 46 Sec. 26, No. 47 Sec. 13, T. 1 S., R. 67 W. No. 48 Sec. 7, T. 1 S., R. 66 W. No. 49 Sec. 31, No. 50, Sec. 30, No. 51 Sec. 7, T. 1 N., R. 66 W. No. 52 Sec. 32, No. 53 Sec. 29, No. 54 Sec. 20, No. 55 Sec. 7, T. 2 N., R. 66 W. No. 56 Sec. 7, T. 3 N., R. 66 W. No. 57 Sec. 31, No. 58 Sec. 28, No. 59 Sec. 15, No. 60 Sec. 9, T. 4 N., R. 66 W.

10 years have been such that less and less water has been delivered to this area by the Greeley Canal No. 2, resulting in an increasing use of ground water. As water supplies improve, it is expected that replenishment will be adequate.

The wells in this area are all less than 60 feet in depth, most of them being less than 50 feet, and the depth to water is less than 20 feet in all cases. A number of plants consist of a battery of from two to five wells. Single wells produce up to about 600 gallons per minute.

South Platte, Denver-Platteville

From Denver to Platteville, irrigation wells are confined largely to a strip about 2 miles wide on the east side of the South Platte, and except for a portion just north of Denver the lands are served by canals. The water-table fluctuations, as shown in figure 13, Nos. 43 to 55, are rather large and correspond with the irrigation season. Where pumping is heaviest, there has been little or no recovery in such years as 1934, 1939, and 1940. Aside from these years, recovery has been consistently regular. The situation just north of Denver near Adams City and Derby, however, is different. Here the water table has receded from 4 to 6 feet since 1929, largely because of pumping and inadequate replenishment. Many gardeners are located in this small area who are dependent entirely on water from wells.

Most of the wells are less than 50 feet in depth. A few on high ground are from 75 to 100 feet deep. Only a few pump capacities exceed 700 gallons per minute, but one well was found only 46 feet deep producing 1,350 gallons per minute.

In the east side of the delta area formed by the St. Vrain and South Platte west of Platteville some fairly good gravels were found in 1934, which resulted in the drilling of about 15 wells between that year and 1940. These wells do not exceed 90 feet in depth, and the water table stands at less than 30 feet. Capacities range up to 1,000 gallons per minute.

South Platte, Platteville-La Salle

The Platteville-La Salle area lies principally from 20 to 40 feet above the present flood plain of the river. Here the valley has increased in width to about 4 miles but becomes narrower on the north as the river bends eastward. The river channel follows generally the west valley boundary, leaving practically all the favorable pumping area on the east side. The area for the most part is underlaid with good water-bearing sands and gravels to a maximum depth of 120 feet. In places clay strata 20 feet thick are found, and along the east border much dirty, fine sand is encountered. The deepest part of the valley lies along a northeasterly line passing near the town of Gilcrest. The depth to water is moderate at all points, the greatest being about 25 feet. Seepage conditions exist on the east side.

Four canals, Farmers Independent, Western, Bucker, and Evans No. 2, with headings in the South Platte, serve the area. Water is turned in usually the latter part of April and out about October 1.

Most of the well development has occurred since 1933, although there were about 25 wells in operation in 1920. The shortage of water beginning in 1933, and the large acreage of early potatoes regularly grown and requiring frequent irrigation, have led to the extensive well development now existing. Nearly every farm has a well and more would be in evidence on the east side but for the poor water formations.

In no other place in the State are the annual water-table fluctuations so great as here. As seen from the observation-well diagrams, a swing of as much as 10 feet may be expected between April 15 and September 15. The soil in this area is very sandy, and the losses from ditches and from irrigation are exceedingly great, accounting for these large contributions to the ground water.

There seems to be no doubt about the adequacy of replenishment in this area. An inspection of the water-table fluctuations in figures 13 and 14, Nos. 56 to 64, reveals no consistent tendency. Recovery occurs commensurate with available water supply to the ditches. The pumping demand varies inversely with the ditch supplies, and in such years as 1934, 1939, and 1940 recovery is only partial. Those years were abnormally low as to stream flow, and residual losses were soon recovered when conditions returned to normal.

Beebe Draw Area

Beebe Draw is a narrow drainage, the upper end of which is about 5 miles east of Brighton and extends north to join the South Platte a short distance east of La Salle. Some wells were drilled in the lower end of the Draw before 1926, but those above La Salle have all been drilled since 1934. Near the upper end the wells are about 40 feet deep; near Hudson a depth of 80 feet can be attained and this depth seems to be the maximum for the remainder of the distance north. The water table is found at a depth of from 6 to 25 feet. Well capacities south of Hudson are rather low, but from Hudson north conditions improve and 1,000-gallons wells are obtainable. There were 22 plants operated in the drainage in 1940, according to the findings in the survey.

A large reservoir, Barr Lake, is situated at the head of the Draw, and seepage from it and the three distributaries flowing north form

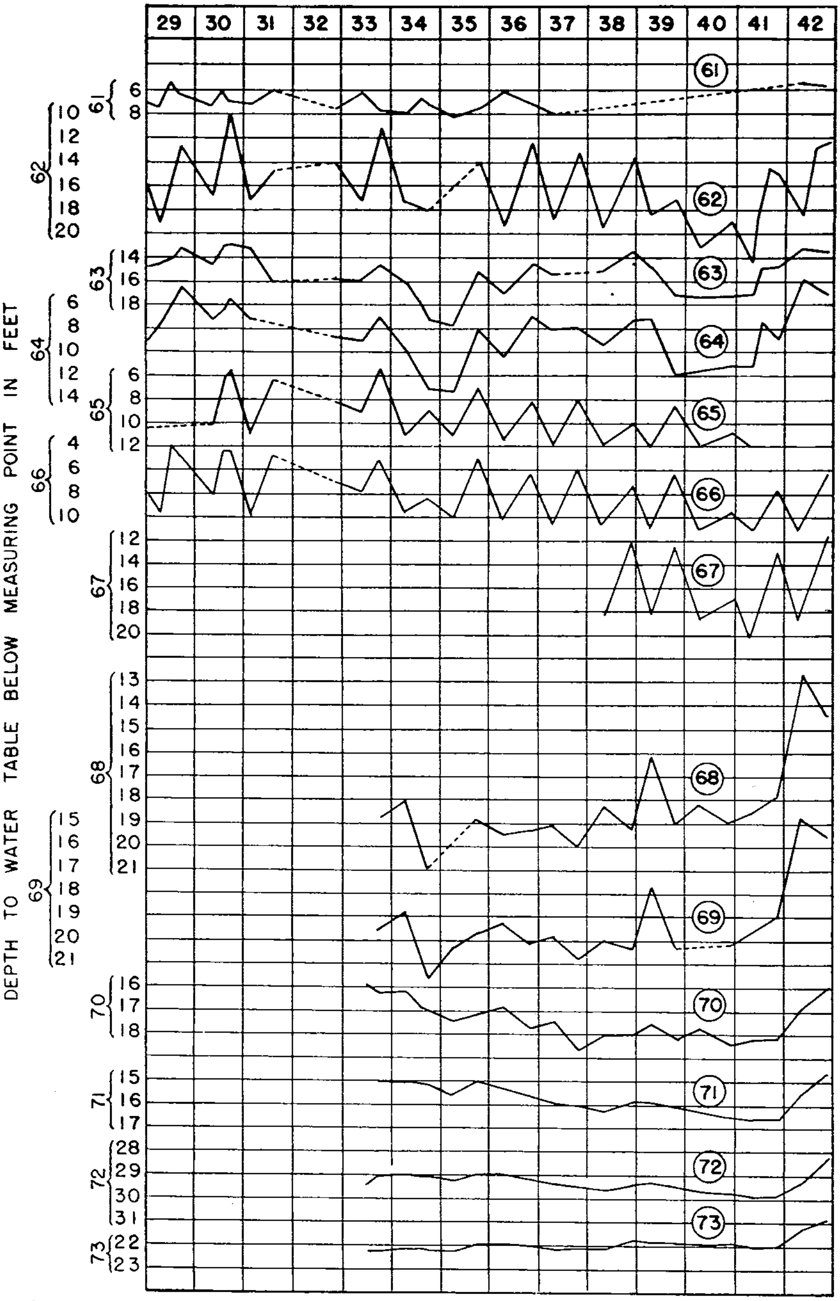

Figure 14.—Fluctuations in observation wells at following locations: No. 61 Sec. 17, No. 62 Sec. 14, No. 63 Sec. 13, T. 4 N., R. 66 W. No. 64 Sec. 18, T. 4 N., R. 65 W. No. 65 Sec. 27, No. 66 Sec. 26, No. 67 Sec. 13, T. 5 N., R. 65 W. No. 68 Sec. 35, No. 69 Sec. 35, No. 70 Sec. 23, No. 71 Sec. 14, No. 72 Sec. 11, No. 73 Sec. 2, T. 1 S., R. 65 W.

practically all the sources of replenishment to its underflow. No records have been collected on water-table fluctuations, but indications are that the present pumping has produced no significant effect.

Box Elder Area (Water District No. 1)

Box Elder Creek has a long, narrow, north-and-south drainage paralleling the South Platte, and its headwaters reach up to elevations of 7,000 feet or more. For about 40 miles the catchment width does not exceed 6 miles. The upper part of the stream is perennial for about 25 miles, but below this point flow occurs only during storms.

There are three areas of ground-water development: One north of Watkins, another near Hudson, and the third south and east of Kersey. The first area depends entirely upon stream flow for recharge, while the other two receive canal irrigation losses in addition.

Development of the area north of Watkins started in 1933, and from 1,000 to 1,400 acres have been lightly irrigated because the crops have been largely grain and forage. The depth to water is between 15 and 25 feet, and the depth of the wells is about 50 feet. Capacities are less than 700 gallons per minute. As shown in figure 14, Nos. 68 to 73, the effect upon the water table has been of no consequence. Those wells nearest the creek are subject to the widest fluctuation and show the effect of stream flow.

The Hudson area is older, the first pumping having been done in about 1924. The wells are from 30 to 65 feet in depth, and the depth to water is from 10 to 25 feet. Well capacities vary between 300 and 800 gallons per minute. From 1934 to 1940 the water table receded 5 feet in places because of short water supplies and local overdevelopment, but substantial recoveries took place in 1941 and 1942.

Pumping began in the area southeast of Kersey in about 1908, but significant development did not take place until 1934. The depth of wells ranges from 50 to 75 feet, and the depth to water from 8 to 20 feet. Well capacities range from 500 to 1,000 gallons per minute. Since observations on the water table were not started until 1940, no statement can be made as to the response to recharge and pumping. Indications are that no significant change has taken place, but in 1940 losses of from 2 to 3 feet occurred.

Throughout the length of Box Elder Creek, 82 pumping plants were found in operation in 1940 which pumped 10,400 acre-feet of water.

Prospect Valley Area

Prospect Valley is in the Henrylyn Irrigation District and lies east of Keenesburg and south of Roggen. This district has never had an adequate water supply, but the situation became very acute in 1932 and in that year a development company was employed to make a survey of irrigation-well possibilities. This company, by means of test drilling, found a long body of gravel only a mile or so wide at the south end, widening to about 5 miles at the north end, which proved to be a good water producer. The first irrigation well was put down in the northern end of the district in 1929, and although successful from the standpoint of capacity it was poorly managed and was very little used. In 1932 a second well was put down farther south which successfully demonstrated the possibilities of ground-water development. Wells went in rapidly during 1933, 1934, and 1935, and the area reached almost complete development by 1937. Previous to the introduction of electric power in 1940, high-speed diesel engines were the principal source of power.

Lost Creek, on the west side of the area, appears to be the west boundary of the underlying gravels at many points. Sand Creek enters the area on the east side from well-developed drainage channels in the south and spreads out into the flat, cultivated land in the northern part.

The understructure of the area is trough-shaped with the deepest part about centrally located and the axis lying in a direction slightly east of north. The depth of alluvium above the shale is about 175 feet at the south end, 130 feet near Prospect which is centrally located, and about 120 feet at the north end of the area. In 1940 the depth to water was about 104 feet at the upper or south end, 65 feet in the central part, and 22 feet at the north end. Water-bearing sands and gravels thin out at the sides with rather definite boundaries which are roughly delineated by the well grouping as shown on the accompanying map in the back cover of this bulletin. The beds of sand and gravel are interspersed with frequent clay strata, both of which vary rapidly in thickness and character in short distances. The best wells occur in the central or deep portion, where pump capacities up to 1,700 gallons per minute are possible. Some wells in the less-favorable localities produce but 300 gallons per minute. With the lowering of the water table, well capacities have been definitely reduced from the original conditions and many pumps have had to be lowered or reduced in capacity.

Water was first applied to this district in 1912 through Henrylyn canals. Evidence of well drillers and others indicates that the water level rose some 18 feet between that date and 1932.

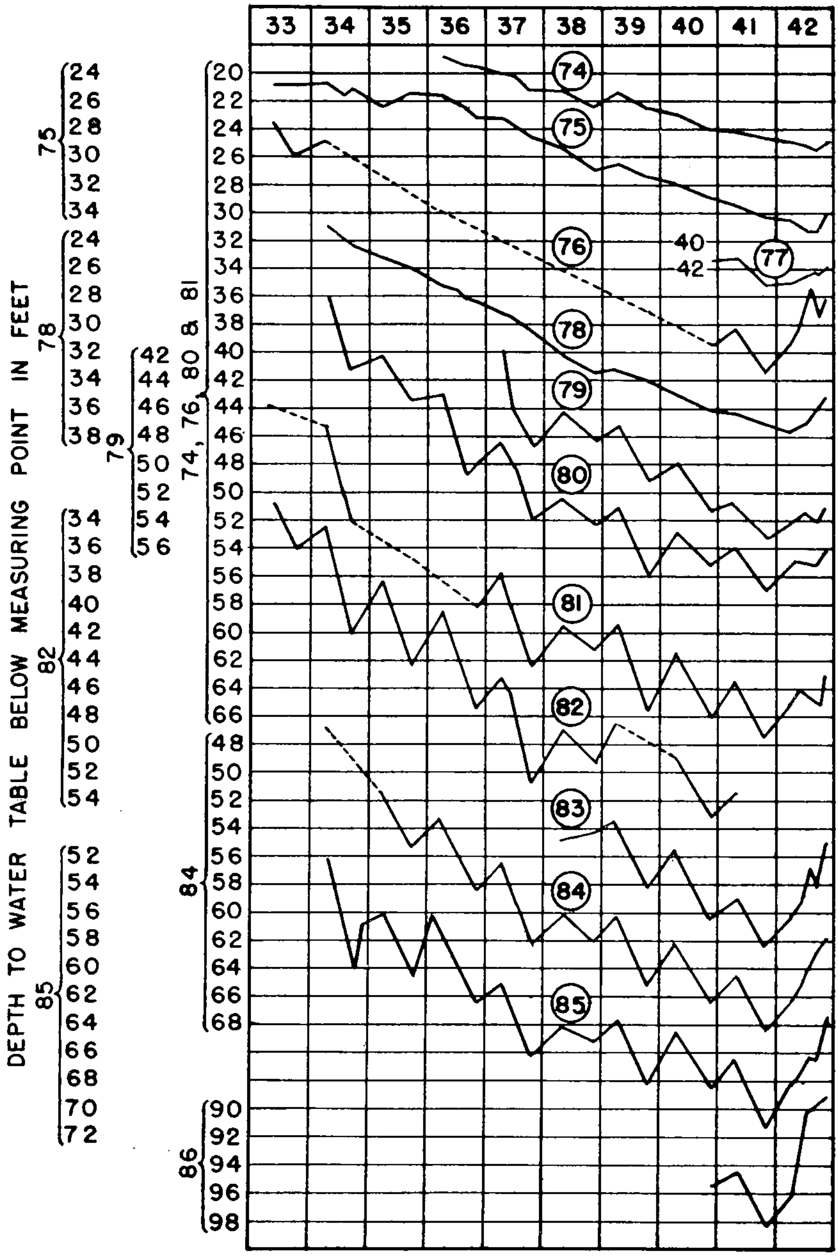

Figure 15.—Fluctuations in observation wells in Prospect area at following locations: No. 74 Sec. 18, No. 75 Sec. 19, T. 2 N., R. 62 W. No. 76 Sec. 22, No. 77 Sec. 25, No. 78 Sec. 32, No. 79 Sec. 36, No. 80 S. E. Sec. 35, No. 81 S. W. Sec. 35, No. 82 N. W. Sec. 34, No. 83 S. W. Sec. 34, T. 2 N., R. 63 W. No. 84 Sec. 3, No. 85 Sec. 10, No. 86 Sec. 22, T. 1 N., R. 63 W.

Measurements on a group of about 10 wells were begun in 1933 and disclosed that, except for the years 1938 and 1942, there was an annual decline of about 2½ feet in the central part of the area. Wells in the pumped area showed a low point each fall, followed by a partial recovery during the winter and spring, while those at the edges showed a continuous decline. Heavy rains in September of 1938 brought an early halt to pumping that year, which was reflected by a less-than-usual decline and a complete recovery the following spring. An unusual recovery took place in 1942. These conditions are well shown by the graphs in figure 15.

No data on pumping are available for the year 1938, but it was definitely less than the average since there was none after September 1. Based on the data gathered on 67 pumping plants operated in 1940, when an estimated 12,700 acre-feet were pumped on 9,850 acres, the 1938 withdrawal was probably about 9,000 acre-feet. The amount of water delivered through canals to farms in the Prospect area is shown in the following table. Since these are measurements at the farmers' headgates, losses from canals and reservoirs are therefore not included.

Year	Acre-feet	Year	Acre-feet
1933	3,520	1937	940
1934	1,120	1938	6,650
1935	810	1939	3,800
1936	1,850	1940	540
		1941	1,320

It would appear then that conditions approximating those in 1938 might result in a stable water table.

The Henrylyn Irrigation District has two small storage reservoirs in the Prospect area: The Olds of about 300 acre-feet capacity, and the Lord of 3,600 acre-feet capacity. The Olds is valueless for storage because of leakage but is of very great importance as a means of ground-water replenishment. This was not recognized until 1938, when it was realized that incoming irrigation water had a definite bearing on the water-table condition. Water was run into Olds in 1938 and 1942, but these were the only times possible since 1928. Losses from these reservoirs and from canals are the principal sources of recharge, although no doubt there are some contributions from flood flows in Lost Creek.

Kiowa Creek Area

Kiowa Creek heads in the Black Forest at the southern boundary of the basin just east of Box Elder Creek. It flows nearly due north, crossing the Union Pacific railroad at Bennett, and joins the South

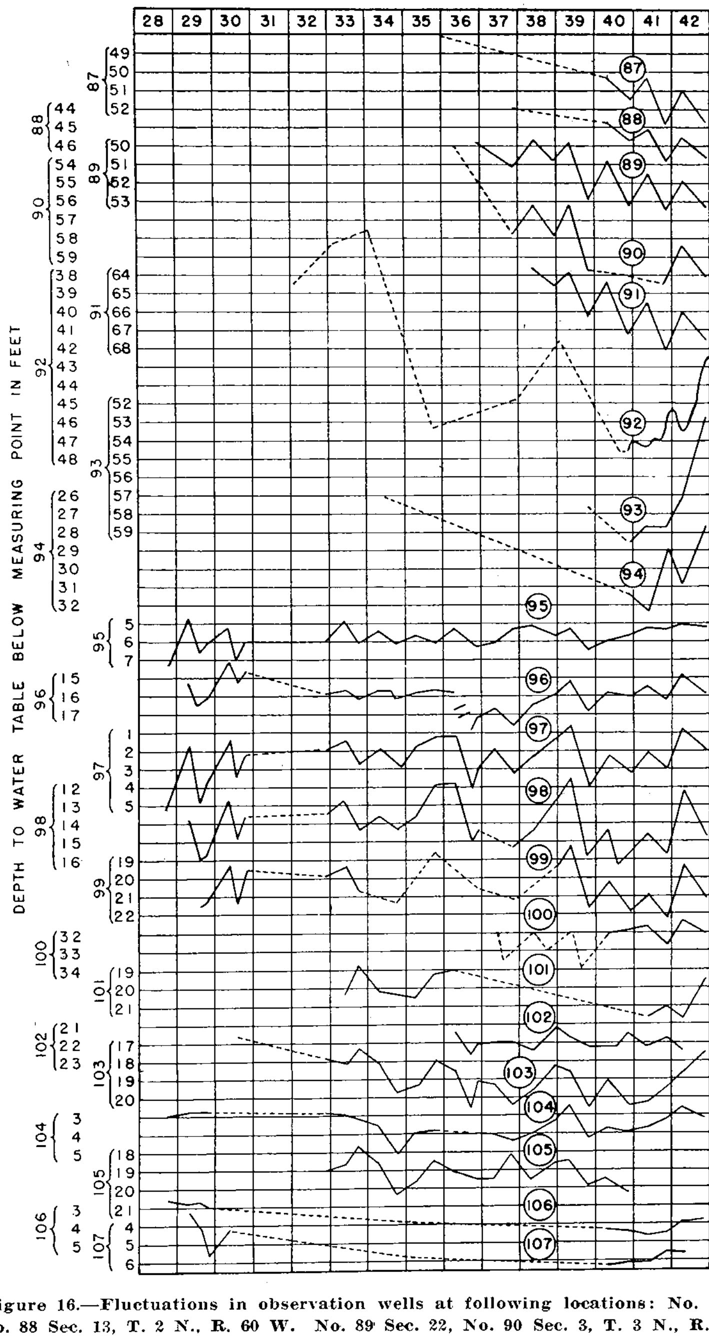

Figure 16.—Fluctuations in observation wells at following locations: No. 87 Sec. 26, No. 88 Sec. 13, T. 2 N., R. 60 W. No. 89 Sec. 22, No. 90 Sec. 3, T. 3 N., R. 61 W. No. 91 Sec. 34, T. 4 N., R. 60 W. No. 92 Ft. Morgan, No. 93 Sec. 11, T. 3 N., R. 58 W. No. 94 Sec. 7, No. 95 Sec. 24, T. 3 N., R. 56 W. No. 96 Sec. 1, No. 97 Sec. 13, No. 98 Sec. 24, T. 2 N., R. 56 W. No. 99 Sec. 30, T. 2 N., R. 55 W. No. 100 Sec. 1, T. 1 N., R. 56 W. No. 101 Sec. 23, No. 102 Sec. 24, T. 4 N., R. 56 W. No. 103 Sec. 9, No. 104 Sec. 4, T. 4 N., R. 55 W. No. 105 Sec. 36, T. 5 N., R. 55 W. No. 106 Sec. 26, T. 7 N., R. 53 W. No. 107 Sec. 10, T. 8 N., R. 52 W.

Platte near Wiggins. The creek is normally dry except for the upper 15 miles. Near the lower end the channel is capable of carrying but a few hundred second-feet, and the occasional large floods spread out over considerable area.

The first irrigation well to be continuously used was drilled in 1934, but most of them have been drilled since 1936. The necessary sand and gravel formations follow a narrow belt along the creek up to a point near Wiggins where the width increases to 3 or 4 miles. The wells are about 60 feet deep 6 miles north of the Adams County line, 110 feet at the Morgan County line, 150 feet at Wiggins, and 230 feet 4 miles north of Wiggins. The depths to water at the places mentioned are approximately 20, 35, 50, and 70 feet, respectively. High-capacity wells have been obtained from the Morgan County line north, several of which have been pumped at a rate of 2,000 gallons per minute.

Since pumping has been in progress practically only since 1937, and since in 1940 only 42 plants were found in the entire length of the stream, an adequate idea of the permanence of the water table cannot be gained at this time. A lowering of 2 or 3 feet (figure 16, Nos. 89, 90, and 91) has been noted near Wiggins, which may or may not indicate the future trend. Recharge is possible only from flood flows from the creek except at the extreme lower end where some influence from a nearby reservoir may be felt. Because of this limitation some degree of caution must be exercised to avoid overdevelopment.

Bijou Creek Area

Bijou Creek has the largest drainage area of any of the tributaries entering the South Platte from the south. It flows nearly due north to Wiggins and joins the South Platte about 4 miles west of Fort Morgan. Flow occurs for long periods after floods in the west branch near Byers, where some water is diverted for irrigation, but otherwise its bed is dry. Frequent floods, some of great magnitude, sweep down its channel; this channel near the Adams County line is about one-fourth mile wide.

Attempts to obtain irrigation wells in Adams County date back to perhaps 1915, but the half dozen or so efforts previous to 1933 have been abandoned largely because of poor well construction and unsuited equipment. In 1940 there were seven plants operated. The alluvium has been found to be 100 feet deep in places, but large areas have not been thoroughly explored. The depth to water varies according to surface topography from 10 to 50 feet. The water-bearing materials are generally quite fine gravel and sand, and great caution is required in drilling. For these conditions the reversed

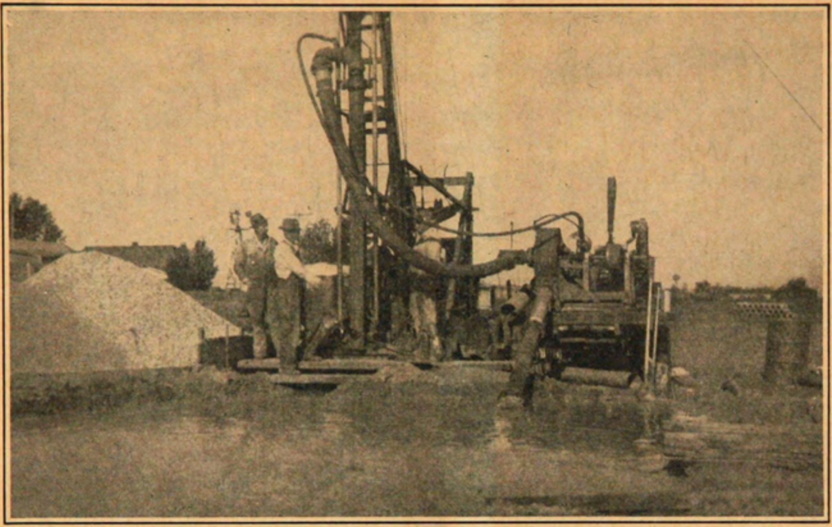

Figure 17.—Drilling well by the reversed rotary method. Drillings are pumped up through rotated drill pipe and water is returned to well.

rotary method (2) of drilling is best adapted (see fig. 17). Wells now operating are not of very high specific yield.

Development in Morgan County began in 1935 and has been more extensive, 37 plants having been operated in 1940. Wells are about 100 feet deep at the county line and become deeper northward to 200 feet and more at the Burlington railroad east of Wiggins. Depth to water at the county line is 18 feet and at the railroad about 50 feet. Pump capacities average about 700 gallons per minute, and the highest measured discharge was 1,130 gallons per minute.

Except for the area containing a small group of wells at the north end under the Bijou Canal, recharge occurs only from flood flow in the creek. Since floods occur with reasonable regularity, it is probable that the recharge factor is quite large. Water-table observations were not begun in this area until 1940; however, from the information gathered, a slight but not significant depletion has taken place since 1936. Fluctuations in two wells are shown in figure 16, Nos. 87 and 88.

The Bijou valley offers opportunity for considerable future development with reasonable safety, but increased use should be attended by careful observation of effects on the water table.

Beaver Creek Area

Beaver Creek drainage extends to about 60 miles south of Brush. A diversion dam is located just below the Morgan County line, and flood waters are diverted to both sides of the valley. Because of frequent damage by floods this system has operated with indifferent success and is not a dependable water supply since stream flow occurs only after periods of heavy precipitation. About 8 miles below this point water usually shows in the creek bottom and there is a small perrenial flow.

The greatest depth of alluvium near the county line is about 70 feet and increases to 100 feet or more near Brush. Irrigation wells are confined to a narrow belt, seldom over a mile wide, in the valley bottom where the favorable water-bearing gravels occur. The depth to water never exceeds 35 feet. The gravels are rather fine in texture, but many high-yielding wells have been obtained with correct well-drilling practice.

Pumping in this valley dates back to about 1910. There was a small steady growth up through 1936, but in the 4 years following the number of plants increased more than two-fold, or to 53 south of Brush in 1940. Electric power became available in 1939. Examination of water-table fluctuations (figure 16, Nos. 95 to 100) shows a temporary response to pumping and stream flow and no general trend. It therefore appears that under present conditions there is no overdraft on the ground water except perhaps temporarily in some local areas where plants are close together.

Fort Morgan-Hillrose Area

The Fort Morgan-Hillrose area is directly tributary to the South Platte and may well be considered one of the best, if not the best, water-producing districts in the State. This is particularly true near Hillrose where specific yields of 150 gallons per minute per foot of drawdown have been obtained.

The deepest wells in the Valley occur in this area. At a point 4 miles north of Wiggins the alluvium is known to be 230 feet deep, in the City of Fort Morgan 242 feet deep, and 2 miles west of Brush 197 feet deep. These points indicate the location of the original channel carved through the Pierre shale, but east of Brush it has not as yet been determined by well drilling. Only a few wells penetrate the full depth, stopping at from 80 to 150 feet to obtain satisfactory capacity. Good water-bearing gravels are usually encountered except in an area south from Fort Morgan where many thick strata of fine sand occur. It was in this area where the inverted rotary method of drilling was developed which has proved so satisfactory for such conditions. The depth to water at Fort Morgan is about 50 feet, while at a point 3 miles south it is only 18 feet. At Brush and Hillrose the depth to water is about 14 feet.

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[11]This instrument is being cared for cooperatively under the supervision of Howard Hutchinson, superintendent of power for the City of Fort Morgan.

The history of the water table in and south of Fort Morgan is quite complete and interesting. Observations on a few wells by the Experiment Station have been made here only since 1940. In November of that year an automatic recorder[11] was installed over an old well in the basement of the City Hall at Fort Morgan, the record from which is reproduced in figure 16 (Well No. 92). The data shown previous to 1940 are those obtained by George G. Cox, former Fort Morgan power superintendent, whose tenure of office dates back to 1904. Mr. Cox also provides the following information:

> The water table near the city hall stood at approximately 60 feet in 1885 and by 1906 it had risen to 52 feet. At that time the depth to water was about 50 feet for many miles south of Fort Morgan. By about 1923 the water table had risen to such a degree that seep conditions began to appear 4 miles south of the city, reaching its highest stage in 1928. In about 1933 the water table began to recede noticeably, and Crouch Lake and other small ponds which had appeared, dried up. This recession of the water table began previous to any pumping in that area.

Mr. W. F. Tormohlen, a long-time resident of the Fort Morgan vicinity, relates the following regarding the water table:

> In 1913 in the NW¼ of Section 32, T. 3 N., R. 57 W., the water table stood at about 45 feet, and by 1928 it had risen to 10 feet from the ground surface. (This location is 4 miles south of Fort Morgan where in 1940 the depth to water was about 15 feet.)

The foregoing two statements are not quite in agreement with respect to conditions between 1906 and 1918, but the general evidence is that the water table south of Fort Morgan rose nearly 50 feet after irrigation began under the Fort Morgan Canal in about 1884 and under the Bijou Canal in about 1908. Pumping in that area should be beneficial in preventing a return of seeped conditions when surface water supplies again become plentiful. It would seem that under the present program of pumping and use of river water the water table will not be seriously affected.

Lower South Platte Area

Good wells are easily obtained all along the bottom lands of the South Platte from Hillrose to the State line, with a depth seldom exceeding 100 feet. The depth to water varies according to topographic location, with a maximum of about 25 feet. Only one observation well at Atwood and one north of Sterling (fig. 16, Nos. 106 and 107), on which discontinuous records have been kept, are available for a check on water-table conditions. These records and other data indicate that along the river bottom no significant changes in the water table have taken place.

The lower part of the Pawnee Valley, as it fans out into the river valley, contains some good water-bearing gravels with a water table at from 10 to 25 feet and a maximum obtainable well depth of about 80 feet. All the wells in the Pawnee Valley have been drilled since 1934 except for one put down in 1916. Observations on water-table fluctuations were not begun until 1940, but information obtained indicates no significant change has occurred. The fact that Pawnee Creek in this locality persists as a living stream corroborates this.

Conclusions

This report shows that approximately 220,000 acre-feet of water were pumped from wells on 165,000 acres of land in the South Platte Valley in 1940. Of this area 136,000 acres, or 82 percent of the total, received well water as a supplemental supply. The replenishment of ground waters in irrigated areas is generally considered adequate, but there are several localities in which this is not true as shown by water-table observations. Such areas, however, have greater recovery potentialities than those depending entirely on losses from stream flow and are subject to relief during periods of adequate river supplies. They therefore may be drawn upon more heavily for reasonable periods of time without danger of serious depletion. Water drawn continually from underground reservoirs receiving but regular, normal contributions from stream flow, must not be taken in such amounts as to produce a steadily declining water table or a point of economic exhaustion will be definitely reached. The time required to reach this point will be determined by the water-bearing depth of alluvium over the rock floor and can be predicted with fair accuracy from water-table trends.

The conception of an inexhaustible ground-water supply has long ago been repudiated. Only in a few exceptional areas may this condition be approached. All developments in untried areas should be extended cautiously and be guided by the interpretation of water-table observations. A rule of thumb, not always reliable but indicative of limitations, is that a normal ground-water reservoir will seldom permit the irrigation of more than one-fourth of the overlying land.

Additional lands susceptible to irrigation from wells are available in the South Platte Valley. These are mainly in the Bijou, Kiowa, and Crow Creek Valleys where it is probable that the ground waters will permit further development. Additional wells for supplemental supplies probably will not be drilled at the rate indicated in the past 10 years, but a small steady growth can be expected. Unnecessary use of supplemental water is not conducive to the best interests of a community depending upon ground water as an ever-ready reservoir in time of decided shortage and is to be avoided.

164-9368

LOCATION OF IRRIGATION WELLS IN SOUTH PLATTE RIVER BASIN IN COLORADO

SURVEY OF 1940

Prepared Cooperatively by
COLORADO WATER CONSERVATION BOARD
and
COLORADO AGRICULTURAL EXPERIMENT STATION
COLORADO STATE COLLEGE

AUGUST 1942

NWS - ACS

Additional copies of this map available from Colorado State College, Fort Collins. Price 15¢

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