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JOSEPH M. TRACY, State Engineer

TECHNICAL PUBLICATION NO. 7

STATUS OF DEVELOPMENT OF SELECTED GROUND-WATER BASINS IN UTAH

By

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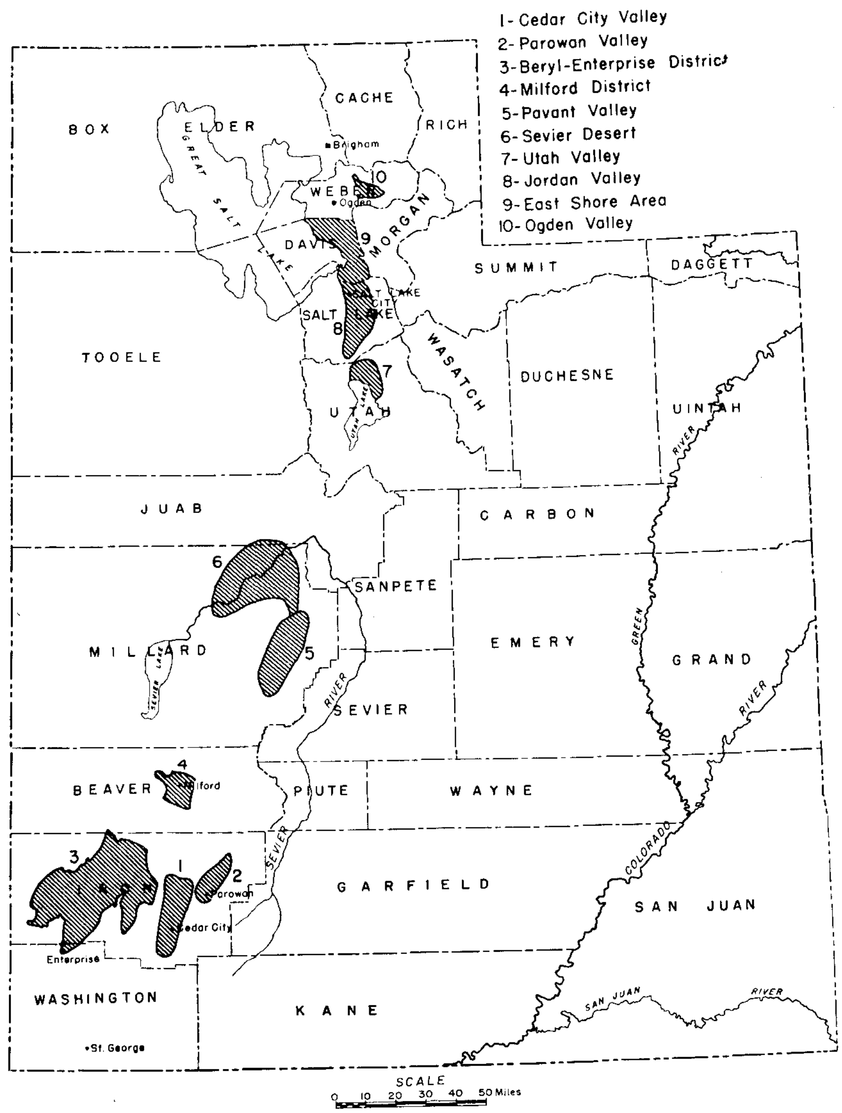

Frontispiece: Index map of Utah showing the location of the 10 ground-water areas discussed in this report.

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PREFACE

This report was prepared as a part of the cooperative State-wide ground-water program, under the direction of A. Nelson Sayre, Chief of the Ground-Water Branch of the United States Geological Survey, and Joseph M. Tracy, State Engineer of Utah. The authors wish to acknowledge their appreciation to John A. Ward of the State Engineer's Office who has reviewed the report and also to Charles W. Wilson of the Salt Lake City Water Department, Loren J. Westhaver, Vice President and Manager of Utah operations, Geneva-Columbia Division, U. S. Steel Corp., and Albert Thornton of the Office of the State Engineer for basic data provided.

This technical publication consists essentially of abstracts of more detailed reports which have been published. Reference to existing reports are given in the text and in the bibliography, page 114.

INTRODUCTION

Utah's ground-water law, which became effective on March 22, 1935, has its basis in certain statutes passed by the Utah Legislature during its 1935 session, with minor additions or revisions during subsequent sessions of that body. This law places in the State Engineer's office the responsibility of controlling the development of all ground water. In order to provide the fundamental ground-water data that are essential for intelligent control of this resource, the Legislature in 1935 and in each succeeding biennium has also authorized the State Engineer to enter into agreements with the Geological Survey, United States Department of the Interior, to survey the ground-water supply of the State of Utah and to investigate sources, quantity of supply, and methods for conserving such waters. The Geological Survey and the State of Utah share equally the expenses connected with these investigations.

These cooperative investigations since 1935 have included (1) determinations of the fluctuations of water levels in selected wells in most of the ground-water basins of the State, based upon measurements that are tabulated and published annually by the Geological Survey; and (2) detailed investigations of specific ground-water areas to determine the quantity and quality of the ground water, and its source, movement, and disposal, and to show the relation of present development to the maximum development of which those areas are capable. Reports covering the detailed studies that have been completed to date appear in technical publications and biennial reports of the State Engineer, in water-supply papers of the Geological Survey, or in scientific journals; they are listed in the bibliography at the end of this paper, and many are referred to in subsequent discussions of specific areas.

The 25th, 26th, and 27th Biennial Reports (1946, 1948, and 1950, respectively), have included technical publications on the ground water respectively in Tooele Valley in Tooele County; the Bountiful district of the East Shore Area, Davis County; and Escalante Valley in Beaver, Iron, and Washington Counties. These and similar reports on other areas have been prepared especially to assist the State Engineer in his control of ground-water development in those areas, in accordance with the ground-water law.

Early in 1952 the State Engineer pointed out the urgent need for a summary of the current status of ground-water development in certain designated ground-water basins in Utah. This technical publication is intended to meet that need. In some of these basins studies were made many years ago, as in Cedar City Valley and Parowan Valley, where detailed investigations were made in 1938 to 1940; for these areas the effects of natural factors and of development are summarized for subsequent years. In several other areas, studies have been completed in recent years, but the subsequent development has been great enough to warrant a supplementary statement as to the current status. In still others, where detailed studies have not been undertaken or reports have not yet been published, the current status is summarized insofar as it is known from unpublished data or from the water-level fluctuations in selected wells.

It is hoped that this technical publication will also be of value to users and applicants for use of ground water, particularly in the basins for which summaries have been prepared. Those who are interested in ground water generally have two basic questions; first, where can a well be developed to produce the quantity of water desired; and then, how can a perennial and sustained supply be assured? The statutes that compose the ground-water law are primarily concerned with this second question, and the following discussion is limited to consideration of the relation of present development to the perennial yield of the respective ground-water reservoirs, insofar as can be determined from available data.

Methods Used in Determining Status of Development

The average citizen knows little about ground water, and this is all right with him so long as everything is going along smoothly—in other words, so long as water is available to him when he wants it, and is not rising to trouble him where he doesn't want it. Ground water becomes of major concern, however, if he is a well owner and finds that the supply from his well is dwindling, or if he is a property owner and is told that he cannot develop ground water to supply his needs for industry or agriculture or other purposes on that property. Naturally he wants to know why.

Most of the ground-water basins discussed in the following pages are "problem" areas in ground-water administration. Development has progressed to the point where the State Engineer has been forced to conclude on the basis of available data that there is no more unappropriated ground water; or well owners having longstanding ground-water rights have been faced with diminishing yields or increased pumping costs to the extent that they believe additional development should be curtailed.

The following sections therefore summarize the data pertinent to the determination as to whether the basins are fully developed. At the outset it must be stated that there can be no sharp line of demarcation between full development and overdevelopment. Our present knowledge of the ground-water resources is so meager that we do not know how much water there is in any of the developed ground-water reservoirs, and for most of them we cannot estimate closely the quantity that flows into the reservoir each year. The total amount of water stored underground is not of immediate importance—we know that some wells obtain usable water from depths as great as 1,200 feet, and no one contemplates mining water to any such depth. The amount of recharge, or inflow to the ground-water reservoir, *is* important, because it sets the sustained yield and therefore forms the firm basis for water rights.

Even with complete knowledge of the ground water, the available supplies could not be distributed with the precision that is possible with surface water. All the flow of a stream can be divided according to priority of rights, and the holder of the next junior right can see clearly that the supply is exhausted, and no matter how dire his need he must do without, unless he can make arrangements with holders of superior rights, or tap some other source. As of today, even in ground-water reservoirs that are overdeveloped, the supply is not exhausted, for there is more water stored at greater depths, which may require greater pumping lifts or even deepening of some wells, but which *can* be drawn out if the need is great. We know, however, that we cannot continue forever the practice of drawing out more water than goes into the reservoir, and that eventually a balance must be achieved.

Ground-water rights could be analogous to the rights to the flow of unregulated streams, if the withdrawals were so regulated as to maintain a certain quantity in storage—that is, by prohibiting withdrawals that would cause water levels in wells to fall below a predetermined level. Such control would give well owners most water in wet years when they need it least, and perhaps none in drought years when they need it most. Fortunately, the total storage in ground-water reservoirs is great enough to make this feast-or-famine control unnecessary. Because of this ground water in reserve, a stable economy can be served by permitting the development of a sustained yield based on the long-term average inflow. If the perennial yield is calculated correctly, wells will partially deplete the storage in the reservoir during years of less-than-average inflow, but this depletion is made up in years of abundant recharge. Because of the vagaries of climate, as well as the meager hydrologic data we have to work with, the computation of this perennial yield is on a trial-and-error basis and may need considerable modification as time goes on.

In attempting to make comparisons between the present development and the development that could be sustained perennially, it is necessary to consider not only the ground water, but also the relation of ground water to surface water and to precipitation. These interrelationships of water in various phases of the hydrologic cycle are becoming more and more significant as we learn more about our water resources.

The Hydrologic Cycle

Man depends upon a multitude of "sources" — streams, reservoirs, lakes, wells, springs, infiltration galleries, cisterns, the soil—for the fresh water that he needs for his own use, for his industries, or for the plants and animals that furnish his food, shelter, and clothing. The ultimate source of practically all this water is precipitation, and the "sources" mentioned will yield a perennial supply only if they are replenished by precipitation seasonally, annually, or at less frequent intervals.

The term "hydrologic cycle" is applied to the march of events marking the progress of a particle of water from the atmosphere through various environments upon or under the earth's surface and back to the atmosphere again. We know that the paths of a particle of water in the hydrologic cycle can be quite variable. Of the water that reaches the land surface by precipitation, some may evaporate where it falls; some may infiltrate into the ground; some may run off overland to evaporate or infiltrate elsewhere or to enter streams. Of the water that infiltrates into the ground, some may subsequently be evaporated; some may be absorbed by plant roots and then transpired; some may percolate downward to ground-water reservoirs. Of the water that enters ground-water reservoirs, some may move laterally until it is close enough to the surface to be subject to evaporation or transpiration; some may reach the land surface and form springs, seeps, or lakes; some is pumped from wells; some may flow directly into streams or into the oceans. Of the water in streams, some may accumulate in lakes and surface reservoirs; some may be lost by evaporation or transpiration of vegetation, including crops that are irrigated by surface water; some may seep downward into ground-water reservoirs, and some may continue on to the oceans or to lakes in closed inland basins. The hydrologic cycle is completed by evaporation from the oceans and closed basins and circulation of water vapor in the atmosphere.

To bring this general statement down to a specific case, let us trace the movements of a hypothetical drop of water in one of Utah's drainage basins. Let it fall as a snowflake upon the high Uinta Range in northeastern Utah (Precipitation). Some of its compatriots never reach the ground but remain upon the branches of pine trees (Interception) and subsequently evaporate and return to the atmosphere (Evaporation). Our snowflake, however, becomes part of a snowbank (Snow storage) which melts in warmer weather, part of the water sinking into the ground (Infiltration) but part flowing away over the bare rock surfaces (Overland flow). Here again some of its fellows (Soil moisture) are consumed by spring flowers of the mountainside (Transpiration), but our particular drop of water percolates downward to where all pore spaces in the rock mantle are saturated (Ground water), and thence moves down slope to a spring that feeds Trial Lake (Reservoir storage) in the headwaters of the Provo River. Late in the summer it becomes part of the water released to meet irrigation needs in Heber Valley, moves down the Provo River (Stream flow), enters a large irrigation canal, and eventually is moving in a ditch between rows of vegetables whose growth consumes some of its fellows (Soil moisture). Again seeping downward to the saturated zone (Ground water), after some time our drop of water reappears at the surface in a small seep near the channel of the river in the lower part of Heber Valley. Again it enters the stream (Stream flow) and moves into Deer Creek reservoir at a season when, because of long-established rights, the natural flow of the river is permitted to pass through the reservoir; our drop continues down the river to the Telluride dam and is there diverted through flume and penstock to the Olmstead plant of the Utah Power and Light Co. where electricity is generated (Nonconsumptive use). Returned to the stream at the mouth of Provo Canyon (Stream flow) it is again diverted, this time into the Provo Bench canal for irrigation of an apple orchard near Orem, in Utah Lake Valley. Again it is part of the excess that percolates downward through the soil-moisture zone, and moves through a gravel bed (Ground water) to the toe of the Orem bench, whence it emerges in the Fugal Springs owned by the Geneva Steel Co. There it enters the circulating system of the plant, cools blast furnaces, gets steamed up, generates power, and does odd jobs (Nonconsumptive uses) until, somewhat polluted (Water quality), it passes from the main waste drain of the plant and flows into Utah Lake (Lake storage).

A large proportion of the total inflow is lost to the atmosphere from shallow Utah Lake (Evaporation), but our erstwhile snowflake remains in the lake until pumped into the Utah and Salt Lake Canal to irrigate crops in the western part of Jordan Valley. There it moves through ditches and in shallow subsurface materials, but successfully evades all plant roots and eventually joints the Jordan River (stream flow), flowing toward Great Salt Lake. Before it reaches the lake, however, it is again diverted and pumped uphill 300 feet into a canal of the Bonneville Irrigation Co. By now our onetime snowflake is carrying about 800 parts per million of dissolved solids, but it is still usable for irrigation.

Applied for irrigation of orchard land near Bountiful, our drop of water percolates downward into the shallow aquifer (Ground water) which yields water by artesian flow farther west in the vicinity of Woods Cross. Some 20 years may be required for this drop to move 2 miles to one of the artesian wells, and during this travel it crosses the Warm Springs fault and is mixed with saline waters that raise the average concentration of mineral matter to more than 1,200 parts per million. The water discharged from the flowing well is used to irrigate pasture land, and is picked up by grass roots (Consumptive use) and finally returned to the atmosphere (Transpiration).

In a distance of slightly more than 100 miles, which has required a travel time of perhaps a quarter of a century, this drop has been classed as ground water for five substantial periods and as surface water for five shorter periods. Although consumptive use has occurred but once (in the pasture near Woods Cross), this drop of water has been applied for irrigation at four other places and has also served industrial and hydroelectric plants for nonconsumptive uses.

Our hypothetical drop of water was intentionally given a long sojourn on earth before its return to the atmosphere, in order to bring out the interrelationships that are inevitable in this cyclic process. The ground-water reservoirs in Heber Valley, Utah Lake Valley, and Jordan Valley are related to some extent because of their relations to the surface water that may pass through all three valleys. The water resources all along the line may be influenced by precipitation; by the type of forest management in the headwaters; by the agricultural practices in several irrigated areas; by the storage, diversion, and use of surface water; by air temperatures (which affect the rate of snow melt as well as the rate of evaporation from free water surfaces or moist soils); by the depth to which the water sinks below the land surface (which sets its availability for use by vegetation); and by other factors.

The relations of ground water to surface water and to precipitation are important elements in the analysis of the status of ground-water development in the basins discussed subsequently.

The Importance of Geology

So long as water remains above the land surface as rain or snow, or in streams, lakes, or reservoirs, the hydrologist can give practically all his attention to the water alone. As soon as it goes underground, however, it becomes involved in pores. These pores are the openings between soil or clay particles, the spaces between sand grains or pebbles, the cracks in various solid rocks, the cavities in such rocks as limestone. Because subsurface water occupies or moves through these pores, the rocks or rock materials form the framework for the operation of the hydrologic cycle in its underground phases. In the study of subsurface water the hydrologist gets nowhere without some knowledge of the characteristics of these rock materials. The science of geology is therefore a basic tool in the study of the occurrence of water beneath the earth's surface.

A distinction is made between the water that has been pulled downward by gravity to a zone where all pores are saturated, and the water held above that zone by molecular or capillary forces. The water in the saturated zone is *ground water,* and that term does not include the soil water or other water above the zone of saturation. This distinction permits both the ground-water scientist and the soil-water scientist to limit the spheres of their activities: they are dealing with water in different phases of the hydrologic cycle and, at any instant, with "different" waters. Inasmuch as the ultimate source of ground water is precipitation upon the land surface, however, there may be close relationships in the occurrence of soil water and ground water. The characteristics of the pore space, whether in soil, clay, sand, gravel, or rock, are of vital importance in studies of ground water as well as soil water.

Some rocks are dense and massive and contain very few cracks or other openings. Other materials may be quite porous, but with spaces so small that water is held in them by molecular attraction. Still others have pores sufficiently large and interconnected that water can travel through them by gravity or hydrostatic pressure. These latter are the permeable materials that form ground-water reservoirs, or aquifers, and they are the ones that yield water to wells. The rate of yield is dependent to an important degree upon the permeability.

There is a definite pattern in the occurrence of the rocks of these various types, sometimes complex, often difficult to surmise from the land surface. But that is the geologist's job, and it is obviously an important one for those who would like to know where and how deep to drill a well. This task is much simplified if good records have been obtained from wells that have already been drilled in the vicinity. Experienced well drillers who assist their clients in selection of well sites call upon their practical geologic knowledge gained from drilling other wells.

The stratigraphy and geologic structure are also very essential in the detailed studies of ground-water basins. In the technical reports describing the occurrence of ground water in several basins in Utah, the longest chapter is ordinarily devoted to a description of the geology. In this report, however, it is felt that the geologic basis of ground-water occurrence in the basins discussed can be omitted. We are considering only the developed basins, where obviously at least some of the permeable materials must have been found in order to achieve that development. We propose therefore to accept the existence of productive aquifers as an established fact, and to go on from there.

Fluctuations of Water Levels in Wells

Fluctuations of water levels in wells are the chief elements used in the analyses of ground-water conditions in specific basins. These fluctuations may be traced to a variety of causes, some related to the storage and movement of ground water and the recharge to or discharge from the reservoir; others to changes in pressure upon confined water. The hydrologist, checking water levels in wells, might be likened to the physician with his stethoscope, checking the circulatory system of the human body.

It is important to know the reasons for the changes of water level in wells, and this is particularly true in areas where a progressive decline has been noted in all wells—that is, where the water levels in wells drop several inches, or perhaps even several feet, in each successive year. These declines, commonly heralded as "falling water tables," are understandably of great concern to the owners of wells in the affected area, because they mean increased cost of pumping, deepening of some wells, and failing supplies from others. As has been pointed out by Thomas (1951, pp. 271-272):

> Declining water levels are inevitable if water is taken from a well, and if the draft is increased the water levels will decline further, whether the increase is obtained by drawing more water from that well or by drawing from more wells. If the creation of this depression results in diversion of water from seeps or other points of natural discharge, the draft may be sustained perennially. The declines might then be viewed with pride, as evidence that the community has not left its talents buried in the ground but has put them to some use. The decline in "water table" may be as much an indication of progress as the carloadings of agricultural or industrial products shipped from the community.
>
> A declining "water table" is also characteristic of the region that has used its water resources not wisely but too well and is taking far

> more from its ground-water reservoir than is replaced naturally. In such a region the reservoir will eventually be emptied unless pumping is reduced or unless some means can be found to put more water into that reservoir than is done by nature. Superficially the records in such an area are the same as those in developed areas where the pumping does not exceed the safe yield—water levels have been lowered since the first well was constructed—and discrimination must be made on the basis of an adequate scientific study.
>
> The public should know also that man is not responsible for all the fluctuations in "water tables," for precipitation is the prime source of replenishment for all water resources, and climatic variations have a profound effect upon the position of the water table.

The description of each basin includes a discussion of the trends of water-level fluctuations in wells, and a comparison of those trends with the trends in natural replenishment and the trends in development, to the extent that records are available. The general relations are summarized briefly here.

Relation to precipitation.—In some wells the water level is known to be affected directly by precipitation to the extent that it rises in response to individual rainstorms, and the amount of rise may be proportional to the amount of rain. These wells tap unconfined water, the water table is commonly only a few feet below the land surface, and the rock materials above that level are permeable enough to permit ready percolation of water. These wells are widely distributed throughout the Nation, especially in the humid Eastern States but also in several of the Western States. Their prevalence in humid areas is understandable, because the storms that affect the water table must be more than enough to bring the soil moisture to field capacity.

In Utah we cannot offer an example of a well in which water levels respond directly to individual rainstorms. One might expect such responses in areas of shallow water table in permeable materials, particularly in the more humid parts of the State, which in Utah are the mountain areas, but there are very few wells in such areas. Most wells in Utah obtain water that is confined under artesian pressure (about 75 percent of all wells are flowing wells), and many of the wells in which water-level fluctuations are observed are likewise artesian wells, in which water has traveled underground for some distance from the place where it first entered the ground.

Nor do the water levels in Utah wells show marked fluctuations in response to seasonal precipitation. Doubtless this is partly because precipitation in most of Utah is distributed rather uniformly throughout the year, and thus contrasts with the marked seasonal pattern that is characteristic of such places as southern California.

With respect to annual precipitation, there is good correlation in nearly all of Utah's ground-water basins between precipitation trends and water-level trends. Inasmuch as precipitation is recognized as the ultimate source of ground water as well as stream flow, this correlation is to be expected under natural conditions, whether the ground water is derived by direct penetration of precipitation or by seepage from streams.

The fact that water-level trends are upward in years of abundant precipitation indicates that in those years, at least, the draft from wells is not exceeding the replenishment to the ground-water reservoir. Such an area, however, will still be overdeveloped if the *average* draft exceeds the long-term average rate of replenishment, and close analysis of records is necessary to show whether this is the case.

Relation to stream flow.—Precipitation upon Utah's agricultural valleys is generally inadequate for crops, although there are some notable exceptions where dry farming is practiced successfully. The water-defiicient areas depend upon irrigation, and the principal source of water is snow on the mountains. Much of the water from the melting snow goes down to the valleys in streams, and in many valleys these streams constitute the principal source of ground water, as well as the source of water for surface reservoirs and irrigation canals and ditches.

In many ground-water basins, the trends of water-level fluctuations in wells are found to correlate closely with the annual discharge of the principal streams that bring water from the mountains to those valleys. In the valleys where there are good records both of stream flow and of precipitation, the water-level trends may correlate more closely with the stream flow than with precipitation. The explanation for this may be that the stream flow is a direct measure of the water yielded from precipitation upon mountain areas, whereas the precipitation is generally measured in the valley area, and although it may be proportional to the mountain precipitation and runoff it is not necessarily so.

Relation to natural ground-water discharge.—A complete accounting of the water in a ground-water reservoir would show the quantity in storage on a certain date, the total recharge during a stated period, and the total discharge during that period; the balance at the end of that period would then show the change in ground-water storage. Such an account would be somewhat similar to a bank statement. Generally, however, the hydrologist must be satisfied with an accounting that is far from complete. He endeavors to select wells in which the water-level trends are representative of the trends throughout the basin, and hopes that those changes are proportional to the actual changes in ground-water storage, because in most basins he does not know the total quantity stored at any particular time, or the quantitative changes in storage in designated periods. His data on recharge are chiefly data on the sources of *possible* recharge, and they are measured in terms of inches of water at precipitation stations or second-feet of discharge at stream-gaging stations—not in acre-feet of ground-water recharge.

Another essential item in the accounting is the discharge from the ground-water reservoir. Excluding for the moment the wells that man uses to obtain water, ground water may be discharged from a reservoir in several ways: by springs, by seepage into streams or lakes, by evaporation in areas where ground water is near the land surface, and by transpiration of vegetation that sends roots down close to the water table.

There is as yet no reliable means of measuring quantitatively this natural discharge from ground-water reservoirs. However, it is evident that in areas unaffected by man's activity there is a natural balance between recharge and discharge. In years of abundant recharge, there is an increase in ground-water storage, but the higher water levels promote increased evaporation, transpiration, seepage, and spring discharge. Conversely, in years of minimum recharge, the natural discharge continues until ground-water storage is reduced, and then there is a gradual "drying up" of springs and seeps, and reduction in evapotranspiration draft.

In the absence of data, it is assumed that under natural conditions the rate of natural discharge from a ground-water reservoir fluctuates in accordance with the changing rates of recharge, doubtless with some time lag. These fluctuations would also correlate with changes in storage as depicted by water levels in selected wells.

Relation to development.—The natural cycle of ground-water recharge, movement, and discharge can be disturbed considerably by man's development of water supplies. The effects of his activities upon recharge are commonly overlooked, but they may be significant in some areas. Probably the greatest modifications in recharge in Utah have been byproducts of the diversion and use of surface water for irrigation; the modifications include both the reduction in recharge along natural channels from which the flow has been diverted, and the augmented recharge by seepage from canals or deep percolation from irrigated lands. However, the pattern of surface-water diversion and use in Utah has been stable for a long time, and there have been only minor changes in most areas in recent years.

The most conspicuous modifications of the natural cycle have been caused by draft from wells. This draft is responsible for a variety of fluctuations of water level, both in the discharging well and in nearby wells. A flowing well may lower the artesian pressure or discharge of nearby wells, even in a ground-water reservoir that is not utilized to capacity. In an area where ground water is used chiefly for irrigation, a pronounced seasonal lowering of water levels may be expected, even though the quantity pumped each year is fully replaced by recharge to the reservoir. If wells year after year draw more water from the reservoir than is replenished, the water levels in wells will show a progressive downward trend, a trend that is inevitable in overdeveloped basins. On the other hand, a progressive downward trend of water levels may occur in an area of incomplete but rapidly increasing development, because of the increasing rate of withdrawal. Thus a downward trend is not necessarily an indication of overdevelopment.

An adequate evaluation of the effect of development upon water levels requires some knowledge of the quantity of water pumped from the ground-water reservoir. Unfortunately we have only very meager data concerning the annual yield of wells in Utah. Meters have been installed on several municipal wells, some industrial wells, and on most of the wells supplying military installations, and for those wells the discharge may be recorded daily, monthly, or annually. For wells having electrically driven pumps, the power bill gives a good indication of the pumpage, provided that a few measurments are made at the well to determine the ratio of power consumption to quantity of water pumped.

For flowing wells and for wells pumped by combustion engines, the annual yield can be computed approximately, provided that the rate of discharge is measured periodically during the season of use, and a record is kept of the number of days of operation. During the years 1938, 1939, and 1940 the State Engineer, assisted by Works Project Administration crews, made such measurements and computations for wells in most of the developed ground-water basins in Utah. In order to obtain similar records each year, the services of a watermaster and several assistants would be required in each of the important ground-water basins.

In the following discussions it will be noted that the annual discharge of wells has been estimated for most basins. These estimates are based chiefly on records of power consumption in the basins in the southwestern part of the State, where most of the water withdrawn is pumped by electric motors. In one area in central Utah detailed studies have developed a rough correlation between the total flow from artesian wells and the water levels in a key observation well. In two of the areas discussed, the discharge from wells is metered. And for some areas it is necessary to make broad assumptions as to the trends in development, based partly on the applications that have been filed with the State Engineer for new wells or new uses of water.

Status of Development in Specific Basins

The water-level trends in wells in individual ground-water basins have long been of great interest to the owners of wells in those basins. Many of the basins discussed in the following pages have been called "critical areas" for many years, and for eight of them the results of a decade of observation were summarized in the State Engineer's 25th Biennial Report (Thomas, 1946a). The conclusions reached at that time are as follows:

> Research during the past ten years (1935-45) has shown that there are large natural losses of ground water from practically every one of the developed ground-water reservoirs in Utah. In individual areas these losses range from 25 to 80% of the average annual recharge to the reservoir. In many valleys the salvaging of water now lost by natural discharge would be difficult, either because of the unsuitability of the land at the locations where wells must be placed to obtain this water, or because of the increased cost of obtaining additional supplies—to the owners of new wells and of existing wells —due to lowering of artesian pressures or increased pumping lifts.
>
> The upward trend of water levels in observation wells in practically all developed ground-water reservoirs in Utah in the decade

ended in 1945 is clear indication that replenishment from recharge was more than adequate to balance discharge from wells plus natural discharge. Close spacing of wells in parts of certain basins has resulted in excessive interference and lowering of water level or artesian pressure in affected wells, but none of the large ground-water areas can yet be said to have been developed beyond its capacity, under the climatic conditions which prevailed between 1935 and 1945. Reduction of waste from existing artesian wells would not only add to the storage available for beneficial use in the ground-water reservoir but would reduce interference in nearby wells and thereby increase their pressure and rate of flow. The State Engineer's program of conservation by control of wells and prevention of waste, begun in 1935, has contributed to the general rise of water levels in wells since that year, and is doubtless primarily responsible for the increases in areas where precipitation has not been above normal.

Richardson in 1906 mentioned the drought of 1899 to 1904, and the resulting low water levels in wells in Utah County. The 1931 to 1935 drought, much fresher in the memories of residents throughout the State, is generally considered to be the worst in history, and water levels in wells are reported to have gone lower than ever before. Precipitation records suggest that the earlier drought may have been at least as serious, but it is quite likely that water levels in wells were indeed at their minimum in 1935, due to the considerable increase in number of producing wells since the earlier drought period. Future dry cycles comparable to the two already recorded in the past 50 years, may result in still lower water levels and artesian pressures, particularly in areas where additional wells are being constructed.

Throughout these discussions the well numbers indicate the location of the wells by land-office subdivision, according to a system in general use by the State Engineer throughout Utah. The State is divided into four quadrants by the Salt Lake Base and Meridian, and each of these quadrants is designated by a capital letter: A for the northeast quadrant representing all townships north and ranges east, B for the northwest quadrant, C the southwest, and D the southeast. In the well number the designation of the township is enclosed in parentheses and includes, in addition to one of these letters, a number indicating the township and a number indicating the range. The number following the parentheses designates the section, and the three lower-case letters after the section number give the location of the well within the section, quarter section, and sixteenth section (the letters a, b, c, and d representing the northeast, northwest, southwest, and southeast quarters of each subdivision). The final number designates the particular well within a 10-acre tract. Thus, well (C-34-15) 3bda-1 represents the first well listed in the NE¼SE¼NW¼ sec. 3, T. 34 S., R. 15 W.

CEDAR CITY VALLEY

Iron County

By H. E. THOMAS

A detailed investigation of the ground-water resources of Cedar City Valley was made during the years 1938 to 1940, but because of World War II the report of these studies was not published until 1946. The conclusions of this report (Thomas and Taylor, 1946, p. 2) are summarized below:

> In Cedar City Valley ground water is derived in large part from water that flows either in streams or as underflow from the canyons that drain the surrounding plateaus, hills, and mountains. Within the valley the ground water moves from the mouths of these canyons—that is, from the apexes of the alluvial fans—toward the central and lower parts of the valley, following closely the interior drainage pattern of the streams in the valleys, except that some ground water moves through the Iron Springs Gap and Twentymile Gap, which are no longer occupied by streams. A small quantity of water moves out of the valley through these gaps into Escalante Valley, but natural disposal of water in the valley is chiefly by evaporation and transpiration from areas of shallow ground water in the lower parts of the valley, particularly around Shurtz and Rush Lakes.
>
> Some of the recent displacements along faults that cross Cedar City Valley affect the circulation of ground water. Along two of these faults, perhaps along others, ground-water dams have been created, owing to the relative impermeability of materials along the line of displacement. So far as known, the faults in the area act merely as barriers to ground-water circulation; no water is believed to be derived from deep sources along these faults.
>
> The relative impermeability of some of the alluvial sediments gives rise to artesian conditions over a large part of Cedar City Valley. Water is most likely to occur under artesian pressure in the lower parts of the alluvial fans, where clay and silt are most common. Near the apexes of the fans, where gravel and coarse detritus predominate, ground water is commonly unconfined. The confining layers responsible for artesian pressure are not believed to be continuous over any considerable portion of the valley; more likely they are irregular and more or less lenticular in shape, as is common for beds of fluviatile origin. They do not form any major separation of the ground-water reservoir into shallow and deep zones, but appear to act as minor baffles to the free circulation of ground water.
>
> The ground-water reservoir in Cedar City Valley has been divided into eight districts. Four of these comprise the alluvial fan of Coal Creek; their separation is based partly on natural barriers and partly on differences in occurrence of ground water, whether artesian or unconfined. The four other districts are distinguished from each other and from those on the Coal Creek fan on the basis of source of ground water.
>
> Construction of wells in Cedar City Valley probably began soon after the arrival of settlers in 1851. Ground water was obtained first from dug wells, later from bored or jetted wells by artesian flow. By 1910 comparatively few wells had been constructed, but these were widely distributed throughout the valley. Between 1910 and 1925 there was great development of wells for artesian flow, and by 1925 a large proportion of the wells in the valley were flowing wells.
>
> Pumping from wells for irrigation was practiced very little before

1925 but began in earnest about that time. Construction of new irrigation wells was intensified particularly during the drought years of 1931 and 1934. The quantity of water pumped for irrigation increased from about 6,500 acre-feet in 1930 to 9,400 in 1938, and to more than 13,000 acre-feet in 1940. This increase was almost entirely due to increased withdrawals from the upper part of the Coal Creek fan. The present discharge from flowing wells is estimated at about 400 acre-feet a year and the discharge by natural processes at about 5,200 acre-feet a year. In the Coal Creek district, which is the principal pumping district, the pumpage from wells averaged 7,500 acre-feet a year in the 2-year period of 1938 and 1939. During that period there was a slight increase in ground-water storage although the precipitation and runoff were slightly below normal.

An accompanying map of Cedar City Valley (fig. 1) shows the boundaries of the eight ground-water districts, and the locations of the observation wells and irrigation wells in the valley.

Water-level fluctuations.—Water levels have been measured annually or oftener since 1938 in 32 selected wells in Cedar City Valley, and in some of these the records were begun as early as 1931. Figure 2 shows hydrographs of seven of these wells, of which six are on the Coal Creek alluvial fan. Characteristically the annual trends in all wells are similar, with rises in 1937, 1938, 1941, 1942, and 1949, and declines in 1939, 1940, 1943, 1950, and 1951. The amount of annual rise or fall is generally greater in wells high on an alluvial fan—as in the Coal Creek district—than in lower wells on the fan. Although the Enoch district obtains its water from a different source, the trends in water-level fluctuations are similar to those in wells in the other districts. Detailed studies have shown that other wells in the valley commonly follow the trends shown in these hydrographs.

The average annual changes in water levels in wells in three districts on the Coal Creek fan (fig. 3) are based upon the changes in 15 observation wells, the average change within each district being derived first, and then the average of the district. This graph shows that the average water level was low in 1936 and rose during the next two years, but by 1940 it had dropped to a level as low as in 1936. In 1942 the average water level was higher than at any time in the period 1936-51. Since 1942 the trend has been generally downward, except in 1949, and by the end of 1951 the average water level was the lowest of record.

Precipitation and runoff.—In the 46-year period 1906-51, inclusive, the annual precipitation at Cedar City has ranged from 6.81 inches in the water year[1] 1951 to 17.53 inches in 1925, averaging 12.55 inches. During the period 1906-32 inclusive, the precipitation was greater than this average in 19 of the 27 years, but from 1933 through 1951 the precipitation was less than normal in 14 of the 19 years. Thus, during the period for which records of streams discharge and water-level fluctuations in wells have

1. The "water year" begins on October 1 of the previous calendar year and ends on September 30 of the calendar year designated. Stream-gaging records are commonly quoted by water years, and are so quoted throughout this report. Precipitation records here are also computed by water years to afford a sound basis for correlation with stream discharge.

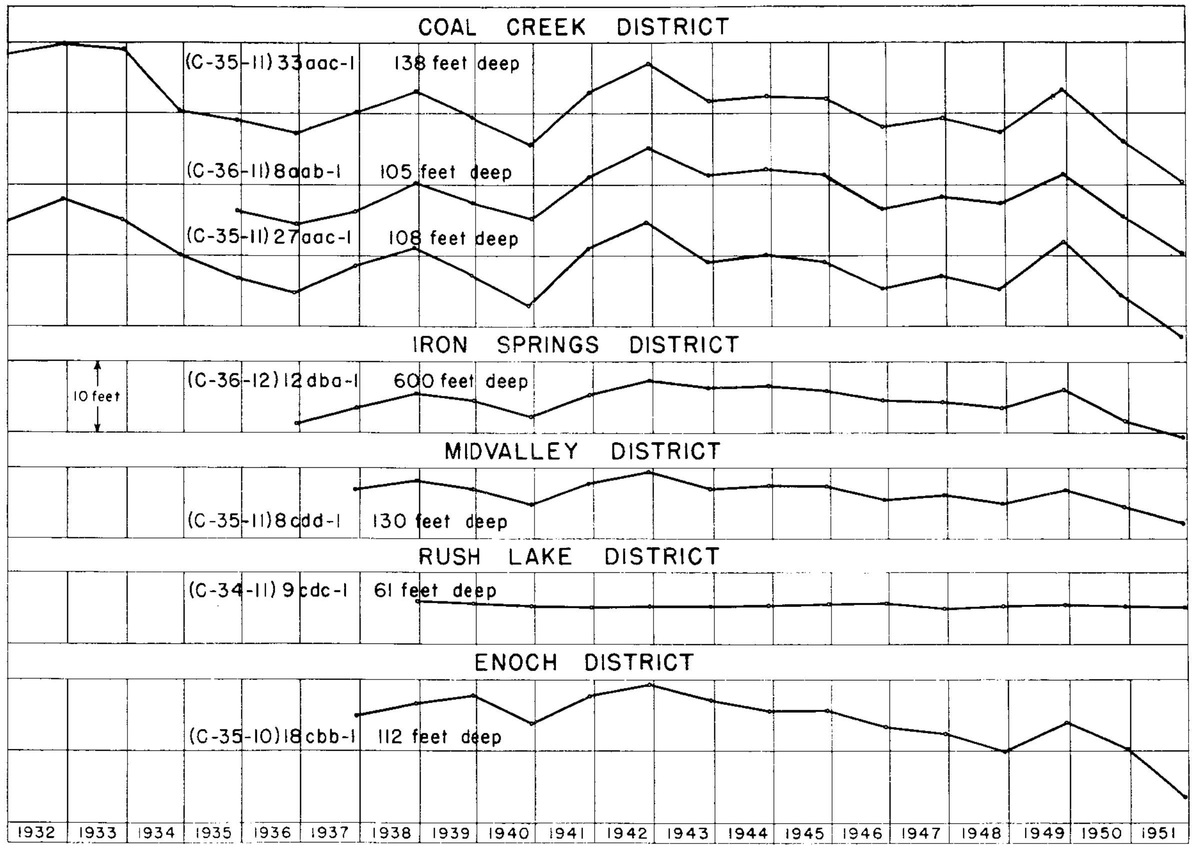

Figure 2. Annual water level trends in seven wells in Cedar City Valley.

been collected, the precipitation has been generally less than the long-term average.

Figure 3 shows the annual precipitation at Cedar City by water years since 1930 and also the cumulative departure from the long-term average. The cumulative-departure curve shows a marked deficiency in precipitation in the years 1933 to 1935, a period of severe drought in a vast area that included the entire State of Utah. The precipitation was close to normal from 1936

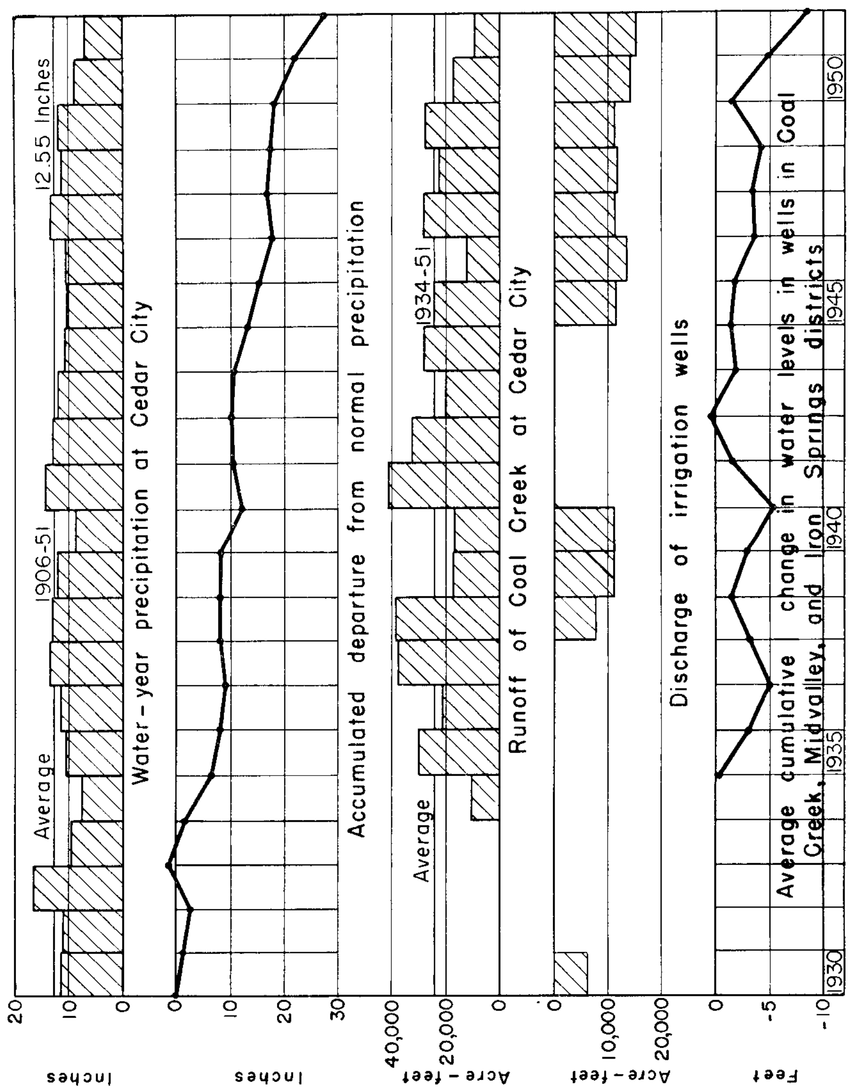

Figure 3. Hydrologic data for Cedar City Valley, 1930-51.

to 1939. The dry year 1940 was followed by the relatively wet years 1941 and 1942. In the following nine years the precipitation was well below normal in every year except 1947, and in that year it was barely above normal. This period was one of severe drought throughout the Southwestern United States, a drought that was especially pronounced in Arizona, southern California, and New Mexico. Studies summarized by the U.S. Department of the Interior (1951) indicate that this drought is one of the eight greatest droughts that have occurred in the past 600 years. Cedar City is clearly within the area affected by this drought. Because of the two intense drought periods in the past 20 years, the accumulated deficiency in precipitation since 1932 was nearly 30 inches by the end of 1951. However, at the time of writing it appears that abundant precipitation in 1952 may tend to offset this deficiency somewhat.

The graph of the annual runoff of Coal Creek, also shown on figure 3, correlates reasonably well with the graph of annual precipitation at Cedar City. The annual runoff reached a maximum of 41,000 acre-feet in 1941, which was the year of highest precipitation since stream-flow records began in 1935; the runoff was less than 10,000 acre-feet in 1934 and in 1951, the years of least precipitation in the period of stream-flow records. However, the correlation between precipitation and runoff is not perfect, particularly in such years as 1944 and 1949. In those years the water-level trends correlate more closely with runoff than with precipitation.

In the 18 years 1934 through 1951 the average annual runoff was about 24,000 acre-feet. There is evidence that this average is less than the long-term average, just as precipitation in those years was appreciably less than the long-term average. Incomplete records indicate that the runoff of Coal Creek averaged about 40,000 acre-feet annually between 1916 and 1926, the maximum being about 74,000 acre-feet in 1923. The runoff of 23,000 acre-feet in 1919 was the least recorded in any of these early years, but was almost as great as the average for the period 1934-51.

Since 1942 the runoff of Coal Creek has been below the 18-year average in all years except 1944, 1947, and 1949. Thus the deficient precipitation during the Southwest drought is reflected in subnormal stream flow. As already mentioned, the water levels in wells have trended generally downward since 1942, and this decline in ground-water storage is undoubtedly caused at least in part by drought.

Ground-water development.—In 1940 there were 350 known wells in Cedar City Valley, of which 125 were not used (Thomas and Taylor, 1946, pp. 114-134). Of these wells, 93 were used principally for stock watering and 63 for domestic purposes; the aggregate discharge from these 156 wells, including 45 wells that flowed by artesian pressure, constituted a very small proportion of the total draft upon the ground-water reservoir.

Nearly all the water drawn from wells in the valley is used for irrigation. In 1940, 68 irrigation wells were listed, of which 57 were equipped with electrically driven turbine pumps, 2 had turbines driven by combustion engines, and the others flowed. About 13,000 acre-feet of water was withdrawn from the 59 pumped wells in 1940, as shown by measurement and computations by the State Engineer's office. This was somewhat more than was pumped from 60 wells in 1939, and probably about 50 percent more than had been pumped in any previous year.

In 1951 there were 66 pumped irrigation wells in operation in the four main pumping districts of Cedar City Valley. Data concerning these wells are presented in table 1. The yearly pumpage from each well was computed from the metered power consumption and the average pumping lift. The average pumping lift was based on two or three measurements during the irrigation season, or, if the lift could not be measured, on estimates based on the performance of nearby wells. The electric energy required to lift an acre-foot of water 1 foot was determined in 43 wells distributed throughout southwestern Utah; the energy requirement ranged from 1.67 to 2.23 kilowatt-hours, depending chiefly upon the efficiency of the pump and motor. The average power consumption in the 43 wells was 1.94 kwh per foot acre-foot. By integration, the total pumpage for irrigation in the four main pumping districts of the valley during 1951 was computed to be about 18,200 acre-feet.

The pumpage during the years 1945 through 1950 was estimated in similar fashion, by computing for each well from the records of power consumption the number of acre-feet lifted 1 foot, and estimating the average lift on the basis of water-level fluctuations in observation wells. No estimates can be made for the years 1941-44, because records of power consumption are not available.

The quantity of water pumped from wells in Cedar City Valley varies considerably from year to year. This is especially true in the Coal Creek district, where 38 wells pump about two-thirds of the valley's total in most years, and where many landowners use wells to supplement surface supplies diverted from Coal Creek. In years of abundant stream flow, some wells may not be operated and others may be pumped for only a short season. None of the stream flow escapes from the valley, and it is practically all used for irrigation except during the relatively short periods when the stream discharge exceeds the combined capacity of the several diversion canals.

The total quantity of water that has been available for irrigation on the Coal Creek fan during years of record is shown on figure 4; these quantities include the pumpage from irrigation wells and the runoff of Coal Creek during the months April through September. It is evident from this graph that pumping tends to smooth out the great variations in the supply produced by Coal Creek. In the dry year 1951, wells provided more than 70 per-

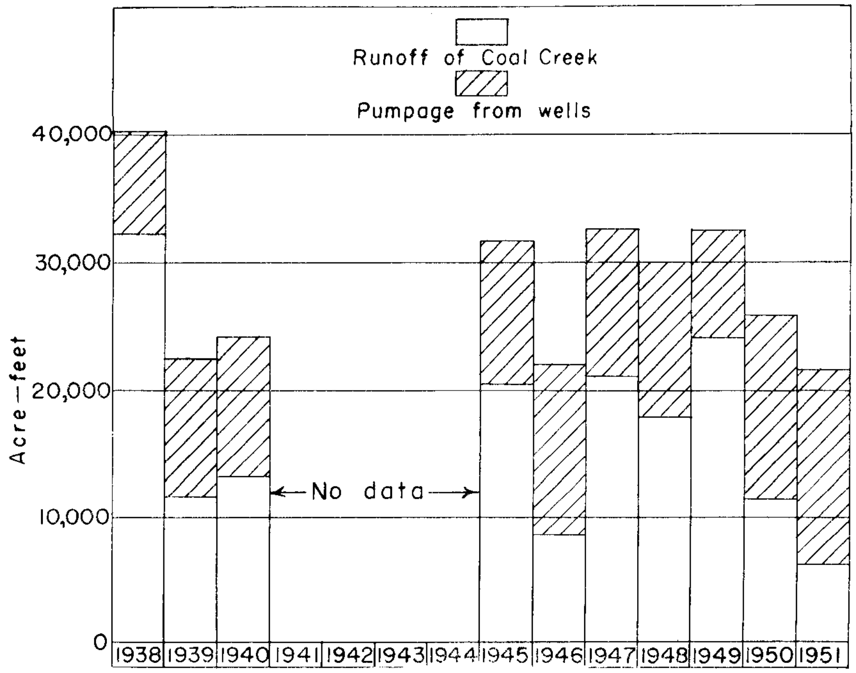

Figure 4. Total water available for irrigation on the Coal Creek alluvial fan, 1938-40 and 1945-51.

cent of the total supply for irrigation, whereas in the wet year 1938 less than 20 percent of the water available to the valley came from wells. Ground water supplements the stream flow imperfectly, however, partly because some surface-water users have no ground-water rights and cannot pump from wells, even though their needs are great; and partly because many well owners have no surface-water rights and must pump all their water from wells. The annual totals in figure 4 do not give a true picture of irrigation use of Coal Creek in wet years, because the unregulated peak flows make available more water than the irrigators can use effectively.

The "closed area."—At the time the ground-water law was passed in 1935, the ground water in Cedar City Valley was believed to be entirely appropriated, and the State Engineer did not approve applications for drilling additional irrigation wells, pending investigation. After the completion of detailed studies in 1940, applications were approved for new irrigation wells in the Enoch district until 1942, and as a result, the number of irrigation wells in that district increased from 7 in 1940 to 14 in recent years. The Kanarraville, Hamilton's Fort, Queatchupah, and Rush Lake districts have been open to applications for additional wells since 1940, and a few irrigation wells have been drilled in recent years; in large parts of these districts, however, geologic conditions do not appear to be favorable for wells of high yield. The Rush Lake district occupies the lowest part of the Coal Creek alluvial fan, but the other districts obtain ground water from other sources tributary to Cedar City Valley.

On the basis of available data, the State Engineer has concluded that all ground water is appropriated in a designated area that includes the central part of Cedar City Valley, and this area has been closed to additional development of ground water, except for domestic and stock wells. The "closed area," shown by shading on figure 1, includes the area of intensive pumping for irrigation on the Coal Creek alluvial fan in the Coal Creek, Iron Springs, and Midvalley ground-water districts, plus the southern part of the Enoch district. No applications for new irrigation rights in the closed area have been approved since 1936, except for those mentioned in the Enoch district.

Within this closed area the pumpage for irrigation was considerably greater in 1950 and 1951 than in earlier years, even though new developments have not been permitted for a decade or more. In part this increased pumping is explained by the greater length of pumping season in drought years, necessitated by less-than-normal stream supplies and precipitation throughout the growing season.

In several wells the rate of discharge has been increased considerably as a result of rehabilitation, either by redrilling or deepening the well or by installation of more efficient pumping equipment. These replacements are authorized by the State Engineer when the yield of a well becomes appreciably less than the established water right, and if they were undertaken at a uniform rate one might expect no over-all increase in valley-wide pumpage. But the wells now in operation were not drilled at a uniform rate —most of them were drilled during the 5 years immediately preceding passage of the ground-water law. Since World War II the drought has pointed up the need for replacements of several of these wells, and high farm prices have provided the wherewithal. As a result there have been numerous replacements in recent years, and the aggregate rate of yield of irrigation wells in the closed area is probably greater than at any time since the passage of the ground-water law.

The number of irrigation wells operating in the closed area has also increased since 1940. In the Enoch district this increase represents approved new development. Elsewhere it represents operation of wells under rights that were established prior to 1935, although no water was pumped under those rights in 1940.

The water account.—It is unfortunate that the public generally regards surface water and ground water as separate and distinct resources, evidencing and emphasizing such separation in the passage of laws, the development and administration of water rights, and the organizations of water users. The misfortune lies in the fact that in so many places the natural hydrologic cycle admits no such distinction.

In Cedar City Valley, and particularly on the Coal Creek alluvial fan where 70 percent of the irrigation wells are located, the close relation of the surface-water and ground-water resources is especially apparent. It is now recognized that both have a common source in the water that flows down Coal Creek canyon; and by using several of the wells to supplement stream supplies the water users themselves have necessitated a comprehensive analysis of all water resources, rather than one limited to ground water alone.

No doubt the ground water could be developed for sustained yield as a separate resource. There are enough data to give a rough approximation of the "safe" yield of the reservoir, and in future years this approximation could be refined as necessary. If each well owner were allotted a constant annual withdrawal according to his rights, the ground-water reservoir would be partially depleted during dry years but would be replenished in years of greater-than-average recharge. The ground-water reservoir has hold-over storage facilities to give well owners a stable supply through wet years and dry.

But such development would ignore the needs of surface-water users, many of whom have established ground-water rights also. They have no hold-over storage facilities from year to year, nor even storage from June to August, and no suitable sites for development of surface storage. Instead they have the flow of an unregulated stream, which in an average year yields more than twice the quantity that is pumped from wells, but in a dry year may be far less than the estimated "safe" yield of the ground-water reservoir.

The following paragraphs are therefore devoted to a discussion of the development and use of all water in the critical part of Cedar City Valley, which is the "closed area." It is necessary to omit the Enoch district, which is replenished from separate underground sources, because there is insufficient information as to the amount of replenishment there. The discussion is therefore limited to the part of the closed area on the Coal Creek fan—in the Coal Creek, Iron Springs, and Midvalley ground-water districts.

In this area we know that diversions from Coal Creek furnish most of the water used for irrigation in an average year, but that the quantity available varies greatly from month to month in each irrigation season (for example, from 21,000 acre-feet in May to 900 acre-feet in September in 1941), and also from year to year (from 450 acre-feet in September, 1936 to 1,200 acre-feet in September, 1937). We also know that there are variations over longer periods, corresponding to those in precipitation, because there have been droughts of several years' duration, as well as relatively wet periods which occurred too long ago for most people to remember.

We know also that wells constitute the only source of irrigation water on many ranches, and that they are supplemental to surface water on other tracts. In years when the runoff of Coal

Creek was near average, as in 1947 and 1949, the irrigation wells on the Coal Creek fan pumped about 11,000 acre-feet of water; but in the wet year 1938 the pumpage was only 8,000 acre-feet, and in the dry year 1951 it increased to more than 15,000 acre-feet.

Detailed studies have shown that Coal Creek is the principal agent for recharge of the ground-water reservoir of the Coal Creek fan, and that the recharge occurs chiefly during the period of runoff from melting snow, in April, May, and June. Thus the April to September runoff of Coal Creek is not only a measure of the quantity available for diversion and irrigation, but also a measure of the quantity available for ground-water recharge. The pumpage from irrigation wells is a measure of the ground-water discharge for beneficial use, because the domestic, stock, and industrial uses are very small in comparison.

The difference between these quantities indicates the spread between *potential* ground-water recharge and actual ground-water discharge. The annual change in ground-water storage, as shown by water-level trends in wells, is a measure of the difference between *actual* ground-water recharge and discharge. There is some correlation between these annual water-level changes and the Coal Creek runoff minus pumpage, as shown graphically in figure 5.

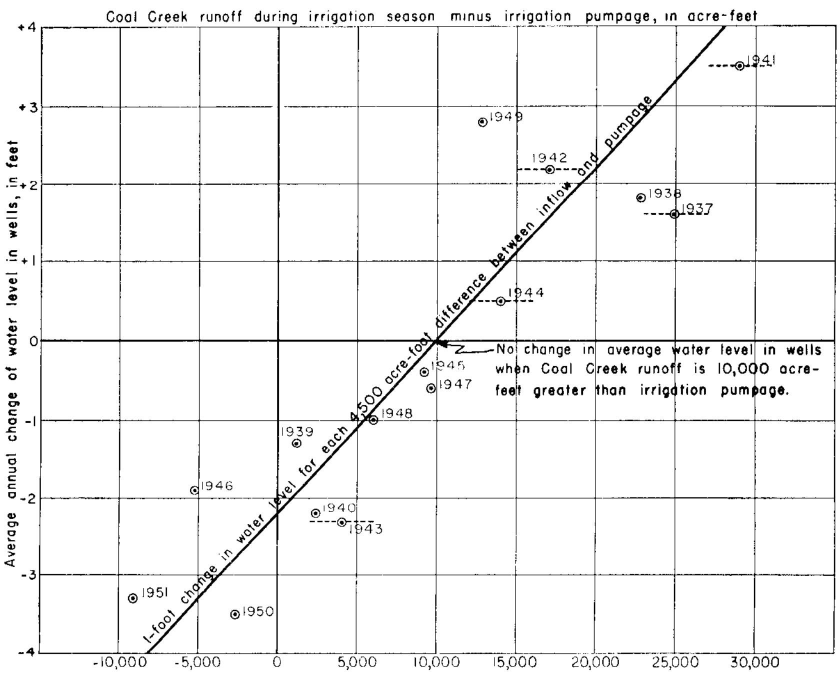

Figure 5. Recharge-discharge relation to annual changes of water level in wells in the closed area.

On this graph the points represent years for which pumpage has been computed. For the years 1937 and 1941-44 the changes in water level are known but the pumpage is not; for these years a line having a 4,000 acre-foot spread is centered at our best guess as to pumpage. The dispersion of points is to be expected because the inflow data pertain to potential rather than actual recharge. The proportion of water that actually reaches the ground-water reservoir depends in part upon the rate of stream flow and upon the areas and quantities used for irrigation by surface water. Particularly in periods of high discharge some water may continue down the channel beyond the recharge area; in periods of low flow the natural channels or ditches may be silted enough to inhibit recharge.

The straight line indicates a relationship that will doubtless be refined considerably as data become available for a greater number of years. Current data suggest that the irrigation-season flow of Coal Creek must total 10,000 acre-feet in order to prevent depletion of ground-water storage, allowing no pumping from wells. Thus in 1946 and 1951, when the runoff was less than this quantity, the water levels in wells would have declined even if pumping had been prohibited. This 10,000-acre-foot flow is a minimum requirement for maintaining equilibrium conditions in the reservoir with no beneficial use. It represents the consumptive use of water by crops irrigated from the streams; the evaporation from ditches, transpiration by bordering willows or native vegetation, and other water that does not reach the ground-water reservoir; and the recharge necessary to balance the natural discharge and movement of ground water from the closed area.

If there is pumping from wells, the irrigation-season flow of Coal Creek must be increased by an amount equivalent to that pumpage in order to hold ground-water storage at equilibrium. Thus in the growing season of 1951, when more than 15,000 acre-feet was pumped, the flow of Coal Creek would have needed to be more than 25,000 acre-feet to balance this rate of withdrawal. Again, this is a tentative relationship based on meager data.

The slope of the line indicates that the average water levels in wells will rise 1 foot if the potential recharge is about 4,500 acre-feet greater than the seasonal pumpage, and will drop at the same rate when the seasonal pumpage exceeds the irrigation-season flow of Coal Creek by that amount. If this straight-line relation holds throughout all ranges, the recharge during a very wet year such as 1922 would be enough to raise the average water levels in the closed area by more than 10 feet. On the other hand, had pumpage since 1945 been at the rate that prevailed in 1951, the average water levels throughout the closed area would have been about 4 feet lower than the actual 1951 levels.

Reference to figure 4 indicates that the closed area has a minimum irrigation requirement of about 22,000 acre-feet of water from both surface and ground sources. In 1946 and 1951 this was all it received and it used only slightly more in 1939, 1940, 1950, and probably 1943. From present data it would appear that the water resources of the area are adequate for sustained and perennial irrigation of the area irrigated in those years.

In several other years, of which 1945, 1947, 1948, and 1949 are typical, the total water available for irrigation was of the order of 30,000 to 35,000 acre-feet. It is not known at this time whether the water resources are adequate to sustain an economy requiring this quantity every year, because the available records cover only a period when precipitation was less than the long-term average, and part of which was an outstanding drought.

In three years (1938, 1939, and 1941) the total available supplies during the irrigation season probably exceeded 40,000 acre-feet, of which some doubtless had a low order of use during the period of peak stream discharge. Surface-water rights permit a greater total acreage to be irrigated during those years, at least during the period of flood runoff. The record suggests that this irrigation of additional acreage during wet years is beneficial, or at least not detrimental, to the water resources. As shown in figure 3, the average water level in wells rose appreciably in each of those years, and it is likely that irrigation by flood water served, as does water spreading, to augment the natural recharge.

Perhaps the greatest danger of overdevelopment lies in the urge to "cover in" these intermittently irrigated areas, and give them a perennial water supply by drilling more wells. And the time of greatest danger is not during a series of dry years, but during a wet period when the depleted ground-water reservoir is being replenished. At such times the rise of water levels is likely to be taken as evidence that there is "unappropriated water," and inevitably the State Engineer will be urged to relax his rigid restrictions on new development.

Residents of the closed area may wonder why they should not be permitted to drill new wells to obtain the ground water that is now moving northward into the Rush Lake district, and why that district is left open to new development of water that is known to have passed through the closed area. The answer to this is largely economic and involves consideration of the quantity of water moving into the Rush Lake district as well as the over-all cost of obtaining it within the closed area. The quantity is of the order of 1,000 to 1,500 acre-feet a year, which is enough for perhaps three to five irrigation wells. But in order to prevent the movement of this water into the Rush Lake district it would be necessary to eliminate the present northward gradient of the piezometric surface. Inasmuch as this surface is more than 50 feet higher at most of the existing irrigation wells than it is at the north boundary of the closed area, it would mean that pumping lifts at all wells would have to be increased by at least 50 feet. Thus, the end product for the owners of existing wells would be greater cost of pumping without any increase in water supply for them, although there would be some increase in total yield of the reservoir within the closed area.

Of course, during the process of reducing storage sufficiently to prevent any flow out of the closed area, large quantities of water would be mined. In this type of overdevelopment each well owner must bear increased costs for power, and commonly also for well deepening and pumps capable of greater lift, but he may have the compensating advantage of more water than would be his share of the "safe" yield of the reservoir. He should know that this is a temporary advantage, and that some day the total withdrawal must drop to the quantity of recharge, and from then on all present well owners would have to lift their water considerably more than is necessary to get the same quantity today.

As to the Rush Lake district, there is no question that the water is there at relatively shallow depths, and also it is not put to beneficial use but is wasting by natural discharge. However, in most places the conditions are not favorable for development of large irrigation wells; these conditions may explain the dearth of applications for new development.

PAROWAN VALLEY

Iron County

By W. B. Nelson and H. E. Thomas

A detailed investigation of the ground-water resources in Parowan Valley was contemporaneous with that in Cedar City Valley, and the findings are summarized in the same report (Thomas and Taylor, 1946, pp. 2-3):

> The occurrence of ground water in Parowan Valley is analogous in most respects to that in Cedar City Valley. The tributary streams and canyons that drain the surrounding highlands constitute the principal sources of ground water, and it moves generally from the mouths of these canyons toward the lowest parts of the valley. The two independent topographic basins within the valley are presumably occupied by ground-water basins separated by a divide along the Summit Creek alluvial fan. Ground water north of this divide moves toward Little Salt Lake, and a very small quantity may leave the valley through Parowan Gap. Natural discharge of ground water from this northern and more important basin is almost entirely by evaporation and transpiration from the lowest parts of the area, and by discharge from numerous springs. Little is known concerning ground water in the small basin (Winn basin) at the south end of Parowan Valley, but it is presumed that movement is generally westward and that there is discharge by underflow through Winn Gap and through the unconsolidated materials at the south end of the valley into the Enoch district of Cedar City Valley.
>
> Displacement along some of the faults that cross Parowan Valley has been so recent that scarps have been formed in the alluvium. Along at least two of these faults ground-water dams have been created, which have locally given rise to numerous springs. As in Cedar City Valley, these faults act only as barriers to circulation of ground water through the alluvial aquifers, and not as conduits for water from sources beneath the valley fill.

Ground water is obtained under artesian pressure throughout the greater part of the area of ground-water development, and about three-fourths of the wells in the valley flow during at least a part of each year. The area of artesian flow occupies the lowest part of the valley, including Little Salt Lake and a considerable area to the east and northeast. Presumably ground water is not confined under artesian conditions near the apexes of the several alluvial fans, where gravel and coarse detritus must be the dominant constituents. The great majority of wells in the valley, however, have been constructed on the middle and lower portions of the fans, where water is generally confined to some extent. According to observations in wells whose depths are known, the water in deeper aquifers commonly has a greater artesian pressure than that in shallower strata. The extent of the separation between aquifers could not be determined because of the common practice of perforating the casings of the deepest wells opposite both deep and shallow aquifers. It is presumed that the confining layers are generally lenticular and not of large extent, analogous to those in Cedar City Valley, and that the deeper and shallower aquifers are therefore more or less interconnected.

The amount of ground-water storage in Parowan Valley, as indicated by reports of well owners, was probably greatest at some time during the decade 1915 to 1925, and was perhaps at a minimum during 1936, owing to the deficient recharge available during the years that culminated in the drought of 1934. Generally throughout Parowan Valley the changes in ground-water storage from year to year are not at all commensurate with the wide variations in precipitation and presumably in runoff and available recharge. Fluctuations in natural discharge, as well as in discharge from flowing wells in response to the changes in recharge, are considered to be chiefly responsible for bringing the storage of ground water to a more or less comparable level each year. Withdrawals for irrigation of course cause considerable seasonal depletion in storage, but the recharge during the year has generally been sufficient to offset this loss. The considerable decline of water levels over a term of years in part of the Little Salt Lake district is exceptional for Parowan Valley, and is attributed to withdrawal of water in quantities greater than could move into the area across a barrier created by faulting. Since 1936 water levels and artesian pressures have risen somewhat each year in most wells throughout Parowan Valley, owing chiefly to increases in storage as well as pressure effects created by closing wells when not in use, in accordance with the State Engineer's program of conservation.

Ground-water development in Parowan Valley began about as early as in Cedar City Valley, but proceeded at a somewhat faster pace so that by 1910 there were more than a hundred wells in the valley. About three-quarters of the existing wells were constructed prior to 1920 and very few have been drilled since 1930. Pumping for irrigation also began early in Parowan Valley, and in 1930 the quantity pumped was about as great as that pumped in recent years—about 6,000 acre-feet.

During each of the years 1937 to 1939 the precipitation at Parowan was approximately normal, and it is presumed that runoff and recharge likewise were fairly constant. During those years the discharge from wells is estimated to have been 7,000 to 8,000 acre-feet annually, of which perhaps 1,500 acre-feet was wasted. The discharge from the valley by natural processes was of the order of 15,700 acre-feet annually, of which perhaps 5,000 acre-feet was discharged by underflow into Cedar City Valley. From these estimates it is evident that the water utilized from wells in Parowan Valley is only a minor proportion of the total ground water available, and that therefore there are excellent possibilities for further development. In this respect the conditions in Parowan Valley are in contrast to those in Cedar City Valley, where most of the ground water available in a normal year is already being utilized.

The several ground-water districts in Parowan Valley are outlined on figure 6. Since 1936 the State Engineer has not approved the development of additional ground-water rights within an area, also shown on this map, that includes the heavily pumped part of the district. However, several irrigation wells have been drilled since 1940 in other parts of the valley. The locations of the irrigation wells drilled prior to 1940, and those drilled since that year, are also shown on figure 6.

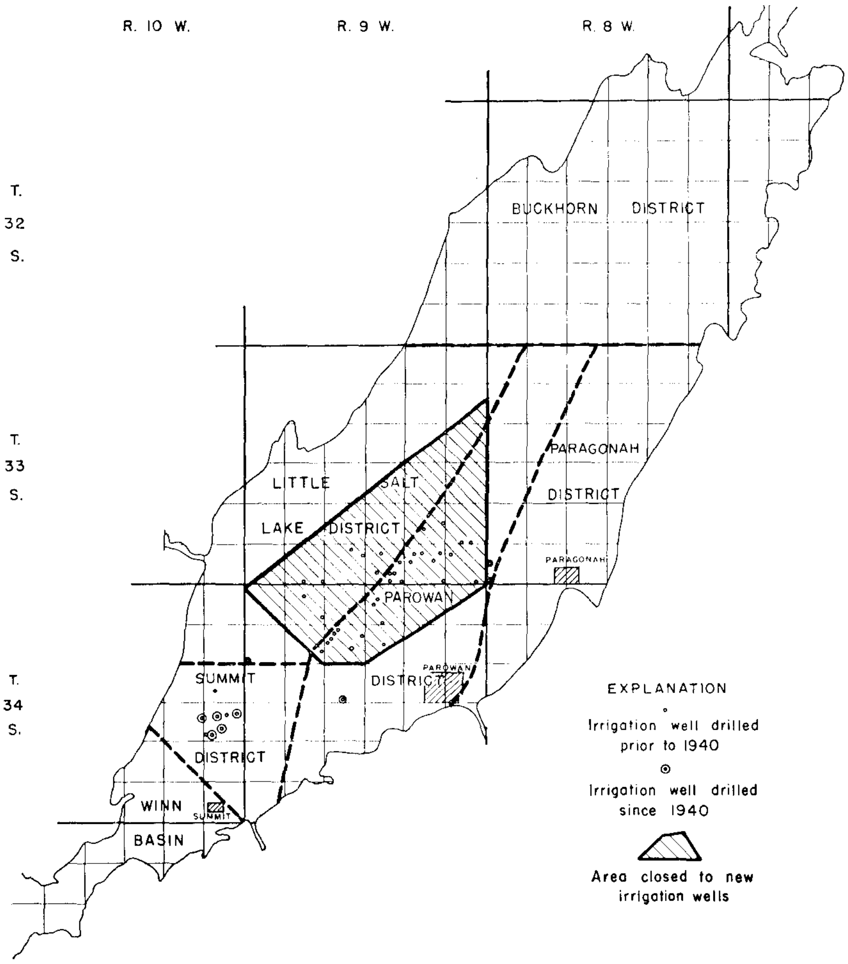

Figure 6. Map of Parowan Valley showing ground-water districts and locations of irrigation wells.

Precipitation and runoff.—Parowan is 19 miles by highway from Cedar City. One might think that in such a short distance he could estimate the precipitation and runoff in Parowan Valley merely by analogy with Cedar City Valley, and he might feel impelled to do this because of the gaps in the precipitation record at Parowan, and because of the shortness of the record of runoff of Parowan (Center) Creek, which is the largest stream and the only gaged stream entering Parowan Valley.

The available records, however, indicate that hydrologic con-

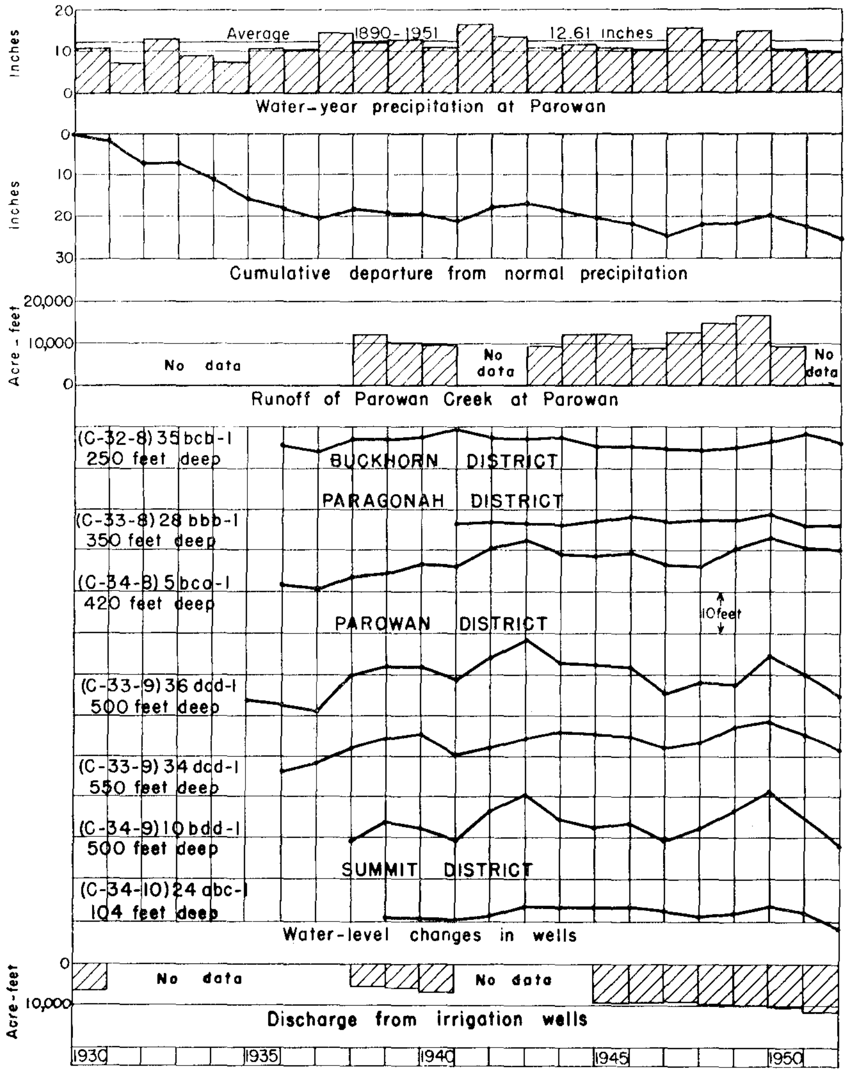

Figure 7. Hydrologic data for Parowan Valley, 1930-51.

ditions in the two valleys are not alike. During the water years 1943 through 1951, when Cedar City was getting less than normal precipitation in every year except 1947 (and just about normal that year), the precipitation at Parowan was normal in 1948, and well above normal in 1947 and 1949. The runoff of Parowan Creek was greater in 1949 than in any other of 11 years of record, and it was almost as great in 1948. If these precipitation and runoff records are representative of Parowan Valley, the drought of the 1940's was less severe and shorter there than in Cedar City Valley (see page 136) and areas farther south.

Water-level fluctuations.—Hydrographs for seven wells in Parowan Valley, based on measurements of water level or artesian pressure toward the end of the winter recovery period, are presented in figure 7, together with graphs showing annual precipitation, runoff, and irrigation pumpage. The hydrographs for most wells correlate fairly well with the graphs of precipitation and runoff. Precipitation was generally below normal during the drought years 1930-36, and when measurements of water level were begun in 1935 those levels were doubtless lower than they had been for at least a good many years. The rising trend in water levels from 1936 to 1942 reflects the general increase in precipitation in those years; in most wells, however, the water-level trend was downward during the dry year 1940. The water levels in most wells reached a maximum in 1942, after the year of greatest precipitation since 1906, and then trended downward until 1947, during four years when the precipitation was probably below normal. The general rise of water level in 1947-49 is correlated with the increased precipitation in that period, and the subsequent downward trend reflects less-than-normal precipitation.

Comparison of these hydrographs with those for wells in Cedar City Valley (fig. 2) shows a general similarity of fluctuations in the two valleys. However, there was a more marked trend in Cedar City Valley during the dry years 1939-40, and relatively little recovery during 1947-49. In Cedar City Valley the water levels in wells were generally lower at the end of 1951 than they had been at the end of the 1930-36 drought. In Parowan Valley this was not the case, except in wells that have been affected by pumping from recently drilled irrigation wells.

Ground-water development.—In 1940 there were 395 known wells in Parowan Valley, of which about 300 flowed by artesian pressure during at least part of the year (Thomas and Taylor, 1946, pp. 176- 198). Thirty wells were pumped for irrigation during 1940, discharging a total of 6,400 acre-feet. This development had been comparatively stable for several years, for 6,150 acre-feet had been pumped from 28 wells during the irrigation season of 1930.

Fifty wells were pumped for irrigation in Parowan Valley during 1951. Data concerning these wells and their discharge are assembled in table 2. The annual discharge from each well is estimated, as for Cedar Valley (p. 137), on the basis of energy consumption and estimated average pumping lift. The total pumpage from wells during 1951 was computed to be 11,500 acre-feet, which is an 80 percent increase over the computed pumpage of 1940. Although the quantity pumped from wells in Parowan Valley is less than that in Cedar City Valley, the *increase* in pumpage since 1940 has been far greater in Parowan Valley, both in acre-feet and in percentage. It is likely that this higher rate of pumping will be maintained year after year, because practically all well owners in Parowan Valley, unlike many of those in Cedar City Valley, are dependent entirely upon wells for irrigation and do not have access to stream supplies even in wet years.

Effects of development.—It is estimated that in 1940 less than half the water that entered the ground-water reservoir in Parowan Valley was used beneficially (Thomas and Taylor, 1946) p. 198). Specifically, the estimates showed 6,400 acre-feet pumped from wells for irrigation, about 700 acre-feet derived from flowing wells for irrigation, a small quantity withdrawn from flowing wells for beneficial purposes other than irrigation, and about 1,400 acre-feet wasting from flowing wells; the total discharge from all wells was about 8,500 acre-feet. The ground-water discharge by springs, and by evaporation and transpiration, was estimated to have been about 10,700 acre-feet. The total ground-water discharge within Parowan Valley in 1940 was therefore of the order of 19,000 acre-feet. The water levels and artesian pressures declined somewhat during 1940, indicating that the recharge during that dry year was somewhat less than this quantity.

In 1951 the pumpage from irrigation wells totaled 11,500 acre-feet, and it is likely that the total discharge from all wells that year exceeded 13,000 acre-feet. The natural discharge by evapotranspiration is unknown, but the total discharge from the ground-water reservoir was obviously greater than the recharge in that dry year, for water levels declined markedly.

Another good year for analysis is 1948, when precipitation at Parowan was approximately normal, and the water levels in representative wells were generally higher at the end of the year than at the beginning. In 1948 about 9,500 acre-feet was pumped from wells, representing an increase of 3,100 acre-feet over the pumpage of 1940. This increased discharge was not obtained from ground-water storage, but it may have been accompanied by a reduction in other forms of ground-water discharge, including the natural discharge by evaporation, transpiration, springs, and the discharge from flowing wells. Pumping is known to stop the flow of many artesian wells during the summer, including some that may be several miles from the pumped wells. Many other flowing wells, particularly in the northern part of the valley, have not been visibly affected by the pumping.

The pumpage in 1951 is believed to be less than the replenishment to the ground-water reservoir in a normal year. Some water is still lost by natural discharge, which could be recovered by pumping and put to beneficial use. However, this pumping would reduce not only the nonbeneficial losses by evapotranspiration, but also the artesian pressures and therefore the flow from artesian wells and springs, some of which serve beneficial purposes.

BERYL-ENTERPRISE DISTRICT OF ESCALANTE VALLEY
Iron and Washington Counties

By

B. E. Lofgren

The Beryl-Enterprise district has grown since 1945 from an area of virtual wasteland to one having the largest area irrigated by wells in the State. All of Escalante Valley in Iron and Washington Counties, together with its tributary drainage basin, was closed to further appropriation of water (except for domestic and stock-watering purposes) by proclamation of the Governor in April, 1946 (Tracy, 1950, p. 22). However the drilling of wells under applications prior to that date has continued to the present, and there are still other approved applications for irrigation wells not yet drilled. In 1951, 165 irrigation wells were in operation in the district, compared with 163 in 1950, and only 37 in 1945.

A progress report of ground-water investigations in the Beryl-Enterprise district was published in 1950 (Fix, Nelson, Lofgren, and Butler, pp. 146-180). The conclusions of this report are summarized below:

> Available hydrologic data show that water is contributed to the ground-water reservoir of the Beryl-Enterprise district both by precipitation and irrigation within the district and by surface or subsurface inflow from the tributary drainage basin. The possible sources of ground-water recharge are distributed widely but irregularly around the margins of the valley and over the valley floor. So numerous are these possible sources, and so variable are the effects of climate and permeability upon the amount of recharge, that a quantitative determination of the total recharge in any period would require an immense amount of field study.
>
> Most of the water that is discharged from the ground-water reservoir in the Beryl-Enterprise district is pumped from wells. The total discharge by natural means probably does not exceed 10,000 acre-feet a year, whereas the pumpage from wells has been greater than that amount in each year since 1945 and is estimated to have exceeded 50,000 acre-feet in 1950. The individual irrigation wells of the district yield water at rates ranging from 400 to 2,500 gallons per minute, but most wells discharge 900 to 1,200 gallons per minute.
>
> The net quantity of water withdrawn—that is, the total pumpage less the amount returned by seepage from reservoirs, ditches, and irrigated lands—in the district so far is believed to have been withdrawn essentially from storage. In other words, it has been mined from the ground-water reservoir. Pumping has changed the form of the water table considerably as much as 2 miles from the pumping area, but at greater distances the position of the water table changed very little during the past decade.
>
> The current investigation has shown that the storage in the ground-water reservoir is being depleted, and that the rate of depletion is practically equivalent to the pumpage minus return seepage from the irrigation operations. Concurrently, there is a considerable loss of ground water by evaporation, and the rate of this natural discharge probably has not been appreciably diminished from the rate that obtained prior to the drilling of wells. Thus, although the current pumpage is far in excess of the natural replenishment to the reservoir, a quantity equivalent to that natural replenishment is lost without serving any beneficial purpose.

Since the completion of that progress report records have been obtained for one more year, 1951. These records do not necessitate any significant modifications of the statements made in the progress report, nor do they furnish a basis for solution of any of the problems discussed therein. In fact, this last year of records may be summarized as more of the same sort of thing that went on during 1950 and to a lesser extent in earlier years. This raises a dilemma in this paper, for it seems wasteful to repeat here any substantial part of the progress report, but on the other hand it is recognized that some readers may not have access to that earlier report. The solution has been one of compromise: the present report includes only discussions and illustrations of items in which there were significant additional changes during 1951.

Ground-water development.—Table 3 lists the number of irrigation wells, irrigated acreage, and estimated annual pumpage in the Beryl-Enterprise district in years for which some data are available since 1937. (See also figure 8.) This table shows the rapid rate of ground-water development during the past few years. Since 1945 there has been a notable increase in yield of individual wells drilled, so that in 1951 about 35 percent more water was produced per well than in 1946, and about twice as much as in 1945. About the same number of wells were pumped in 1951 as in 1950, even though 10 irrigation wells not used in 1950 were pumped in 1951. This is accounted for by the fact that farming in the district is not the easiest way to earn a living, and several properties are vacated in practically every year. About 30 wells equipped for irrigation were idle during 1951.

Practically all the water drawn from the underground reservoir in the valley is used for irrigation, although the domestic and stock watering demands of the farms in the valley are also supplied entirely from this source. Most of the wells are equipped with electric motors which not only provide a relatively cheap, reliable source of power but also permit a close estimate of the amount of water pumped by each year. Of the 165 irrigation wells operating in the valley in 1951 only 9 used gas or diesel engines for power, a marked change from conditions prior to 1945, when almost every pumped well was equipped with a combustion engine of one sort or another.

The expansion in the past few years has been concentrated in the central and southern portions of the valley, and largely on undeveloped tracts adjacent to producing farms. The accompanying map, figure 8, shows that the irrigation wells now are mostly on the higher, better land in the southern part of the district where the water table ranges from 25 to 100 feet below the flat valley floor.

Because few of the wells in the Beryl-Enterprise district are used to supplement the supply from surface streams that enter the valley, the quantity of water produced from each well varies only slightly from year to year. The changes in total pumpage within the valley are therefore a result of the increased number of wells put in operation, or of the discontinuance of pumping on abandoned farms.

Water-level fluctuations.—In general, water levels in all wells in the area where irrigation wells are concentrated have declined since the advent of heavy pumping, except in the vicinity of the Clarke ranch in the northeast part of T. 35 S., R. 15 W. The decline has been especially great where large producing wells have been clustered together, and in a number of instances it has necessitated the lowering of pump columns in the affected wells. The hydrographs of selected observation wells in the valley (fig. 9) indicate the declining trend of water levels. By plotting only the year-end water-level measurements as shown, the wide range of seasonal fluctuations is eliminated and the trend of the hydrograph suggests the changes of ground-water storage that are occurring from year to year. Rates of decline of 2 or 3 feet in a

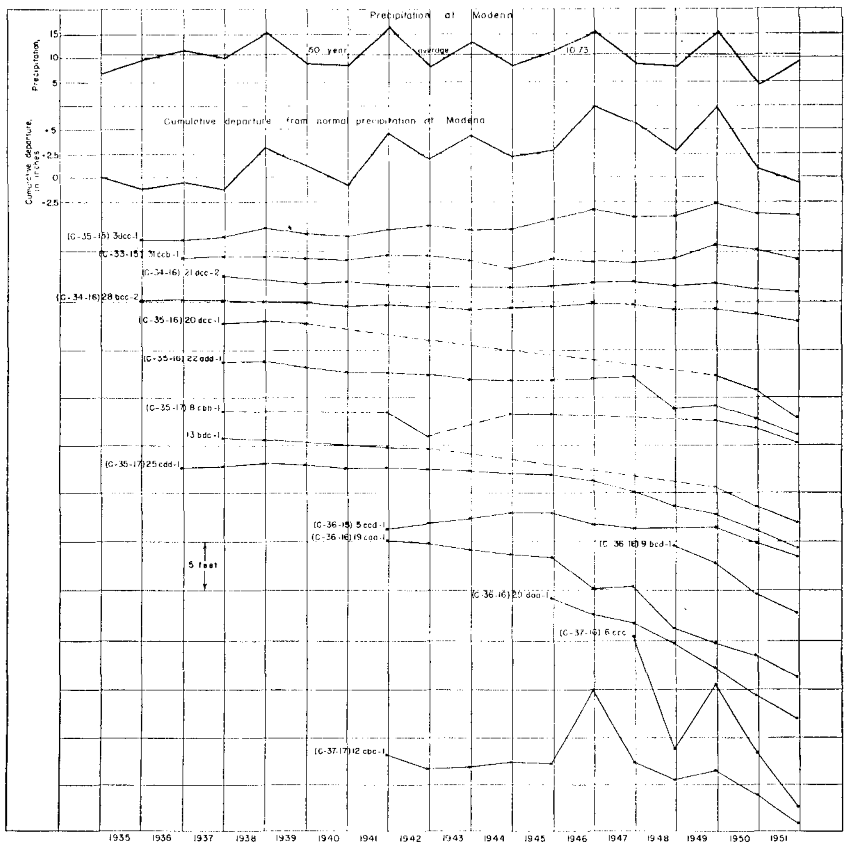

Figure 9. Annual water-level trends in 15 wells in the Beryl-Enterprise district, and other hydrologic data.

year are not uncommon in many wells in the heavily pumped area, and declines of as much as 13 feet have been noted in the southern end of the area since 1946. The general downward trend of water levels appears to be caused almost exclusively by the pumping of irrigation wells.

As noted in figure 10, the recent pumping in the heavily developed area south of State Highway 56 has produced a broad cone of depression in the water table, radially inward toward the center of heavy pumping. Midsummer measurements indicate that, in the middle of the irrigation season, gradients into this cone of depression are considerably steeper than are suggested by the December contours shown. It is quite apparent, therefore, that pumping within this area far exceeds the natural inflow of water during the pumping season, and also that this depletion in storage is not replaced by inflow during the ensuing winter.

The two profiles of figure 11 show the decline in water levels between 1949 and 1951. The locations of the two profiles are shown on figure 8. In the northern part of the district where the water table is less than 8 feet below the land surface and therefore where evapotranspiration losses can be expected, water levels have been affected only slightly by pumping. Thus, evapotranspiration is not significantly less than under natural conditions prior to pumping. Water levels in the southern part of the pumping area must be lowered 50 to 75 feet before the natural ground-water losses would be materially reduced.

Significance of recent trends.—In the heavily pumped areas of the valley, and especially in the southern part of the Beryl-Enterprise district, the marked decline of water levels is directly related to the quantities of water pumped from irrigation wells. The amount of water pumped each year in the district represents several times the average annual recharge, and although the size of the reservoir is tremendous, the amount that the water levels have been lowered in some areas is significant (see fig. 9). Prior to 1946, water levels in scattered wells changed very little or declined slightly, perhaps in response to long-term precipitation trends. Beginning in 1946, however, and continuing at an accelerating rate to the present, the measured declines have been roughly proportional to the quantities of water pumped.

During the spring of 1952 the abnormally high runoff from the mountainous areas surrounding the Beryl-Enterprise district furnished far more water to the valley than had been received for many years. The effect of this water upon ground-water storage is being watched closely, because it may provide important additional information on the characteristics of replenishment to the ground-water reservoir.

At the present time the problems raised by the recent development of wells in the Beryl-Enterprise district are essentially those that were stated in the progress report. The discussion in that report (pp. 175-179) is therefore repeated below.

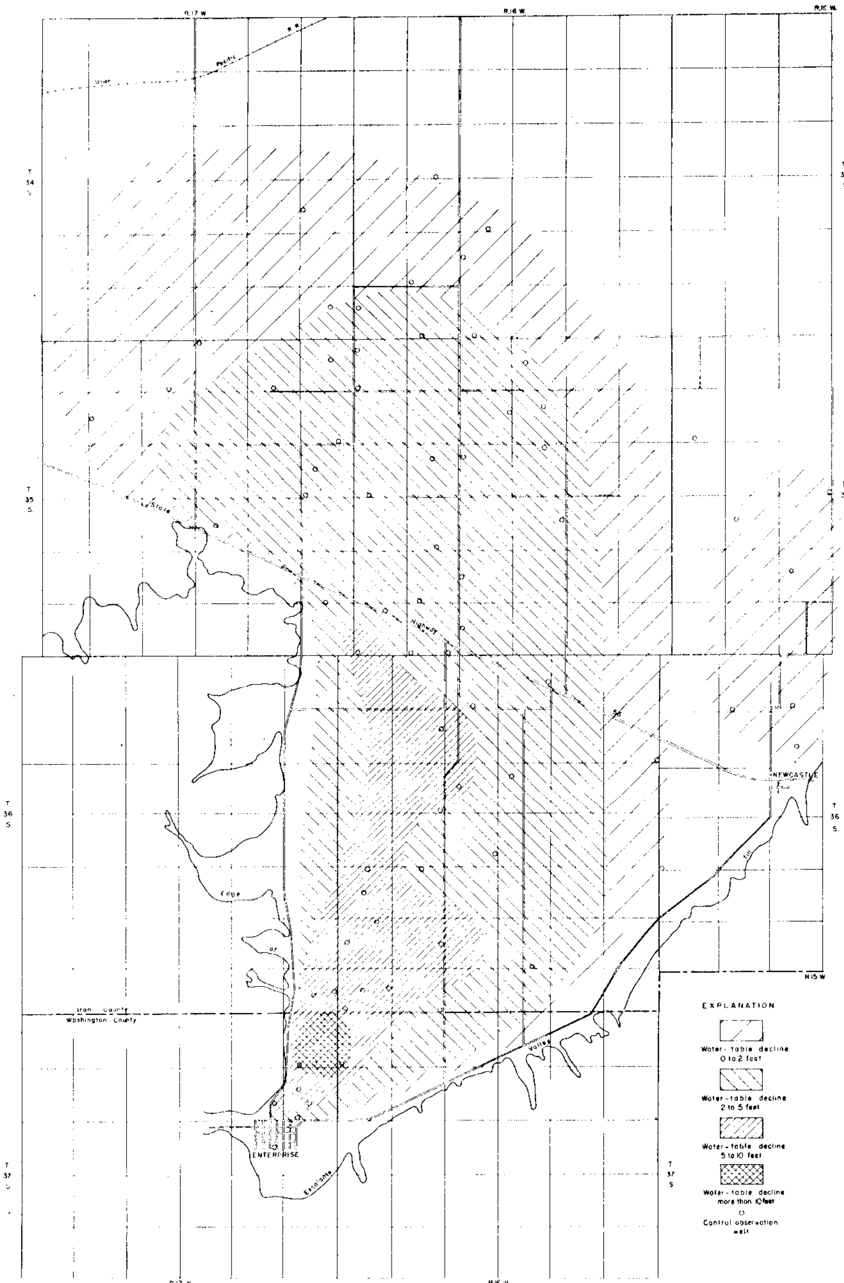

Figure 10. Map of part of the Beryl-Enterprise district showing decline of the water table from 1945 to 1951.

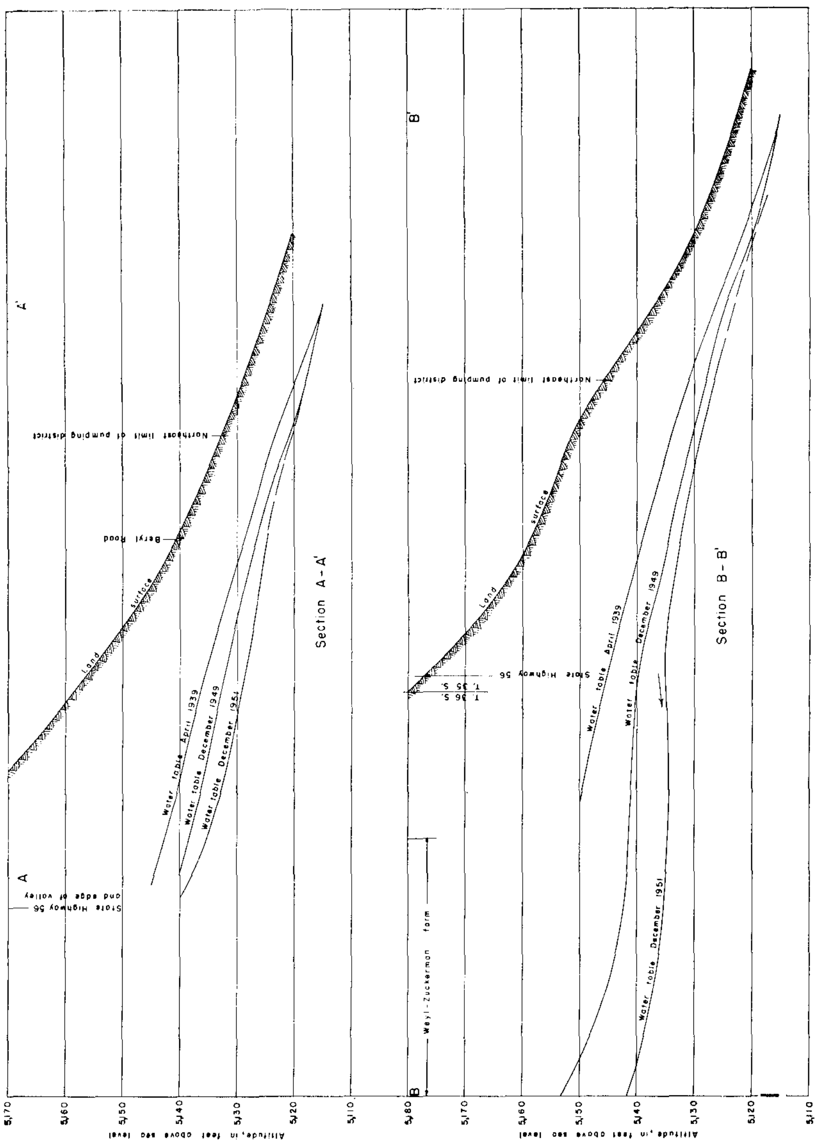

Figure 11. Profiles of the Beryl-Enterprise district showing position of water table.

The Salt and Alkali Problem

It is inevitable that the total quantity of soluble materials in the soils and water of the district will increase, because of the lack of facilities for flushing those salts into other areas. But the problem is not only for future generations, for there are already great quantities of soluble salts within the district. White, commenting on the 17 idle pumping plants in the Beryl district in 1927, said: "Not all the reasons for failures are known, but the use of shallow alkali ground water and the poor quality of the land selected for irrigation undoubtedly caused part of the failures."

Studies to date have shown that the valley fill in many parts of the district is permeable enough for percolation of water from the land surface down to the water table. Such percolation does occur from lands that are irrigated, as well as from other areas when they receive heavy precipitation. Chemical analyses show a greater proportion of dissolved materials in water from shallow wells than in water from nearby deep wells, and it is likely that this is due at least in part to the addition of waters that have percolated downward from alkaline or saline soils, or through earth materials that contain soluble matter. Further, the investigation has shown that the aquifers of the valley fill are more or less directly interconnected, so that if water is pumped from deep wells, replacement may occur from shallower zones. Thus eventual deterioration in the quality of the deeper waters due to pumping is a distinct possibility.

For maximum beneficial use of the ground-water reservoir over the longest period of time, it is desirable to irrigate soils that contain the least amounts of alkali and salt. Aside from the generally greater productivity of these soils, they will cause least deterioration in the quality of ground water when water returns to the reservoir from irrigated areas.

Rather generally, water of sustained higher quality will be obtained from wells tapping deeper aquifers, provided that well casings are not perforated in the shallowest water-bearing zone. Although the various aquifers are considered to be interconnected, those connections are generally by devious natural routes. Wells perforated opposite several zones at and below the water table, however, provide direct access for the shallow water of inferior quality.

The Problem of Salvaging Natural Losses

The discharge of ground water by evaporation and transpiration in the Beryl district, as outlined by White, has been estimated to be of the order of 5,000 acre-feet a year. Farther northeast, toward Lund, the water table is closer to the surface and the total natural discharge in the area south and west of Lund, including that in his Beryl district, may well be double the amount estimated by White. In areas where the water table is shallow enough, water may rise to the surface by capillary action, where it is evaporated and any dissolved salts are left behind. Most of the natural discharge from the Beryl-Enterprise district, however, occurs by transpiration from phreatophytes, that is, from plants that depend upon ground-water supplies.

Greasewood *(Sarcobatus vermiculatus)* is common in parts of the Escalante Valley where the depth to water ranges from about 3 to 15 feet and other conditions are suitable, and is found in some places where the water table is as much as 40 feet below the surface. Other phreatophytes, such as salt grass *(Distichlis spicata)* and pickleweed *(Allenrolfea occidentalis)*, occur where the water table is less than about 8 feet below the surface. In all investigations involving the determination of the consumptive use of water by phreatophytes, there has been evidence that the amount of water consumed decreases as the depth to the water table increases. Thus, the natural discharge from the district would be reduced if the water table in the area could be lowered sufficiently.

Pumping from wells is an effective method of lowering the water table. However, there are several objectionable features to any program for pumping from wells located within the area of natural discharge. For one thing, clay and silt are predominant in the valley fill in that part of the district, and productive wells are not easily obtained. Another and major objection is that soluble salts are prevalent both in the soils and in the shallow ground water of the area. Such water used for irrigation probably would not produce a satisfactory crop. There is at present little pumping of ground water within the area of natural discharge, except from deep wells at Lund for railroad use.

The Problem of Mining Ground Water

The current investigation has proceeded far enough to show that pumpage from the ground-water reservoir is in excess of the natural replenishment. Most of the net withdrawal (the pumpage minus the return seepage from irrigation) is being taken from accumulated storage in the valley. It is certain that pumping cannot be continued at current rates forever, and that the sustained perennial yield must be a much smaller quantity than is being withdrawn annually today.

However, there is no likelihood of early or sudden exhaustion of the ground-water reservoir unless the rate of pumping is increased markedly above that in 1950. The quantity of water in that reservoir is not yet known, but present information shows that there is probably at least several million acre-feet, and each million acre-feet would be enough for about 2 decades of pumping at 1950 rates. Further, the water table in the pumping district is declining at a rate of less than 2 feet a year, so that the energy requirement for lifting the water is increasing only rather slowly. If the reservoir extends to sufficient depth, the economic factor of pumping cost, rather than the hydrologic factor of reservoir exhaustion, may set the date for reduction or cessation of pumping.

Progressive ground-water depletion in the Beryl-Enterprise district creates a major problem. Ground water in the district is not renewable at the rate of current pumpage. Indeed, it is possible that few of the irrigation wells are in locations where the water pumped out is fully replenished by nature at the current position of the water table. Even the few wells operated prior to 1940 may have been mining ground water locally to some extent, although their pumpage was so small that the effect upon total storage in the reservoir was negligible. On the other hand, there is some replenishment to the ground-water reservoir. The average annual replenishment is considered to be essentially equivalent to the loss by natural discharge, a quantity far less than current pumpage, but nevertheless substantial.

Mining of ground water from areas remote from the areas of natural discharge is one method, and perhaps the most feasible method, of making the maximum beneficial use of the water resources while salvaging as much of the water now lost by natural discharge as may be practicable. It has been stated that pumping to date has probably not made any material reduction in evapotranspiration because the water table has not been lowered where it is closest to the surface, and has been lowered less than 3 feet where it was once within 12 feet of the surface. But, in comparison with the effects of pumping in many areas in certain other States, the water table has not yet been lowered very much in any part of the district.

The water table throughout the area of greatest concentration of wells (in Tps. 35 and 36 S.) probably would need to be lowered about 60 feet in order to halt the flow of ground water toward Lund. When it reached that position, the pumping lifts in some of the higher wells might exceed 200 feet. But salty water from the present discharge area might encroach on the wells before this would be accomplished.

If mining becomes an approved practice, some techniques of the petroleum industry might be used to improve the extraction of water. In particular, some form of unitization of the ground-water

> reservoir might be desirable, in order to assure most effective extraction by controlling the spacing, depth, and production of wells. Maintenance of suitable quality of water would require that the alkalinity or salinity of soils be considered in such unitized development. The alternative of haphazard development, with heavy pumping concentrated within small parts of the ground-water reservoir, must inevitably create deep cones of depression in those areas, with consequent high pumping costs to the owners of closely spaced wells.

In figure 9, the hydrograph of the Carlson well, (C-33-15) 31cab-1, in the northern part of the district, shows ground-water trends under practically natural conditions, inasmuch as virtually no ground water has been pumped in the vicinity. The hydrograph correlates with the trend in precipitation at Modena and suggests that ground-water storage in this part of the valley probably is related closely to precipitation in the valley and to recharge from adjacent low hills and mountains. The Owen and Fisher wells, (C-34-16) 21dcc-2 and (C-34-16) 28bcc-2, display a general downward trend throughout the 16 years of observation, little correlation with records of precipitation, and a rather marked decline since 1947 caused by pumping from nearby wells.

In general, ground-water fluctuations throughout the northern part of the Beryl-Enterprise district are small, indicating that the quantity of water drawn from storage by natural losses or by pumping, and the quantity of water returned to storage by recharge from watever source, are small compared to the size of the underground reservoir and the amount of water maintained in storage.

Detailed ground-water studies have not been made in this northern part of the district, which extends north and northeast from Beryl to the county line. General reconnaissance and records of water-level fluctuations in a few wells suggest that this isolated and undeveloped area has some ground water in storage, but that replenishment is largely by precipitation in the vicinity, and that discharge from the ground-water reservoir is chiefly by evapotranspiration in the lowest parts of the valley. It is unlikely that the area receives any substantial contribution of water by underflow from the developed part of the district farther south, or that it makes any appreciable contribution to the Milford district to the north. Tentatively, therefore, it would seem that development of wells in the Nada-Lund area could be encouraged, in the hope that ground water now wasted might be put to beneficial use.

MILFORD DISTRICT OF ESCALANTE VALLEY

Beaver County

By W. B. Nelson and H. E. Thomas

The Milford pumping district occupies the northern part of the Beaver River alluvial fan and constitutes only a small part of the Beaver County portion of Escalante Valley. The Beaver River alluvial fan, whose apex is near Minersville, has an areal extent of about 90 square miles. The 125 irrigation wells that were pumped in 1951 are distributed over 26 sections of this fan, but 89 of the wells are concentrated in a 10-square-mile area that lies 2 to 7 miles south of the town of Milford. An accompanying map (figure 12) shows the distribution of irrigation wells and the areas irrigated from them in the Milford district.

A progress report on ground-water investigations in the Milford District was published in 1950 (Fix, Nelson, Lofgren, and Butler, pp. 180-210). Summary statements from this report are given below:

> The major source of replenishment to the ground-water reservoir of the Beaver River alluvial fan is the Beaver River. Prior to man's occupancy of the area this recharge occurred by seepage from the river channel and from lands overflowed by the river in time of flood. As man has subjected the stream to his regulation and use, substantial ground-water recharge has resulted from diversion of surface water into canals, and from irrigation of land.
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> The amount of water contributed annually to the ground-water reservoir by the river is not known, but it must be less than the total inflow of the river into Escalante Valley. In 37 years the average annual runoff of the Beaver River near Minersville has been slightly less than 30,000 acre-feet. The average ground-water recharge to the alluvial fan would be only a fraction of this amount, depending upon how much surface water is returned to the atmosphere by consumptive use of irrigation crops and by other evaporation and transpiration.
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> The Milford district as delimited in this report receives only a part of the ground water that is derived from the Beaver River. Before settlement it must have received a major part, for the channel of the river runs through the district. Since the regulation of river flow by storage in the Rockyford Reservoir, the ground-water contribution to the Milford district has fluctuated from year to year, depending upon how much surface water was diverted into the district for irrigation.
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> Precipitation within the Milford district is a minor source of ground water, but substantial recharge may occur as a result of exceptional storms. There are several other possible sources of recharge to the ground-water reservoir, but further field work is required before any estimates can be made of the quantity derived from them.
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> The natural discharge from the ground-water reservoir of the Milford district was computed to have been about 11,000 acre-feet in 1927, and is considered to have been very nearly as much in recent years. This natural discharge has been by evaporation and transpiration, by springs, and by underflow to the north.
>
> In the past two decades the total pumpage from wells in the Milford district has ranged from about 12,000 acre-feet in 1938 to about 30,000 acre-feet in 1950. Most of the water was pumped for

irrigation, and doubtless a substantial amount returned to the ground-water reservoir by deep percolation from the irrigated fields. On the other hand, in the lower parts of the Milford district the water table is shallow enough that alfalfa can obtain its water supply by sub-irrigation. It is not known whether the transpiration by these sub-irrigated crops is comparable in amount to the deep seepage from pumped irrigation water within the district. In any case, the total net ground-water discharge is considered to have ranged from about 20,000 to 40,000 acre-feet a year. The differences from year to year are accounted for chiefly by variations in annual pumpage.

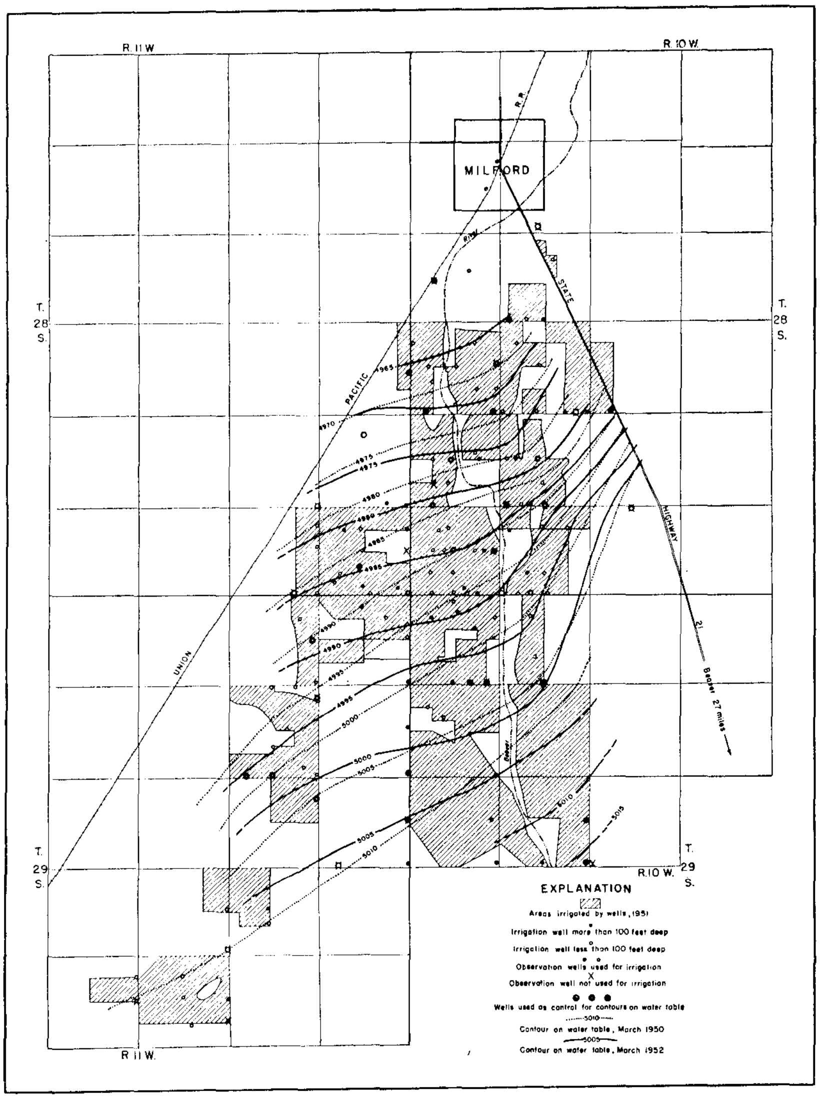


Figure 12. Map of Milford district showing irrigation wells, areas irrigated by wells and water table contours for 1950-1952.

The following discussion, like that of the Beryl-Enterprise district, deals chiefly with the data collected in 1951, subsequent to the completion of the progress report.

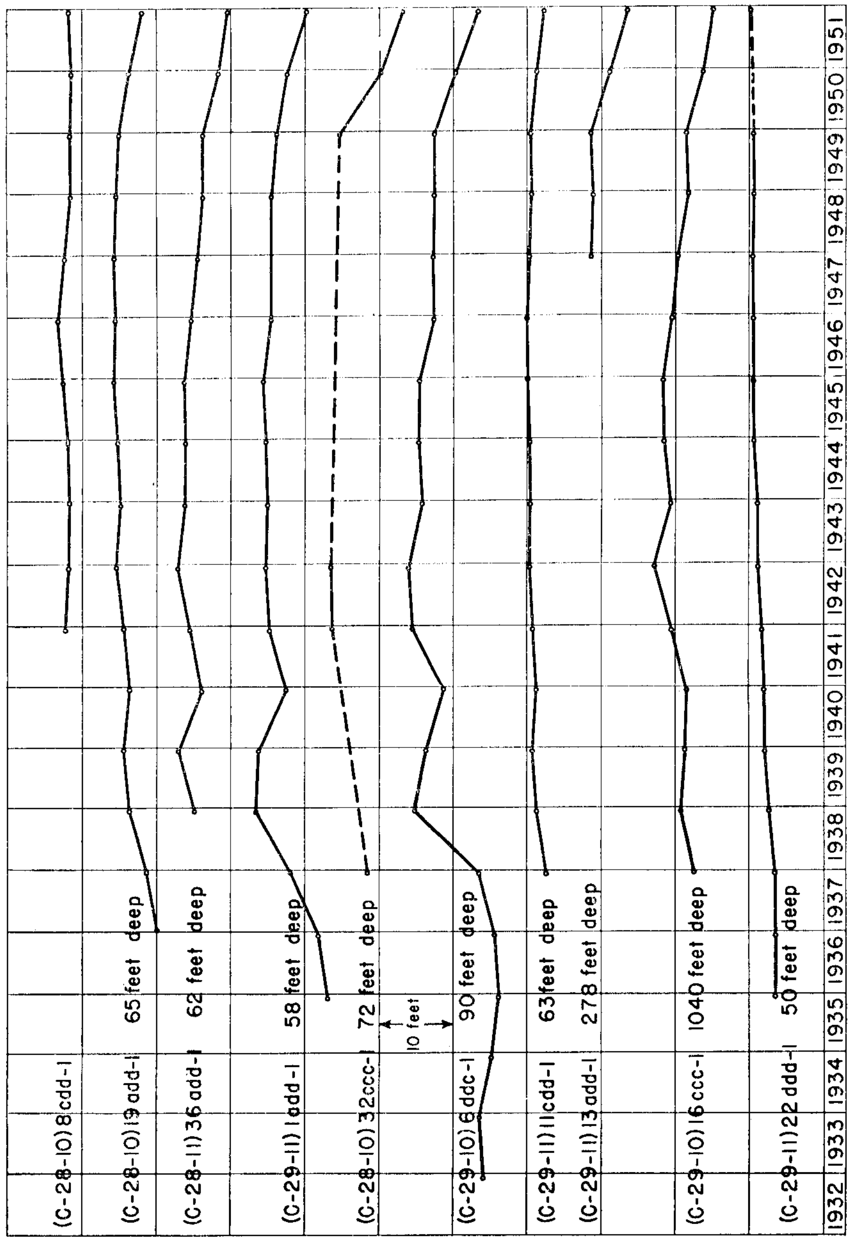


Figure 13. Ground-water level trends in ten wells in the Milford district.

Water-level fluctuations.—Hydrographs based upon measurements of the water level in December in 10 selected wells are shown in figure 13. Eight of these hydrographs were presented for years prior to 1951 in figure 13 of the progress report, in which they are discussed on pages 201-205. Most of the wells show the same general trends each year, although the magnitude of the annual changes varies considerably.

There has been relatively little change from year to year in wells near the north and south ends of the district (the top and bottom graphs). Water levels in the Haworth well, (C-29-11) 22ddd-1, in the southwestern part of the district, have risen gradually but progressively since the beginning of record in 1935. Water levels have risen also in other wells in its vicinity, and springs have appeared near Laho. The rise may result from the applica-

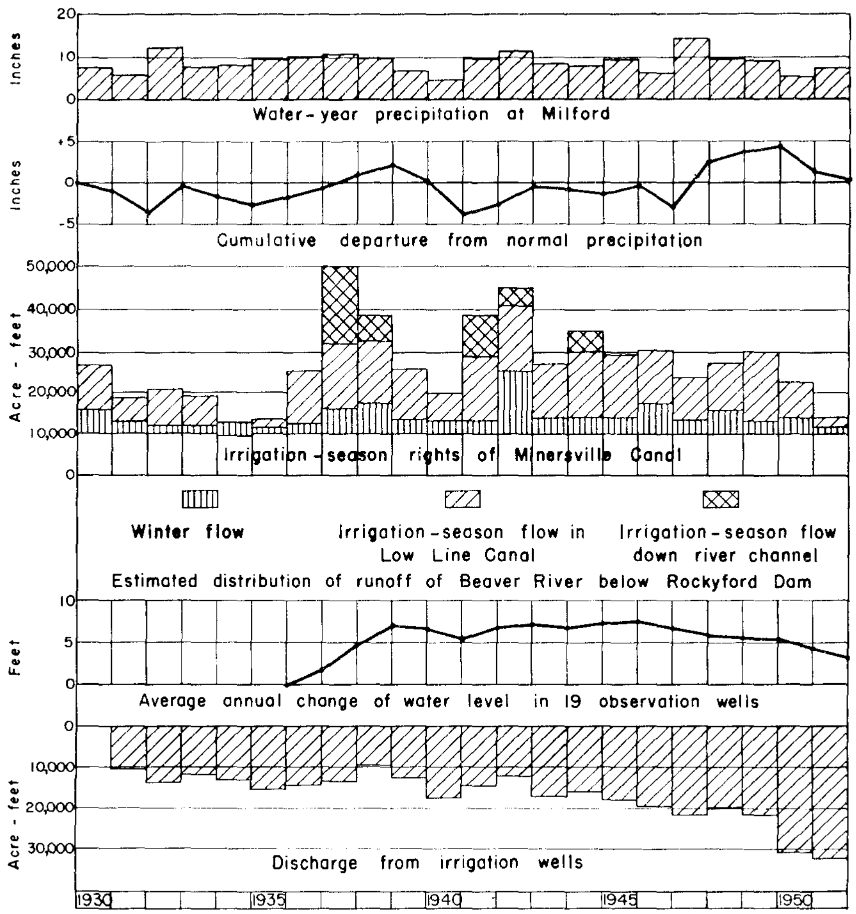


Figure 14. Hydrologic data for the Milford district, 1930-51.

tion of irrigation water to land in the Minersville area, but as yet there is no proof of this.

The average change of water level in 19 selected wells in the Milford district is shown in figure 14, together with data concerning annual precipitation at Milford, discharge of the Beaver River, and pumpage from irrigation wells in the Milford district. The 19 wells are in the areas of older development, and they

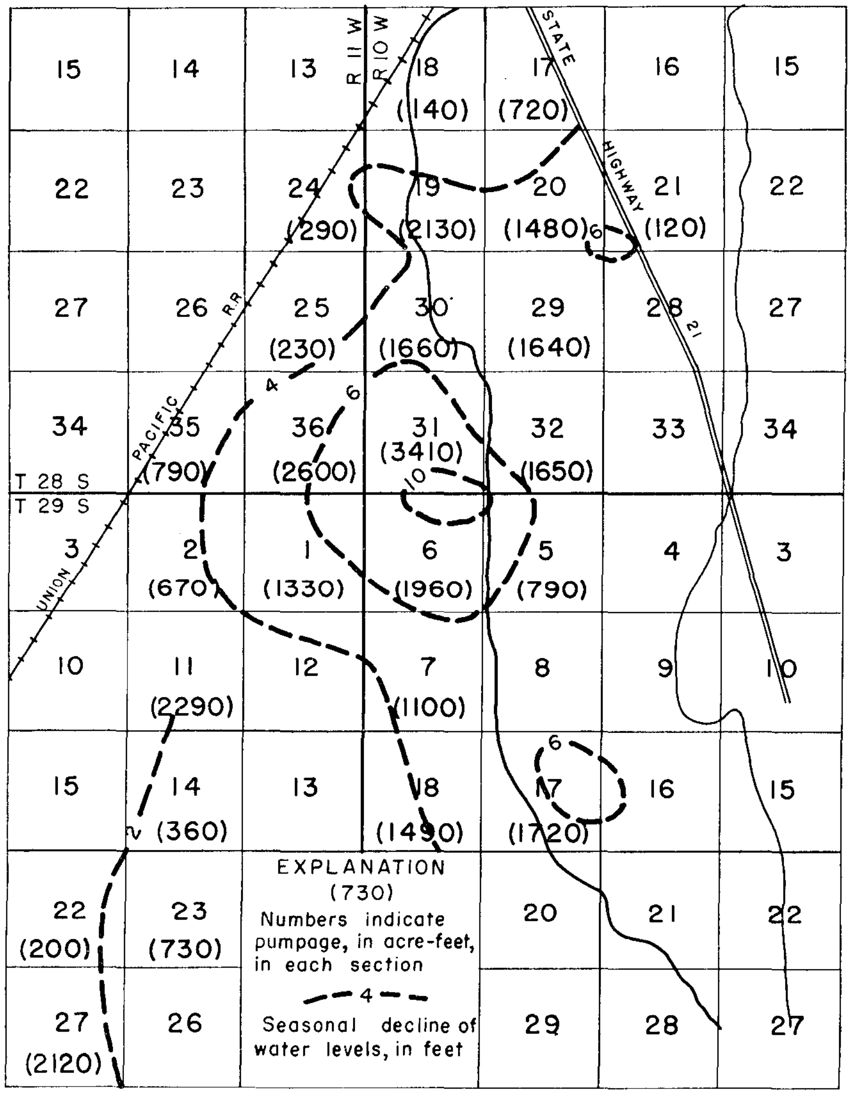


Figure 15. Approximate seasonal decline of water levels in wells, and distribution of pumpage in 1951 in the Milford district.

generally do not record the effects of pumping from wells drilled in 1950 and 1951. Nevertheless, this graph shows a marked downward trend in 1950 and 1951, similar to that shown in several individual wells (fig. 13). There was a marked increase in pumping in the two years, which may have been chiefly responsible for this decline in water levels. However, the precipitation at Milford was 3.14 inches less than normal in 1950 and 1.11 inches below normal in 1951, and the runoff in the Beaver River in both years was well below the long-term average. Thus, water levels in wells probably would have declined because of less-than-normal recharge, even if there had been no increase in pumping during those years.

Water levels were measured in a number of wells in March, 1951, and again in October about 2 weeks after the pumps had been turned off. The decline of water levels in these wells ranged from 1 to 11 feet and is attributed to pumping. Contours showing the approximate seasonal decline of water levels, and distribution of pumpage in 1951, are shown in Fig. 15. There were no data to show the amount of decline east of the heavily pumped area.

The water table in March, 1952, was as much as 6 feet lower than it had been in March, 1950, as shown by the contours of figure 12. Thus the depletion of storage caused by pumping during the two irrigation seasons was not replenished entirely during the months when the pumps were idle.

Ground-water development.—Most of the wells in the Milford district prior to 1947 were less than 100 feet deep and were equipped with centrifugal suction pumps; generally each discharged less than 450 gpm and irrigated not more than 40 acres. Most of the new wells go down far deeper than a hundred feet — the deepest to 431 feet; their average discharge is more than 1,000 gpm, and some yield more than 2,000 gpm. Most of these new wells irrigate about 160 acres each.

During 1950 and 1951 the water table declined in the heavily pumped area until it was beyond the reach of most of the centrifugal pumps. The owners of many of these wells have had replacement wells drilled and equipped with turbine pumps of greater capacity.

The irrigation wells in the Milford district in 1950 are listed in table 4, together with estimates of the annual pumpage from 1931 to 1951. In 1951 eight additional irrigation wells were pumped, and the aggregate pumpage from them is estimated to have been about 2,200 acre-feet during the year. On the other hand, seven wells from which about 1,530 acre-feet was pumped in 1950 were idle in 1951. For the district as a whole, 125 irrigation wells yielded about 32,200 acre-feet of water in 1951, as compared with 124 wells yielding 30,300 acre-feet in 1950.

Relation of surface water to ground water.—One of the conclusions of the progress report (p. 184) was that "the ground-water reservoir of the Milford district receives most of its replenishment from the natural channel of the Beaver River and from irrigation canals and irrigated lands supplied by that river." The stream-gaging station on the Beaver River below Rockyford Dam provides a record of extreme importance to the Milford district, because it measures practically all the water that flows into Escalante Valley from that source; the total includes water diverted through canals and used for irrigation, water that recharges the ground-water reservoir, and, in years of greatest runoff, some water that continues down the natural river channel and flows northward out of the district.

The recharge to the Milford district may not be proportional to the quantities measured at this gaging station, however, because of complications introduced by the development and use of surface water as well as of ground water. Rights to the first 10,000 acre-feet of Beaver River water go to fields southwest of Minersville, and in years of low runoff practically all the surface water is diverted in that direction. Ground-water recharge in those years would be principally in the southern half of the Beaver River alluvial fan and outside the Milford district. (Some water may reach the southern part of the district, however, as mentioned on page 162). In most years the runoff of the Beaver River is greater than 10,000 acre-feet, so that some water has been available for diversion into the Low Line canal which traverses the Milford district. When water is available, this canal may carry as much as 16,000 acre-feet in an irrigation season. In some years, including 1937, 1938, 1941, 1942, and 1944, the maximum flow has exceeded the total diversions into both the Minersville and Low Line canals, and the surplus went down the natural channel and out of the Milford district. Thus there are opportunities for recharge by seepage from surface water in the Milford district during years of high and medium runoff, but little during years of minimum flow.

In the past, some lands in the Milford district have been irrigated from canals when water was available, and from wells in other years. Thus wet years are doubly beneficial to ground-water storage, because of increased recharge opportunity and decreased draft by pumps.

An accompanying graph (figure 16) shows the relation of the average annual change of water level in 19 wells in the Milford district to the difference between surface diversions and ground-water pumping within the district. The surface diversions are estimated by deducting from the total river flow the 10,000 acre-feet to which the Minersville fields have rights. There is a moderate amount of scatter in the points representing years prior to 1950, but these points suggest a straight-line trend. In 1950 and 1951 the pumping was distributed over a wider area, some of which is remote from the observation wells used, and the decline of water levels was far less than if the total quantity had been withdrawn from the wells pumped in 1949 and earlier years.

Investigations are continuing in the Milford district, and it is anticipated that much more will be learned about recharge during 1952. Up to the time of this writing the year 1952 has been exceptionally wet, with abundant snow in the winter, record flows in the Beaver River as the snow melted, and runoff in the small canyons of the Mineral Range which are ordinarily dry year after year. During May 1952 the discharge of the Beaver River at Milford has been as great as 100 cfs. This is outflow from the Milford district of water that has evaded all opportunities for recharge to the ground-water reservoir. Thus, if the maximum benefits of exceptionally wet years are to be realized, it appears that the district might well endeavor to supplement the natural recharge by artificial means, and thus capture as much as possible of the flood runoff.

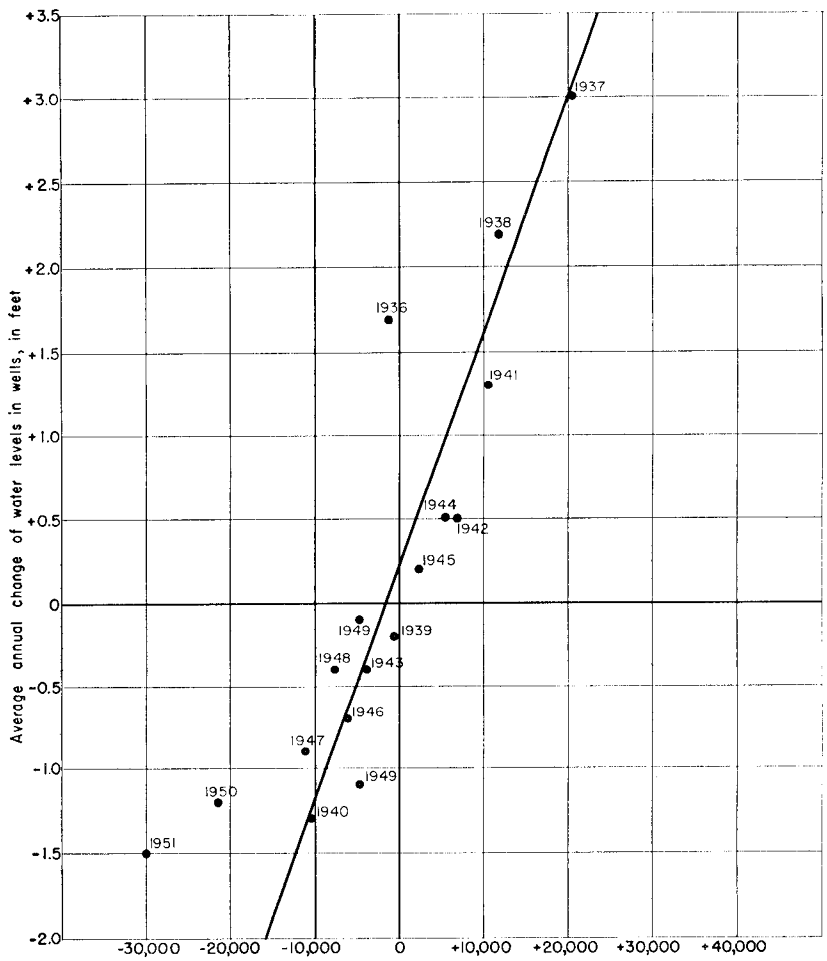


Figure 16. Relation of average annual change of water level in wells to surface-water diversions minus pumpage in Milford District.

PAVANT VALLEY
Millard County

By W. B. Nelson and H. E. Thomas

Several reports have been published on Pavant Valley on the basis of detailed ground-water studies from 1941 to 1945. Maxey (1946) described the geology of the valley and of the tributary drainage basin, and Livingston and Maxey (1944) analyzed the leakage from artesian wells in the Flowell area. The ground-water conditions in Pavant Valley were described by Dennis, Maxey, and Thomas (1946), and the following summary is taken from their report (pp. 5-6):

> Ground water occurs principally in the unconsolidated sediments of the valley fill, dominantly gravel, sand, silt, and clay of Recent and Pleistocene age. It occupies the interstices between the individual grains of these sediments, which are essentially a ground-water reservoir bounded by the consolidated rocks that form the Pavant and Canyon Ranges and underlie the valley fill at depths of a few feet to 500 feet or more. The reservoir may leak considerably along its western margin, which is formed of basalt cones and lava fields. The valley fill consists of relatively long, thin, and narrow lenses of poorly assorted alluvial fan gravel, sand, silt, and clay, interbedded with the more widespread and continuous deposits of well-assorted lacustrine clay, marl, silt, and near-shore sand and gravel. The sand and gravel beds of this fill constitute the ground-water aquifers. They are the conduits through which the water is transmitted underground from intake areas along the upper parts of the alluvial slopes to wells and points of natural discharge westward and northwestward. These beds of coarser materials are also the chief reservoirs in which the water is stored until discharged. They are more extensive and are composed of coarser, more permeable material near the mountain front; they become progressively less permeable westward. Lacustrine clay beds form the chief confining beds. Thus the valley fill contains a number of interconnected aquifers extending westward in finger-like projections from their more thoroughly interconnected portions which outcrop at the surface near the mountain front.
>
> As water moves westward in the aquifers beneath the clay beds, it is confined by them, giving rise to the artesian conditions which produce flowing wells at the lowest elevations in the valley. The principal artesian aquifers are penetrated at depths of 200 to 400 feet in most wells. Ordinarily, at least three or four and sometimes six or more water-bearing beds are encountered. On the other hand, the water in aquifers on the higher parts of the alluvial slopes and in the shallowest aquifer over much of the lower valley is essentially unconfined and its upper surface constitutes a water table.
>
> The area underlain by the ground-water reservoir in Pavant Valley has been divided into six districts based upon differences of geologic and hydrologic conditions and economic development. They have been designated the Fillmore, Flowell, Meadow, Hatton, Kanosh, and Pavant districts. Of these the Flowell district is by far the most important economically. Of a total of about 17,000 acre-feet yielded annually by wells in Pavant Valley, more than 75 percent is discharged by the 100-odd artesian wells of the Flowell district.
>
> The total discharge from the Pavant Valley ground-water reservoir amounts to more than 40,000 acre-feet in a normal year, of which less than half is discharged from wells, and only about a third is put to economic use. About 5,000 acre-feet a year may be wasted from

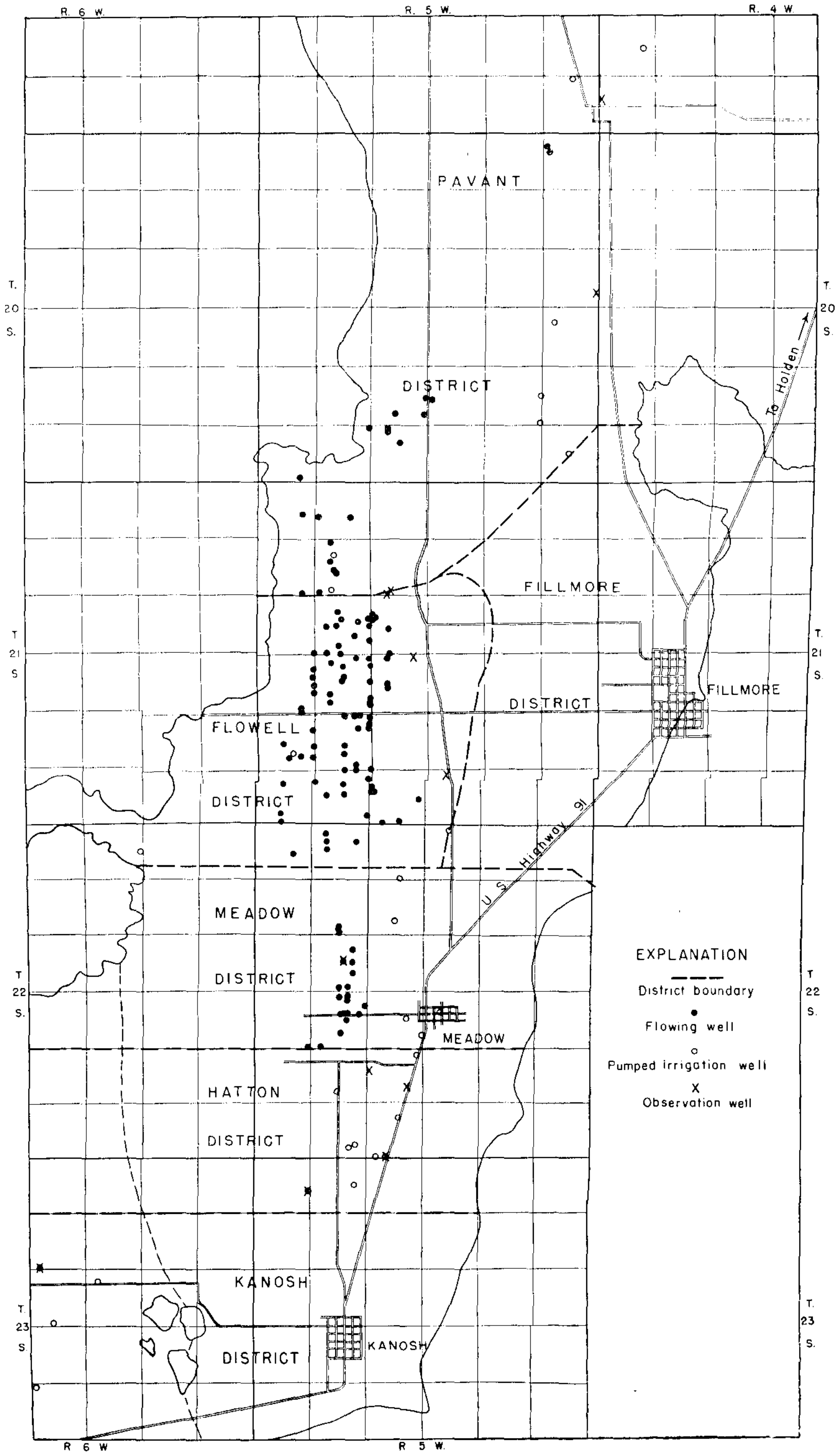


Figure 17. Map of Pavant Valley showing ground-water districts and location of irrigation wells.

uncontrolled or leaking wells, and about 25,000 acre-feet annually is lost by spring discharge, evapotranspiration, and underground movement toward the Sevier desert.

Since 1945 there have been relatively few changes in the development and use of ground water in those areas where irrigation water is obtained from flowing wells, notably in the Flowell district. However, several large wells were drilled during 1950 and 1951 in the parts of Pavant Valley that are outside of the area of artesian flow. Most of these new pumped wells are in the Pavant and Hatton districts, but there are some also in the Meadow, Kanosh, and Flowell districts (see fig. 17).

Trends in precipitation, runoff, and water levels in wells.—According to the 60-year record for Fillmore, precipitation in Pavant Valley varies markedly from year to year. However, as shown by the graphs of figure 18, there are series of "wet" years in which precipitation is consistently above normal (1905-09, 1920-25, and 1944-48), periods when precipitation is not far from average (1892-99, 1910-19, and 1935-44) and "dry" periods when precipitation is appreciably less than the mean (1900-04, 1926-35, and 1949-51). In these dry years drought conditions were widespread in Utah and adjacent States. Pavant Valley was not seriously affected by

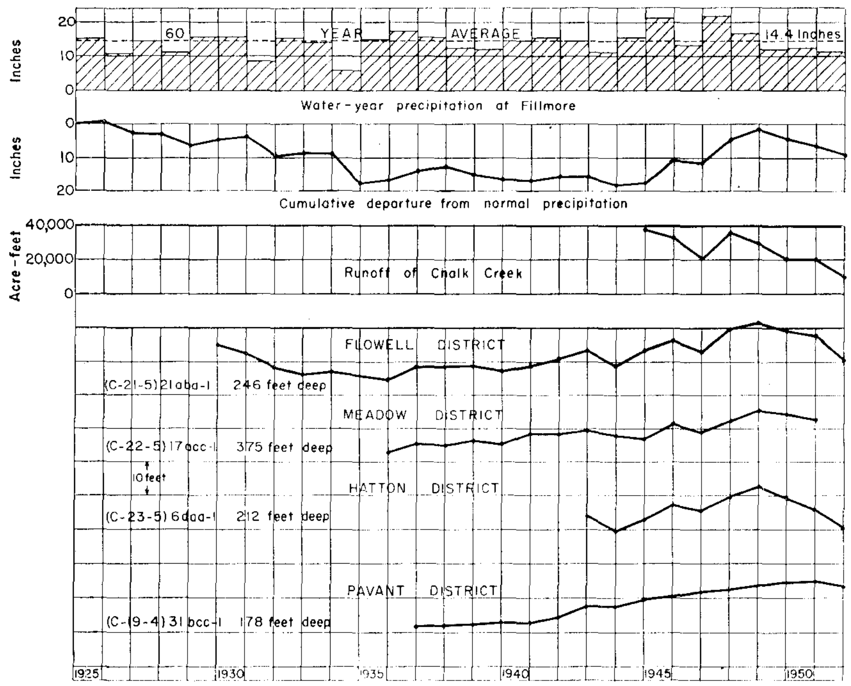


Figure 18. Hydrologic data for Pavant Valley, 1925-51.
Table 6. Irrigation wells in the Sevier desert.

the drought that encompassed much of southern Utah in 1943-51 (see page 136); although precipitation at Fillmore was deficient in the last three years of that period, it was well above normal in earlier years.

The trend in annual runoff of Chalk Creek since 1944, also shown on figure 18, generally follows the trend in precipitation. So, too, do the trends in water level in the three observation wells in the Flowell, Meadow and Hatton districts. However, since 1940 there has been a gradual but progressive upward trend in water levels in the wells representing the Pavant and Kanosh districts; these two wells are in undeveloped areas.

Ground-water development.—The development and use of flowing wells tapping the artesian aquifers in Pavant Valley have been stable for a good many years. Since the enactment of the ground-water law in 1935, the State Engineer has not approved applications for new irrigation wells tapping these aquifers in the Flowell district. In consequence the artesian water has been drawn from the same group of more than 80 irrigation wells year after year. Most of these wells are opened on April 1 and capped on October 1 of each year, but a few "edge" wells that cease flowing in the summer are permitted to open a month earlier and close a month later.

The discharge of the wells in the Flowell district has been measured at various times during the irrigation seasons of 1928 to 1943, and the total discharge during these periods of measurements has ranged from 10,500 gpm in September, 1939, to 17,200 gpm in May, 1928. There appears to be a direct relation between the total discharge from wells and the water level in the "State" well (C-21-5) 21 aba-1 (see fig. 18), which is near the eastern edge of the area of artesian flow. For each foot of decline or rise of water level in the State well there is a decrease or increase of about 850 gpm in the total flow of all wells in the district. Dennis, Maxey, and Thomas (1946, pp. 70-74) have used this relationship as a basis for estimating the annual discharge from wells in the Flowell district in 1930-45. Similar estimates for subsequent years are presented below.

Estimated discharge from flowing wells in Pavant Valley (Quantities in acre-feet)

Water year	Flowell District: Irrigation season	Flowell District: Winter (30 percent of preceding irrigation season)	Flowell District: Total	Meadow District (15 percent of total discharge from Flowell District)	Pavant District	Total
1945	14,300	3,300	17,600	2,600	1,000	21,200
1946	14,100	4,300	18,400	2,800	1,000	22,200
1947	14,600	4,200	18,800	2,800	1,000	22,600
1948	17,800	4,600	22,400	3,400	1,000	26,800
1949	16,400	5,300	21,700	3,300	1,000	26,000
1950	14,800	4,900	20,700	3,100	1,000	24,800
1951	14,300	4,400	18,700	2,800	1,000	22,500

Only six wells were pumped for irrigation in Pavant Valley prior to 1950. One of these is an artesian well in the Flowell district, and another is a shallow well tapping unconfined water in the same district. Five wells in the Hatton district were drilled to supply supplementary water to irrigated land; the oldest of these was drilled in the village of Hatton in 1934 by the Drought Relief Administration.

In 1950 and 1951, 24 irrigation wells were drilled, of which 9 are in the Pavant district, 6 in the Hatton district, 5 in the Meadow district, 3 in the Kanosh district, and 1 in the Flowell district. These new wells yielded about 5,300 acre-feet in 1951, used for irrigating about 2,100 acres of land.

The pumped irrigation wells in Pavant Valley are listed in table 5, with data as to depth and date of construction. The total pumpage in Pavant Valley was of the order of 7,700 acre-feet in 1951. Thus the aggregate withdrawal from all wells, flowing and pumped, was about 30,000 acre-feet during that year.

Effects of development.—The ground-water reservoir is recharged chiefly by seepage from streams and by underflow in canyons that drain into Pavant Valley from the Pavant and Canyon Ranges, and probably also by infiltration of precipitation and of water applied for irrigation into permeable rock mantle in some parts of the valley. The ground water under natural conditions is discharged by evaporation and transpiration in the lower parts of Pavant Valley, and by westward movement underground toward the Sevier Desert, where much of it may appear at the surface in the springs that feed Clear Lake (Dennis, Maxey, and Thomas, 1946, pp. 52-56).

The development of artesian wells, starting in 1915 in the Flowell area, caused a progressive lowering of artesian pressures for several years, but a new equilibrium was eventually established. Since 1929, the first year for which there are any ground-water records, both the water levels in wells and the discharge from flowing wells have fluctuated in response to the precipitation and runoff which are responsible for the replenishment of the ground-water reservoir. Under this new equilibrium the flowing wells are as much a part of the hydrologic cycle as if they were natural spring openings; their discharge increases as a result of the replenishment in wet years, and decreases during drought.

Prior to 1950 the discharge from flowing wells constituted less than 40 percent of the total discharge from the Pavant Valley ground-water reservoir. (Dennis, Maxey and Thomas, 1946, p. 80). The remainder, estimated to be more than 25,000 acre-feet, escapes from Pavant Valley and is not beneficially used, except possibly at Clear Lake.

The ultimate effect of the pumping of the 24 irrigation wells drilled in 1950 and 1951 cannot be evaluated at this time. In March, 1952, the water levels in several of these wells were 1 to 9 feet lower than they had been a year earlier, suggesting that pumping during the 1951 irrigation season caused some reduction

Table 5. Pumped irrigation wells in Pavant Valley.

Coordinate No.	State No.	Owner	Year drilled	Depth (feet)
		PAVANT DISTRICT		
(C-19-4) 30dab-1	Ap. 21772	Eugene Stephenson	1950	502
(C-19-5) 36baa-1	Ap. 22238	Jay Dastrop	1950	500
(C-20-5) 1bcb-1[1]	Ap. 17596	Otto T. Hunter	1948	430
" 1bcb-2[1]	Ap. 21540	Otto T. Hunter	1951	500
" 24bbd-1	Ap. 21937	Leo Stott	1950	390
" 26add-1	Ap. 21928	J. C. Rasmussen	1951	314
" 26ddd-1	Ap. 21915	Wm. E. Higgins	....	....
(C-21-5) 8bbd-1	Ap. 22038	Albert Swallow	1950	407
" 8ccd-1	Ap. 21865	Francis Johnson	1950	246

[1]Flowing well not pumped.

Estimated total discharge in 1951 .... 2,000 acre-feet
Estimated area irrigated in 1951 .... 650 acres

Coordinate No.	State No.	Owner	Year drilled	Depth (feet)
		FLOWELL DISTRICT		
(C-21-5) 21bba-1	C 7683	W. D. Tomkinson	1918	292
" 30dbc-2	Ap. 18002	Ivin Christensen	1947	150
(C-22-5) 3baa-1	Ap. 22061	Reay Brothers	1951	380

Estimated total pumpage in 1951 .... 200 acre-feet
Estimated area irrigated in 1951 .... 100 acres

Coordinate No.	State No.	Owner	Year drilled	Depth (feet)
		MEADOW DISTRICT		
(C-22-5) 4dcc-2	Ap. 15376	Hazen Stevens	1950	250
" 9cad-2	Ap. 21941	W. A. Paxton	1951	310
" 21acd-1	Ap. 21718	Leo Stott	1951	430
" 21dad-1	Ap. 21757	Meadow Irrigation Co.	1950	370
" 22bac-1	Ap. 21758	Meadow Irrigation Co.	1950	607

Estimated total pumpage in 1951 .... 1,500 acre-feet
Estimated area irrigated in 1951 .... 700 acres

Coordinate No.	State No.	Owner	Year drilled	Depth (feet)
		HATTON DISTRICT		
(C-22-5) 28aad-1	Ap. 22766	L. M. Bushnell	1951	354
" 29cdd-1	Ap. 13159	O. E. Beckstrand	1940	250
" 32dac-2	a 2204	Frank Paxton	1951	182
" 32dca-1	Ap. 22210	Frank Paxton	1951	200
" 33abc-1	Ap. 18018	O. E. Beckstrand	1947	250
" 33ccd-1	Ap. 21746	A. Lavoy Kimball	1950	240
" 33cdd-1	Ap. 13367	A Lavoy Kimball	1940	152
(C-22-6) 3add-1	Ap. 21831	Joseph Edmonds	1951	328
(C-23-5) 5adc-1	Ap. 21483	Preal George	1951	180
" 6daa-1	C 8201	Hatton Irrigation Co.	1934	212

Estimated total pumpage in 1951 .... 3,300 acre-feet
Estimated area irrigated in 1951 .... 900 acres

Coordinate No.	State No.	Owner	Year drilled	Depth (feet)
		KANOSH DISTRICT		
(C-23-6) 9-ccd-1	a 2001	G. P. Wright	1947	136
" 15bbd-2	a 2482	Alton Staples	1950	141
" 16cdd-1	Ap. 22139	Alvin Englestead	1950	148
" 28bbb-1	Ap. 21511	Alvin Englestead	1950	194

Estimated total pumpage in 1951 .... 700 acre-feet
Estimated area irrigated in 1951 .... 450 acres

in ground-water storage. But depletion of storage is a common feature of the initial stages of well development in most places, and it may be years before it can be determined whether the replenishment will be adequate to support the new discharge.

The new wells are generally on the alluvial fans of Corn Creek, of Cottonwood, Sunset, and Meadow Creeks in the southern part of the valley, and of Eightmile Creek and minor canyons of the Canyon Range in the northern part of the valley. Practically no information is available as to the propensities of these streams for recharging the aquifers in their respective alluvial fans.

It is inevitable that one result of pumping from these new wells will be the reduction of discharge from the ground-water reservoir at some other place. If the reduction is in natural and nonbeneficial discharge from ponds or swamps or tules or greasewood, the new development is all to the good. However, if the water supplies to other wells are reduced, their owners will doubtless protest against the new wells.

Investigations prior to 1945 showed that the Flowell district (which included most of the irrigation wells in the valley at that time) received replenishment chiefly from the east, and therefore chiefly from Chalk Creek. But ground water also moved northwest and north through the Hatton and Meadow districts so that some wells in Flowell may have yielded water derived from the southern part of the valley.

The detailed studies prior to 1945 were concentrated in the area that was developed at that time, which was essentially the artesian area between Flowell and Meadow. These studies are inadequate for the evaluation of the effect of the new pumped wells on the valley's resources. A prerequisite for such evaluation is the extension of these detailed studies into the areas of new development, especially in the Pavant, Hatton, and Kanosh districts, and also into the areas of probable natural discharge, including Clear Lake.

SEVIER DESERT
Millard County

By W. B. Nelson

There have been no detailed studies of the ground water in the Sevier Desert as a whole, but the development of water supplies at one locality, the Topaz War Relocation Center, has been described by Nelson and Thomas (1952). The conclusions that were reached concerning the pumping at Topaz are considered to be applicable also to many other closed basins in Utah and other Western States

Ground-water development.—The development and use of wells for irrigation in the Sevier Desert began in 1950. Prior to that time there were hundreds of small-diameter artesian wells, some of which flowed and others were pumped to provide water for domestic or stock use. The only large pumped wells were the municipal wells of the city of Delta, the railroad wells at Delta and Lynndyl, and the wells at Topaz.

The irrigation wells drilled in 1950 and 1951 (fig. 19) include some along the base of the Canyon Range, near Lynndyl, Oak City, and McCornick and some within the area of artesian flow, and therefore at lower elevations on the Sevier Desert. Those along the base of the Canyon Range obtain water under conditions similar to those in the Pavant district of Pavant Valley (p. 171), and may be regarded as occupying a northward extension of the same water-bearing zone. They tap aquifers of gravel and sand that probably were deposited by streams draining the slopes of the Canyon Range. The ground water may be replenished from the same source, but no data are yet available on this. The seven wells drilled in 1950 and 1951, listed in table 6, range in depth from 114 to 668 feet, and the pumping lifts probably range from 50 to 275 feet. It is estimated that these wells yielded about 1,200 acre-feet to irrigate about 900 acres of land in 1951. Several other wells listed in table 6 yield water for irrigation by artesian flow. These wells are 6 to 8 miles north of Delta, and their yields range from 400 to 800 gpm.

Table 6. Irrigation wells drilled in the Sevier Desert, 1950-51.

Coordinate No.	State No.	Owner	Year drilled	Depth (feet)
		PUMPED WELLS NEAR LEAMINGTON AND DELTA		
(C-14-5)35cbd-1	Ap. 21890	Jack Nielson	1950	291
(C-15-4)8bcc-1	Ap. 21944	A. M. Harder	1951	114
" 17dab-1	Ap. 22418	Clead Nielson	1950	350
" 18adc-1	Ap. 22314	Gerald Nielson	1951	406
" 34bdd-1	Ap. 22559	Fool Creek Irrigation Co.	1951	668
(C-15-5)1ccb-1	Ap. 21890	Fred Greathouse	1951	300
(C-17-6)3ada-1	Ap. 21955	Lafe Morley	1950	580
		Estimated total pumpage in 1951 .... 1,200 acre-feet		
		Estimated area irrigated in 1951 .... 900 acres		
		FLOWING WELLS NORTH OF DELTA		
(C-15-7)35bcd-1	Ap. 22705	V. H. Anderson	1951	
(C-16-7)12baa-1	Ap. 21172	Henry Hansen	1951	470
" 12cdc-1	Ap. 21686	Ralph Pallens	1951	582
		PUMPED WELLS NEAR McCORNICK		
(C-18-5)27bab-1	Ap. 22024	Lawrence Clark	1951	397
" 27dba-1	Ap. 22437	Allen Stephenson	1951	520
" 34adb-1	Ap. 22178	Grant Hurst	1950	354
" 34baa-1	Ap. 21744	Lee Callister	1950	658
" 34bba-1	Ap. 21476	McCornick Well Co.	1950	518
" 34bca-1	Ap. 21612	McCornick Well Co.	1950	400
(C-19-5)4ddd-2	Ap. 22019	Ralph Morrison	1950	521
		Estimated total pumpage in 1951 .... 3,300 acre-feet		
		Estimated area irrigated in 1951 .... 1,400 acres		

There have also been some applications for pumped irrigation wells within the area of artesian flow, but none have yet been drilled. Judging by the experience at the Topaz War Relocation Center, such wells would create some difficulties for the many owners of small-diameter artesian wells, because of the extensive area in which a pumped well can lower artesian pressure. At Topaz the pumped wells obtained water from aquifers of sand; their yield was low and their area of influence per foot of drawdown was large.

Water-level fluctuations.—There is relatively little change in water level or artesian pressure from year to year in wells on the

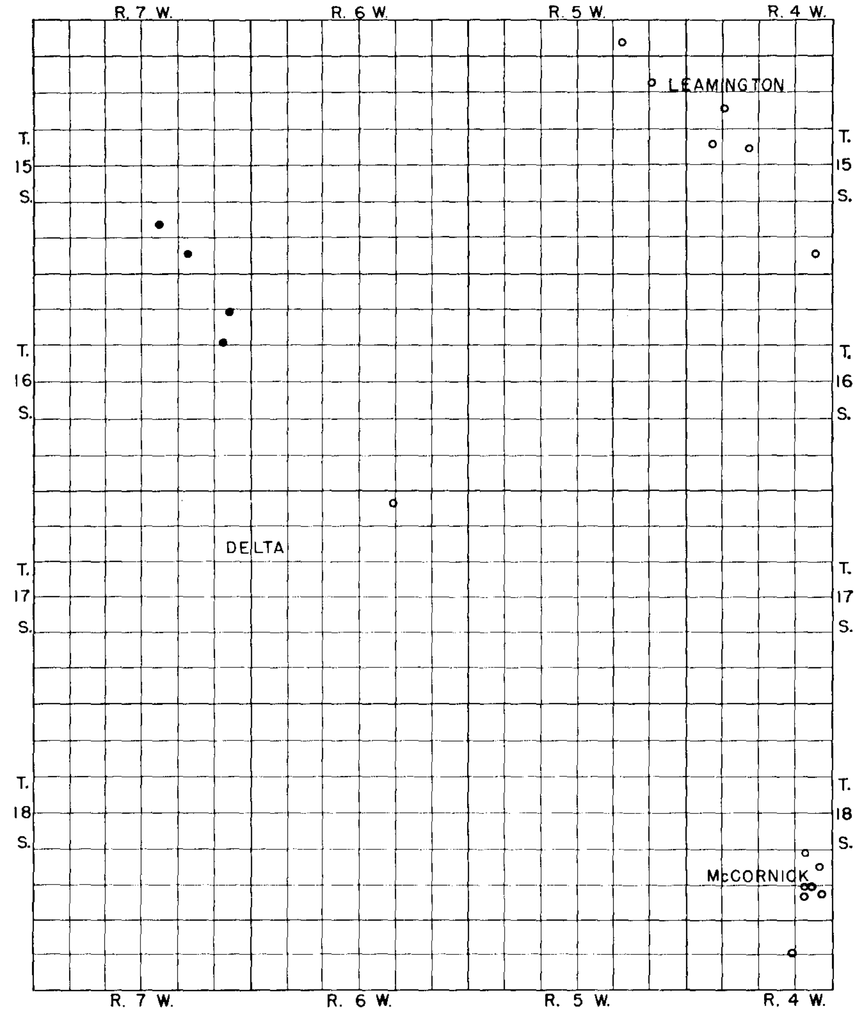


Figure 19. Irrigation wells in the Sevier Desert in 1950 and 1951.

floor of the Sevier Desert, except in those wells that are affected by interference of nearby discharging wells. In particular, the water levels in those lowest wells respond very slightly to variations either in annual precipitation or in annual runoff of the Sevier River, the only major stream that enters the Sevier Desert. This absence of response to factors that control replenishment is a rather common feature of wells in the lower parts of many developed artesian basins in Utah. (See hydrographs for well (C-34-11) 9cdc-1 on fig. 2, well (C-33-15) 31cab-1 on fig. 9, well (C-28-10) 8cdd-1 on fig. 13, and well (B-1-1) 33ada-1 on fig. 23.) In contrast, hydrographs for wells tapping the coarser and more productive aquifers higher in these basins are likely to correlate closely with fluctuations in precipitation and runoff. Apparently the lowest wells in a basin reap no particular gain from a year of abnormal replenishment, probably because factors other than the rate of replenishment control and limit the movement of water underground toward the lowest part of the basin. Undoubtedly one of these controlling factors is the decreasing permeability of aquifers with increasing distance from the canyons that were the sources of both the water and the sediments.

This contrast in water-level fluctuations may have some bearing upon the question as to the effect of pumping from the new wells along the edge of the Sevier Desert upon the older artesian wells on the desert floor. If the pumped wells cause no greater depletion of storage than would occur naturally during drought periods, the effect upon the artesian wells might be barely noticeable, because those wells at the end of the 1931-35 drought had artesian pressures nearly as great as those measured in subsequent years.

Such philosophic discussion, however, is no satisfactory substitute for factual data and scientific study. We do not know whether the artesian wells depend partly upon the slopes of the Canyon Range or entirely upon the Sevier River for their recharge. Nor do we know whether the ground-water recharge to the valley from the Canyon Range drainage basins is enough to take care of present pumping, and possibly of increased demands in the future. The pumping development has been too recent to permit a determination of its effects even within the pumping district. The effect of the pumping upon wells within the area of artesian flow will take a longer period of detailed studies.

UTAH VALLEY
Utah County

By H. E. THOMAS

Utah Valley is a part of the drainage basin of the Jordan River, which extends over five counties (Salt Lake, Juab, Wasatch, and Summit) and includes more than half the population of Utah. The Jordan is first among the drainage basins of the State in quantity of surface water utilized for irrigation and other purposes. It also leads the State in number of wells and in discharge of ground water from wells and springs. Within this drainage basin Utah Valley harvests the water crop of tributary basins that include high mountains having abundant precipitation. So productive are these tributary basins that, in comparison with most other areas in the State, Utah Valley is exceptionally well provided with water.

It does not follow that Utah Valley has no water problems. This relative abundance of water has encouraged intensive development and use of water for irrigation and for municipal and industrial purposes not only in Utah Valley but in Jordan Valley to the north, which includes Salt Lake City and a broad suburban area. Because of this development and the large population that looks to Utah Valley for its water supply, that valley has produced its share of disputes over water, involving court actions as well as some actions not sponsored by the courts, such as the destruction of dams on the Jordan River in pioneer days "by a person or persons unknown." Development has long since reached the point where serious shortages are experienced by many water users in years of less-than-average precipitation and runoff.

Some of the water problems in Utah Valley have pertained to ground water, but in general those difficulties have been local rather than valley-wide in scope. Consequently there has been less demand for detailed information concerning the ground-water resources than in many other ground-water basins, particularly those in the southwestern part of the State. Quantitative studies of the source, movement, and discharge of ground water have not been made in Utah Valley.

Detailed geologic studies have been made of the unconsolidated valley deposits, which constitute the source of practically all the ground water used in the valley, by Hunt, Thomas, and Varnes, (in preparation), and Bissell, (in preparation). The reports of these studies provide some qualitative information on the occurrence of ground water in the valley. "Diversion and Use" surveys were made in the period 1938-40 by the State Engineer, assisted by the Works Projects Administration, and these provided data as to the number of wells in use, and the annual draft from wells for irrigation and other purposes (Humpherys, 1940).

Water-level fluctuations.—Beginning in 1935, water levels or artesian pressures have been measured annually or oftener in selected wells distributed throughout Utah Valley. Recording gages have provided a detailed record of water-level fluctuations in wells at Lehi, American Fork, Geneva, Provo and Payson. The average water-level trend shown in figure 20 is based on measurements at the end of each year in 30 to 33 wells since 1939, and in a somewhat smaller number of wells in earlier years. As shown by the graph, the average water level rose from 1935 to 1938 and has been close to the 1938 level in most subsequent years; however, the average in 1939 and 1940 was considerably below, and in 1945-47 substantially above, that in other years since 1938.

Precipitation and runoff.—The annual precipitation at Provo in Utah Valley, and at Heber in the drainage basin of the Provo River, are also shown graphically on figure 20, together with the culmulative departure since 1935 from the long-term mean. The records from these two stations are not quite concordant, as for instance in the years 1947-50, when the precipitation at Heber was about average, and that at Provo was consistently below average. Both records indicate that the driest period in the past quarter century extended from 1928 to 1935, a period of conspicuous drought in Utah. Precipitation was also less than average in 1939-40, generally above average in 1936-38, 1941, and 1944-46, and not far from average in other years.

The annual runoff of the Provo River at Vivian Park, also shown on figure 20, (quantities diverted from the Weber River are deducted) is offered as representative of the stream inflow to Utah Valley. Both the runoff and the fluctuations of water levels in wells reflect the series of wet and dry years shown by precipitation records.

Ground-water development.—In 1939 (Humpherys, 1940, pp. 33-39), there were 3,933 wells in Utah County, of which 2,691 were flowing artesian wells, 526 were pumped wells, and 716 were unused wells of both kinds. These wells yielded 42,900 acre-feet in 1939, of which 33,700 were used for irrigation, 1,600 for other purposes, and 7,600 were wasted. Utah County includes ground-water basins in Cedar Valley and Goshen Valley, as well as in Utah Valley, but there is very little development or use of wells in those valleys, and the data for Utah County are essentially those for Utah Valley.

Data are not available as to the yield of wells in Utah Valley since 1939. The State Engineer's office reports a continuing demand for new wells, as shown in the following tabulation of applications filed during the years 1940-51. If these applications have all been followed up by drilling, the number of wells in the county—and presumably in Utah Valley—has increased about 20 percent since 1940. About 270 of the new wells were intended to be used for irrigation or industry and are presumably of fairly large yield. Measurements in selected wells (fig. 20) show that the artesian pressure in recent years has been appreciably higher than in 1939 and 1940, and it may be presumed that the rate of

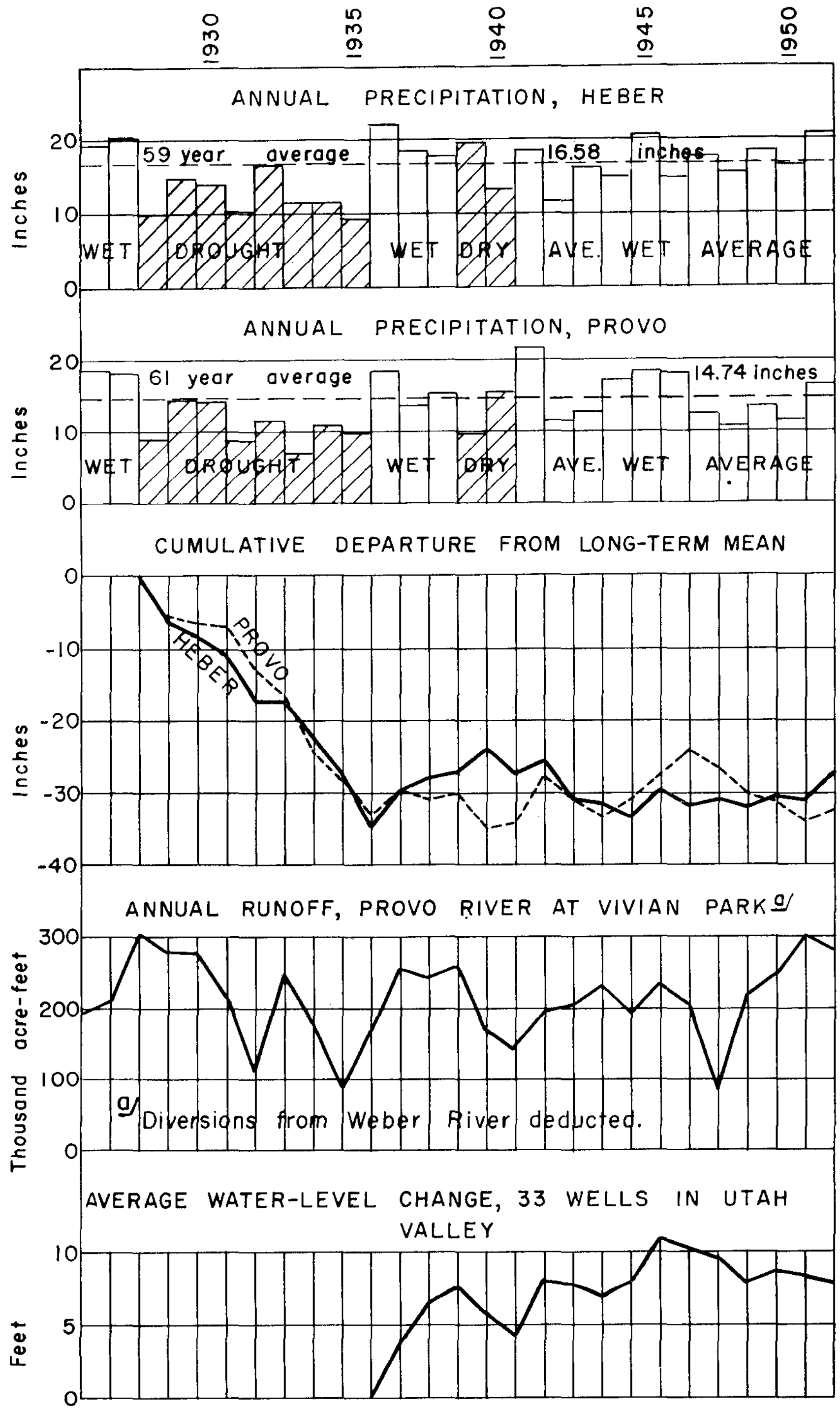


Figure 20. Hydrologic data for Utah Valley, 1926-51.

discharge of the wells drilled prior to those years has also increased, because most of them are flowing wells. Thus, even though quantitative data are not available, it must be concluded that the total draft from the ground-water reservoir is now substantially greater than in 1939.

Table 7. Applications for new wells in Utah County. (Based on records of the State Engineer.)

	Wells for irrigation	Wells for industrial use	Other wells	Total wells
Wells listed as of June 30, 1940				3,619
Applications filed July 1 - Dec. 1, 1940	3	1	7	11
Applications filed in				
1941	7	0	21	28
1942	5	1	23	29
1943	3	5	41	49
1944	19	9	46	74
1945	25	0	38	63
1946	48	5	51	104
1947	20	3	48	71
1948	19	2	53	74
1949	15	4	35	54
1950	25	3	42	70
1951	45	2	36	83
Total applications in period July 1, 1940 - Dec. 31, 1951	234	35	441	710

Although records are lacking for Utah Valley as a whole, there are excellent records of a development within the valley which rates as the most intensive of any in the State in the past decade. Within its plant area of 1,500 acres the Geneva-Columbia Division of U.S. Steel Corp. drew 14,000 acre-feet of water from flowing wells during the water year 1951, of which more than 6,000 acre-feet came from wells drilled during the year and operated for only 4 months. Present indications are that the 20 flowing wells of the company can yield as much as 20,000 acre-feet a year. By contrast, during the water year 1940 when the area was one of irrigated farms, about 2,900 acre-feet was discharged by the 128 wells that were used for irrigation and domestic purposes.

Inevitably questions arise as to the effect of this new development and increasing draft upon the discharge from other wells in the valley and upon the ground-water resources generally; and, more broadly, as to the impact of the Geneva Works with its vast water requirements, upon all the water resources of the Jordan River basin. Fortunately, hydrologic records have been obtained prior to and during the operation of the steel plant which are sufficient to provide quantitative answers to these questions.

Water use at the Geneva Works.—The Geneva Works "uses" about 80,000 gallons of water per ton of ingot steel produced; with steel production of 3,000 tons daily the water requirements would approximate 240 million gallons a day. The *consumptive* use of water—the return to the atmosphere by evaporation from reservoirs and blowdown, coke quenching and descaling, etc.—is only a small fraction of this amount, roughly 2,500 gallons per ton of ingot steel. Even so, the water requirements of the plant are large: in recent years the plant has required 25,000 to 30,000 acre-feet a year, of which 8,000 to 9,000 acre-feet has been consumed within the plant.

The water is drawn from many sources. Purchase of the land brought rights to 128 wells having a claimed combined yield of about 4,400 acre-feet a year, plus rights in the irrigation season to the flow of several springs and drains and to some water diverted from the Provo River. Under a 10-year contract ending in 1952 (and subsequently extended) the company obtained as much as 3,000 acre-feet of water a year from the Deer Creek Reservoir, on the Provo River. Under these several rights and contracts the company has obtained the water used consumptively within the plant.

The steel plant's vast requirements for circulating (nonconsumptive) water are met by diversions from the Provo River, by both pumping and canal, under a contract which obligates the company to return to Utah Lake a quantity of water equivalent to the water diverted from the river, plus the non-irrigation-season flow of springs and drains, plus all water developed within the plant area by subsurface drains.

The 128 wells on the property were plugged in 1942, and a dozen wells of large capacity were drilled to similar depths near the center of the property. These new wells have yielded as much as 6,400 acre-feet a year (in 1950), whereas the 128 wells formerly on the property discharged only 2,900 to 3,400 acre-feet annually from 1938 to 1940. This increased draft, however, has caused no observable loss in pressure head in private wells adjacent to the steel mill, for artesian pressures in the vicinity have fluctuated in response to precipitation and runoff in the same degree as other wells in Utah Valley. Hydrographs of several wells in the vicinity of Geneva are presented in figure 21. The steel-mill wells, because they are remote from the plant boundaries, cause less interference in many outlying wells than was created by individual wells that formerly discharged within the plant area but nearer its boundaries.

Since 1947 the steel plant has drilled five large wells to depths of 830 to 1,190 feet, and thus has tapped aquifers deeper than any previously penetrated in Utah Valley (Thomas, Hansen, and Lofgren, 1952). These wells are highly productive, and the water is of better quality than that obtained from shallower wells. Four of the wells have flowed continuously since June, 1951; their combined discharge declined gradually from 10,000 gpm on June 30,

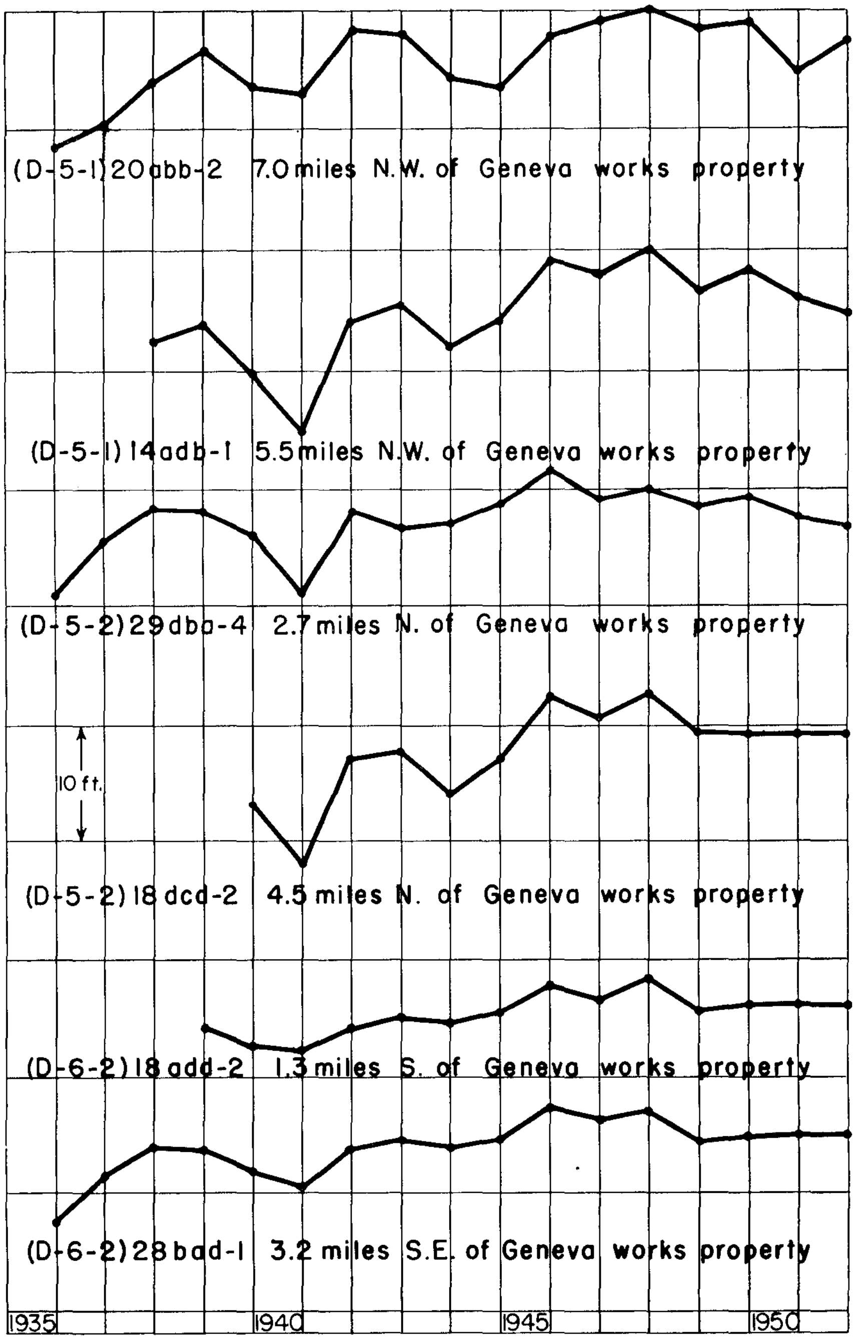


Figure 21. Hydrographs of 6 wells in the vicinity of Geneva, Utah.

1951, to 7,200 gpm on April 24, 1952, and then increased to 8,200 gpm by June 19, 1952. This increased flow is interpreted as indication that the deep aquifers have been replenished, as have the shallower developed aquifers, by water entering the valley in the spring of 1952 as the snow melted in the tributary drainage basin. Thus these deep wells evidently do not tap new and independent sources of water, but a part of the valley fill that is replenished, as are the shallower aquifers, by water from precipitation or from streams.

Water account for the Geneva Works.—The water account presented in the accompanying table 8 is based upon data collected by the Geneva-Columbia Steel Division, in order to meet the terms of its contract obligations in the use of waters of the Utah Lake drainage basin. The account shows that the water taken into the plant has increased from about 18,000 acre-feet in the water year 1946 to 30,000 acre-feet in 1951, and indicates the various sources from which this water has been obtained. Of this total, the water used consumptively within the plant has been of the order of 8,000 to 8,800 acre-feet in recent years.

However, the steel plant has not depleted the water resources of Utah Valley by any quantity approaching the amount used consumptively within the plant. Records are kept of all the water that is released from the plant to Utah Lake through various drains and wasteways. Each year the total measured outflow has been of the same order of magnitude as the total intake, including the measured draft from all wells, springs and drains, the diversions through canals, and the pumpage from the Provo River. In two years the outflow from the plant has exceeded the total intake, and in the other five full years of record it has been 30 to 1,700 acre-feet less than the intake. In seven years the average net depletion of the valley water resources has been about 300 acre-feet a year, which is less than 4 percent of the recorded consumptive use.

Such a finding demands some explanation, and perhaps the first question is whether, prior to the establishment of the steel plant, the area may have contributed similar quantities of water to Utah Lake. Fortunately there are excellent records of the total surface inflow to Utah Lake during the years 1938 to 1940, obtained by Watson, Gardner, and Harding (1941) for the Board of Canal Presidents of the Associated Canals (the Associated Canals divert Utah Lake water into Jordan Valley). A total of 122 sources were listed and measured, of which 14 discharge from the area now occupied by the Geneva Steel plant. These include springs, wells, canal wasteways, and drains. The measured outflow from the steel-plant area was 2,100 acre-feet in 1938, 2,000 acre-feet in 1939, and only 1,400 acre-feet in the relatively dry year 1940.

The water supply for the area during the years 1938 to 1940 was 2,900 acre-feet or more from flowing wells, an estimated 4,000 acre-feet or more from springs and drains rising within the area,

Table 8. Water Account for Geneva Works. (All quantities in acre-feet.)

Water year:	1944 (9 months)	1945	1946	1947	1948	1949	1950	1951
PLANT INTAKE								
Nonconsumptive rights								
Pumping from Provo River	2,980	3,580	1,680	6,940	6,380	8,370	6,290	5,670
West Union Canal	1,540	2,350	2,020	2,360	2,270	2,100	1,420	1,440
Lake Bottom Canal	2,080	1,840	1,780	2,840	3,150	3,190	3,150	2,660
Springs and drains	1,170	1,560	1,990	1,950	1,460	1,530	1,580	1,970
Sub-Total	7,670	9,330	7,470	14,090	13,260	14,980	12,440	11,740
Consumptive rights: Surface Water & Springs								
Deer Creek Reservoir	1,730	2,670	3,020	1,050	3,280	1,900	1,640	—0—
West Union Canal	1,030	1,150	1,000	1,930	1,140	1,490	1,210	1,010
Springs and drains	1,780	2,880	2,670	2,700	2,490	1,530	2,990	2,920
Sub-Total	4,540	6,700	6,690	5,680	6,910	4,920	5,840	3,930
Consumptive rights: Wells								
Shallow wells	1,330	2,200	2,040	2,050	3,330	2,740	5,160	4,420
Intermediate wells	2,130	1,520	1,720	1,850	1,410	1,330	1,230	1,300
Deep wells	—0—	—0—	—0—	—0—	680	1,200	2,090	8,310
Sub-Total	3,460	3,720	3,760	3,900	5,420	5,270	8,480	8,310
Total intake	15,670	19,750	17,920	23,670	25,590	25,170	26,760	29,700
PLANT DISCHARGE								
Outflow to Utah Lake	15,210	20,710	16,230	22,400	25,560	26,330	26,280	29,010
EFFECT UPON VALLEY WATER RESOURCES								
Net depletion	460		1,690	1,270	30		470	690
Net contribution		960				1,160		
Average annual water-resource depletion: 300 acre-feet.								
Consumptive use in plant					8,830	8,280	7,970	8,800

and probably 2,000 acre-feet or more by diversions from the Provo River via the West Union and Lake Bottom canals. Thus, under an agricultural economy, a water account would show that at least 9,000 acre-feet was provided to the area each year, of which the return flow to Utah Lake was 2,100 acre-feet or less. The remainder was returned to the atmosphere within the plant area, by consumptive use of crops or by other transpiration or evaporation; some may also have moved to Utah Lake by subsurface flow, but presumably the amount would be very small because the plant area is underlain by fine-textured and relatively impermeable clay deposited on the bottom of ancient Lake Bonneville.

From these calculations it appears that the water used consumptively within the area under an agricultural economy was of the same order of magnitude as that now used by the steel plant. But under agricultural conditions this quantity represented a depletion of the valley's water resources, whereas the steel mill has been able to return water to Utah Lake in quantities substantially equal to all the water that is obtained from all sources. It is believed that this achievement can be attributed chiefly to the effect of the plant's subsurface drainage system, which presumably has lowered the water table and thus has reduced the evapotranspiration within the plant area.

The company's records show that in each month the quantity of water collected by its subsurface drains and discharged into Utah Lake exceeds the monthly intake or makeup of water. This excess, listed by the company as the water "developed by subsurface drains," bears some relation to the total intake, as indicated by the following tabulation, because it has been far greater in recent years than in the early years when less makeup water was required.[1] However, the quantities are not directly proportional. In nearly every month the water "developed by subsurface drains" has been at least 20 percent, and in some months it has exceeded 50 percent, of the total makeup.

Table 9. Relation of total makeup to water developed by subsurface drains.

Water year	1 Total intake (acre-feet)	2 Water developed by subsurface drains (acre-feet)	Ratio $\frac{\text{Col. 2}}{\text{Col. 1}}$
1945	19,750	3,190	0.16
1946	17,920	Record incomplete	
1947	23,670	5,410	.23
1948	25,590	8,800	.34
1949	25,170	9,440	.37
1950	26,760	7,290	.27
1951	29,700	8,140	.27

1. The apparent increase in subsurface drain water in 1948 and subsequent years is attributed at least in part to more complete measurement of outflow, after installation of weirs on two channels not previously measured.

The other factors that affect the rate of subsurface drainage are not known to the writer, although some of the variation doubtless results from steel-plant operations. An effort to correlate the water developed by subsurface drains with natural factors has met with indifferent success. Precipitation has some effect, for in October, 1946, when precipitation of 5.39 inches at Provo was higher than in any other month since 1943, the subsurface drains yielded more water than in any other month in the water years 1944-47. After adjusting for changes in storage in Geneva's reservoir, the net yield of the subsurface drains approached the annual maximum in June, 1948, May, 1949, and November, 1950; in each of these months the precipitation exceeded 2 inches. But there is no close correlation between monthly precipitation and the rate of subsurface drainage. Evapotranspiration may also be expected to be a factor, and in many years the subsurface drains yield least during one or more of the summer months; but on the other hand, August, 1948, was one of the months of maximum yield.

Although the available data do not show the sources of the water developed by subsurface drains, it is evident that the steel plant has salvaged within its area enough water to balance its consumptive-use requirements. The quantity thus salvaged is reported to be of the order of 5 acre-feet per acre, which is about 4 times the average annual precipitation, and higher than one might expect. It is possible that some of the water estimated to be used consumptively finds its way instead into Utah Lake.

At any rate, Utah has gained a major industry having large water requirements, but with practically no depletion of the State's developed water resources. By economical water management, including salvaging of ground water formerly lost by natural processes, the Geneva Works returns to other water users in the Jordan River drainage basin more water than had been left to them by former occupants when the same area was agricultural land.

JORDAN VALLEY
Salt Lake County

By B. E. LOFGREN

In July, 1931 the Geological Survey, in cooperation with Salt Lake City, began an investigation of the ground-water resources of Jordan Valley. This cooperative study continued for 4 years. Its results are summarized below, from the report by Taylor and Leggette (1947, pp. 1-4).

> The Jordan Valley is a small part of a larger area that during the glacial epoch was covered by an ancient lake known as Lake Bonneville. The Jordan River, the natural drainage path from Utah Lake, flows northward through the center of the valley and empties into Great Salt Lake. The Jordan Valley is a rock-bottomed valley in which a great thickness of clay, silt, sand, and gravel has been laid down irregularly.

The thickness of this material is not definitely known, but wells in the valley have penetrated as much as 2,000 feet without encountering bedrock. These sediments are chiefly stream and lake deposits. The material at the surface of the valley was deposited in an ancient lake which at its highest stage stood about 1,000 feet above the level of Great Salt Lake. The shore deposits laid down in this lake occur in the form of terraces or benches around the margin of this basin. The two most prominent benches are known as the Bonneville and Provo benches. The Bonneville bench was formed during the highest stage of the lake, and the Provo bench during a later stage about 400 feet lower.

Ground water occurs in the valley as (1) shallow ground water overlying the confining layer creating the artesian basin, (2) local perched water bodies, and (3) pore spaces of the sand and gravel of the stream and lake deposits. The most permeable water-bearing material occurs near the foot of the Wasatch Mountains in the area occupied by the Provo and Bonneville benches. At some distance from the mountains beds of finer material—dense silt and clay—alternate with more permeable beds of sand and gravel, giving rise to artesian conditions. On the Provo and Bonneville benches the water levels lie at considerable distances below the surface; but in the lower areas along the Jordan River and west of Salt Lake City as far as the lake, artesian conditions exist and many flowing wells have been drilled.

The principal sources of ground water in the Jordan Valley are the water that seeps into the ground from the streams entering the valley, the water that penetrates directly from the rain and snow that fall upon the bench lands on the east side of the valley, and the water that percolates downward from irrigation canals and from irrigated lands, chiefly derived from Utah Lake. In addition some deep-seated thermal water rises along the Wasatch fault.***

Discharge of ground water occurs in the Jordan Valley through the flow of springs, evaporation from the soil and transpiration from plants in the shallow-water areas, and withdrawals from flowing and non-flowing wells. A large part of the discharge occurs through the several thousand flowing wells that have been drilled in the valley, many of which are allowed to flow continuously.

There are numerous springs in the Jordan Valley. East of the Jordan River the upper limit of the area of springs is below the edge of the Provo bench and may be indicative of an overflow from the ground-water reservoir. Much of the water discharged by the springs at altitudes lower than those of the main irrigation canals may be supplied by seepage from the canals and irrigated lands. Considerable areas of land adjacent to the Jordan River are wet and swampy because of spring discharge. Several springs emerge directly from the beds of the streams entering the valley from the east, and it is possible that springs occur in the bed of the Jordan River. There is also some evidence that there are springs in the bed of Great Salt Lake. The water emerging along the upper line of springs, which lie below the Provo bench, may represent overflow from the main ground-water reservoir, or it may be the drainage from a water table perched above the main ground-water reservoir. However, the manner in which the sediments of the valley were laid down makes it probable that the water from the upper line of springs represents overflow from the main ground-water reservoir.

A considerable amount of ground water is discharged by evaporation directly from the soil in the areas where the water table is within a few feet of the surface, and also by transpiration from the vegetation on the lower lands, especially by the grasses along the Jordan River and the trees along its tributaries.

Most of the artificial discharge of ground-water in the Jordan Valley takes place through flowing wells. In an area of about 7 square miles in the northeast corner of T. 2 S., R 1 W., and the northwest corner of T. 2 S., R. 1 E., there are more than 1,000 flowing wells.

The total minimum ground-water discharge from the artesian basin was estimated to be about 300 cubic feet per second.

The pressure head of the ground water is greatest on the sides of the valley, adjacent to the Wasatch and Oquirrh Mountains, and declines from both sides toward the Jordan River. There is also a general decline in head toward the north and northwest, in the direction of Great Salt Lake, which indicates a general movement of the ground water in that direction. Most of the wells in the northwestern part of the valley yield waters containing from 1,000 to 15,000 parts per million of chloride, but a tongue-shaped area of water low in chloride extends northward, and this is believed to indicate movement of the fresh ground water toward Great Salt Lake, with possibly some discharge into the lake.***

During the drought of 1934, Salt Lake City Corporation averted a major water famine by the rapid drilling of 17 wells of large diameter (12 to 20 inches) in the benchlands east of the Jordan River. Fourteen of these were producing wells, yielding 46 cubic feet per second at a total cost of about $250,000. One of the wells yielded about 10 cubic feet per second with about 40 feet of drawdown.

Since 1935 the Geological Survey's program in Jordan Valley has been limited to the periodic measurement of a dozen selected observation wells. In addition, Salt Lake City Corporation has recorded the fluctuations of water level in more than a hundred wells, of which 17 have been equipped with recording gages. The hydrographs for several of the wells shown on figures 22 and 23 are based on the records obtained by Salt Lake City.

Since the enactment of the ground-water law in 1935, the State Engineer has collected a considerable amount of ground-water data for all areas of the State. His files include claims for wells drilled and used prior to 1935, and applications for drilling of wells since that year. Claims and applications are supported by data as to depth and diameter, yield and use of water from each well, date of completion, and, if available, a log of the materials penetrated. His "Diversion and Use" survey during the water year 1939 showed that there were then about 6,650 wells in Salt Lake County, and that the annual yield of those wells totalled about 29,500 acre-feet, of which 6,700 was used for irrigation and 18,800 for demestic, industrial, and miscellaneous purposes. Since 1939 there have been no surveys of water use or computations of total yield of wells in Jordan Valley.

The current situation with respect to ground water in this most populous of Utah's valleys may be summarized as follows: There are probably about 8,000 wells in Jordan Valley; they obtain water from numerous aquifers down to depths as great as 1,000 feet, and it is likely that there are productive horizons at still greater depths. Records of water-level fluctuations in selected wells have been maintained for 20 years, and these show the composite effects of withdrawals from wells, natural discharge, and recharge to the aquifers by various means.

We do not know the extent of the development by means of wells, however, nor is there quantitative information on the natural discharge or recharge. By intensive field studies, including tests of selected groups of wells, and by analysis of the imposing array of basic data in the files of the Salt Lake City Water

Department and the Utah State Engineer, a quantitative inventory of the valley's water supplies could be developed which would show the extent to which the valley's water resources are developed. Such an inventory is justified by the present uses and prospective needs of water in the Salt Lake City metropolitan area. But the magnitude of the task is its chief drawback. Doubtless more than 25 percent of all the wells in the State are in Jordan Valley, and a comprehensive study of that valley would require several years of work by a staff as large as that now engaged in the entire State-wide cooperative ground-water program.

Although a quantitative analysis of ground-water development in Jordan Valley is not possible at this time, some inferences may be drawn from study of the water-level trends in the observations wells in Jordan Valley. In several wells located in the higher, marginal parts of the valley, the fluctuations of water level correlate reasonably well with the fluctuations in annual precipitation and stream flow (fig. 22); these wells are presumably in or near the recharge areas for the aquifers of the valley fill. In wells that are within the area of artesian flow, the water levels may likewise reflect the changing rates of recharge, or they may fluctuate in response to discharge from wells in the vicinity, or they may change very little from year to year (fig. 23).

Water-level trends in wells in or near recharge areas.—The climatological history of Jordan Valley in the past two decades may be summarized briefly: precipitation markedly deficient during the drought years 1931-35, and approximately normal in the next three years; a dry year in 1939 and two wet years in 1940-41; precipitation rather close to normal in the decade 1942-51, and not deviating more than 3 inches from the long-term average in any single year. The runoff of the streams entering Jordan Valley fluctuates in accordance with this general pattern as shown by the hydrographs for the Jordan River and Big Cottonwood Creek on figure 22.

The wells whose hydrographs are shown on figure 22 are near the channels respectively of Little Cottonwood, Big Cottonwood, and Red Butte Creeks and the Jordan River, within a few miles of the mouths of their canyons. In each of these wells the water level at the end of the 1931-35 drought was the lowest of the 17- to 20-year period of record. In each well, also, the water level trended upward from 1936 to 1939, although the precipitation and runoff in those years were not notably above average. A slight downward trend in 1939-40 shows the effect of the dry year 1939; and similarly, the upward trend in 1941-42 reflects the abundant precipitation of those years. In the Keyser well the water level in 1942 was the highest of record, but the other three wells have reached greater maxima in subsequent years. In the well (C-2-1) 22bd, in the southern part of the valley, the water level has trended generally upward since 1936, and in 1951 it was the highest recorded in 20 years.

In this group the water levels reach annual maxima in April or May in the Salt Lake City well (D-1-1) 9aca-1 along Red Butte Creek, in July or August in the Keyser well along Big Cottonwood Creek, and in October or November in the other two wells. These seasonal fluctuations are presumably to be correlated with the periodicity of the recharge from the respective streams.

Water-level trends in the area of artesian flow.—In the Templeman well (fig. 23) the water-level trends are similar to those of wells near the recharge areas, although seasonal fluctuations and annual changes have somewhat less amplitude. This well is near the upper edge of the area of artesian flow, and in some years the water level has dropped below the land surface.

The seasonal fluctuations of water level in the other four wells represented on figure 23 are caused principally by the varia-

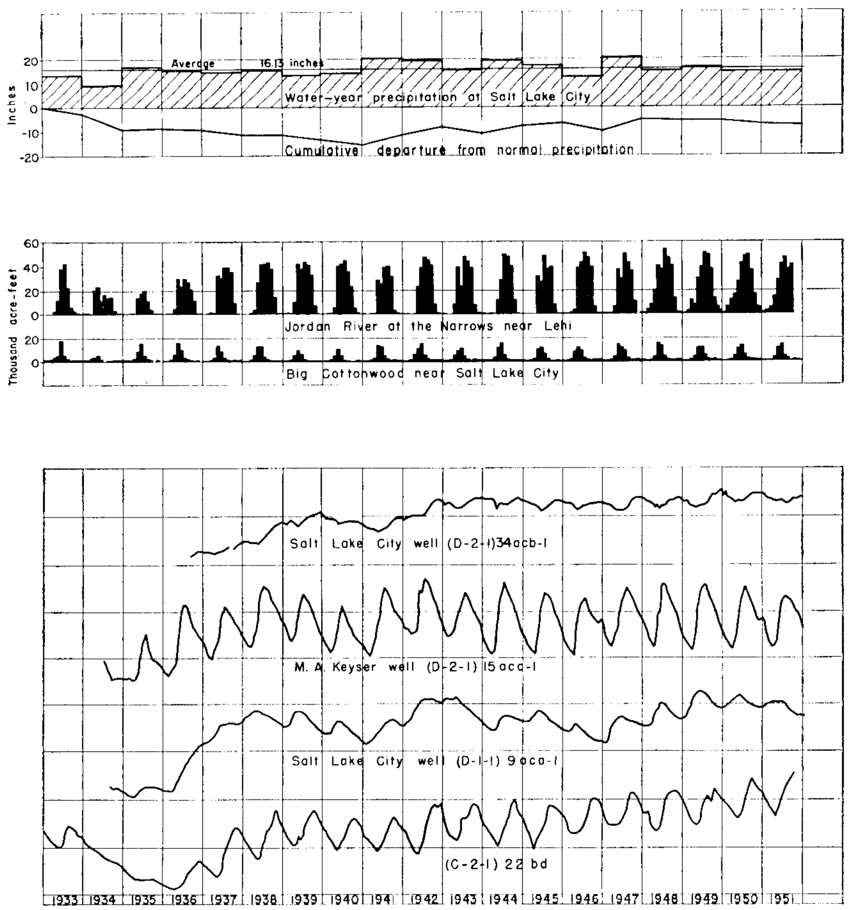


Figure 22. Relation of precipitation and stream flow to water levels in selected wells in Jordan Valley.

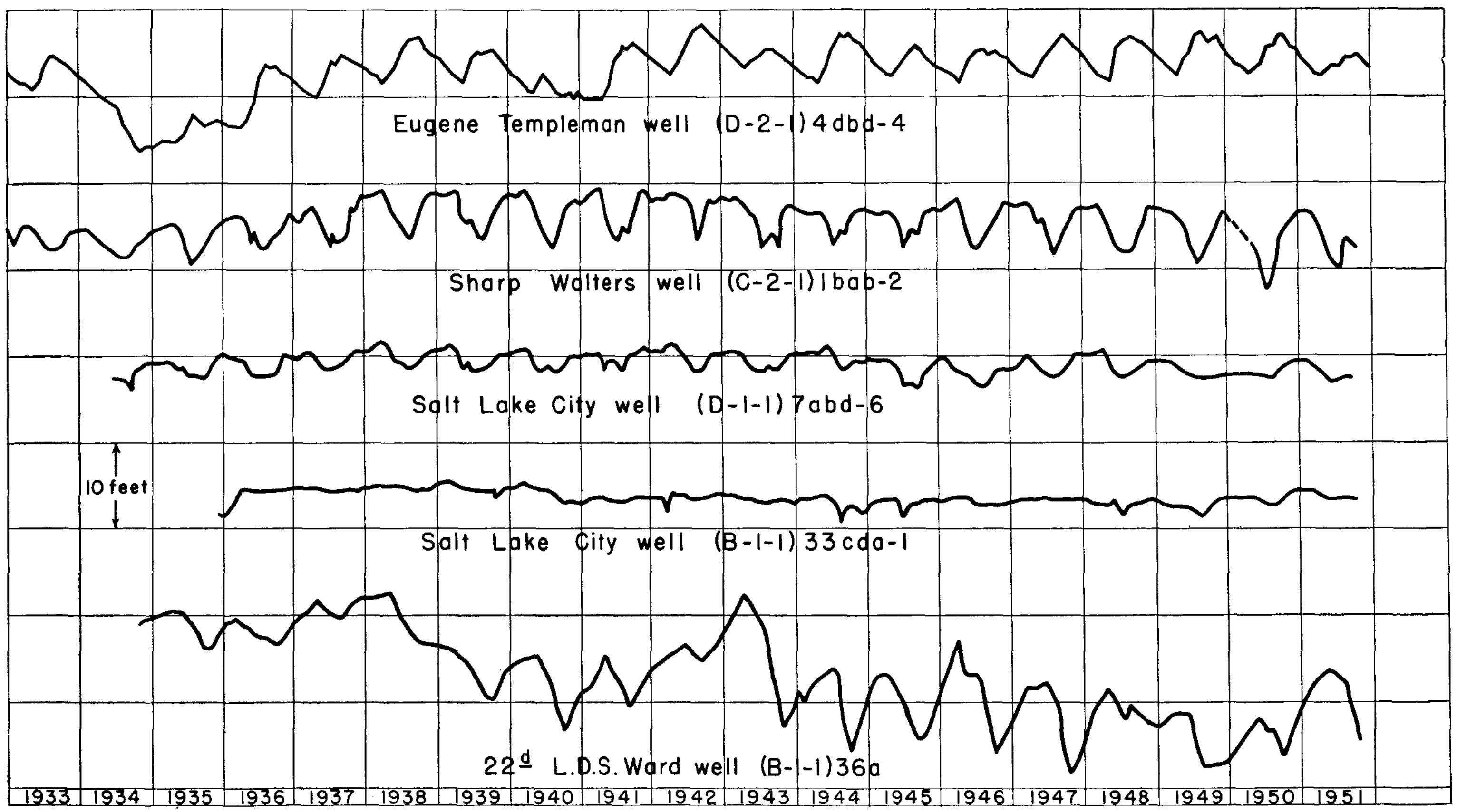


Figure 23. Hydrographs for 5 wells in the area of artesian flow in Jordan Valley.

tion in discharge from other wells. In the Sharp Walters well, west of Murray, the low levels from May to October are doubtless the result of draft for irrigation. The Salt Lake City well (D-1-1) 7abd-6 is in the midst of an urban area served by the municipal water system, and the demand upon the ground-water supply is relatively light. Nevertheless there appears to be a variation in draft from winter to summer. In both wells the water level was highest of record in the wet year 1942 and has trended downward slightly in the following decade.

The Salt Lake City well (B-1-1) 33cda-1, at the municipal airport, is in the lowest part of Jordan Valley where the aquifers are of relatively fine texture and not very productive, and where the soils in extensive areas are saline and poorly suited to agriculture. There are few wells in the area, and those are of small yield. The hydrograph indicates little seasonal variation in rate of discharge, and a gradual downward trend since 1939. This downward trend may have only local significance. On the other hand, it may be a resultant of the increasing development of ground water in the valley, for this well is in a good position to indicate changes in the rate of ground-water outflow from the valley toward Great Salt Lake.

The 22d LDS Ward well is in the northwestern part of the city, where there is considerable pumping from wells for industrial and municipal use. The sharp seasonal fluctuations reflect this pumping, and the general downward trend since 1935 probably has been caused by a progressive increase in draft. Superimposed upon the general trend are an accelerated downward trend in 1939 and a marked rise in 1942, which are attributed to variations in the rates of recharge to the ground-water reservoir.

Potential additional development.—Each spring flood water wastes into Great Salt Lake from each of the streams that enter Jordan Valley. This is especially true in years of high precipitation and when melting of snow occurs rapidly in the spring, but in almost every year there is an appreciable quantity of water that could be diverted for recharging the underground reservoirs if facilities were available. The potentialities for artificial recharge are especially good on Big and Little Cottonwood Creeks, which each year waste hundreds of acre-feet of water into the lake, but may apply also to City Creek, which discharges into the northwest section of Salt Lake City where water levels have trended downward during the last few years.

Springs and marshy areas, especially in the lower areas but also to some extent in higher areas within the valley, suggest that the underground reservoir remains at "full" level and therefore is not able to serve as efficiently as if water levels were drawn down during the summer months of high demand and permitted to refill during the following winter and spring months.

In 1932 Leggette and Taylor estimated roughly the total groundwater discharge from Jordan Valley as follows (1949, p. 46):

The total visible ground-water discharge, estimated as the sum of the discharge from nonthermal springs, the gain in stream flow, and the discharge from wells, is about 300 second-feet, or 217,000 acre-feet per year. This includes visible discharge from both the artesian basin and the shallow water body overlying the artesian basin and may be considered as a minimum ground-water discharge —invisible underflow out of the valley toward the northwest, and evaporation and transpiration. As this investigation was concerned primarily with the artesian basin, we may for the purposes of this report ignore the discharge from the shallow water body. However, if we assume that the invisible underflow out of the valley and from the artesian basin is about equal to the discharge from the shallow water body included above in the measured discharge, the total estimated ground-water discharge from the artesian basin would remain about the same—300 second-feet, or 217,000 acre-feet per year.

It is apparent that a large percentage of the total quantity of ground water discharged each year from the underground reservoir is lost each year into the lake. Much of this could be put to more beneficial use in the future, though at the expense of a general lowering of the water-levels throughout the valley. With a proper understanding of the recharge, storage, and discharge possibilities of the valley, the ground-water levels in the aquifers could be so regulated that practically all early-spring stream flow could be diverted to underground storage, thus considerably increasing the utility of the ground-water reservoir and salvaging water that at present is flowing to waste.

EAST SHORE AREA
Davis County

By R. G. Butler and H. E. Thomas

The population of Davis County doubled between 1940 and 1950, and it thus rates as the fastest-growing county in the State. The military installations at Hill Field, Clearfield, and the Ogden Arsenal, developed or greatly expanded during World War II, have been largely responsible for this increase, particularly in the communities of Clearfield, Sunset, Layton, and Sahara Village. In part the increase in population is attributed to the country's position between the metropolitan centers of Salt Lake City and Ogden, and its attractiveness to suburban residents and industries.

During the decade there has been increasing use of water by the military installations, as well as by municipalities and industries. At present most communities are seeking more water supplies for their expanding population, and some industries are likewise looking for additional supplies. It is likely, however, that the agricultural use of water, chiefly for irrigation, has not increased. Indeed, in the conversion of various agricultural lands to other purposes, the water appropriated for irrigation has also been converted to these other uses. Although the use of water for irrigation has remained practically static for some time, there is irrigable land that could be put into production if additional water supplies were available.

A detailed study of the ground water in the southern part of Davis County was completed in 1947 and was described in the State Engineer's 26th Biennial Report (Thomas and Nelson, 1948). This investigation was undertaken in cooperation with Bountiful City and Davis County. The conclusions of the study are summarized as follows, pp. 59-61):

> The Bountiful district is a fertile agricultural area favorably situated between the largest cities in the inter-mountain area and athwart the major routes of transportation and communication, but development of its residential, industrial, and agricultural potentialities will be restricted until existing water resources are supplemented by importation from other drainage basins that now have surplus water supplies. . . .
>
> All the streams entering the Bountiful district from the adjacent Wasatch Range are small, the largest being less than 7 miles long. The total discharge of these streams is estimated to average about 24 second-feet, or 18,000 acre-feet a year. This water, which constitutes the major source of ground water and surface water for irrigation in the Bountiful district, has long been insufficient to meet requirements. For the past 26 years water of poor quality has been pumped from the Jordan River for irrigation of lands near the city of Bountiful, and in recent years about 4,000 acre-feet has been pumped annually. From 11,000 to 15,000 acre-feet of water has been obtained annually from the 1,440 wells and water tunnels in the district, mostly by artesian flow, although there are about a dozen pumped municipal, industrial, and irrigation wells and scores of smaller wells that are pumped for domestic supply. This ground water comes from a reservoir that is recharged chiefly by seepage from stream channels and irrigated lands, supplemented by precipitation upon the eastern part of the district.
>
> Although it is evident that a large proportion of the water that flows into the Bountiful district is being used, there are several opportunities to conserve water and thus increase the beneficial use of existing supplies. Measurements of surface water flowing through the district show that 2,000 to 6,000 acre-feet has been lost in recent years to Great Salt Lake, chiefly during the spring runoff from melting snow. None of the tributary streams has suitable reservoir sites, and if this water is to be utilized it must be stored in the underground reservoir, which would require diversion into the recharge areas for the artesian aquifers. Also, many flowing wells waste considerable quantities of water, some by failure of their owners to cap them when not being used beneficially and some because of faulty well construction which permits water to leak around the well casing. The quantity wasted from flowing wells amounted to about 2,000 acre-feet in 1946. Much of this water could be saved for beneficial use at comparatively small expense. Finally, a considerable amount of water is lost from the artesian reservoir each year through springs and by upward movement in the western part of the district, where it evaporates or is transpired by salt grass and associated plants. In order to reduce this loss it would be necessary to lower the artesian head in aquifers by pumping. Thoroughgoing measures of conservation might increase the water available for beneficial use by as much as 5,000 acre-feet in an average year.
>
> Study of the geology of the area shows the effect of a most spectacular geologic process upon the ground-water reservoir. This process, the destructive mud-rock flows that result from cloudburst floods, has been witnessed by present inhabitants. In 1930 debris as much as 12 feet thick was deposited over the fertile lands near the mouths of several canyons as the result of intense summer rainstorms upon steep mountain slopes, where deep soils have developed in past geologic ages.

Similar deposits have accumulated in a belt along the base of the range for a long time, and are more than 750 feet thick at one well site. These torrential deposits are characteristically unsorted and relatively impermeable, and wells drilled in this belt commonly yield little water. Thus conditions in the Bountiful district contrast with those found near Salt Lake City, Ogden, and elsewhere along the base of the Wasatch Range, where wells have produced abundant water supplies from sites in similar topographic positions. Because of the relative impermeability of the torrential deposits, little water is added to the ground-water reservoir where they occur at the surface; the bulk of recharge to artesian aquifers occurs farther west and at greater distance from the mountains.

The Bountiful district was inundated by ancient Lake Bonneville, and the shore lines of that lake are prominent along the eastern margin of the district. Permeable beds of gravel and sand deposited along these shores yield water to water tunnels, drains, and wells in the bench lands east of Bountiful. The artesian wells farther west, however, obtain water from gravel and sand beds deposited by streams prior to the existence of Lake Bonneville. Clay and silt were deposited on the bottom of the lake upon these alluvial beds, and confine the water under sufficient pressure to flow from wells.

The western base of the Wasatch Range is marked by a fault zone 2 to 3 miles wide, in which displacement with upward movement on the east side has been chiefly responsible for the present height and steep west slope of the range. There has been movement along at least three individual faults within this zone since the recession of Lake Bonneville. This movement has left escarpments as much as 75 feet high, has increased the gradients of tributary streams, and no doubt has contributed to the volume and extent of mud-rock flows below the escarpments. Warm springs rise along the westernmost escarpment, and farther north small quantities of warm saline water are contributed to the artesian reservoir along the fault.

The water pumped from the Jordan River has a high mineral content, and is notably different from other waters in the Bountiful district. Wells west of the upper canal yield waters similar to that of the canal and indicate that the canal water has moved as much as 2½ miles westward through aquifers as much as 200 feet deep. It is concluded that the lands irrigated by the upper Bonneville canal are within the recharge area for those aquifers, and that not only the canal water but the precipitation, water applied from streams for irrigation, and the seepage from cesspools and septic tanks in the residential areas of Bountiful and Val Verda serve to recharge the artesian reservoir.

In the northern part of Davis County an inventory of well discharge was made in 1946, and a county-wide inventory of well discharge was completed in the summer of 1952. These records for 1946 and for 1952 will show the effects of the development since 1939, when the State Engineer reported (Humpherys, 1940, pp. 3-39) that there were 2,230 wells in Davis County, of which 1,290 were flowing wells, and that these wells discharged 15,000 acre-feet of water during the year, of which 8,800 was used for irrigation and 1,700 for domestic, industrial, and miscellaneous purposes, and 4,500 acre-feet was wasted.

Since 1939 applications have been filed with the State Engineer for more than 350 new wells, of which about 70 are relatively large wells intended for irrigation or industrial use. Thus by the end of 1951 the number of wells in the county was about 15 percent greater than in 1939.

The principal hope for meeting Davis County's increasing requirements for water lies in the Bureau of Reclamation's Weber Basin project, authorized by Congress in 1948. This project proposes storage of water on the Weber River and diversion by tunnel and canal southward as far as the southern limit of the county, and construction is scheduled to begin in 1952. Special ground-water studies related to the Weber Basin project have been started in both Weber and Davis Counties, and are currently (July, 1952) in progress. These studies have not been undertaken as a part of the State cooperative program but have been supported by the Utah Water and Power Board, the Bureau of Reclamation, and the Weber Basin Water Conservancy District.

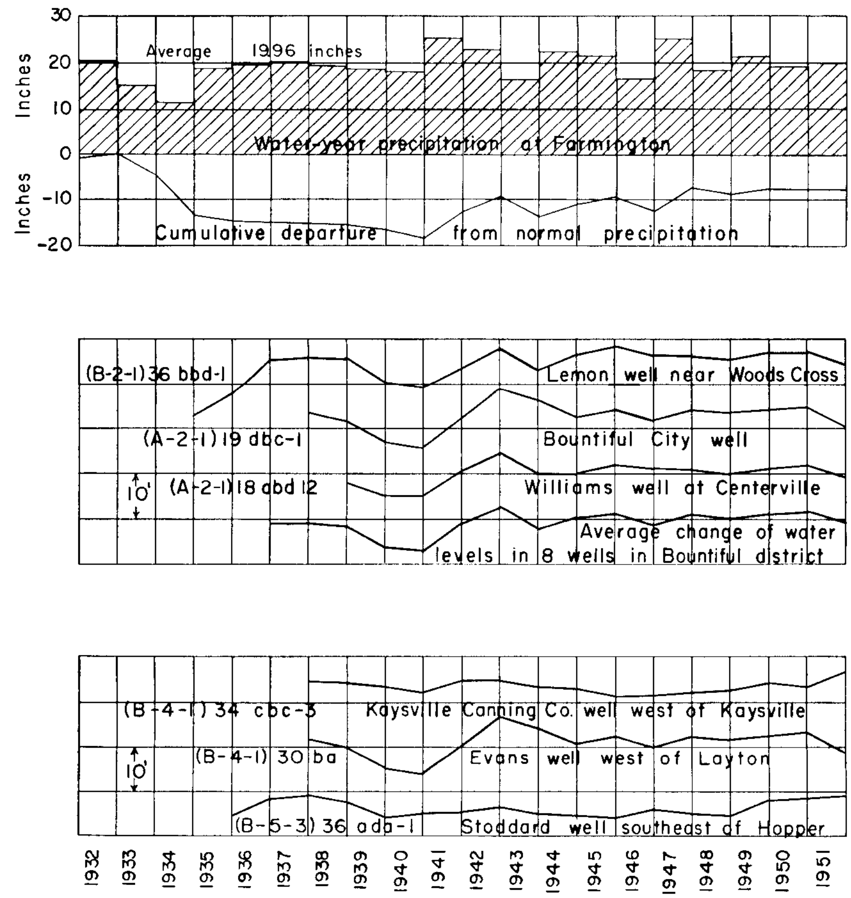


Figure 24. Annual water-level trends in several wells in the East Shore area.

The State cooperative program in Davis County, as in other ground-water basins in the State, has provided long-term records of fluctuations of water levels in selected wells, and these records form the basis for inferences as to the changes in ground-water storage, whether as a natural result of climatic variations or as an artificial result of draft from wells.

Water-level trends in relation to precipitation. — The water-level trends in most observation wells are correlative with the trends in annual precipitation as recorded at Farmington. In the wells of longest record, the lowest water levels were recorded after the 1931-35 drought, in 1935 or 1936. In most wells the highest water levels were recorded in 1942, after the year of greatest precipitation since 1916. The correlation between precipitation and water levels is well shown in figure 24, particularly as to wells in the southern part of the county.

In the northern part of the county the water levels in some wells have risen appreciably in recent years, as shown by the hydrographs for the observation wells at Kaysville and Layton. The cause of these recent rises in water level is not yet known.

Annual discharge by wells.—According to the State Engineer's Diversion and Use Survey (Humpherys, 1940) the wells in Davis County discharged 15,000 acre-feet during the water year 1939. In that year the discharge from wells in the Bountiful district was 10,400 acre-feet, or 70 percent of the county total.

Data are available as to well discharge in the Bountiful district in several other years. William Peterson of the Utah State Agricultural College tabulated measurements of flow in August, 1932, (unpublished data), which suggest a total yield of about 13,000 acre-feet in that year. Thomas and Nelson (1948, p. 191) computed the annual discharge to be 10,600 acre-feet in 1937, 11,300 in 1938, 9,500 in 1940, and 12,200 in 1946. The total discharge from wells in these years (most of which was from flowing wells) bears a direct relation to the average water level in eight selected wells in or near the recharge area for the artesian aquifers. As pointed out in the study of the Bountiful district Thomas and Nelson, 1948, (p. 191):

> This direct relation between storage and discharge exists also in other artesian basins, in Utah, and is in contrast to that in many ground-water basins where water must be pumped, and where discharge is inversely proportional to relative storage because of increased demand for water during dry years when storage is low. The relationship is only a rough approximation, because many instances can be cited of well owners using their wells very little in years when there is much ground water in storage, because of adequate stream supplies, and drawing heavily on wells when surface supplies and ground-water storage are low. The fact that there is even a rough direct correlation indicates that most wells are open for approximately the same periods year after year, and that discharge is therefore dependent largely on artesian pressure, which in turn is determined by the quantity of water in storage.

Judging by this approximate relationship in five years when discharge from wells was measured, the total discharge of artesian wells in the Bountiful district in the past decade is believed to have ranged from about 9,000 acre-feet in 1941 to 13,000 acre-feet in 1943. Pumpage from wells within the recharge area and discharge of tunnels and drains in the foothills would represent an additional draft upon the ground-water reservoir, not included in these estimates.

OGDEN VALLEY

Weber County

By H. E. Thomas

Ogden Valley has an area of less than 25 square miles, but it is exceptional if not unique in its water-storage facilities. Pineview reservoir, created when Pineview dam was completed by the Bureau of Reclamation in 1936, has a capacity of 43,600 acre-feet. It occupies the lower part of Ogden Valley and covers part of the area underlain by an artesian ground-water reservoir. Both reservoirs are of great economic importance to the city of Ogden and nearby towns and irrigated lands in Weber and Box Elder Counties. The artesian reservoir provides all but a small part of the municipal water supply for the city, and the surface reservoir provides water for irrigation of about 16,000 acres of suburban and farm land.

A detailed study of Ogden Valley prior to the construction of Pineview dam led to the following conclusions (Leggette and Taylor, 1937, pp. 99-100,):

> Ogden Valley is a fault trough bounded on both the east and west by faults that dip toward the middle of the valley. This fault trough contains unconsolidated deposits of clay, sand, and gravel, whose thickness is more than 600 feet.* * * These sediments include about 70 feet of clay, sand, and gravel in alternating layers, below which is a bed of varved clay whose maximum thickness is about 70 feet. This clay is continuous under the lower parts of the valley and is the confining bed that producers the artesian conditions.*** Wells drilled through the clay confining bed encounter water that is under artesian pressure.* * *
>
> Natural discharge of ground water from the valley occurs chiefly as flow from springs, return flow to streams, transpiration by plants, and evaporation from soil. Artificial discharge occurs by the withdrawal of water from flowing and nonflowing wells. The greater part of the artificial discharge of water from the artesian reservoir occurs in Artesian Park, where there are 48 wells connected to the municipal water system of the City of Ogden. During 1933 and 1934 the discharge from these wells ranged from about 12.9 to 20.5 second-feet.

Analysis of hydrologic data obtained in Ogden Valley prior to 1941 resulted in some additional findings (Thomas, 1945, pp. 5-6):

> (1) The artesian reservoir is filled to capacity nearly every year during the spring runoff from melting snow; (2) after the annual freshet, the recharge to the reservoir is insufficient to balance the discharge from artesian wells, which ordinarily is at a maximum

during the summer; the reservoir is depleted and is not filled again until the following spring; (3) during the periods when the artesian reservoir is not full the rate of recharge is more or less proportional to the inflow to the valley by streams, except that rain on the recharge area may be of sufficient intensity to contribute some water by infiltration and deep penetration; and (4) the artesian reservoir thus serves to store water that would otherwise be lost to Great Salt Lake in the excess spring overflow and available records indicate that water used by increased draft from wells would be replenished in normal years by increased recharge during the spring freshets.

Since 1941 there has been a progressive increase in ground-water draft by the city of Ogden, and in 1951 the discharge from artesian wells was 70 percent greater than in 1941. There has been some conjecture as to the effect of this increasing draft upon the reservoir, and whether there is any indication of progressive depletion in storage. The hydrologic data from Ogden Valley, however, show clearly that the recharge to the artesian reservoir during these years has been sufficient to prevent any progressive depletion in storage.

Water-level fluctuations.—In 1932 the Geological Survey had a test well (called the "Tower well") drilled in the eastern part of the artesian reservoir, and for 20 years recording gages on this well have provided a nearly continous record of water-level fluctuations. Analysis of these records indicates that this well provides a good index of storage in the artesian reservoir (Thomas, in preparation). From 1932 to 1936, before the completion of Pineview dam, the water level in the Tower well was highest in May or June of each year, and these yearly maxima varied within a range of less than a foot. During those years there was a wide range in the stream inflow to Ogden Valley—about 5 times as much in 1936 as in 1934—and it is reasoned that the artesian reservoir has a limited capacity in comparison with the water available for recharge, so that it is filled approximately to capacity each year. In this respect it is somewhat like Pineview reservoir, whose capacity is only about one-fifth the average outflow from Ogden Valley.

Since 1937, with Pineview reservoir in operation, the highest water level each year in the Tower well has varied within a range less than 2 feet, and this constancy in level also may be due partly to a relatively constant quantity of water in storage at the time of highest level. However, the maximum level is about 5 feet higher than the highest level recorded in the well prior to 1937, and inasmuch as it is generally attained during periods when Pineview reservoir is full, this maximum reflects not ground-water storage alone, but also the effect of the weight of water in Pineview reservoir upon the underlying artesian reservoir.

Detailed studies show that there is a close correlation between fluctuations of water level in the Tower well and changes of stage in Pineview reservoir, especially when Pineview is nearly full and when its shore-line is within half a mile of the well. The ratio of water-level change to reservoir-level change may be as great as 65 percent; this ratio is a measure of the incompetency of the intervening clay bed to resist changes in pressure, and is thus analogous to the tidal efficiency of artesian wells along the seacoast. Even when Pineview reservoir is nearly empty, and when its shore line is more than 2 miles from the Tower well, changes in reservoir level have some effect upon the water level in the well. These changes in water level have been determined to be proportional to the changes in weight upon the ground-water reservoir, and therefore to the changes in storage in Pineview reservoir: for each 3,000-acre-foot increase in surface storage the water level in the Tower well rises about 1 foot. The pressure effect of Pineview reservoir on the well reaches 14.5 feet when the reservoir is at spillway level.

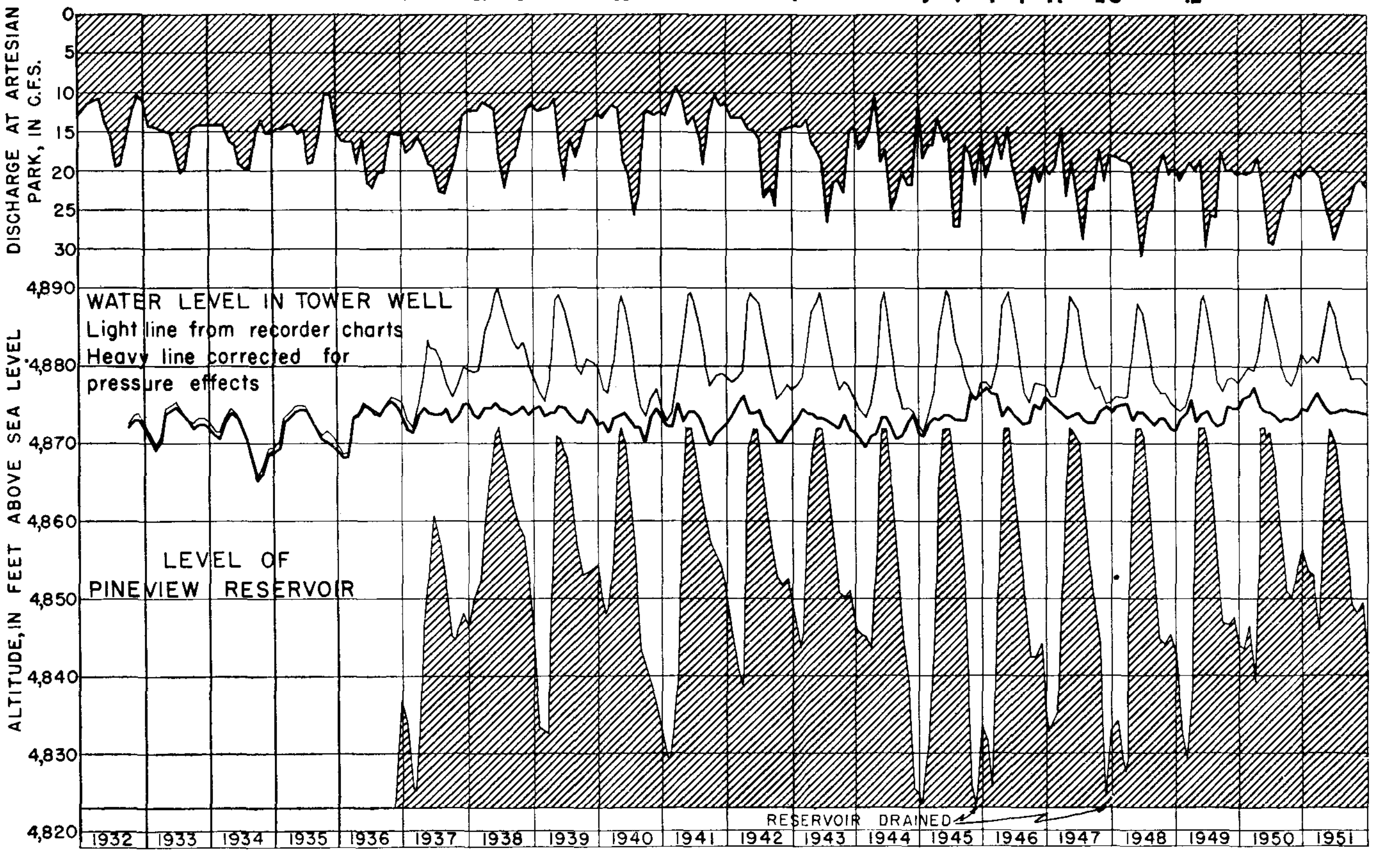
The water level in the Tower well is also affected by changes in rate of discharge from the Ogden municipal wells. Detailed studies, both before and after completion of Pineview dam, show that the water level is lowered about 0.1 foot for each second-foot increase in rate of discharge by those wells. These are the effects of changing pressure caused by interference; they do not reflect changes in storage in the artesian reservoir, for they have been observed even at times when the recharge to the reservoir is known to be greater than the rate of discharge. The water level in the well is also influenced by changes in atmospheric pressure, but these effects are very small in comparison with the other pressure effects.

To determine the effect of changes in ground-water storage upon the water level in the Tower well, it is necessary to correct for all these pressure effects. The hydrograph as charted from the recording gage and the hydrograph corrected for pressure effects are shown on figure 25. The corrected hydrograph shows a fair constancy in maximum water levels from year to year since 1933. In several years the time of maximum ground-water storage has coincided approximately with the peak flow of the principal streams tributary to the valley. In many other years the ground-water storage has reached a maximum during the first 3 months of each year, corresponding to the period of snow melt in the valley.

In the dry years 1934, 1935, 1940, and 1944 the highest water level was more than a foot below the level generally attained. And in the winters of 1942, 1946, 1950, and 1951 the water level in the Tower well rose more than 3 feet above this usual maximum. These exceptional maxima followed years of exceptionally abundant precipitation in Ogden Valley.

The corrected hydrograph also shows that the increasing draft from the Ogden artesian wells has caused no progressive depletion in storage. In January, 1946, the storage was greater than at any time since 1932, and it was nearly as great in March, 1950. Storage reached a 20-year minimum in September, 1934; although the draft that month was at an average rate less than 20 second-feet, and in several months since 1946 the draft has exceeded 25 second-feet, the minimum levels in recent years have not even come close to those recorded in 1934.

Figure 25. Hydrologic factors causing pressure effects in the Tower Well in Ogden Valley.



Ground-water development.—The rate of discharge from Ogden's 46 municipal wells is recorded continuously by venturi meter. These wells, located in a small area known as Artesian Park, now submerged by Pineview reservoir, constitute the principal means of discharge from the artesian reservoir. In the water year 1934 (Leggette and Taylor, 1937, p. 141) the Artesian Park wells discharged 11,700 acre-feet, all other artesian wells in the valley discharged about 1,700 acre-feet, and the natural discharge by outflow down Ogden Canyon and by seepage through the clay confining bed or around its edges was estimated to be not more than 5,800 acre-feet. The maximum rate of discharge by the Artesian Park wells that year was 20.5 second-feet.

In preparation for storage of water in Pineview reservoir, the outlets of the Artesian Park wells were lowered as much as 10 feet, and all other artesian wells in the valley were plugged. The underflow down Ogden Canyon was practically eliminated by the cut-off of Pineview dam, and the upward seepage was doubtless reduced by the downward pressure of the water in the surface reservoir. Since these changes, the maximum discharge from the Artesian Park wells has increased to more than 33 second-feet, and those wells have become the *only* avenues of discharge from the artesian reservoir, except for the unknown but presumably small quantity that may seep upward through the confining clay. In 1951 the metered discharge of the wells was 16,800 acre-feet, nearly 50 percent more than was withdrawn during the drought year 1934.

Precipitation and runoff.—The only precipitation station in the Ogden River drainage basin is at Pineview dam. The record there began in 1935, and in the period 1935-51, inclusive, the average annual precipitation was 29.17 inches, with a range from 21.0 inches in 1935 to 39.3 inches in 1945. An earlier record at Huntsville, in the southeast part of Ogden Valley, covered 30 years of the period 1895-1930, during which the average annual precipitation was 20.4 inches. Absence of overlap makes correlation of these two records impossible, but it appears that Pineview dam may receive considerably more precipitation than does Ogden Valley, as a rule.

The gaging station on "South Fork Ogden River near Huntsville," established in 1921, is in South Fork canyon about a mile upstream from the edge of Ogden Valley; it measures the discharge of the South Fork into Ogden Valley. The drainage basin above the gaging station has an area of about 148 square miles. The inflow to Ogden Valley from the Middle and North Forks and from minor tributaries is not measured.

The gaging station on "Ogden River near Ogden" measured the total surface outflow from Ogden Valley between October, 1932, and October, 1937. The drainage basin above this station has an area of about 321 square miles. Records obtained at the same site since October, 1937, published as "Ogden River below Pineview Dam," show only the flow in the river channel and do not include the diversions through the Pineview pipeline. For the water years 1938 through 1951, the total outflow has been estimated approximately by summation of the recorded diversions into the north and south pipelines and the powerhouse penstocks, plus the discharge in Ogden River below the dam. Since October, 1951, a venturi meter has been operated in the Pineview pipeline, so that the total surface outflow from Pineview reservoir can be computed accurately.

There appears to be a rather consistant relation between the annual surface outflow from Ogden Valley and the annual inflow from South Fork: South Fork contributes about 16,000 acre-feet plus about 38 percent of the total outflow as measured below Pineview Dam. This straight-line relationship held in the driest year, 1934, when South Fork inflow of 26,800 acre-feet was nearly as great as the outflow of 27,400 acre-feet, and also in the wettest year, 1936, when South Fork inflow (124,000 acre-feet) was less than half the total outflow (279,000 acre-feet).

Hydrologic analysis of the Tower well records.—The usual method of determining changes of storage in a ground-water reservoir involves making records of the water-level changes in a network of selected wells, and then computing volumes of aquifer that are saturated or unwatered in designated periods. In Ogden Valley such a volumetric analysis would be more costly than in most places, because the existing wells are not distributed throughout the valley but are concentrated in the Artesian Park area, and a network of observation wells could be developed only by drilling.

As an alternative, the water-level changes in a single well may, in some places, serve as an index to changes of storage in the ground-water reservoir, provided that it is possible to identify the hydrologic factors that cause those changes and then to assess the measure of responsibility of each factor for the changes recorded in the well.

Hydrologic analysis of the Tower well record began when it was recognized that the well was recording pressure effects of such magnitude as to mask any effect of changes in storage. The water-level changes caused by changing pressure alone were therefore determined, corrections were applied, and the corrected hydrograph of figure 25 is the result.

This corrected hydrograph, raised more questions than it answered, which inevitably led to further analysis of the relations of the computed water-level changes (now presumably reflecting only changes in storage) to the factors of discharge and of recharge that would cause the changes in storage (see fig. 26). The factor of discharge is considered first, because practically all the discharge from the ground-water reservoir is believed to be by the Artesian Park wells, and that is measured.

The discharge from the Artesian Park wells exceeds the recharge to the ground-water reservoir during each month when the water-level trend in the Tower well is downward in the corrected hydrograph of figure 25. Plotting the monthly discharge against the monthly decline in corrected water level establishes a tentative relation that the water level in the Tower well is lowered at a maximum of 1.0 foot for each 450 acre-feet withdrawn from the Artesian Park wells. When the water level in the Tower well declines at a lesser rate, it is assumed that the effect of discharge is being partly offset by recharge.

Since 1932 the monthly draft from the Artesian Park wells has ranged from 550 acre-feet in April, 1941, to 1,740 acre-feet in July, 1950. From the relation established above, the effect of discharge alone upon the water level in the Tower well was computed for each month. With this monthly discharge component, and the previously computed water-level change caused by net changes in ground-water storage, it is a matter of simple arithmetic to derive the amount of rise in water level each month due to recharge. In some months, by this computation, there was no recharge; these are the months that define the 1-foot-to-450-acre-foot discharge ratio. The computed monthly recharge component was generally of the order of 2 to 3 feet, and it reached a maximum of 7 feet in March, 1936.

These recharge components have been analyzed with respect to the principal sources of recharge: direct infiltration of precipitation and seepage from local runoff, and seepage from the larger tributaries to Ogden Valley. The runoff from the large tributaries occurs chiefly during the spring freshet, from April through July, and local runoff is most likely to occur as the snow melts in February or March. Recharge from precipitation can occur in any month of abundant precipitation, but it cannot readily be discriminated from seepage of surface water in the spring and early summer. Any large amount of recharge in the autumn can generally be attributed to precipitation, because the perennial streams are at low stage and the ephemeral streams are ordinarily dry at that time.

By plotting the precipitation at Pineview dam against the recharge components during various autumn periods, the following approximate relation is developed: ordinarily no recharge results from the first 1½ inches of precipitation upon a moisture-deficient soil; when precipitation exceeds that amount, the water level in the Tower well rises about 1.2 feet per inch of precipitation. Applying this relation to the records of other months, it is found that precipitation (including snow melt) has been great enough to account for the calculated recharge in the months of November to April of practically all water years, and in many months there has been an excess that probably contributed to local runoff. Precipitation has also been sufficient to account for some of the recharge components in the summer. If it be assumed that a 1-foot rise in water level in the Tower well reflects a 450-acre-foot increase in storage in the ground-water reservoir (analagous to the relation established for discharge), the recharge from precipitation and snow melt has ranged from 5,500 acre-feet in 1938 to 13,000 acre-feet in 1945, which was the year of greatest recorded precipitation at Pineview dam.

The calculated recharge from streams is the residual that is not accounted for by infiltration of precipitation as calculated above. Translated into acre-feet, it is computed that the recharge from the larger tributaries has ranged from 1,900 acre-feet in 1947 to 6,300 acre-feet in 1936, which was the year of greatest inflow from the South Fork in the period 1935-51.

The following table presents a tentative water budget for the artesian reservoir in Ogden Valley, based on this hydrologic analysis of records from the Tower well. This budget does not include estimates of the natural discharge from the reservoir, which would be offset by an equivalent amount of recharge. In the 17-year period the Artesian Park wells have yielded an average of 13,400 acre-feet a year. This has been more than replaced by recharge directly from precipitation at an average annual rate of 9,100 acre-feet, and by recharge from tributaries at an average rate of 4,500 acre-feet a year. Thus, the record from the Tower well does not support the statements in earlier reports that the artesian reservoir is recharged chiefly by the streams tributary to Ogden Valley. Artesian Park discharge therefore does not necessarily represent a direct depletion of the flow of the Ogden River, because the stream system accounts for only about a third of the recharge to the artesian reservoir.

Table 10. Tentative water budget for the Ogden Valley artesian reservoir. (Quantities in Acre-Feet.)

Calendar year	Artesian Park discharge	Recharge			Net changes in storage	
		Precipitation	Streams	Total	Annual	Cumulative
1935	11,700	8,700	2,600	11,300	-400	-400
1936	12,800	8,600	6,300	14,900	+2,100	+1,700
1937	12,700	8,000	5,500	13,500	+800	+2,500
1938	10,400	5,500	4,600	10,100	-300	+2,200
1939	10,800	6,300	3,600	9,900	-900	+1,300
1940	11,500	7,200	5,000	12,200	+700	+2,000
1941	9,900	7,600	2,000	9,600	-300	+1,700
1942	11,900	7,300	4,500	11,800	-100	+1,600
1943	13,000	9,200	3,500	12,700	-300	+1,300
1944	13,700	8,100	5,400	13,500	-200	+1,100
1945	14,000	13,000	3,500	16,500	+2,500	+3,600
1946	15,200	9,300	5,600	14,900	-300	+3,300
1947	15,100	12,400	1,900	14,300	-800	+2,500
1948	15,300	8,800	5,400	14,200	-1,100	+1,400
1949	15,800	12,400	5,000	17,400	+1,600	+3,000
1950	16,500	10,000	6,000	16,000	-500	+2,500
1951	16,700	11,800	6,100	17,900	+1,200	+3,700
17-year average	13,400	9,100	4,500	13,600		

In accepting this "budget" as applicable to the artesian reservoir, several assumptions must be made. It must be assumed that the reservoir operates as a single storage unit rather than as a group of semi-independent or separated aquifers. This assumption is supported by the observed effects upon the water level in the Tower well of Artesian Park discharge 2 miles away, and also of Pineview storage even when only the westernmost part of the artesian reservoir is covered by the surface reservoir.

On the other hand, the record from the Tower well may indicate a somewhat greater proportion of recharge from precipitation, and less from the major streams, than obtains for the artesian reservoir as a whole. The Tower well is distant from the major stream channels, in a place where precipitation might be expected to be the chief source of recharge.

Further geologic studies of Ogden Valley are in progress during 1952, especially for the purpose of defining the limits of the clay confining bed and delineating the recharge areas. It is hoped that these studies will also throw further light on the adequacy of the Tower well as an indicator of changes of storage in the artesian reservoir.

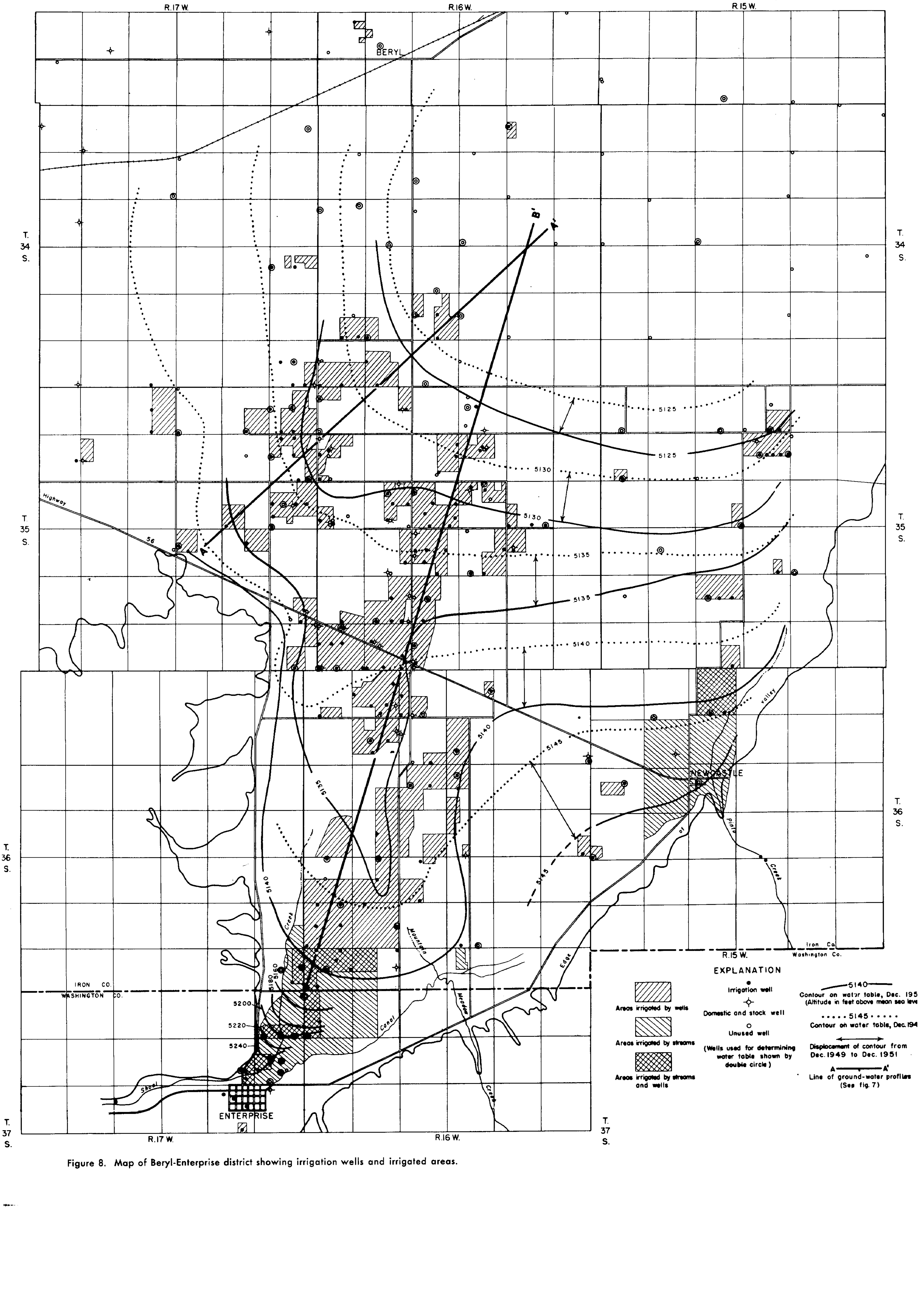


Figure 8. Map of Beryl-Enterprise district showing irrigation wells and irrigated areas.