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THE OGDEN VALLEY ARTESIAN RESERVOIR

Weber County, Utah

By H. E. THOMAS

Prepared in cooperation with the

UNITED STATES DEPARTMENT OF THE INTERIOR

Geological Survey, 1945

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INTRODUCTION

Ogden Valley, in Weber County, Utah, contains an artesian reservoir from which the city of Ogden obtains all except a small part of its municipal water supply. A detailed investigation of the ground-water resources of Ogden Valley, and particularly of this artesian reservoir, was made by the Geological Survey, United States Department of the Interior, in cooperation with the city of Ogden between 1932 and 1934, and the results of this investigation have been reported by Leggette and Taylor.[1] The present paper, which might be termed a sequel to that report, is based on data collected during those years, augmented by records that have been obtained (1935-1940) by the Geological Survey as part of a State-wide project in cooperation with the Utah State Engineer. The conclusions drawn from the study of these records and presented in detail in the following pages are as follows: (1) The artesian reservoir is filled to capacity nearly every year during the spring run-off 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 rec-

[1] Leggette, R. M., and Taylor, G. H., Geology and ground-water resources of Ogden Valley, Utah: U. S. Geol. Survey Water-Supply Paper 796-D, pp. 99-161, 1937.

ords indicate that water used by increased draft from wells would be replenished in normal years by increased recharge during the spring freshets.

The study of Ogden Valley has been under the general supervision of O. E. Meinzer, geologist in charge of the division of ground water of the Federal Geological Survey. The writer is also indebted to P. E. Dennis, R. M. Leggette, G. H. Taylor, and L. K. Wenzel for critical reading of the manuscript.

Location and General Features of Ogden Valley

Ogden Valley is in the eastern part of Weber County, Utah, about 12 miles east of the city of Ogden. The valley has an area of about 23 square miles, and is completely surrounded by mountains, of which several peaks east and west of the valley rise to more than 8,500 feet above sea level, or 3,500 feet above the valley floor. The valley is drained by the Ogden River, which flows westward through Ogden Canyon—a picturesque gorge cut into the Wasatch Range—and empties into Great Salt Lake. Various hydrologic features of the valley are shown in plate 36 of Water-Supply Paper 796, reproduced here with slight modifications as figure 1.

Ogden Valley is one of the "back valleys" of the Wasatch Range that have been described by Gilbert[2] as grabens, separated from the Great Basin farther west by the horst that has formed the Wasatch Range, which is 6 or 8 miles wide opposite Ogden Valley. Since its inception during the Tertiary period, this structural trough has been the site of a great amount of aggradation, while the bordering highlands, composed chiefly of Paleozoic sediments, have been subjected to erosion, so that the present topographic expression represents only part of the displacement along the faults that bound the valley. The total thickness of the valley fill is not known, but wells have penetrated unconsolidated deposits of clay, sand, and gravel to a depth of 600 feet without encountering bedrock.

Pine View dam is located in Ogden Canyon about a mile below Ogden Valley. It is an earth-fill dam with concrete cut-off wall that extends to bedrock beneath the floor of the canyon at an elevation of 4,679 feet above sea level. The spillway of the dam has an elevation of 4,872 feet, and the reservoir when filled to this level has a surface area

[2] Gilbert, G. K., Studies of Basin Range structure: U. S. Geol. Survey Prof. Paper 153, pp. 54-62, 1928.

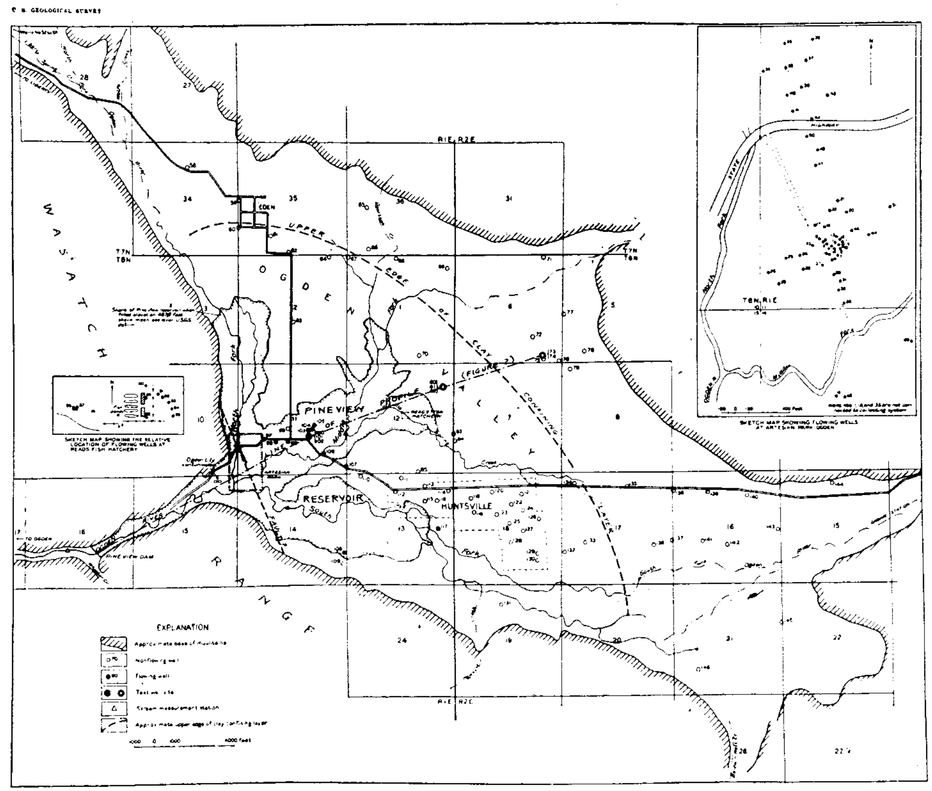

Figure 1.—Map of a part of Ogden Valley, Weber County, Utah.

of about 1,800 acres and a capacity of about 45,000 acre-feet. This surface reservoir covers only a part of the artesian reservoir, and is separated therefrom throughout its entire area by the clay confining layer that gives rise to the artesian conditions (fig. 1).

Source, Movement, and Disposal of Water in the Artesian Reservoir

The occurrence of water under artesian conditions in Ogden Valley has been considered in detail by Leggette and Taylor,[3] and the source, movement, and disposal of this artesian water are described fully in their report. Briefly, the artesian conditions are found to be created by a bed of varved clay that was deposited during the highest (Bonneville) stage of Lake Bonneville, when Ogden Valley was inundated. This clay bed is presumed to be continuous under the lower part of the valley, where its thickness as shown in well logs averages about 70 feet. The position of the upper edge of the clay bed (fig. 1) marks also the upper limit of the artesian area.

Water enters the artesian area by southwestward movement into the aquifers beneath the upper edge of the clay confining layer. Thus the recharge area for the reservoir is in the higher northeastern portion of the valley, where the sediments are predominantly coarse and include a considerable amount of gravel and boulders. The water that enters the artesian reservoir is derived partly by deep penetration of rain or melting snow that falls on the recharge area, and partly by seepage from stream channels, from irrigation ditches, and from excess irrigation of cultivated lands. The proportions that are derived by deep penetration and by seepage from stream flow cannot be determined satisfactorily, but the effects of the recharge from these two sources upon the artesian reservoir may be discriminated, because Ogden Valley is at considerably lower altitude than the headwaters of the streams, and downward penetration of water from melting snow is ordinarily greatest in March or April rather than in May when stream flow usually attains its maximum.

Some of the characteristics of the valley fill, and particularly the position of the clay confining layer that creates the artesian reservoir in Ogden Valley, are shown in a profile along a line extending approximately N. 70° E. from Pine View dam (fig. 2.) The profile is based on logs of wells and of boreholes drilled by the Bureau of Reclama-

[3] Leggette and Taylor, Op. cit., pp. 119-141.

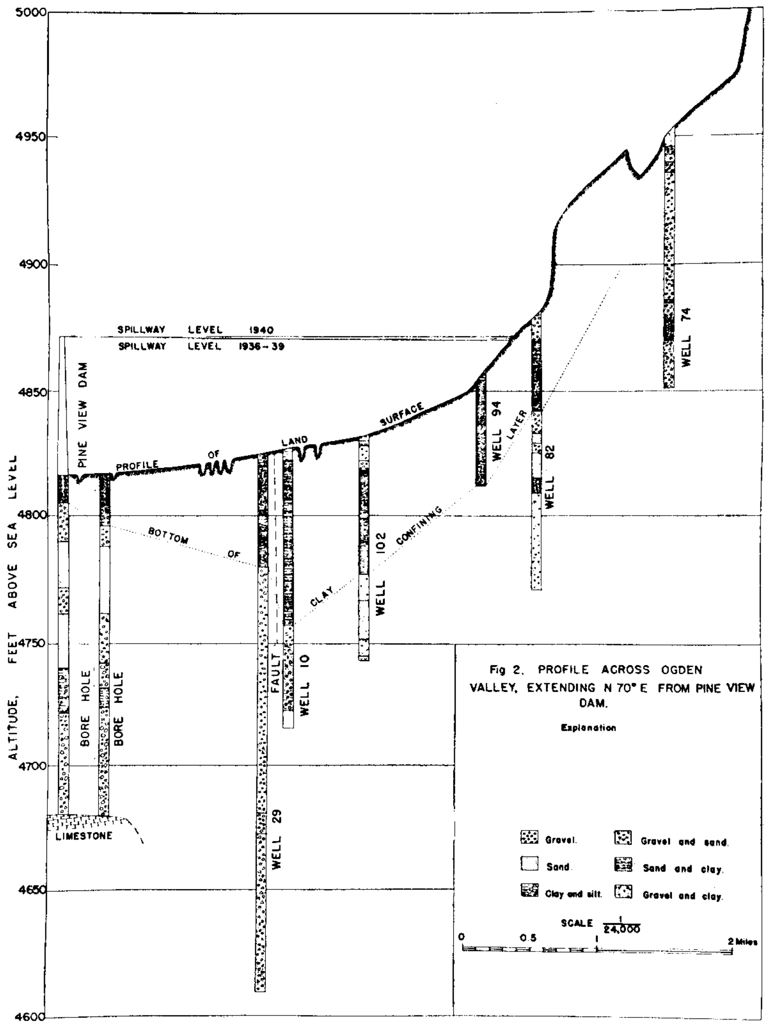

Fig 2. PROFILE ACROSS OGDEN VALLEY, EXTENDING N 70° E FROM PINE VIEW DAM.

tion, except that well 94—the shallowest of 10 closely-spaced flowing wells for which no logs are available—is presumed to have been drilled to the minimum depth necessary to obtain a flow, and therefore the depth of the well is assumed to be the depth to the bottom of the clay bed. The easternmost well of the profile is beyond the upper edge of the clay bed and rather close to the steeply-sloping eastern edge of the valley; the materials penetrated are poorly sorted and are probably derived chiefly from wash down the slope. In the next four wells along the profile, the base of the clay bed is shown to have a fairly regular slope to the west, but between wells 10 and 29 there is a marked difference in the position of the base of the clay bed, perhaps because of displacement on a fault along the west margin of Ogden Valley, perhaps merely because of inaccuracies of the driller's logs.

Water was discharged from the artesian reservoir prior to 1936 chiefly by 51 wells that furnish the municipal supply of the city of Ogden, and in much smaller quantities from about 30 other flowing wells and 2 non-flowing wells that tapped the artesian reservoir. Natural discharge from the artesian reservoir was estimated to be less than 5 second-feet,[4] most of which was considered to have moved through the lower ends of the aquifers at the head of Ogden Canyon. As indicated in figure 2, all except the upper 100 feet of these aquifers are cut off by the rock sill under the floor of Ogden Canyon. The clay bed that overlies the artesian reservoir is considered to be practically impermeable, and upward movement of water through it therefore negligible.

Since November 1936, the discharge from the artesian reservoir has been limited essentially to the quantity withdrawn by the city of Ogden, for all other flowing wells in the valley were plugged at that time, and underflow from the lower end of the reservoir into Ogden Canyon was stopped by the Pine View dam.

Available Records of Stream Flow and of Artesian-Well Discharge.

Records of the discharge of the South Fork of Ogden River, measured at the gaging station near the mouth of the canyon about 5½ miles east of the town of Huntsville, have been obtained continuously since April 1921, and are published annually in water-supply papers of the Geological

[4] Op. cit., p. 139.

Survey. During the period of record the average daily discharge has ranged between 22 second-feet on several days in July and August 1934, and 1,640 second-feet on May 5, 1936, and the annual run-off between 25,400 acre-feet in 1934 and 125,700 acre-feet in 1936. The run-off has a marked seasonal fluctuation, as shown by the graphic representation of the average monthly discharge since 1932 (fig. 3). The greater part of the annual run-off—commonly as much as 60 to 80 per cent—occurs during the 4 months from March to June, as a result of melting snow. Discharge ordinarily reaches a peak in May, although in certain years the maximum discharge occurs late in April. The large range in annual discharge is caused chiefly by the variation in the quantity of this run-off from melting snow. During the rest of the year the rate of discharge is fairly constant. Between August and February the discharge is ordinarily between 30 and 40 second-feet; since 1930 it has not dropped below 25 second-feet except during the drought year of 1934, and it has rarely exceeded 50 second-feet during those months.

The discharge of the South Fork is only a part of the inflow to Ogden Valley, but there is very little information concerning the flow in other tributary streams. Leggette and Taylor[5] show the total inflow to Ogden Valley during certain days in August or September of 1921, 1925, 1928, and 1934, on which days the discharge of the South Fork alone constituted 70 to 80 per cent of the total. The drainage basin of the South Fork (148 square miles) constitutes about half of the area tributary to Ogden Valley, and in the absence of adequate data it can only be assumed that the flow of the South Fork is generally at least half of the total surface inflow to Ogden Valley. There are only very small diversions above the gaging station on the South Fork, and therefore the measured discharge includes not only the water that continues down the channel but also that which is diverted into irrigation ditches and applied for irrigation. Thus, the discharge measured at the gaging station includes all the water available for recharge to the artesian reservoir from the South Fork. In the absence of any continuous records for the other streams entering the valley, it is assumed that the fluctuations in discharge of those streams are comparable to the fluctuations in the measured discharge of the South Fork, and that therefore,

[5] Op. cit., p. 117.

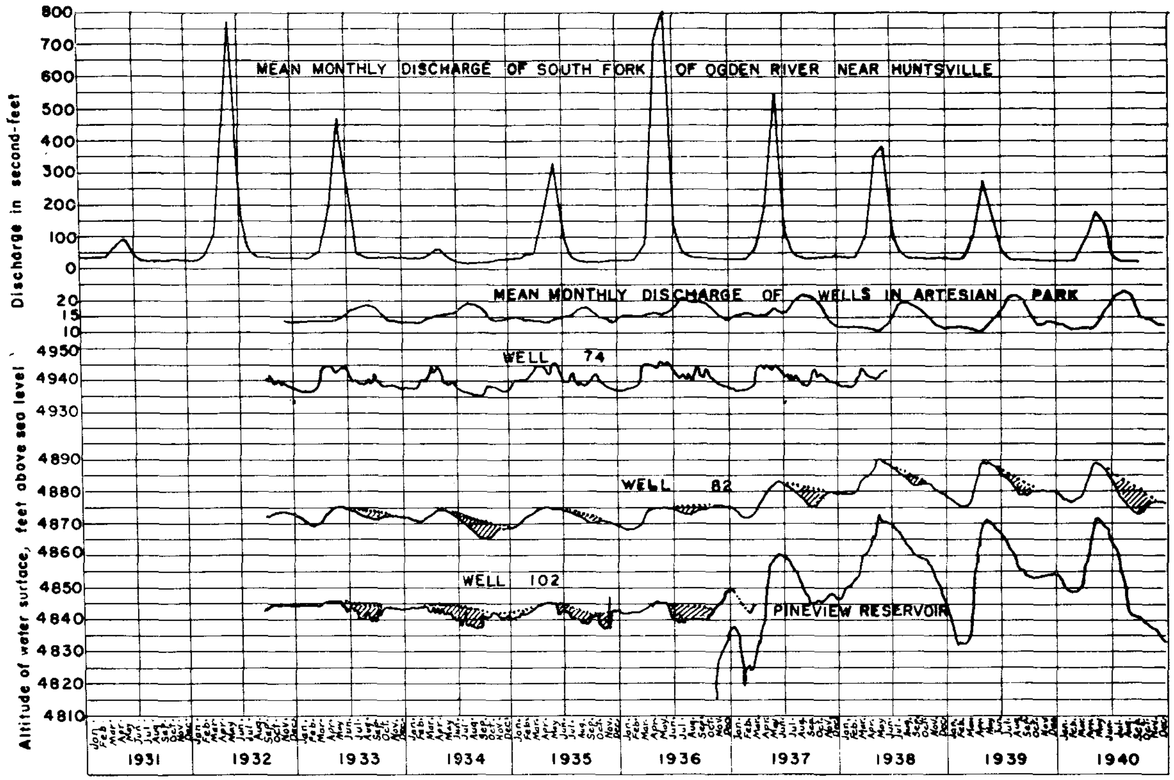

Figure 3.—Graphs showing discharge of the South Fork of Ogden River, discharge of Ogden city wells at Artesian Park, water level in Pine View reservoir, and water-level fluctuations in three wells in Ogden Valley, 1932-40.

the curve representing discharge of the South Fork (fig. 3) would also represent approximately the fluctuations in inflow to the valley from all sources.

The major part of the discharge from the artesian reservoir—that from the Ogden city wells in Artesian Park —is measured by a venturi meter that has been maintained by the Ogden city engineer since 1932 (fig. 1). The daily discharge from these wells has ranged between 10 second-feet (April 5-15, 1940) and 26¼ second-feet (August 1, 1940), and the annual withdrawal has varied from 10,400 acre-feet in 1938 to 12,800 acre-feet in 1936.

The discharge from all other artesian wells in Ogden Valley prior to 1936 was considered by Leggette and Taylor to range between about 1½ and 2½ second-feet.[6] So far as known, these wells were permitted to flow continuously, and the rate of discharge is therefore presumed to have been fairly constant throughout the year but would likely be somewhat greater during the spring, when artesian pressures are highest, and would decrease gradually until the following winter, when artesian pressures are low. Since the completion of Pine View dam and the plugging of all artesian wells except those at Artesian Park, practically the entire discharge from the artesian reservoir is believed to be included in the quantity measured by the venturi meter, now located in Ogden Canyon several hundred feet below Pine View dam.

Water Levels in Observation Wells

The hydrographs of three wells in Ogden Valley are assembled in the lower half of figure 3. These wells were drilled by the Geological Survey in August and September 1932 along the line represented in profile in figure 2, which shows for each well the position, depth, and log of the materials encountered. This line extends from the Artesian Park area, in which the artesian discharge from the valley is largely concentrated, to the nearest part of the recharge area. The profile may thus be along the direction of maximum slope of the piezometric surfaces for the artesian aquifers, but available data are insufficient to show this to be so, and indeed a large proportion of the recharge to the aquifers is believed to come from the South Fork, which enters the valley some distance south of the line of the profile.

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[6] Op. cit., pp. 139-140.

Well 102.—Well 102, the lowest of the three wells, was located about half a mile east of Artesian Park. Its hydrograph is marked by sharp fluctuations, which have been shown[7] to be chiefly in response to change in rate of withdrawal from wells at Artesian Park, the water levels in the well being lowest during the months of maximum withdrawal. During the winter months, when the discharge from Artesian Park was held at a fairly uniform rate, these abrupt fluctuations did not occur in the observation well. Except in the summer, the discharge from Artesian Park was reduced to this rate (about 14 second-feet) during portions of practically every month in the year. In figure 3 the points in the hydrograph established during periods when the discharge was about 14 second-feet have been connected by a dotted line. The shaded area between this dotted line and the actual graph represents approximately the pressure effect caused by increased discharge from Artesian Park. The dotted lines, together with the actual hydrograph during the months when the rate of discharge was held at about 14 second-feet, form a curve that represents approximately the hydrograph of the well under conditions of constant discharge from Artesian Park. A single projection above this line—on November 24, 1935—resulted from cutting off all flow from Artesian Park while the new pipe line through the dam was being connected.

Well 74.—Well 74 is about half a mile beyond the upper limit of the clay confining bed, but is centrally located in the recharge area of the artesian reservoir, and its hydrograph shows fluctuations that are typical of the recharge area. Characteristically, the water level in this well is lowest during January or February, and then rises some 6 or 8 feet during March or early April. This rise is commonly several weeks earlier than the peak of the spring run-off in the three principal branches of Ogden River, whose headwaters are high above the valley where melting of snow occurs generally during May and June. The rise is attributed to direct penetration of water from melting snow on the recharge area, seepage from early diversion of water through irrigation ditches near the well, and seepage from local run-off from adjacent foothills. After this first peak the water level ordinarily declines somewhat and then rises to a second peak during the time of maximum run-off in South Fork, which is probably practically contemporaneous with the peaks of the Middle and North Forks. As the discharge of streams declines from this peak (usually in June but sometimes as early as May), the trend of the

[7] Op. cit., p. 125.

water level in well 74 is generally downward, but this trend may be interrupted by rather sudden rises in response to irrigation in the vicinity of the observation well or to rainfall upon the recharge area. The highest water levels attained during the summer and fall as a result of this local irrigation or rainfall penetration are generally several feet lower than the high levels of the spring.

During the spring recharge, whether from the melting of snow in and adjacent to Ogden Valley or the subsequent run-off occasioned by thawing at higher elevation, the water table at well 74 rises each year to an elevation about 4,945 feet above sea level. The reason for the uniformity of maximum elevation from year to year is suggested in the profile of figure 2. There is a shallow valley just west of the well whose bottom elevation along the line of the profile is about 4,935 feet. When the water table reaches a certain elevation there is seepage into this channel and run-off toward the lower part of Ogden Valley; or in other words, recharge is balanced by natural discharge and the water table rises no higher. During years when there is a considerable excess of water (as in 1936), this small channel may have an appreciable amount of run-off, yet the water level in the well rises only a foot or so above the 4,945-foot limit. In these years of abundant water supplies, however, the water level in the well may be kept near the maximum for 3 months or longer, while in years of deficient moisture (as in 1934), the water level may reach the 4,945-foot limit for only a day or two. Similar seepage into channels and discharge from springs throughout the recharge area disposes of water that is rejected when no further increase in storage is possible.

Well 82.—Well 82 is located about midway between wells 74 and 102, above the upper limit of the Pine View reservoir and about half a mile below the upper limit of the clay confining bed. The record obtained from this well shows significant relationships with the recharge and discharge of the artesian reservoir, and merits discussion in considerable detail. The hydrograph exhibits an annual cycle in which four major trends consistently appear: (1) A rapid rise in water level during the months from February to April or May, culminating in the highest water levels reached during the year; (2) a substantial decline throughout the period of heaviest ground-water withdrawals from Artesian Park with a low stage toward the end of that period, in late September or early October; (3) a rise to a secondary high stage in November or early December;

and (4) a further decline until January or early February to a low stage which is generally but not always lower than that of the preceding autumn.

The rapid rise of water level during the spring ordinarily begins in March and is practically contemporaneous with the first rise in well 74, which has been ascribed to deep penetration of water derived from rain and melting snow in Ogden Valley and the adjacent foothills. The water level continues to rise until the peak of the annual freshet in the South Fork has passed, and the highest water level is reached ordinarily within two or three weeks after the time of maximum stream discharge. The highest water level is reached during the time of year when the quantity of water available for recharge from inflowing streams is greatest, for the freshets in the Middle and North Forks are presumably practically contemporaneous with that in the South Fork, since their headwaters are at comparable altitudes. But the amount of rise of water level bears no relation to the quantity of water available for recharge. Rather, the position of highest water level is fairly constant even though stream flow varies within wide limits. Thus, in 1933, 1935, and 1936 the highest water levels reached in the well varied within limits of less than 0.3 foot. These highest levels occurred during periods when the water table in the recharge area was highest, as shown by the hydrograph of well 74, and further recharge was being rejected. These high water levels were maintained throughout most of May and June of each year—that is, throughout the latter part of the period of high spring run-off. The constant level reached during these 3 years, about 4,875 feet above sea level, is the highest water level attained in the well prior to construction of Pine View dam, regardless of the water available as precipitation and run-off of streams entering the valley. During these years the water in well 102 also approached a constant maximum stage, slightly less than 4,846 feet above sea level. In 1934 the high-water level in both wells was 6 or 8 inches lower than during the other 3 years. In that year the precipitation over the drainage basin was extremely low, and the run-off during the spring freshet was the lowest on record, judging by data collected on the South Fork.

The relative magnitude of the recharge derived by direct penetration from rain and snow on the recharge area and that derived by seepage from streams and the irrigation ditches that take water from those streams may be inferred from the hydrograph of well 82. In each year the greater part of the rise of water level in the well occurs before the peak of the freshet, and is evidently due to recharge from local sources. On the other hand, the highest water level in the well is not reached until after stream discharge has reached its maximum. Thus it appears that a large proportion of the recharge to the artesian reservoir is derived from local sources, but that the proportion derived from stream seepage is small, chiefly because the reservoir has already been filled nearly to capacity by water derived earlier from these local sources.

After the annual freshet the discharge of the streams entering Ogden Valley subsides to a low and fairly constant flow for a period of 6 to 8 months. During this period the discharge of South Fork is commonly 30 to 40 second-feet. The water level in well 82 ordinarily starts to decline from its highest stage in the latter part of June, but in some years this decline may begin in May. Under the natural conditions prevailing prior to the fall of 1936, the fluctuations in this well between July and February generally correlated closely with the major changes in discharge, particularly those created by the fluctuating demand on the Ogden city wells at Artesian Park.[8] These withdrawals are of course greatest during the summer, soon after the artesian reservoir has attained its maximum storage for the year. The rapid decline of water levels from June to September coincides with the period of greatest discharge from Artesian Park, and the reduction in discharge during October and November is generally accompanied by a slight rise in water levels during those months. Fluctuations since November 1936 have been markedly influenced by changes in the burden upon the artesian reservoir produced by the water in Pine View reservoir.

Inferences as to capacity of the artesian reservoir.— The hydrographs of the three wells described above form the basis for certain conclusions regarding the artesian reservoir and its capacity. The general conditions of occurrence of water in this reservoir have been described, and the upper boundary of the clay bed that gives rise to the artesian conditions has been shown. Upstream from the upper limit of this clay bed lies the recharge area for the artesian reservoir. The upper or eastern edge of this clay bed is also the upper or eastern limit of the artesian conditions. Water discharged from the artesian aquifers is replaced by water from the deposits underlying the recharge

[8] Op. cit., p. 124, fig. 3.

area farther east, and the artesian pressure in those aquifers is largely controlled by the ground-water level in that part of the reservoir.

The hydrograph of well 74 suggests that there is a definite limit to the quantity of water that can be stored beneath the recharge area, and that this limit is fairly constant regardless of the quantity of water available. This limit is apparently determined by the upper edge of the clay confining layer, and when that layer is overtopped the part of the reservoir underlying the recharge area has taken all it can hold. At any rate, recharge above a certain limit is rejected. It may be discharged directly into stream channels or it may move into shallow strata above the artesian aquifers and may then be discharged by springs or seeps at lower elevations in Ogden Valley. The fluctuations of the water level in well 74 show the conditions of storage beneath the recharge area very poorly owing to frequent irrigation in the vicinity of the well during the summer and fall. These irrigations cause fluctuations of water level in the well which partly obscure the regional conditions.

The highest water levels in well 82 and also in well 102 are approximately coincident with those in well 74 and thus occur at the time of maximum storage in that part of the artesian reservoir underlying the recharge area. The water levels in these wells are of course influenced by other factors than the height of the water table beneath the recharge area, and are especially affected by the rate of discharge from the artesian reservoir. However, during the periods when these high-water levels were reached each year the discharge from the reservoir was fairly constant. The withdrawals from the Ogden city wells ranged between 15 and 17 second-feet, and the discharge from all other wells is presumed likewise to have been fairly constant, amounting to about 2 second-feet. The natural discharge, chiefly by underflow into Ogden Canyon, is also assumed to have been fairly uniform during these periods, because of the comparable artesian pressures each year as shown by the water levels in observation wells. Thus during the period each year when the water level in well 82 was highest, the discharge from the artesian reservoir was uniform and its effect on water level in the well presumably constant.

During 1933, 1935, and 1936 the water level in well 82 reached a maximum stage about 4,875 feet above sea level, indicating that the artesian reservoir, including that part underlying its recharge area, was filled to a common level each year. Since the precipitation and run-off varied considerably for those years, it is evident that this level represents the capacity of the artesian reservoir. In 1934 the high-water level was 6 or 8 inches lower than during these years when the reservoir was filled, and thus the local precipitation and the spring freshet of that year did not furnish a sufficient quantity to recharge the artesian reservoir to capacity. The run-off in 1934 was the lowest on record, and even so the artesian reservoir lacked very little of being filled. It is believed that in almost every year the quantity of water available for recharge is sufficient to fill the artesian reservoir, and that generally there is an excess that is rejected.

In proportion to its size the Ogden Valley artesian reservoir evidently has a large quantity of water available for recharge. In this respect it is believed to be exceptional if not unique among the artesian basins of Utah. In many of those basins the annual recharge available from precipitation and seepage from surface water is small in comparison to the size of the reservoir, and is frequently exceeded by the discharge from springs, wells, evapotranspiration, and underflow from the lower part of the reservoir. The quantity of water stored annually in these reservoirs fluctuates according to the available recharge, as shown by the correlation between precipitation and run-off and the water levels in wells in or near the recharge area. In contrast, Ogden Valley has an artesian reservoir of small areal extent, with an annual discharge (chiefly from wells) so limited that it is exceeded nearly every year by the recharge made available to it by streams and other sources.

The declining trend of water levels during the summer and fall in wells in and near the recharge area (represented by wells 74 and 82) indicates that the water entering that area in those months is insufficient to offset the discharge therefrom, and therefore part of this discharge is at the expense of storage. In large part this discharge is by lateral movement into the artesian aquifers to replace water withdrawn from artesian wells and discharged through natural outlets.

Some water may be discharged from the reservoir, particularly when water levels are high, without entering the artesian aquifers. In the discussion above it has been suggested that the limit of storage beneath the recharge area may be determined by the upper edge of the varved clay. This clay bed doubtless becomes thinner toward its upper edge, and may include sandy lenses or other permeable zones, so that there may be some leakage from the reservoir through the confining bed at its upper edge. Leakage might be expected also at the points where the principal streams have eroded the upper edge of this clay bed, particularly when storage in the recharge area is at its maximum. Leggette and Taylor[9] show that there was some discharge from beneath the recharge area into the principal streams throughout 1933, but that in 1934, when the water levels in the recharge area were at their lowest, this discharge was stopped. Huntsville Spring Creek, which heads approximately at the outcrop of the varved clay, evidently derives its flow from that portion of the reservoir underlying the recharge area through one of these cols. The discharge of these springs is greatest when the reservoir is filled, and declines as the storage diminishes.

Effect of Pine View reservoir on highest yearly water level.—The high-water levels observed in well 82 and also in well 102 prior to July 1936 have been exceeded during the spring of each year since Pine View dam has been completed. In part, these higher levels result from compression of the artesian aquifers by the increased weight of water in Pine View reservoir. When the water in that reservoir attains a level more than 4,855 feet above sea level the fluctuations of water level in the two wells respond closely to those of the reservoir level, indicating that changing load upon the artesian strata has become a dominant factor in the fluctuations of the artesian head as recorded by the water levels in the observation wells. In part, the higher water levels result from reductions in discharge from the artesian reservoir, shown most clearly in the fall of 1936, before any water had been impounded in the Pine View reservoir. The water level in well 82 was higher in November of that year than it had been during the annual freshet 6 months earlier. This rise probably resulted from the plugging of several flowing wells during the summer and the elimination of natural underflow into Ogden Canyon by the construction of Pine View dam. Since the construction of the dam and subsequent use of the reservoir the artesian head in well 82 reaches a maximum stage about 4,889 feet above sea level when Pine View reservoir is filled.

The maximum elevation of water levels in well 74 during 1937 and 1938 was about the same as in previous years, and filling of the Pine View Reservoir clearly had no effect

[9] Op. cit., p. 145.

upon the water level. The well is beyond the limits of the artesian reservoir, and the water level in it is unaffected by the compression of artesian aquifers when Pine View reservoir is filled.

Correction of hydrograph of well 82 for certain pressure effects.—Certain fluctuations of the water level in well 82 are caused by changes in barometric pressure, and others result from interference caused by discharge from Artesian Park. Both are independent of the amount of storage in the artesian reservoir. Of these, the barometric effect may be evaluated in terms of atmospheric pressure, and the interference effect in terms of the rate of discharge from wells at Artesian Park. Corrections for these effects, which are derived in subsequent paragraphs, may be applied to the recorded water levels in well 82 to determine approximatly the hypothetical water level under conditions of constant barometric pressure (25.50 inches) and of constant discharge (16 second-feet) at Artesian Park.

Well 82 is clearly within the area of influence of Artesian Park wells, for certain fluctuations of the water level in the well are correlated directly with changes in the rate of discharge. The following table shows the amount of rise or fall of water level in well 82 in response to changes of discharge at Artesian Park during several periods when the correlation is most clearly evident. Ordinarily the fluctuation in the well begins within 6 to 12 hours of the time of the change at Artesian Park. The maximum effect of the increase or decrease in discharge ordinarily occurs within 48 hours after the change, but in some cases the lag may be as long as 4 days.

Correlation of Water-Level Fluctuations with Changes in Discharge from Wells

Date	Change in discharge at Artesian Park (second-feet)	Change of water level in well 82 (feet)
June 2-4, 1933	+1.4	—0.14
June 14-16	+2.1	— .10
Aug. 19-21	—4.3	+ .24
Sept. 16-18	—3.0	+ .25
Sept. 18-20	+2.8	— .25
Sept. 25-29	—4.6	+ .41
Sept. 28 - Oct. 4, 1935	—4.0	+ .25

The discharge from Artesian Park causes interference at well 82 even during periods of minimum discharge but the interference remains practically constant as long as the discharge is constant. As the rate of withdrawal increases, the interference increases more or less proportionately. During the periods listed in the table the change of water level ranged from 0.05 to 0.10 foot for each second-foot change in discharge. The corrections applied to the hydrograph of well 82 have been on the assumption that the interference effect is 0.1 foot per second-foot of discharge.

The water levels in certain wells in Ogden Valley have been shown[10] to correlate closely with changes in atmospheric pressure. In well 82, and presumably in other wells, the fluctuations are more prominent during the months from November to May than during the rest of the year, both because the barometric fluctuations are commonly greater during those months and because the water-level fluctuations are less likely to be obscured by fluctuations due to other forces. Even though the barometric effect may be obscured during certain days or certain seasons, it is considered that it is always a factor influencing water levels, and that for every rise or fall of barometric pressure there is a proportionate rise or decline of the water level in the well.

Correlation of barometric and water-level fluctuations can best be made when fluctuations due to other forces are at a minimum. These conditions are satisfactorily met during November 1933, for the discharge from Artesian Park was held constantly at 14 second-feet, and the water level during the month fluctuated through a very narrow range. In figure 4 the depth to water at noon each day is plotted against the contemporary barometric pressure at Salt Lake City. The graph indicates that the water level in the well rises about 0.3 foot in response to a decrease of 1 inch in pressure of a mercury barometer, so that the well during this period was approximately 22 per cent efficient as a water barometer. The dispersion of the points is doubtless due partly to slight fluctuation in water levels due to other causes. The degree to which the water level in the well reflects barometric fluctuations doubtless varies somewhat, depending partly on the rate of change of the barometric pressure. For the corrections of water level in this report, a barometric efficiency of 22 percent, corresponding to that derived on figure 4, has been assumed.

[10] Leggette and Taylor, Op. cit., pp. 126-128, fig. 25.

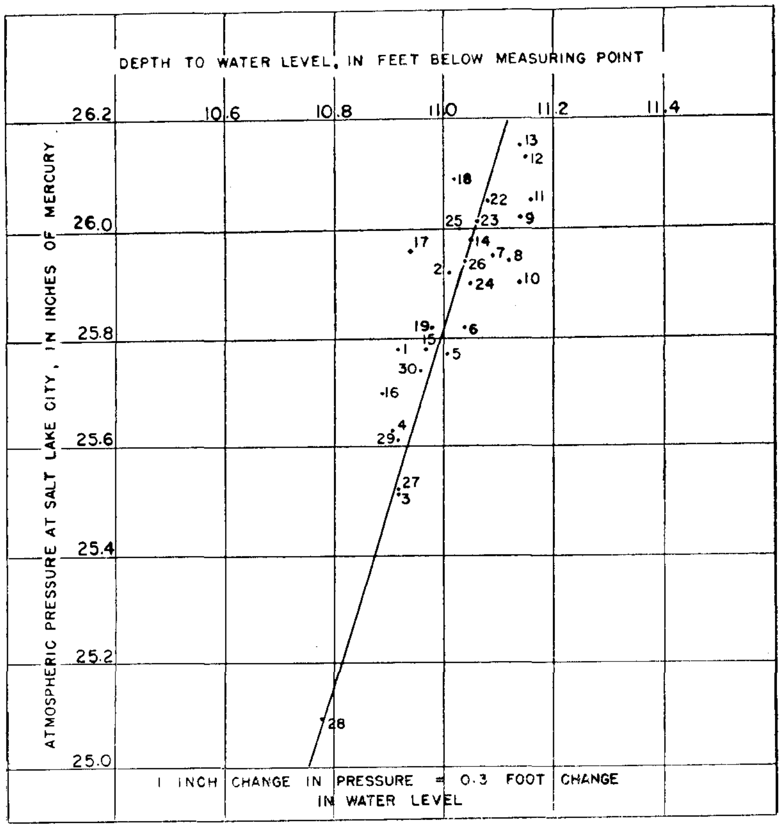

Figure 4.—Relation of water level in well 82 to atmospheric pressure in November 1933. Numbers refer to dates in month.

Rate of Recharge to the Artesian Reservoir

Records of water-level fluctuations in well 82 were obtained for a period of about 4 years prior to the completion of the Pine View dam and the first filling of the surface reservoir. During one or more months in each year the artesian reservoir was full or so nearly full that there was likelihood of some rejected recharge, according to the hydrographs of well 82 and of well 74 in the recharge area (fig. 3). In 38 months during that period the artesian reservoir was not filled to capacity, and must therefore have been capable of accepting any increments that were made available to it. During these months the rate of recharge would thus be governed by the deep penetration of water that was disturbed over the recharge area as precipitation or irrigation water and the seepage from stream and irrigation ditches that distribute water therefrom, but would not be dependent upon the amount of water stored in the artesian reservoir nor upon the rate of discharge of that water. It is for these months that correlations of water-level fluctuations with changes in rates of deep penetration of rain and of seepage from streams are attempted in following paragraphs.

Recharge by penetration of rain or melting snow.— Additions to the ground water in the recharge area are affected by the infiltration of water that falls as precipitation, as shown by fluctuations of water level in well 74. The effect of penetration of water from melting snow on the recharge area have been described briefly (p. 14). Intense rain storms upon the recharge area may also cause an apprciable rise of water level in the well, caused by deep penetration after the soil moisture deficiency has been satisfied. Storms during which the rainfall is less than half an inch ordinarily have no effect upon the water level in the well, but individual storms of larger magnitude may cause the water table in the recharge area to rise several inches. On the hydrograph of well 74 the effects of certain intense storms have been obscured by the more pronounced effects of irrigation of land adjacent to the well; during midsummer storms of fairly large magnitude may have no effect upon the water level, probably because the rainfall had first to replenish a high soil-moisture deficiency; and each winter there are several months when precipitation falls as snow, and there is no rise in water level until the snow begins to melt in the spring. During the 38 months between November 1932 and November 1936 when the artesian reservoir was not filled to capacity, six storms had a recognizable effect upon the water level in well 74. These storms and their effects are listed below.

Effect of Storm Rainfall upon Water Level in Well 74

Date of storm	Rainfall at Ogden (inches)	Rise of water level in well 74 (feet)
June 6-7, 1934	.61	.08
June 24-25, 1934	.98	.08
July 20-22, 1934	1.01	.19
Nov. 17-19, 1934	2.26	.25
Oct. 19-20, 1936	1.40	.15
Oct. 30 - Nov. 2, 1936	2.43	.30

The effect of these rains upon the water level in well 82 cannot be discriminated, perhaps partly because of lag but chiefly because of the pressure effects created by reduction of discharge from Artesian Park during these storms. It is believed, however, that storage in the recharge area that serves the artesian reservoir was replenished by deep penetration, not only from these storms but from many others of comparable magnitude during the 38 months when the reservoir was not filled to capacity. The water level in well 82 would therefore presumably be higher following these storms because of this increased storage. The net change of water level in well 82 during each of these 38 months is shown in the table below, corrected for pressure effects as explained in preceding paragraphs. The table also shows the monthly rainfall at Ogden, the amount of rainfall in storms of high intensity, and the average monthly discharge of the South Fork.

Monthly Changes in Water Level in Well 82, and Data on Precipitation and Run-off

Month	Change in water level (feet)	Precipitation at Ogden (inches) Total	Precipitation at Ogden (inches) During storms totaling more than 0.5 in.	Discharge of South Fork (sec.-ft.)
October 1932	+1.10	0	0	38
November	+ .55	1.05	.59	38
December	—1.14	*	*	35
January 1933	—1.66	*	*	36
February	—1.30	*	*	36
March	+1.19	.98	0	57
April	+3.53	2.40	1.17	197
August	—1.13	.59	.57	38
September	— .79	.64	.53	35
October	+ .56	.37	0	40
November	— .02	.10	0	38
December	— .48	*	*	38
January 1934	— .92	*	*	38
February	— .38	2.41	1.89	37
March	+1.57	.56	0	48
May	— .63	.09	0	38
June	—1.13	1.81	1.74	28
July	—2.02	1.04	1.01	24
August	—2.59	.80	.51	23
September	—2.31	.85	.85	24
October	+ .78	1.17	.85	29
November	+2.58	4.10	4.00	32
December	+ .17	*	*	34
January 1935	+ .71	*	*	37
February	+2.18	*	*	48
March	+1.46	1.90	1.40	60
April	+ .81	3.92	3.48	207
August	—1.29	.36	0	31
September	—1.66	.83	.63	28
October	+1.00	.76	0	30
November	— .90	1.75	1.40	32
December	—1.35	*	*	32
January 1936	—1.22	*	*	32
February	+ .42	*	*	37
March	+4.60	2.46	2.06	84
August	— .36	.79	0	44
September	+1.22	.11	0	39
October	+ .55	3.07	2.74	39

*Average temperature in Ogden Valley below freezing; precipitation accumulating as snow.

During 21 of the 38 months listed, the recharge to the artesian reservoir by deep penetration of precipitation is believed to have been negligible, either because of lack of precipitation or because the precipitation was accumulating as snow. During 5 other months the storms were of sufficient magnitude to have effected some recharge, provided the soil-moisture deficiency was not too great. In every year there have also been one or more months in the spring (12 months in all) when storms have been intense enough to have caused some recharge, which, however, could not be discriminated from the contemporaneous deep penetration of melting snow and the seepage from streams.

Especially noteworthy are the months during the summer and fall of certain years, when storms have probably been of sufficient magnitude to have contributed to the ground water in the recharge area: June to November 1934, November 1935, and October 1936. These storms occurred when stream flow and seepage therefrom were low, and when there was no deep penetration of water from melting snow. The increments from these storms thus arrived at a time when recharge from other sources was at low ebb. The rate of recharge from these storms cannot be evaluated, but the water level in well 82 is evidently affected, as indicated in the discussion below. According to Leggette's figure 21 (Water-Supply Paper 796-D, p. 119), the reservoir beneath the water table is an integral part of the artesian reservoir. "Simple penetration of water to the water table" in the recharge area here would add water to the artesian reservoir.

Recharge by seepage from streams.—The table on page 26 shows, in addition to data on water levels and on rainfall, the average monthly discharge of the South Fork, which for lack of adequate records is necessarily taken as representative of the total inflow to the valley, although it is not known whether its discharge is a constant proportion of the total inflow to the valley. The gaging station is located above all diversions for irrigation and thus measures all the water that enters Ogden Valley from the South Fork. During certain seasons a large proportion may be diverted for irrigation, but these diversions likewise cross the recharge area in channels where seepage is probably comparable to that in the stream channel. Some of the water is used to irrigate lands in the recharge area, and excess irrigation contirbutes to ground-water storage there.

During the 35 months prior to July 1936 listed in this table the average rate of discharge of the South Fork was

38 second-feet or less in each month when the net change in water level in well 82 was downward. Conversely, when the net change in water level in the well was upward, the average discharge of the South Fork was ordinarily 38 second-feet or more. A notable exception to this generalization occurred during the last quarter of 1934, when the water level in the well rose more than 3½ feet, although the run-off of the South Fork averaged less than 32 second-feet. This rise is attributed chiefly to recharge by deep penetration of rain during the numerous storms in the latter half of that year, particularly in November.

In order to show the relation of changes of water level to both the discharge from Artesian Park and the inflow to the valley, the 38 months listed above have been divided into periods during which the withdrawals from Artesian Park have totalled 1,000 acre-feet. These periods are listed in the following table together with net changes of water level in well 82 and the run-off from the South Fork during those periods. The data of this table are presented graphically in figure 5, using net changes of water levels corrected for barometric and interference effects, which ordinarily differ by less than a tenth of a foot from actual changes. There is a moderate dispersion of these points, which might be expected from the incompleteness of data as to total recharge and discharge of the artesian reservoir. Nevertheless, a trend appears to be established by these points, indicating some correlation between net change of water level and run-off from the principal tributary stream. The dispersion of the points may result partly from the use of the record of the South Fork as representative for the inflow to the reservoir, whereas well 82 is evidently within the area recharged from the Middle Fork, whose fluctuations may deviate appreciably in time from those of the South Fork. A large part of the dispersion is probably caused by the variable rate of recharge from local sources, by deep penetration of rainfall or melting snow upon the recharge area. Thus the five points lying farthest to the right represent periods during the winters of 1932-33 and 1933-34, of which the former was exceptionally severe, when precipitation in Ogden Valley was accumulating as snow, and downward penetration of moisture was presumably negligible. The point farthest to the left represents a period in 1934 when precipitation at Ogden totalled 4.4 inches—3 inches greater than normal—and the water level in well 82 was undoubtedly raised considerably because of recharge due to deep infiltration from this precipitation.

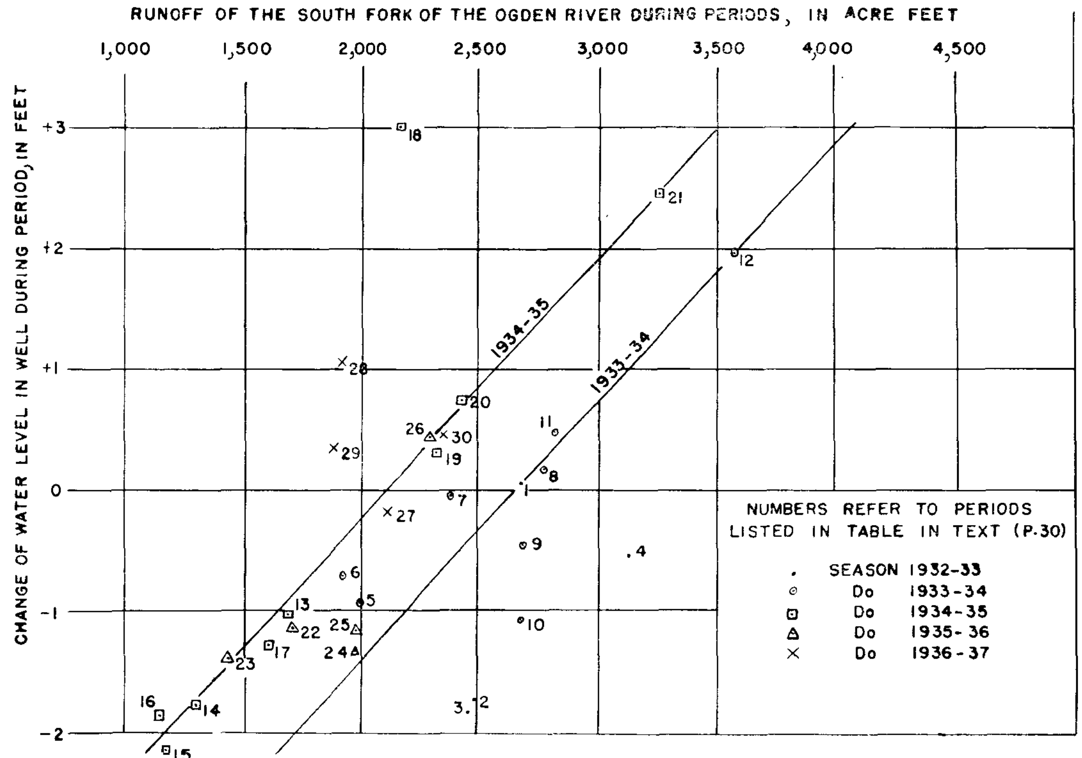

Figure 5.—Relation of changes in water level in well 82 to run-off in the South Fork of Ogden River during periods of equal withdrawal from Artesian Park. Numbers refer to periods listed in table, p. 30.

Periods During Which the Withdrawals From Artesian Park Totaled 1,000 Acre-Feet and Data Concerning Stream Flow and Water Levels in Those Periods

No. on figure 5	Duration of period	No. of days in period	Net change of water level in well 82 during period (feet): From recorder charts	Net change of water level in well 82 during period (feet): Corrected*	Run-off from South Fork in period (acre-feet)
1	Nov. 1, 1932 - Dec. 6, 1932	36	+ .07	+ .05	2,690
2	Dec. 7, 1932 - Jan. 11, 1933	36	—1.70	—1.72	2,490
3	Jan. 12, 1933 - Feb. 15, 1933	35	—1.75	—1.82	2,470
4	Feb. 16, 1933 - Mar. 23, 1933	35	— .37	— .55	3,130
5	July 29, 1933 - Aug. 23, 1933	26	— .53	— .92	2,000
6	Aug. 24, 1933 - Sept. 19, 1933	27	—1.05	— .70	1,920
7	Sept. 20, 1933 - Oct. 21, 1933	32	+ .48	— .05	2,400
8	Oct. 22, 1933 - Nov. 26, 1933	36	+ .12	+ .16	2,780
9	Nov. 27, 1933 - Jan. 1, 1934	36	— .31	— .46	2,700
10	Jan. 2, 1934 - Feb. 6, 1934	36	—1.12	—1.09	2,690
11	Feb. 7, 1934 - Mar. 14, 1934	36	+ .39	+ .47	2,830
12	Mar. 15, 1934 - April 15, 1934	32	+1.80	+1.96	3,580
13	June 1, 1934 - June 30, 1934	30	—1.34	—1.02	1,690
14	July 1, 1934 - July 27, 1934	27	—1.69	—1.77	1,300
15	July 28, 1934 - Aug. 22, 1934	26	—2.17	—2.14	1,180
16	Aug. 23, 1934 - Sept. 16, 1934	25	—1.89	—1.86	1,150
17	Sept. 17, 1934 - Oct. 17, 1934	31	— .84	—1.29	1,610
18	Oct. 18, 1934 - Nov. 20, 1934	34	+3.00	+3.01	2,160
19	Nov. 21, 1934 - Dec. 24, 1934	34	+ .37	+ .32	2,330
20	Dec. 25, 1934 - Jan. 27, 1935	34	+ .61	+ .74	2,440
21	Jan. 28, 1935 - Mar. 3, 1935	35	+2.77	+2.45	3,260
22	Aug. 1, 1935 - Aug. 28, 1935	28	—1.09	—1.13	1,710
23	Aug. 29, 1935 - Sept. 23, 1935	26	—1.37	—1.40	1,430
24	Dec. 1, 1935 - Dec. 31, 1935	31	—1.12	—1.33	1,980
25	Jan. 1, 1936 - Jan. 31, 1936	31	—1.23	—1.16	1,980
26	Feb. 1, 1936 - Mar. 2, 1936	31	+ .44	+ .44	2,310
27	Aug. 1, 1936 - Aug. 24, 1936	24	— .08	— .18	2,120
28	Aug. 25, 1936 - Sept. 18, 1936	25	+1.02	+1.06	1,970
29	Sept. 19, 1936 - Oct. 13, 1936	25	+ .34	+ .35	1,890
30	Oct. 14, 1936 - Nov. 12, 1936	31	+ .89	+ .47	2,360

*Corrected to constant barometric pressure and interference from Artesian Park (see pp. 21-23).

If the points representing periods within a single season only are considered, the dispersion is considerably less than that for the entire group of points. Thus, the points representing periods in the season 1934-35 are generally to the left of the main group. Seven of these points define a fairly straight line that would give the following relationship between recharge and discharge: The recharge is sufficient to offset discharge and maintain a constant water level in well 82 when the run-off from the South Fork is about twice as great as the discharge from Artesian Park —or in the periods representing withdrawals of 1,000 acre-feet from Artesian Park, if the run-off of the South Fork is about 2,000 acre-feet. The trend of the line indicates that, for each 400 or 500 acre-foot increase in run-off during the period, the water level in well 82 would rise about a foot, and conversely for each 400 or 500 acre-foot decrease in run-off the water level would decline 1 foot. Points representing periods during the 1933-34 season define a line approximately parallel to that drawn for 1934-35, but farther to the right, so that a run-off of about 2,700 acre-feet from the South Fork is shown to be required to offset a withdrawal of 1,000 acre-feet from Artesian Park and hold the water level constant in the well. Five points representing periods in 1935-36 evidently define a line intermediate between these two lines, but during the 1932-33 season the plotted points are still farther to the right, and suggest that in that year the run-off from the South Fork would need to be even higher in order to maintain a constant level in well 82 while the Artesian Park wells were discharging 1,000 acre-feet.

Several suggestions are offered in explanation of this evident shift from one year to another in the position of the line expressing relationship between recharge from streams, discharge from wells, and water level in well 82. A dominant factor appears to be the recharge by infiltration of precipitation upon the recharge area. During seasons when storm rainfall upon this area is slight and infiltration therefore low, a greater amount of recharge and therefore a greater quantity of stream discharge is required to offset the withdrawal of a certain quantity of water from the artesian reservoir. Thus, during the period in 1934-35 represented by points 13 to 21 on figure 5, the storm rainfall at Ogden was about 9 inches. The rainfall during the 1935-36 season was about 4 inches, and points 22 to 26 are generally farther to the right. During the 1933-34 season, when precipitation was about 3 inches, points 5 to 12 are still farther to the right; and in the 1932-33 season, when storm rainfall was less than an inch, the water level in well 82 declined even though the run-off in the South Fork was normal or above normal (points 1 to 4).

Another factor that has not been measured or estimated is the natural discharge that reduces storage below the recharge area, including the springs located along the outcrop of the varved clay and the artesian discharge other than that from Artesian Park, especially by underflow into Ogden Canyon and by about 30 flowing wells. The discharge from the recharge area by springs—of which those at the head of Huntsville Spring Creek are the largest—decreases as the storage in the reservoir decreases, and was especially low during the drought year of 1934. The artesian discharge also would doubtless be smaller in 1934 than in other years, because recharge was so deficient that the artesian reservoir was not filled, and Artesian Park withdrawals were heavy to offset the effects of drought, so that the pressure head at each well or natural outlet would be lower than normal, and the outflow would be correspondingly decreased. The smaller discharge would be balanced by a smaller rate of recharge, and would require a lesser amount of seepage from streams to maintain the balance. Thus the points representing periods in 1934-35 would be generally to the left of those in other years, when the measured discharge was greater. On the other hand, in such years as 1932 and 1936 the inflow to the valley was sufficient to keep the artesian reservoir practically full for several months, and natural discharge as well as discharge from flowing wells in these years might be expected to be greater. This increase in unmeasured discharge is indicated by the positions of points representing periods in 1932-33, generally to the right of the norm.

A third factor that may cause some shift in relationship is suggested by study of records of inflow to the valley. The South Fork is the only tributary whose discharge is measured, and it has been assumed that the inflow from other tributaries is roughly proportional to this discharge. As a matter of fact, the drainage basin of the South Fork is only about half of the area tributary to Ogden Valley, and yet miscellaneous measurements already referred to (p. 11) indicate that during several periods of low flow in late summer the run-off of the South Fork has constituted as much as 80 per cent of the total inflow to the valley. Conceivably, the run-off of the South Fork is a greater percentage of the total inflow during periods of low stage than during the spring freshets, and hence the recharge to the valley may be somewhat smaller during such years as 1934-35 and larger during years of abundant run-off than is indicated by the discharge of the South Fork.

Recharge in relation to inflow to Pine View reservoir.— The artesian reservoir obtains a considerable part of its recharge by direct infiltration of water that falls as precipitation upon the recharge area in Ogden Valley and upon the adjacent foothills. Under the natural conditions prevailing before the development of artesian wells, this water replaced losses due to outflow from the lower end of the reservoir, moved down the aquifers toward that outlet, and eventually also contributed to the flow of the river through Ogden Canyon. All other recharge to the artesian reservoir is effected by seepage from streams tributary to Ogden Valley and from ditches and irrigated lands that receive water from these streams. Prior to drilling of wells the water obtained by this seepage likewise moved toward the lower end of the artesian reservoir and eventually reentered Ogden River. Since this underflow was probably less in amount than the total ground-water discharge, it is likely that a greater proportion of recharge was rejected in the upper part of the reservoir.

By the development and use of artesian wells and the subsequent construction of Pine View Dam, two reservoirs have been developed, both of which are replenished from the same sources—by precipitation in Ogden Valley and by inflow of tributary streams. Both attain their maximum storage during the spring due to the melting of the winter's accumulation of snow, and both store this water for use during periods of greater demand in the summer and fall.

The flow of the streams entering Ogden Valley is ordinarily more than sufficient to fill both the artesian and surface reservoirs, and Pine View reservoir has spilled water each year since it was first filled in 1938. As shown by the following table, the annual discharge of the South Fork alone has exceeded the capacity of Pine View reservoir during all but 2 years in the 16-year period 1922-37. In the 20-year period from 1922 to 1941 inclusive the average discharge of the South Fork was about 100 second-feet, and the average annual run-off about 75,000 acre-feet. The annual surface outflow from Ogden Valley, measured at a gaging station in Ogden Canyon, has ordinarily been about twice the discharge of the South Fork into Ogden Valley. During the period 1904-12 the annual discharge at this station ranged from 2 to 8 times the capacity of Pine View reservoir. Thus, the discharge of Ogden River has exceeded the capacity of Pine View reservoir during 26 of the 28 years of available records. In the future, likewise, it may be assumed that Pine View reservoir (and necessarily also the artesian reservoir, because it fills first) will probably be filled to capacity and will spill water into Ogden Canyon during 9 out of 10 years. Water that enters the artesian reservoir during the freshets of these years would otherwise be added to flood waters that are spilled down Ogden Canyon. A large proportion of this flood water is wasted into Great Salt Lake.

Quantity of Water, in Acre-Feet, Discharged Annually by the Ogden River and by the South Fork of Ogden River

(From Records of the Geological Survey)

Hydrographic year	South Fork of Ogden River near Huntsville	Ogden River near Ogden
1904	....	210,000*
1905	....	101,000
1906	....	180,000
1907	....	364,000
1908	....	121,000
1909	....	325,000
1911	....	154,000
1912	....	220,000
1922	115,000	....
1923	110,000	....
1924	64,700	....
1925	76,900	....
1926	59,500	....
1927	99,900	....
1928	96,800	....
1929	90,600	....
1930	49,900	....
1931	32,600	....
1932	107,000	245,000
1933	77,200	161,000
1934	26,600	27,400
1935	61,000	119,000
1936	124,000	279,000
1937	78,600	180,000
1938	78,900	†
1939	54,200	†
1940	43,400	†

*Estimated.

†Pine View reservoir in operation.

In extremely dry years the artesian reservoir may be filled even though run-of is insufficient to fill Pine View reservoir. Thus, during the driest year on record (1934) the artesian reservoir was filled nearly to capacity, but the run-off in the Ogden River below Ogden Valley totaled only about 27,000 acre-feet, or about 60 percent of the capacity of the subsequently-established Pine View reservoir. In these years the depletion of storage in the artesian reservoir by withdrawals from wells would diminish the amount of water available for storage in Pine View reservoir, because surface supplies would obviously be greater if there were no seepage into the artesian reservoir, and seepage would be limited to the quantity necessary to replace the natural discharge if the artesian reservoir were not drawn upon by wells.

Even though both reservoirs may be filled during the spring freshet, the run-off during the summer months may not be sufficient for all needs. During this season a large proportion and perhaps all of the flow of streams tributary to Ogden Valley may disappear by seepage, of which some certainly enters the artesian reservoir unless that reservoir is filled to capacity. As indicated in the discussion of changes in storage on pages 27 to 32, the quantity of water entering the partly-filled artesian reservoir is evidently closely related to the flow of the tributary streams. In this respect the artesian reservoir is analogous to the surface reservoir. Changes in storage in the artesian reservoir indicate the balance between the rates of recharge and of discharge. When the flow of the South Fork exceeds 40 second-feet, the inflow to the valley generally provides sufficient seepage into the recharge area to offset the normal draft by the Ogden city wells and to increase the storage available to the artesian reservoir; and when the run-off of the South Fork is less than 35 second-feet the normal discharge from the artesian reservoir ordinarily exceeds the recharge and causes a decrease in storage, unless this recharge is sufficiently augmented by deep penetration of precipitation.

The quantity of water that reaches the artesian reservoir from the several streams of the valley cannot be measured directly, but may be estimated during certain periods when discharge from Artesian Park was low. Thus, between February 10 and March 15, 1939, the wells at Artesian Park discharged at a constant rate of 12 second-feet. The water level in well 82 declined 0.9 feet during this period, indicating a decrease in storage. (The quantity of water in Pine View reservoir was practically constant throughout the period, so that none of the fluctuations of water level in well 82 could be attributed to changes in load upon the aquifer.) Since the completion of Pine View dam the discharge from the artesian reservoir is believed to be essentially limited to that from Artesian Park. The rate of recharge to the artesian reservoir must therefore have been less than the 12 second-feet that was being withdrawn from Artesian Park. Considering the appreciable decline of the water level in well 82 during the period, it is likely that this recharge was not over 10 second-feet. In other words, the total contribution to the artesian reservoir from the channels of the three forks of the Ogden River and of minor tributaries was not over 10 second-feet during a period when the average discharge of the South Fork was about 36 second-feet. During nearly every winter there have been similar periods when the draft of the Ogden city wells has been less than 15 second-feet, and when the decline of water level in well 82 has indicated that part of this withdrawal has been from storage, and that therefore the rate of recharge to the reservoir was substantially less than 15 second-feet. During the irrigation season of most years, particularly in August and September, the discharge of the South Fork is less than 36 second-feet, and it is inferred that the recharge to the artesian reservoir by seepage from streams at these times is proportionately less than 10 second-feet.

The withdrawals from Artesian Park may be considerably in excess of this rate of recharge. The excess is withdrawn from storage, and is replenished from flood waters during the following spring when the artesian reservoir is again filled. Thus the artesian reservoir operates very much like Pine View reservoir, storing flood water during the months of greatest run-off and yielding this water throughout the rest of the year according to the needs of the water users.

From the preceding discussion it is evident that the development of the Ogden Valley artesian reservoir by means of wells has had the same effect as would have been produced by building a dam and constructing a surface reservoir, to the extent that the artesian reservoir each spring stores water which would otherwise go to waste in Great Salt Lake. Furthermore, available records show that even with this development there is a surplus of water during the spring freshets of most years, for some water still enters Great Salt Lake.

The Ogden metropolitan area is expanding rapidly, and the city is already searching for a greater water supply to satisfy increasing demands. Increased draft upon wells to satisfy these demands would lower the storage in the artesian reservoir, but this storage would be replenished in normal years by increased recharge during the time of the spring freshet, and the increased recharge would make available for beneficial use this water that would otherwise spill into Ogden Canyon and flow to Great Salt Lake. It should be pointed out, however, that this increased draft would result in lower artesian pressure during certain periods of each year, and therefore the rate of flow of individual wells would be diminished. Thus the city might be required to drill additional wells and perhaps resort to pumping to obtain this increased supply.