GEOLOGY AND GROUND-WATER RESOURCES OF OGDEN VALLEY, UTAH

by

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ABSTRACT

Ogden Valley, in Weber County, is a fault trough or graben. It is known as one of the "back valleys" of the Wasatch Range. Consolidated rocks of pre-Tertiary age, unconsolidated and poorly consolidated rocks of Tertiary age, and unconsolidated rocks of Quaternary age constitute the rocks of Ogden Valley and its watershed.

The pre-Tertiary rocks are exposed in the mountains surrounding the valley. These rocks range in age from Precambrian to late Paleozoic. Several stratigraphic gaps exclude the rocks of Ordovician, Silurian, much of the Devonian, and the Permian systems from the area. The pre-Tertiary rocks are not very significant as water bearers in the area.

The Tertiary rocks include Knight Formation, Norwood Tuff, and upper Pliocene(?) Fanglomerate and range in age from early(?) Eocene to late Pliocene(?). Miocene rocks are missing. The Knight Formation supplies about 860 acre-feet of water annually to Bennett Spring. The Norwood Tuff has a low permeability and acts as an underlying confining bed in Ogden Valley. The upper Pliocene(?) Fanglomerate is unconsolidated and unsorted. The formation has a relatively low permeability; therefore, it will not receive much recharge from precipitation.

The Quaternary rocks include more than 400 feet of unconsolidated sediments of the Pleistocene and Recent epochs deposited within the graben. The Pleistocene sediments consist of pre-Lake Bonneville and Lake Bonneville gravels, sands, silts, and clays. The Recent deposits

are fan gravels, flood-plain gravel, sand, and silt, landslide deposits, and slope wash deposits. Pre-Lake Bonneville deposits include fan gravels and stream-laid deposits of gravel, sand, silt, and clay; they make up the artesian aquifer, whose waters are confined by the overlying silt and clay of the Alpine Formation of Lake Bonneville age and by the relatively impermeable underlying Norwood Tuff. Overlying the Alpine Formation are the sands and gravels of the Bonneville Formation which, together with Recent sands and gravels, contain perched water bodies. In the recharge area these Bonneville and Recent deposits are hydraulically connected with the artesian and water-table aquifer.

Ogden Valley is drained by three forks of Ogden River, and the flow of this river is regulated by the earth-fill dam which impounds the water of Pineview Reservoir.

Recharge to the ground-water reservoirs is by seepage from waterways and irrigated lands, and infiltration of precipitation. The estimated minimum recharge in 1970 was 34,300 acre-feet. The greatest contribution to this recharge is from seepage waters from the waterways and irrigated land.

Discharge from the ground-water reservoirs is by (1) wells, (2) evapotranspiration, and (3) springs. The estimated minimum discharge in 1970 was 34,000 acre-feet, of which 20,000 acre-feet was discharged by evapotranspiration.

The most important causes of water-level fluctuations in the artesian wells are discharge from the wells and loading by Pineview Reservoir.

Since November 1936, Pineview Reservoir has created a unique situation in Ogden Valley by adding a load on the underlying artesian aquifer. Thus, with an increase in the storage of the surface reservoir, the artesian aquifer is compressed and the water levels in the wells start to rise. An increase of about 4,800 acre-feet in the storage of Pineview Reservoir corresponds to a rise of water level in the test well, (A-6-2) 18 bab-1, of one foot.

The chemical quality of the ground water in Ogden Valley is good and the water is suitable for household and irrigation purposes. The results of bacteriological analyses of water samples from ten wells indicate that the water in six wells is satisfactory, but the water in four wells around Eden may be classed as unsatisfactory for drinking purposes.

The artesian aquifer in Ogden Valley probably could be developed further if the present users would be willing to accept a reduction in pressure in exchange for the additional water. The water-table aquifer probably could be developed to yield five times its present yield of 100 acre-feet per year.

INTRODUCTION

Location and Extent of the Area

Ogden Valley is in the eastern part of Weber County, Utah, about 12 miles east of the City of Ogden (fig. 1). The valley has an area of 37 square miles, and is completely surrounded by mountains.

Ogden Valley is situated between 41° 13' 15'' and 41° 22' 30'' latitude and 111° 41' 15'' and 111° 53' 45'' longitude. The valley trends northwest and is approximately 12 miles long and 3 miles wide.

The City of Ogden is accessible from Salt Lake City by Interstate Highway 15, and the two roads that connect Ogden Valley with the City of Ogden are located along Ogden Canyon and North Ogden Canyon. The three towns of Ogden Valley are Huntsville, Eden, and Liberty; of these, Huntsville, population 494, is the largest.

Pineview Dam is located in Ogden Canyon about 3 miles west of Huntsville. Pineview Reservoir, when filled to capacity, occupies an area of 2,900 acres. Pineview Reservoir is used extensively for recreation purposes, and the recreational facilities are being greatly expanded under the Weber Basin Project of the United States Bureau of Reclamation.

Purpose and Scope of the Study

This investigation was undertaken to determine (1) the geology of the area with emphasis on the occurrence of ground water; (2) the recharge, use, and discharge of ground water; (3) the chemical quality

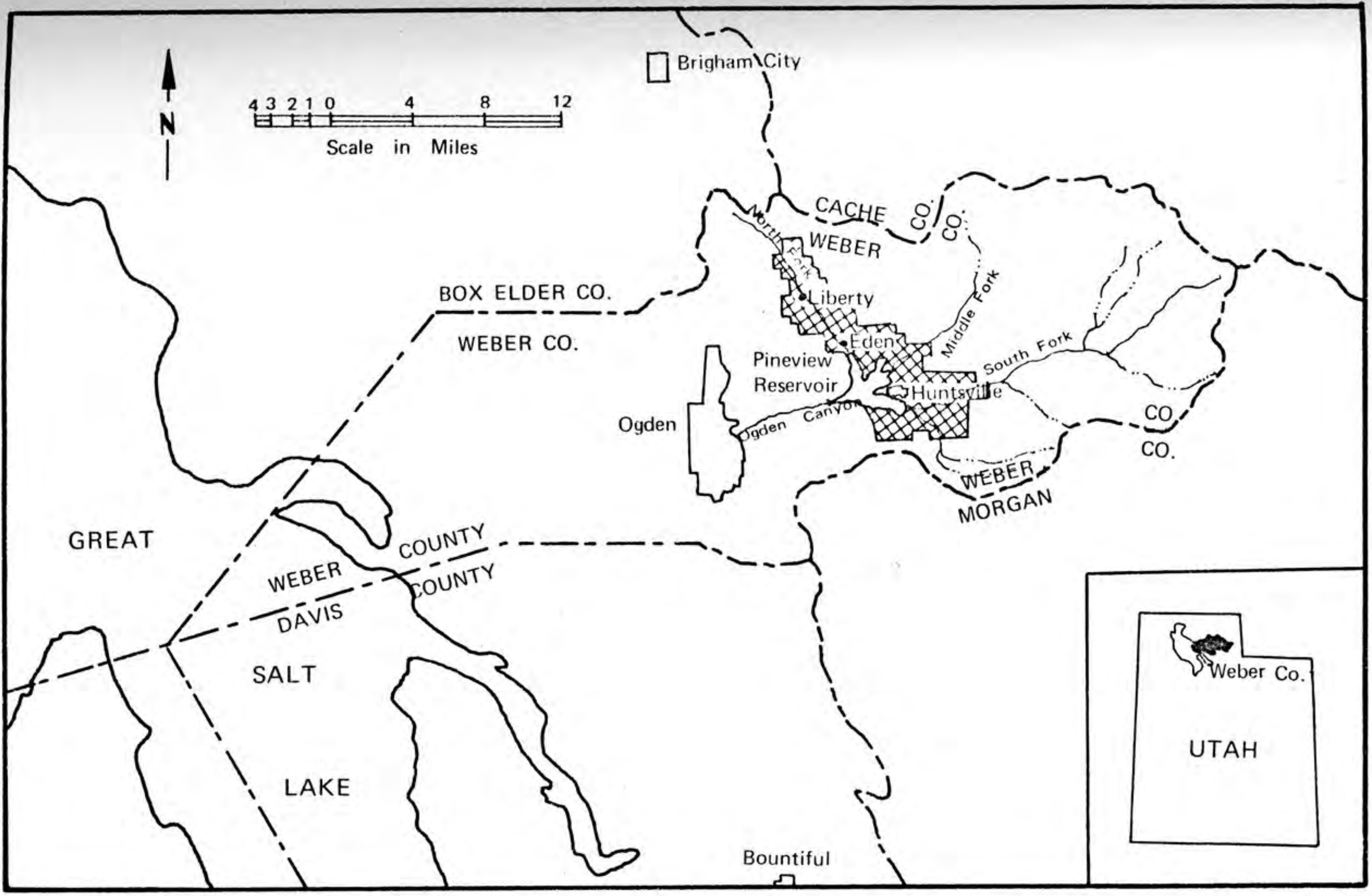

Figure 1. Map of Weber County, Utah, showing the location of Ogden Valley (crosshatched).

of ground water; (4) the amount of ground water available for development; and (5) the effect of a surface reservoir on an artesian aquifer. The investigation was concerned almost entirely with unconsolidated deposits of the area. Consolidated rocks were studied only where such data were needed to understand the ground-water conditions.

The investigation was carried out in four phases. The first phase consisted of extensive library research, which included the collection of geological information, surface-water data, and climatological data. The records of existing wells were obtained from the Office of the State Engineer, and the long-term water-level measurements for the three observation wells were obtained from U.S. Geological Survey.

The second phase included the fieldwork starting in May 1970 and ending in July 1971. During this phase all the existing wells were located on topographic sheets, twenty-three representative wells were selected and the water levels were measured at monthly intervals, a geological field check was conducted, the types and the areal extent of the vegetation were determined, and the water samples were collected from eleven representative wells for chemical and bacteriological analyses.

The third phase included the laboratory work. Water samples were analyzed to determine the chemical quality of ground water. The bacteriological analyses were done by Utah Division of Health. Collection and analysis of water samples were done according to the procedures described by Brown, Skougstad, and Fishman in Methods for Collection and Analysis of Water Samples for Dissolved Minerals and Gases: Techniques of Water-Resources Investigations of the United States Geological Survey, 1970.

The fourth phase included the correlation and interpretation of data. This report discusses the status of ground water at the time of the investigation. Certainly this status will change as development proceeds and water use by the Weber Basin Project increases. The features that are related to geology, however, are permanent and subject to negligible change.

Previous Investigations

The first detailed investigation of geology and ground-water resources of Ogden Valley was completed by Leggette and Taylor in 1937. Their report includes information concerning geology, ground-water conditions, and wells, and also contains a map showing the area of flowing wells. In 1945, Thomas made an investigation of the Ogden Valley artesian reservoir. His report is a sequel to the one prepared by Leggette and Taylor, and is based on data collected during 1932-34, augmented by records that had been obtained (1935-40) by the U.S. Geological Survey as part of a State-wide project in co-operation with the Utah State Engineer. A second investigation by the same author in 1953 describes the geologic and hydrologic features of Ogden Valley.

In this open-file report, an emphasis was given to the factors producing fluctuation of water levels in the Tower well.

Certain physiographic and structural features of Ogden Valley have been described by Gilbert (1928) and by Blackwelder (1910). In 1944, Eardley conducted a comprehensive regional investigation, mapped the north-central Wasatch area, and worked out many of the complex structural relations of the region. His work furnished the background for subsequent studies on the unconsolidated sediments of the valley fill. Later, Lofgren, 1955, discussed the Tertiary and Quaternary stratigraphy of Ogden Valley.

Several unpublished M.S. theses, Coody (1957) on the geology of the Durst Mountain-Huntsville area, Laraway (1958) on the geology of the South Fork of Ogden River area, and Eriksson (1960) on the geology of the Upper Ogden Canyon, give geologic information for Ogden Valley and its vicinity. These theses also contain detailed geologic maps of respective areas.

PHYSIOGRAPHY

Ogden Valley lies within the Great Basin physiographic province. It is one of the "back valleys" of the Wasatch Range that have been described by Gilbert (1928) as grabens, separated from the Great Basin farther west by the horst that has formed the western frontal ridge of the Wasatch Range.

Topography and Drainage

Ogden Valley is elliptical in shape, mostly flat at an average elevation of 4,900 feet, and is surrounded by Wasatch Mountains. The area is drained by three forks of Ogden River. The South, Middle, and North Forks of Ogden River enter the valley from east, northeast, and north, respectively. These forks discharge into Pineview Reservoir and the excess water from the reservoir flows westward through the Wasatch Range by way of Ogden Canyon. Several creeks that rise in the surrounding hills join the major streams within the valley.

Gilbert (1928, p. 57) describes the mountains as follows:

> The portion of the Wasatch Range opposite Ogden Valley has two members distinguished by their physiographic habit. The western member has rugged summits, with many crags of resistant rocks. The eastern member has rounded summits, and its entire sculpture is of a mature or subdued type. 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 three forks of Ogden River cut deep and narrow canyons within the resistant Paleozoic terrain and these canyons become broader as the streams enter the valley. The valleys of Middle and South Fork Ogden

Rivers run across geologic structures and thus they may be classed as "transverse valleys". The streams have opened narrow terraced valleys in the alluvium of the plain.

Ogden Canyon is another example of a transverse valley. Its course cuts across geologic structures and forms a deep and steep-sided gorge.

The most commonly encountered drainage pattern is dendritic. Dendritic pattern is characterized by irregular branching of tributary streams in many directions and at almost any angle. These patterns are commonly formed by Middle and South Fork Ogden Rivers. They develop upon the uniform Paleozoic rocks and imply a notable lack of structural control.

About five miles north of Ogden Canyon the Wasatch Range is deeply grooved by a cross valley, North Ogden Canyon. The pioneer trail and first wagon road from the Salt Lake plain to Ogden Valley followed this route. The summit lies close to the eastern face of the range and the pass, as seen from east, has the appearance of a hanging valley. Gilbert (1928) concludes that this pass is an "air gap" which marks the course of a stream that once crossed the range from east to west.

Landforms

The major landforms of Ogden Valley include lake terraces, river terraces, alluvial fans, and fault escarpments. The processes of development of these landforms are erosional, depositional, and diastrophic.

During the late Pleistocene epoch 19,750 square miles of western Utah was covered by a pluvial lake, known as Lake Bonneville. The altitude of the Bonneville shore line is about 1,000 feet above Great Salt Lake and about 5,135 feet above the sea level. According to Gilbert (1890) the eastern shore of the main body followed the steep base of the Wasatch Mountains, where it was modified by the estuaries of Box Elder Creek, Ogden River, and Weber River. Ogden Canyon was occupied by a long and narrow strait, communicating with a bay several miles broad, hemmed in by mountains. Ogden Valley contained a bay of Lake Bonneville and retains some of the higher shore terraces. The lake terraces thus formed may still be observed at the mouths of Middle and South Fork Ogden Rivers and along the southeastern border of the valley. At other places the lake terraces are probably concealed by post-Lake Bonneville slope wash deposits.

During the Provo epoch of Lake Bonneville the shore line was 375 feet lower than the Bonneville shore line and 625 feet higher than the water of Great Salt Lake. The fall of the lake drained the upper valley (Ogden Valley) and led to the building of a broad delta just outside the mouth of Ogden Canyon; but this delta is exceptional to the general rule in that it is somewhat below the Provo horizon (Gilbert, 1890, p. 163).

The lower part of Ogden Valley was degraded during the Provo epoch of Lake Bonneville. Since that time, the streams have opened narrow, terraced valleys in the alluvium of the plain. The terraces are generally only a few feet high, composed of sand, silt, and gravel.

Alluvial fans are formed at the mouths of small streams as the heavily loaded streams emerge from hills or mountains onto a lowland. Such fans may be observed at the mouths of Broadmouth Canyon, Wolf Creek, Geertsen Canyon, South Fork Ogden River, and Bally Watts Creek.

The fault scarps on the east and west margins of Ogden Valley are somewhat modified by erosion. However, along the base of mountain front west of Liberty, a fault scarp can be traced easily for several miles.

CLIMATE

The climate of Ogden Valley is temperate and semiarid. The summers are relatively short, and temperatures are moderate. The mean annual temperature is about 44° F with recorded extremes of 35° F below zero and 104° F above zero. Temperatures below zero are common during a cold winter, although periods of severely low temperatures are not prolonged because the mountains ward off most of the intensely cold air masses. The frost-free growing season ordinarily includes the five months from May through September.

Winds are usually light to moderate, normally ranging from 7 to 10 miles per hour. The percentage of sunshine during the day ranges from 60 to 80, and the relative humidity is low, commonly dropping below 30 percent during midsummer days. The windiness, high percentage of hours of sunshine, and low atmospheric humidities in the summer tend to promote high rates of evaporation from water and moist land surfaces and high rates of transpiration from plants.

Average annual precipitation at Pineview Dam for the period 1935-70 was about 28.49 inches. The only precipitation station within the Ogden River drainage basin is at Pineview Dam, in Ogden Canyon about a mile below the lower end of Ogden Valley. The record began in January 1935. An earlier record at Huntsville in the southeast part of Ogden Valley covered 30 years of the period 1895 to 1930, during which the average annual precipitation was 20.4 inches. Absence of correspondence between the records of the two stations may be explained by the orographic influence of the Wasatch Mountains. The Wasatch Mountains greatly distort the pattern of precipitation along the path, producing greater precipitation where the air masses are forced to rise and less precipitation where the air masses drop down after passing the mountains. As a result of this orographic influence, the Pineview Dam station receives considerably more precipitation than the Huntsville station.

Graph showing the annual rate of precipitation against time is plotted as bar graph, figure 2. Another type of plot, the moving mean graph, is also illustrated by the dashed line on figure 2, in which each plotted position shows the mean precipitation for the three years centering on the year indicated. In such moving mean graphs the minor fluctuations are smoothed out, making it possible to pick out critical low periods and to study wet and dry climatic variations. Figure 2 shows that the wet periods were centered around the years 1937, 1941, 1946, 1956, and 1964 and the dry periods were centered around the years 1939, 1943, 1953, 1960, and 1966.

The cause of precipitation other than dew and frost is adiabatic-expansion cooling through lifting (Butler, 1957, p. 8). In Ogden Valley, this lifting occurs by means of orography. The predominant westerly winds bring moisture-laden maritime air, and the Wasatch Mountains lie almost perpendicular to the inflowing winds. The areas of heavy precipitation are produced by the mountain slopes acting almost as permanent warm

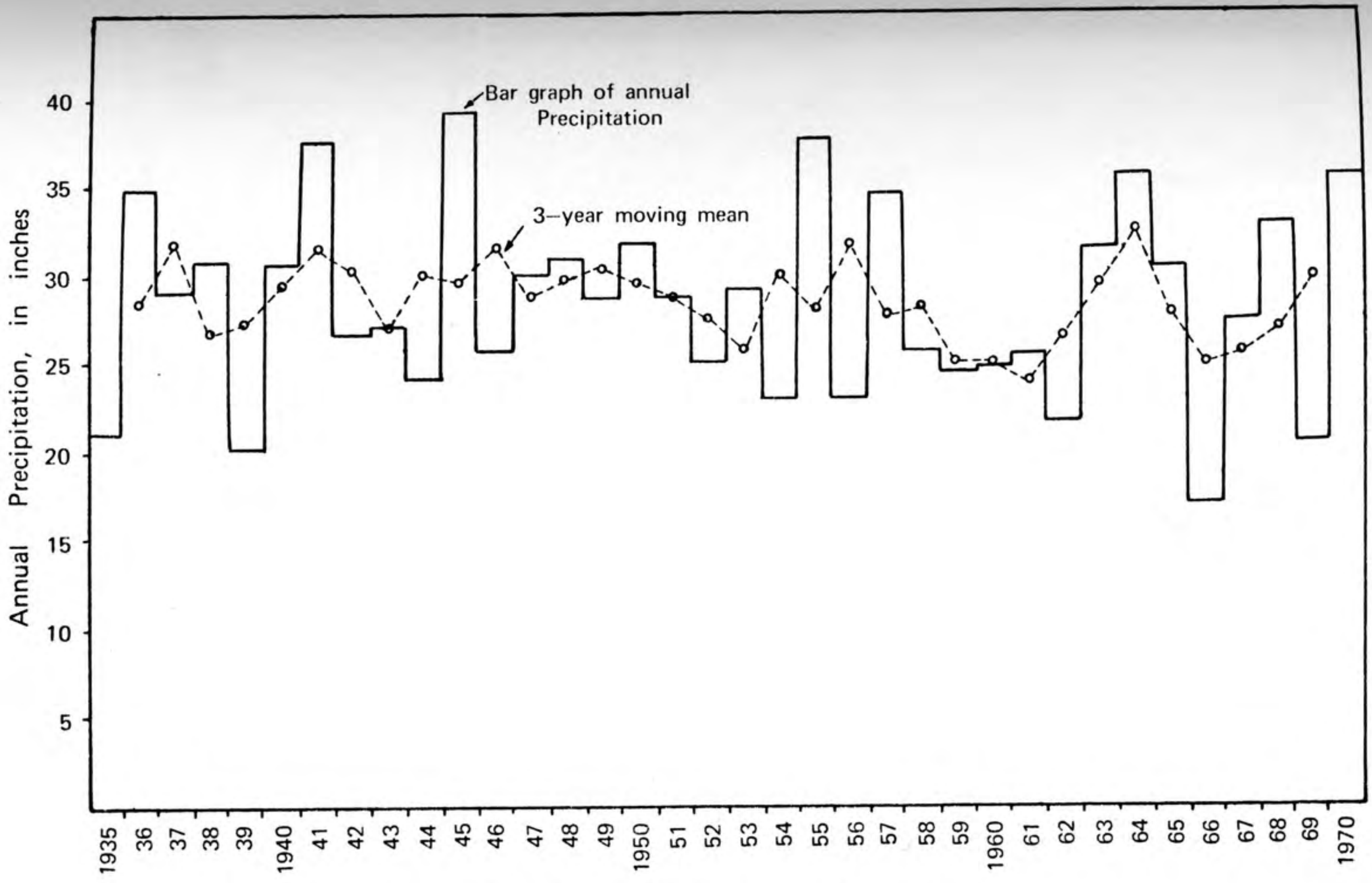

Figure 2. Precipitation in Ogden Valley, Utah. Record of station located at Pineview Dam.

frontal surfaces up which the precipitation-producing air masses are driven by the westerlies. Between mountain ranges precipitation decreases sharply as the air masses descend from the peaks to the valley. This descent of the air masses along the easterly slopes is known as subsidence and has the effect of warming the air mass in a fashion similar to the cooling caused by ascent (Bruce and Clark, 1969, p. 13). Much of the rain and snow, therefore, falls on the windward slopes rather than on the leeward slopes and the valley floor.

GEOLOGY

Geology is the major factor controlling the occurrence, quality, and availability of ground water in Ogden Valley. The ground-water reservoir consists of unconsolidated sediments that have been deposited in a large structurally-controlled basin of consolidated rocks. The thickness of the unconsolidated rocks is perhaps more than 400 feet. The consolidated rocks of pre-Quaternary age form the boundaries of the ground-water basin. The unconsolidated sediments in the basin contain the ground water presently developed and available for development, and they include many strata of low permeability that confine water in more permeable beds, causing artesian conditions in the lower parts of the valley.

The lithology of the various deposits largely determines the areas of recharge and of natural discharge of ground water. Lithology also determines the yield of the aquifers and the depth to which development of ground water is presently feasible, and it is an important determinant of the chemical quality of ground water within the basin.

Rocks and Their Water-Bearing Properties

The rocks in Ogden Valley and its watershed were divided into three principal groups - consolidated rocks of pre-Tertiary age, unconsolidated and poorly consolidated rocks of Tertiary age, and unconsolidated rocks of Quaternary age.

Rocks of pre-Tertiary Age

The pre-Tertiary rocks of Ogden Valley are exposed in the mountains surrounding the valley (Plate 1). These rocks range in age from Precambrian to late Paleozoic. Several major stratigraphic gaps interrupt the sequence of the exposed rocks. In general, these gaps exclude from the area the Ordovician, Silurian, much of the Devonian, and the Permian systems of the Paleozoic era. Table 1 is a generalized stratigraphic column of all the rocks in and adjacent to Ogden Valley.

The oldest rocks that crop out in the surrounding mountains are a thick series of Precambrian metamorphic rocks. These rocks constitute part of the eastern, northern, and western boundary of the ground-water basin.

During spring runoff, some water may enter these rocks through fractures, joints, and bedding planes. A small part of this water probably moves gradually downward and finds its way into the sand and gravel aquifers along the western mountain front where the beds dip toward the valley.

Rocks of Paleozoic age crop out along Ogden Canyon a mile west of Pineview Dam, on both sides of the South Fork Ogden River between Magpie Canyon and Cobble Creek, and about two miles south of Monastery between Bally Watts Creek and Sheep Herd Creek. The outcrops along the South Fork Ogden River are large enough to receive appreciable recharge largely from snowmelt. Part of this recharge water probably provides a base flow

Table 1. Thickness, description, distribution, and water-bearing properties of rocks exposed in Ogden Valley and its watershed.
Sources: Coody, 1957; Eardley, 1944; Eriksson, 1960. Laraway, 1958; Lofgren, 1955; and Veatch, 1907.

Era	System or Period	Series	Formation	Thickness (ft)	Description	Distribution	Water-Bearing Properties
Cenozoic	Quaternary	Recent			Fan gravels, flood-plain gravel, sand, and silt, slope wash deposits, and landslide deposits.	Best exposures are located along the northern parts of the valley.	Probably will yield water in moderate quantities. Yield limited mostly by the thickness of the deposits.
		Pleistocene	Lake Bonneville Group: Bonneville Formation	10-40	Mostly lacustrine sand and gravel. Poorly to moderately sorted.	Constitutes part of the valley fill below 5,135 ft.	Local perched water bodies above confining layer. Forms the confining bed of the artesian aquifer.
			Lake Bonneville Group: Alpine Formation	10-100	Lacustrine silt. Sorting is excellent. Shows varving.		
			Pre-Lake Bonneville Deposits	300	Fan gravels. Interfingered lenses of fine-grained sediments within the gravel. Mostly horizontally bedded. Well sorted.	Constitutes part of the valley fill.	Most wells in the Artesian Park area obtain water from the gravel and sand deposits of the upper parts.
	Tertiary	Upper Pliocene(?)	Upper Pliocene(?) Fanglomerate	300-800	Unconsolidated, poorly sorted boulder fanglomerate. Quartzitic boulders of Precambrian and Cambrian age are predominant. Weathers to surfaces of bouldery soil.	Forms low ridges. Crops out northeast and south of Ogden Valley.	It has a relatively low permeability, will not receive much recharge.
		Lower Oligocene	Norwood Tuff	400-800	Light-colored to white tuff. Well-stratified and lithified. Persistent bedding suggests fluviatile-lacustrine deposition. Lenses of volcanic conglomerate not uncommon. Weathers to white rolling hills. Permeability is low.	Forms a ridge between Ogden and Morgan Valleys. Constitutes a major part of the eastern, western, and southern boundary of Ogden Valley.	Acts as an underlying confining belt to hold water in the valley fill. Supplies water of good quality to Hawkins spring. Yield unknown.
		Lower (?) Eocene	Knight Formation	1,200	Coarse, red, cliff-making conglomerate. Well-rounded boulders, chiefly Precambrian and Paleozoic quartzite, embedded in fine-grained red matrix. Crude, massive bedding, with widespread uniformity.	Constitutes a small part of the southeastern valley boundary.	Yields water of unknown quantities to several springs. Supplies water of good quality to Bennett spring.
Paleozoic	Mississippian		Brazer Formation	1,100	Medium gray, finely crystalline limestone, tan to red sandstone, and purple to olive shale.	Crops out principally near head of Ogden Canyon. Small outcrops located 1.5 mile south of Monastery.	Small outcrops not know to be water bearing in the area. Because of the geographic position of the outcrops, not practical for ground-water exploration.
			Humbug Formation	800	Light gray, thin-bedded, highly jointed quartzites and dark gray to black, thin-bedded, finely crystalline dolomite.		
			Deseret Limestone	175	Thin-bedded, slightly argillaceous, dark blue limestone.		
			Madison Limestone	675	Gray, coarsely crystalline, massive dolomite in upper parts, thin-bedded, gray, medium-crystalline limestone in lower. Fossils are common.		
			Unconformity				
	Devonian		Jefferson Formation: Beirdneau Member	1,200	Buff-weathering sandstones. Intercalated with dolomite and limestone at the bottom.	Crops out only in Ogden Canyon.	Probably will yield some water. Outcrop areas of both members are not large enough for yields of large quantities.
			Jefferson Formation: Hyrum Member		Black dolomite and limestone. Fossils are abundant.		
	Cambrian	Upper Cambrian	Upper Cambrian undivided	1,300	Basal unit is a dark limestone, banded with mudstone and beds of oolitic and pisolitic limestone. Dark gray and crystalline dolomite member. Tan to olive shales interbedded with carbonate units.	Small exposures along the South Fork Ogden River.	Outcrops are large enough to receive appreciable recharge. Only one spring issues from Brigham Quartzite and its yield is not known. The outcrops are not in a favorable geographic position to supply water to Ogden Valley.
		Middle Cambrian	Blacksmith Formation	700	Medium to dark gray limestone, commonly oolitic.		
			Ophir Shale	200	Brown to olive green upper and lower shale members, and the middle limestone member.		
			Langston Formation	400	Basal, black arenaceous dolomite, gray limestone, and green shale. Shale member contains fossils.		
			Unconformity				
		Lower Cambrian(?)	Brigham Quartzite	1,500	Buff, yellow, and pink quartzite.	Crops out principally near mouth of South Fork Ogden River.	
Precambrian			Undifferentiated	7,000	Predominantly purplish and rusty-weathering quartzitic sandstones.	Crops out in the mountain mass east, north, and west of Ogden Valley.	May contain some water within the fissures, joints, and other openings and may recharge ground-water aquifers along the western mountain front.
				3,000	Arkosites and phyllites interbedded with gray to green to purple quartzites.		

for South Fork Ogden River and part may gradually move downward and form small aquifers at the subsurface. Only one spring issues from Brigham Quartzite but its yield is not known.

Rocks of Tertiary Age

Much of the eastern, western, and southern boundary of Ogden Valley consists of rocks of Tertiary age. These rocks include Knight Formation, Norwood Tuff, and upper Pliocene(?) Fanglomerate and range in age from early(?) Eocene to late Pliocene(?). Miocene rocks are missing.

Overlying the steeply dipping Paleozoic series east of Ogden Valley, horizontally bedded conglomerates dominate the landscape. These conglomerates were named Knight Formation by Veatch (1907) for exposures near Knight Station, Wyoming. This 1,200-foot-thick formation consists of well-rounded quartzite boulders embedded within a matrix of fine-grained red sediments. The log of the well, (A-6-1) 23 caa, (fig. 3) indicate that the formation consists of alternating layers of sandstone, conglomerate, and siltstone or shale. Coody (1957, p. 29) reports that the conglomerate contains boulders as much as 8 feet in diameter. The formation is generally lightly to firmly cemented and the boulders are easily removed from the matrix. A loose bouldery surface is everywhere present and the formation is generally covered by a thin and permeable blanket of red soil. Because of its soil cover and extensive outcrops, the formation may receive appreciable recharge. The Knight

Formation yields water of unknown quantities to several springs but one spring, Bennett spring, discharges about 860 acre-feet of water annually. The quality of this water is considered to be good (see table 16).

The Norwood Tuff composes the entire mass of the low hills separating Ogden Valley from Morgan Valley (located 7 miles south of Ogden Valley). It consists of a sequence of deformed beds chiefly of volcanic detritus, and is considerably younger than the Knight Formation (Lofgren, 1955, p. 75). The same unit also defines the northeastern and parts of the western boundary of Ogden Valley. The tuff was named by Eardley (1944) for Norwood Canyon in Morgan Valley, where it is well exposed. The Norwood Tuff is a well stratified and well-to-poorly indurated light-colored tuff, which consists of interbedded layers of tuff, sandstone, and volcanic agglomerate (fig. 3). It probably constitutes the largest part of the bedrock of Ogden Valley. It has low permeability and thus it probably acts as an underlying confining bed to hold water in the valley fill. Hawkins Springs issue from the porous beds of the formation and yield water of good quality.

The upper Pliocene(?) Fanglomerate was recognized in the Morgan area by Egbert (1954) and Schick (1955), and was also recognized in the vicinity of Huntsville by Lofgren (1955). This formation crops out in the northern and southern part of Ogden Valley. It is unconsolidated and unsorted throughout its observed thickness. Quartzitic boulders of Precambrian and Cambrian age predominate. The formation has a relatively low permeability therefore, it will not receive much recharge.

Rocks of Quaternary Age

The Quaternary rocks include the unconsolidated sediments of the Pleistocene and Recent epochs. The Pleistocene sediments consist of the pre-Lake Bonneville alluvial gravels and sands and Lake Bonneville gravels, sands, silts, and clays. All these sediments were derived from the surrounding watershed and deposited within the valley trough. The Recent deposits are fan gravels, flood-plain gravel, sand, and silt, slope wash deposits, and landslide deposits that have moved downslope into the valley trough from the surrounding mountains. From the available well logs it is estimated that these sediments are more than 400 feet thick.

The accumulation of more than 300 feet of these sediments below the bedrock outlet of the valley indicates that these sediments were deposited within a graben. Ogden Valley is similar in many respects to other structural "back valleys" east of the Wasatch Front. Eardley (1955) suggested large-scale block faulting in Morgan and Cache Valleys. This faulting started in late Pliocene time, and the downthrown blocks remained the locale of sedimentation all during the Pleistocene and even to the present. The same block faulting probably created the graben in Ogden Valley in which more than 400 feet of Quaternary sediments were deposited.

The events that resulted in the filling of the lower parts of the fault trough are not known in detail. It is, however, reasonable to assume that during the dry periods alluvium was deposited by streams entering the valley and during the wet periods the valley probably contained a pre-Lake Bonneville Pleistocene Lake. During the late Pleistocene epoch a pluvial lake, commonly known as Lake Bonneville, was formed in Great Salt Lake Valley. An arm of Lake Bonneville extended into Ogden Valley, and the deposits laid down in that arm form much of the upper 100 feet or more of the valley fill.

Pre-Lake Bonneville Deposits (Pleistocene)

Pre-Lake Bonneville deposits include fan gravels and stream-laid gravels, sand, silt, and clay. In the foothills along the east side of the valley an alluvial fan deposited at the mouth of Geertsen Creek consists of boulders, pebbles, and locally sand. Bedding is generally weak to obscure, sorting fair to very poor, and the gravel angular to subrounded. The fan gravel is obviously the result of deposition by a stream subject to heavy floods. Some of the deposits show better bedding and thus suggest deposition by nonflooding streams. The fan is older than Lake Bonneville for the high-water mark of the lake is impressed on it, and the lake deposits overlap the fan.

The gravel, sand, silt, and clay observed north of Liberty were probably deposited by North Fork Ogden River prior to the invasion of

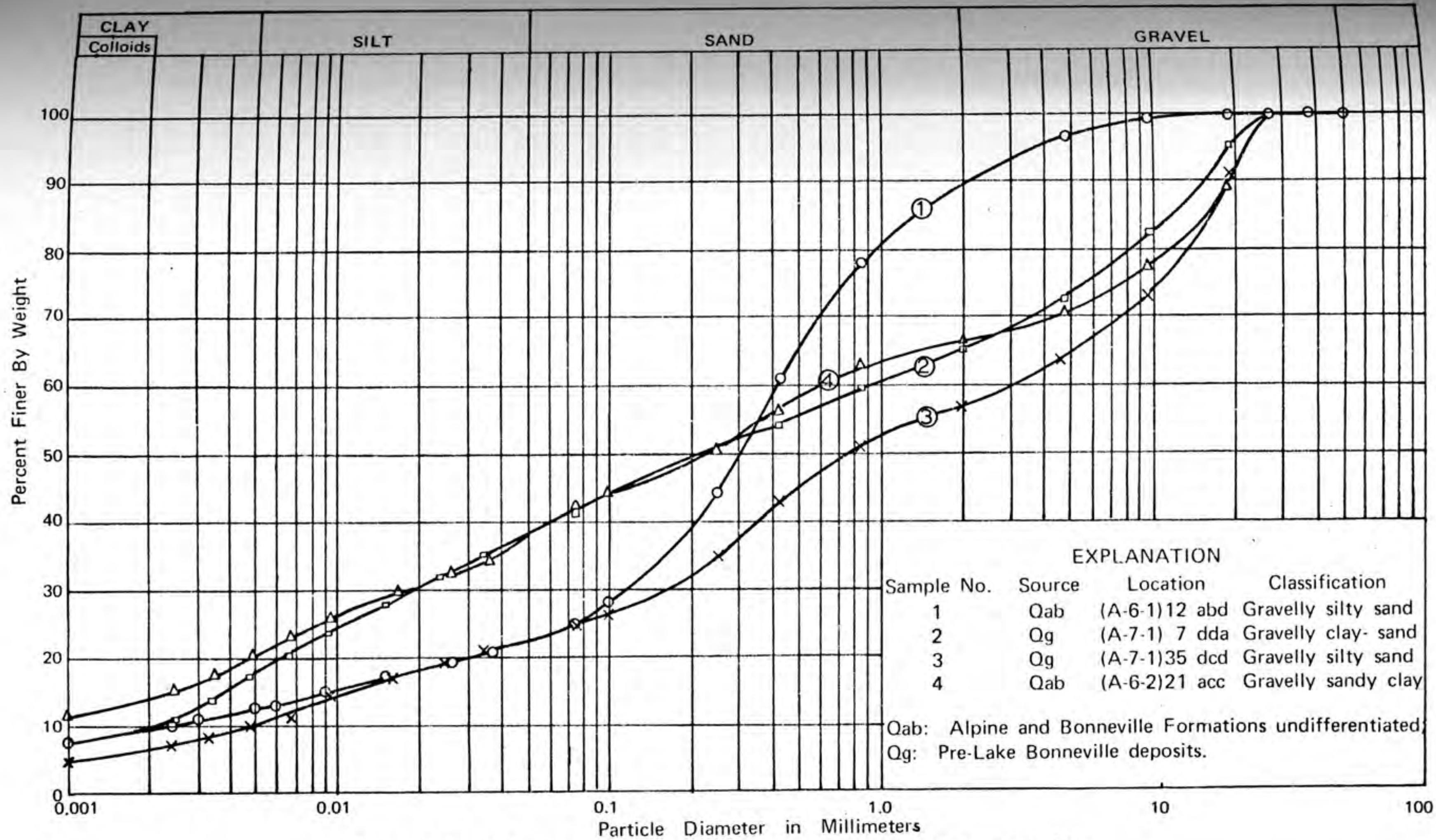

Figure 4. Grain-size accumulation curve of soil samples collected from Ogden Valley.

Ogden Valley by Lake Bonneville. The gravels are horizontally bedded and consist of a mixture of boulders, cobbles, pebbles, granules, and materials of sand and silt size. The pebbles are generally subrounded to rounded and the coarser components are mostly subangular. Curve no. 2 in figure 4 represents the grain-size accumulation curve of a gravel sample collected from $1\frac{1}{2}$ mile north of Liberty. The results of mechanical analyses indicate that the sediment consists of 35% gravel, 28% sand, 19.5% silt, and 17.5% clay. Sample no. 3 in figure 4 was collected 3/4 mile east of Eden. The hand auger first penetrated a 3-foot-thick bluish clay layer and then a saturated gravel sequence. The clay layer probably belongs to the Lake Bonneville group and the gravel is probably pre-Lake Bonneville. The mechanical analyses of the gravel sample obtained between the depths of 3 and 5 feet indicate that the sample consists of 43.6% gravel, 34.4% sand, 11.6% silt, and 10.4% clay.

Pleistocene pre-Lake Bonneville deposits under Ogden Valley are several hundred feet thick. These deposits have been penetrated by several deep wells. From the logs of wells it is inferred that the top of the pre-Lake Bonneville deposits is commonly from 70 to 150 feet below the land surface. The log of well, (A-6-1) 14 bba-1, in figure 5, indicates that the top of pre-Lake Bonneville deposits is about 100 feet below the surface and that their thickness is about 320 feet. The well also penetrates a thick clay deposit which represents the Alpine Formation.

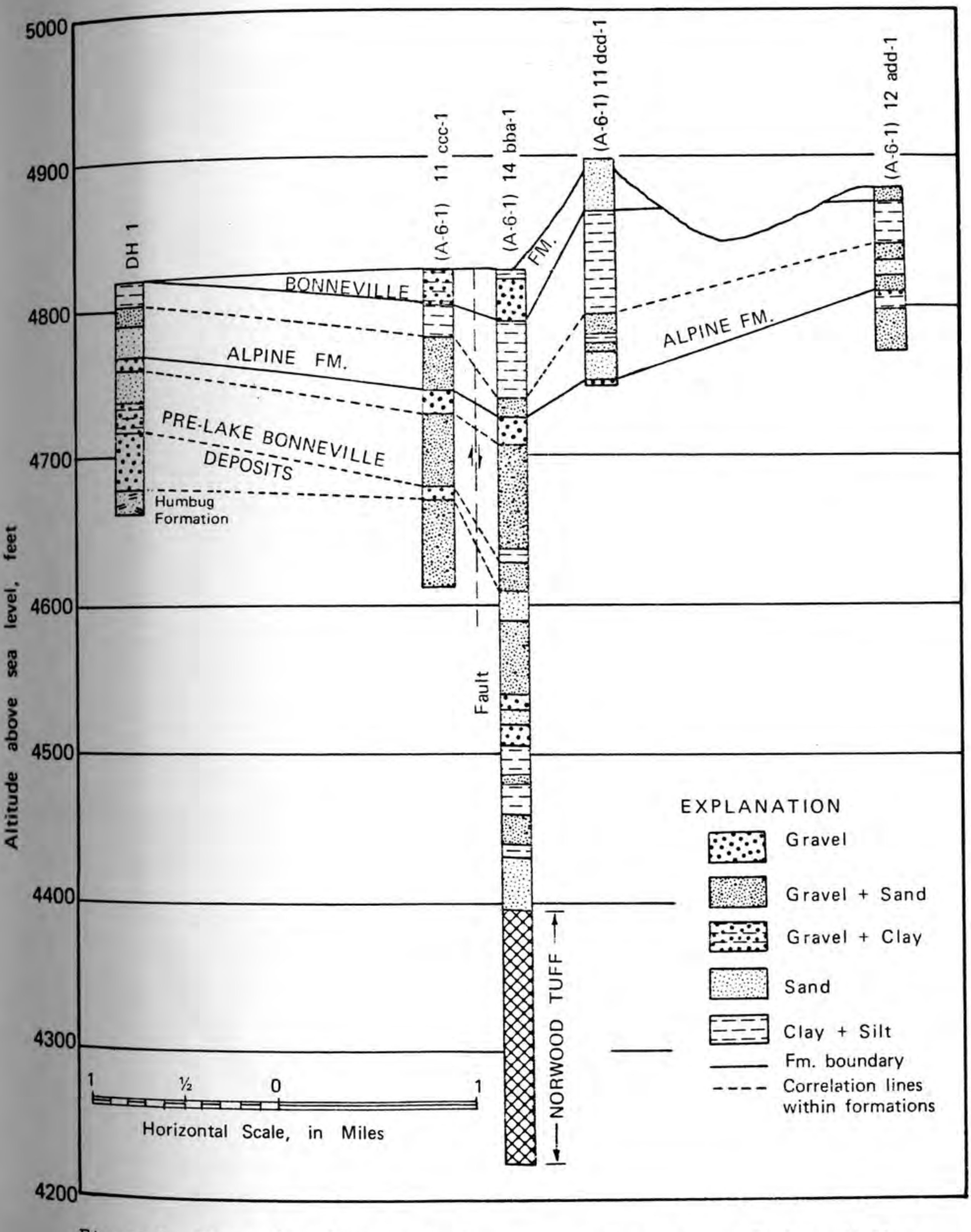

Figure 5. Generalized geological cross-section across Ogden Valley, extending N 70°E from Pineview Dam.

A clean well-sorted gravel marks the top of the pre-Lake Bonneville deposits, which constitute the principal artesian aquifer in the lower parts of Ogden Valley. Most wells in the Artesian Park area obtain water from the uppermost pre-Lake Bonneville gravel, for which the overlying Alpine Formation forms the confining layer.

Some interfingered lenses of fine-grained sediments within the gravel are horizontally bedded and well sorted, and suggest lacustrine sedimentation. Although several of these lenses of silt and clay form confining beds within the gravel, these lenses are not of wide extent, and the entire system behaves hydraulically as a single aquifer (Lofgren, 1955, p. 80).

Lake Bonneville Deposits

Lake Bonneville, the last of the great Pleistocene lakes that flooded Ogden Valley, covered almost 20,000 square miles in western Utah and had a maximum depth of about 1,000 feet. The deposits that were laid down in Lake Bonneville were divided into three formations by Hunt (1953, p. 17), each of which represents a different stage in the history of the old lake. These are the Alpine, Bonneville, and Provo Formations, of the Lake Bonneville Group, and they correspond respectively to what Gilbert (1890) referred to as the Intermediate, Bonneville, and Provo stages of the lake. Around Great Salt Lake, Gilbert recognized a fourth stage that he named the Stansbury. This is the youngest stage and represents a lake level lower than the other three. The deposits of Provo and Stansbury stages were deposited only at elevations below the lowest point in Ogden Valley and hence do not occur in there.

Alpine Formation . Oldest of the Lake Bonneville Group is the Alpine Formation, which was deposited while the lake was at the 5,100-foot level. Typically, the Alpine Formation contains a high proportion of fine-textured sediments, mostly silt. Sorting is excellent; the bedding is very distinct and in the finer-grained sediments individual beds commonly are only a fraction of an inch thick.

In the interior of the valley the formation thickens westward from about 5 to 10 feet to about 100 feet. The silt and clay member of the Alpine Formation is of great importance to the ground water in Ogden Valley, because it is the confining bed that produces the artesian condition. The member is thinly and evenly bedded. Individual beds range from 1/8 to 2 inches in thickness and principally consist of silt and clay with sparse sand and fine gravel in alternating layers.

In places there are the laminations that are thin enough to be suggestive of varves. The varves consist of alternating thin layers of dense, sticky, puttylike clay and silt, usually grayish blue and brown. "An approximate count of the varves indicates that about 25,000 years is represented by the total thickness of the clay bed" (Leggette and Taylor, 1937, p. 110). Leggette and Taylor (1937, p. 120) also reported that the coefficient of permeability of clays was less than 0.01 showing that the clay is essentially impervious.

Bonneville Formation . The Bonneville Formation includes those deposits that accumulated in the lake during its highest stage. The shoreline of the Bonneville stage may be seen at the mouths of Middle and South Fork Ogden Rivers, especially southward toward the Monastery. This is the highest bench, elevation 5,135 feet, observed in the valley.

> The lower bench, composing the dissected surface of most of the Ogden Valley floor, including the area of Huntsville, Eden, and the promontory of Cemetery Point, is graded downward from elevation 4,950 to elevation 4,915 throughout the central part of the valley. From this it is inferred that, during the Provo stage of the ancient lake, excavation of the higher sediments of the Bonneville stage took place, with planation throughout Ogden Valley and Ogden Canyon graded to a Provo lake level (elevation 4,800 feet) at the mouth of Ogden Canyon (Lofgren, 1955, p. 82).

In the vicinity of Huntsville and Monastery some beds assigned to the Bonneville Formation are sands and sandy gravels. Curves 1 and 4 in figure 4 represent the results of mechanical analyses of samples that were collected by hand auger from depths of 2 to 5 feet. Sample 1 was collected from a small promontory about a mile north of Huntsville. It consists of 10.5% gravel, 67.5% sand, 10% silt, and 12% clay. The classification of the sample using triangular charts (Hough, 1957, p. 24) is gravelly silty sand. The sediment shows good gradation and moderate sorting. Sample 4 was collected from a mile west of Monastery. It consists of 33.8% gravel, 28.8% sand, 17.4% silt, and 20% clay.

Recent Deposits

The recent deposits include fan gravels, flood-plain gravel, sand, and silt, slope wash deposits, and landslide deposits.

The fan gravels, composed of coarse, angular, and poorly sorted sediments, have been deposited in the foothills along the east side of the valley. The best exposures are at the mouths of Broadmouth Canyon, Wolf Creek, Middle Fork Ogden River, and Bally Watts Creek.

Flood-plain deposits form rather narrow belts along the channels of North Fork and South Fork Ogden Rivers. These deposits consist of mixtures of gravel, sand, and silt, in which the gravels are generally well rounded and range in size from small pebbles to large boulders.

The slope wash deposits are mapped along the western and northeastern mountain fronts as continuous belts overlying the pre-Lake Bonneville and Lake Bonneville deposits. These deposits are characterized by poor sorting and a high content of clay and silt size materials mixed with angular gravels.

A rather large landslide or mud flow deposit is exposed about $\frac{1}{2}$ mile north of Eden. It overlies the Lake Bonneville deposits in this location and it is easily recognized by its hummocky topography.

GEOLOGIC STRUCTURES

Principal structural elements of Ogden Valley include a north-south trending syncline, high-angle normal faults which form the sides of the graben along the east and west margins of the valley, and a thrust fault west of the valley.

Eardley (1944) described a broad syncline, chiefly in the Knight Formation, in Morgan Valley. His observations indicate that the same syncline continues northward across the divide into Ogden Valley. The folding took place after the deposition of Knight Formation and its age is probably late Eocene.

"Ogden Valley is a fault trough bounded on both east and west by faults that dip toward the middle of the valley" (Leggette and Taylor, 1937, p. 99). These faults strike approximately in the northwest direction. Lofgren (1955) summarizes the evidence for the western fault as follows:

> Along the west margin of the valley and paralleling the general trend of the structural trough, a scarp having several tens of feet of displacement is clearly defined. Although this scarp is somewhat modified by erosion, it is recent enough to be traceable in relief for several miles, and is evident along the base of the mountain front west of Liberty. Along this fault trace arise several springs, which in the area west of Liberty yield sizable quantities of cold water of good quality. South and east of the large Liberty springs, a series of small springs follows the base of the fault scarp...

In 1956, Stewart conducted a gravity survey in Ogden Valley. His studies indicate a fault along the east margin of the divide of the valley with a total vertical displacement of about 2,000 feet. He also postulated two faults along the west margin of the valley with vertical displacements ranging from 500 to 2,000 feet.

Blackwelder (1910) first recognized the Willard thrust, and named it from exposures in Willard Canyon. This thrust fault in the Wasatch Mountains immediately west of Ogden Valley is exposed for a distance of 20 miles and has a low dip eastward. "It emplaces younger Precambrian strata on Paleozoic strata and older Precambrian crystalline rocks, in which younger Precambrian beds are missing" (Eardley, 1969, p. 670).

Controversy has existed among the geologists for many years concerning the direction from which the Precambrian thrust mass came. Blackwelder (1910) made the first suggestion that the Willard thrust mass was a southwest moving sheet. Eriksson (1960) conceived the Willard thrust as a gravity slide structure marginal to the Northern Utah uplift. The thrust sheet was thus represented as coming from the west. Eardley (1969) reviewed the controversy surrounding the Willard thrust and presented a clearly developed case for east to west movement on the fault due to gravity induced sliding from the southwest edge of an extensive uplift in northeast Utah. Hammond (1971) conducted a petrofabric study on the Tintic quartzite in the area of the Willard thrust. His studies indicate that the movement was originated in the west and directed toward the east.

The age of Willard thrusting has been fairly well determined. Eardley (1962) dates the faulting through stratigraphic and structural evidence as occurring during the Montana epoch of the late Cretaceous.

SURFACE-WATER RESOURCES

The surface-water resources of Ogden Valley include three major rivers and a surface reservoir. Several intermittent streams also discharge some water into the valley but no data are available for them.

The South, Middle, and North Forks of the Ogden River enter the valley respectively from the east, northeast, and north. The valley is drained by the Ogden River, which flows westward through the Wasatch Range by way of Ogden Canyon, and then joins the Weber River which empties into Great Salt Lake.

The South Fork Ogden River contributes about 73 percent of the total inflow into the valley. Middle Fork contributes only 19 percent of the total inflow. During the irrigation season most of the waters of the three forks have been diverted into irrigation ditches and canals.

Streamflow data for the three major rivers in Ogden Valley were obtained from the U.S. Geological Survey Water-Supply Papers (1950, 1960), U.S. Geological Survey Surface Water Records of Utah (1964-69), and from Barnett's Annual Report Ogden River System (1970).

South Fork Ogden River near Huntsville

Monthly and annual runoff of South Fork Ogden River for the period 1921-70 is tabulated in table 2. The flow of the river for the same period is shown by a hydrograph in figure 6. From table 2 it will be seen that the maximum discharge, 131,200 acre-feet, was during the water-year of 1952. The mean discharge, however, for 49-year period was about 78,000 acre-feet. Table 2 also shows that the maximum discharge is in

Table 2. Monthly and yearly runoff, in acre-feet, of South Fork Ogden River near Huntsville, Utah.

Sources: Records 1921-50 from WSP 1314, 1950-60 from WSP 1734, 1961-64 from Surface Water Records of Utah, 1965-69 from Water Resources Data for Utah, and 1970 from J. F. Barnett's Annual Report Ogden River System.

LOCATION – Lat 41°16′07″, long 111°40′24″, in SE¼NE¼SW¼ sec. 12, T.6 N., R.2 E., Weber County, on right bank 0.5 mile downstream from Magpie Creek, 1 mile upstream from Huntsville Mountain Canal, 5 miles downstream from Causey Dam, and 5.5 miles east of Huntsville.

DRAINAGE AREA – 148 sq mi.

PERIOD OF RECORD – March 1921 to current year.

GAGE – Water-stage recorder. Altitude of gage is 5,190 ft (by barometer). Prior to Aug. 14, 1934, at site 300 ft upstream at different datum.

AVERAGE DISCHARGE – 49 years, 78,000 acre-ft per year.

EXTREMES – Period of record: Maximum discharge, 1,890 cfs May 3, 1952 (gage height, 5.98 ft); minimum, 13 cfs Dec. 16, 1965.

REMARKS – Records good. One small diversion above station. Flow regulated by Causey Reservoir since Jan. 4, 1966.

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	The year
1921	–	–	–	–	–	–	21,900	54,400	18,700	5,770	3,810	3,310	–
1922	3,280	3,230	3,300	3,310	2,980	6,400	15,800	51,300	14,500	4,790	3,550	2,980	115,000
1923	3,100	3,020	2,930	3,010	2,750	4,620	18,300	47,800	12,600	5,460	3,740	3,020	110,000
1924	3,350	3,080	2,780	2,590	3,050	3,510	12,600	19,300	6,370	3,220	2,500	2,310	64,700
1925	2,510	2,530	2,500	2,610	3,240	6,820	17,600	20,700	8,510	4,210	2,930	2,760	76,900
1926	2,880	2,670	2,670	2,290	2,180	5,200	19,500	11,500	3,720	2,570	2,210	2,120	59,500
1927	2,320	2,300	2,500	2,600	2,930	6,130	20,500	38,100	12,300	4,320	3,060	2,860	99,900
1928	2,920	2,980	3,200	3,070	3,160	10,500	16,900	38,000	6,960	3,690	2,860	2,580	96,800
1929	2,750	2,620	2,460	2,460	2,230	5,530	14,500	38,400	10,200	3,740	2,850	2,810	90,600
1930	2,680	2,530	2,570	2,520	2,340	3,820	12,300	10,100	4,060	2,420	2,380	2,210	49,900
1931	2,450	2,270	2,310	2,360	2,180	2,660	4,800	6,150	2,310	1,750	1,680	1,670	32,600
1932	1,890	1,880	1,940	1,970	2,270	5,610	23,200	47,300	11,800	4,030	2,520	2,290	107,000
1933	2,310	2,240	2,150	2,210	1,980	3,490	11,700	28,700	14,800	3,180	2,340	2,090	77,200
1934	2,440	2,280	2,330	2,340	2,030	2,920	3,970	2,320	1,690	1,460	1,420	1,440	26,640
1935	1,800	1,900	2,110	2,290	2,640	3,680	12,300	20,580	7,640	2,530	1,880	1,670	61,020
1936	1,880	1,930	1,980	1,980	2,140	5,150	41,770	50,300	8,670	3,730	2,680	2,320	124,500
1937	2,380	2,250	2,220	2,300	2,190	4,370	13,130	34,150	7,580	3,510	2,450	2,130	78,660
1938	2,460	2,440	2,550	2,550	2,160	6,030	21,010	24,210	7,070	3,450	2,610	2,320	78,860
1939	2,320	2,330	2,300	2,210	2,000	6,630	16,700	9,990	3,480	2,310	1,990	1,940	54,200
1940	2,070	1,930	1,970	2,010	2,200	5,140	10,920	9,340	2,600	1,830	1,650	1,700	43,360

Table 2 -- Continued

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	The year
1941	1,890	1,900	1,830	1,870	2,080	3,510	7,850	13,260	3,670	2,120	1,860	1,750	43,590
1942	2,010	1,990	2,150	1,950	1,900	3,300	20,570	15,890	6,340	2,680	2,000	1,900	62,680
1943	2,030	2,020	2,100	2,280	2,950	6,450	30,490	19,800	9,760	3,860	2,680	2,280	86,700
1944	2,400	2,270	2,230	2,220	2,140	2,680	7,200	22,640	10,540	3,480	2,460	2,250	62,510
1945	2,350	2,320	2,170	2,170	2,310	4,050	10,060	27,070	16,380	4,540	3,130	2,530	79,080
1946	2,600	2,800	3,180	3,250	2,850	8,720	39,620	21,420	7,710	3,610	2,770	2,490	101,000
1947	2,810	2,750	2,880	2,340	2,430	5,200	12,270	20,880	6,850	3,730	2,930	2,560	67,630
1948	2,580	2,490	2,560	2,690	2,420	2,930	17,460	38,790	9,060	3,860	2,710	2,390	89,940
1949	2,500	2,500	2,600	2,460	2,400	6,630	27,380	30,530	9,400	4,250	3,040	2,650	96,340
1950	3,030	2,700	2,640	3,450	3,990	7,160	26,950	40,500	16,940	5,520	3,640	3,030	119,600
1951	2,980	3,320	3,820	3,370	5,040	6,630	32,330	41,110	10,760	4,570	3,510	2,870	120,300
1952	3,030	2,860	3,000	3,070	2,970	3,950	33,780	53,610	12,730	5,230	3,800	3,140	131,200
1953	3,070	2,930	2,820	3,270	2,720	5,130	12,040	21,340	16,900	4,410	3,040	2,580	80,250
1954	2,650	2,530	2,560	2,760	2,450	3,790	14,080	10,990	3,870	2,630	2,240	2,070	52,620
1955	2,220	2,290	2,250	2,190	1,950	3,050	9,160	24,360	6,960	3,090	2,520	2,090	62,130
1956	2,280	2,330	6,240	4,970	3,330	7,820	22,200	24,910	7,050	3,560	2,760	2,390	89,840
1957	2,610	2,480	2,570	2,380	3,190	5,270	10,600	39,450	16,560	4,730	3,050	2,550	95,440
1958	2,620	2,510	2,550	2,430	3,380	4,940	13,230	30,820	6,230	2,890	2,350	2,160	76,110
1959	2,260	2,420	2,480	2,300	2,250	3,250	7,420	10,820	4,520	2,320	2,120	2,110	44,270
1960	2,350	2,280	2,140	2,000	1,940	5,540	12,970	15,010	3,700	2,210	1,990	1,970	54,100
1961	1,990	1,990	1,980	1,940	1,920	2,700	4,230	5,290	2,070	1,530	1,530	1,550	28,720
1962	1,700	1,810	2,030	2,060	4,780	4,610	28,450	22,920	7,780	3,120	2,330	2,110	83,700
1963	2,280	2,070	1,940	1,950	2,670	3,430	9,650	25,270	6,180	2,800	2,280	2,070	62,590
1964	2,280	2,370	2,040	2,020	1,810	2,110	9,630	34,630	12,840	4,730	2,780	2,370	79,610
1965	2,490	2,390	4,820	3,740	4,050	4,450	24,110	38,260	15,720	5,330	3,600	3,270	112,200
1966	3,050	3,210	1,630	1,520	1,130	4,240	14,340	19,070	7,090	4,150	3,150	2,170	64,740
1967	2,616	2,370	2,440	2,290	1,670	5,790	6,960	28,240	15,620	6,140	6,080	3,770	84,000
1968	2,290	1,340	3,320	1,710	1,880	3,180	14,440	15,750	13,040	5,620	4,530	4,330	71,440
1969	4,640	1,610	1,410	2,400	2,110	3,540	30,460	32,200	7,520	5,790	5,840	4,190	101,700
1970	2,950	2,470	2,660	3,020	2,990	3,930	5,120	27,180	10,540	5,260	5,450	2,360	73,940

May of each year. During the period of 1921-70, the maximum discharge, 1,890 cubic feet per second, was in May 3, 1952 and the minimum, 13 cubic feet per second, was in December 16, 1965.

During the irrigation season, part of the water in the channel of the South Fork is diverted into nine irrigation ditches. During the water year of 1970 the total amount of irrigation diversions was about 16, 400 acre-feet. Some of this water joins the ground-water reservoirs, some is consumed by plants, some is lost by evaporation, and an unknown portion again joins the stream channel.

Middle Fork Ogden River near Huntsville

The Middle Fork Ogden River enters Ogden Valley from northeast and flows westward toward Pineview Reservoir. No long-term measurements of the flow of Middle Fork were available. Monthly and annual runoff of the Middle Fork is tabulated in table 3 for the period 1964-70. A hydrograph showing monthly discharge for the same period is given in figure 7.

The maximum discharge of the Middle Fork, 25,710 acre-feet, was during the water year of 1969. The mean discharge for 7-year period was about 20,800 acre-feet. During the period 1964-70, the maximum discharge, 744 cubic feet per second, was in May 18, 1967, and the minimum, 0.4 cubic feet per second, was in August 18, 1964 and August 18, 1966.

Table 3. Monthly and yearly runoff, in acre-feet, of Middle Fork Ogden River above diversions, near Huntsville.

Sources: Records 1964 from Surface Water Records of Utah, 1965-69 from Water Resources Data for Utah, and 1970 from J. F. Barnett's Annual Report Ogden River System.

LOCATION – Lat 41°19'59", long 111°44'04", in NE¼NW¼SW¼ sec. 33, T.7 N., R.2 E., Weber County, on right bank 0.2 mile above diversion headgate, 3 miles northeast of Huntsville, and 6.5 miles upstream from Pineview Dam.
DRAINAGE AREA – 31.3 sq mi.
PERIOD OF RECORD – October 1963 to current year.
GAGE – Water-stage recorder. Altitude of gage is 5,400 ft (from topographic map).
AVERAGE DISCHARGE – 7 years, 20,800 acre-ft per year.
EXTREMES – Period of record: Maximum discharge, 744 cfs May 18, 1967 (gage height, 3.66 ft); minimum, 0.4 cfs Aug. 18, 1964, Aug. 18, 1966.
REMARKS – Records good. No regulation or diversion above station.

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	The year
1964	154	287	147	148	138	197	3,660	10,810	2,690	320	82	73	18,710
1965	204	304	1,160	851	1,020	1,120	8,690	9,500	1,800	352	157	160	25,320
1966	138	314	379	336	334	2,500	6,220	4,640	578	94	38	68	15,640
1967	123	169	217	212	320	1,450	2,830	12,680	4,530	609	95	82	23,320
1968	157	210	269	259	513	1,470	2,760	8,730	2,870	299	178	120	17,840
1969	204	209	228	652	611	1,450	10,780	10,190	877	328	105	78	25,710
1970	179	150	132	300	609	944	2,330	11,790	2,280	288	74	110	19,190

Table 4. Monthly and yearly runoff, in acre-feet, of North Fork Ogden River near Eden.

Sources: Records 1964 from Surface Water Records of Utah, 1965-69 from Water Resources Data for Utah, and 1970 from J. F. Barnett's Annual Report Ogden River System.

LOCATION – Lat 41°23'23", long 111°54'51", in NW¼SE¼NE¼ sec. 35, T.8 N., R.1 W., Weber County, on right bank 0.4 mile upstream from flood-retarding dam and 7.5 miles northwest of Eden.
DRAINAGE AREA – 6.03 sq mi.
PERIOD OF RECORD – October 1963 to current year.
GAGE – water-stage recorder. Altitude of gage is 5,750 ft (from topographic map).
AVERAGE DISCHARGE – 7 years, 8,500 acre-ft per year.
EXTREMES – Period of record: Maximum discharge, 156 cfs Jan. 21, 1969 (gage height, 2.72 ft), from rating curve extended above 75 cfs; minimum recorded, 0.8 cfs Jan. 23, 1964.
REMARKS – Records good. No regulation or diversion above station.

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	The year
1964	246	290	196	173	160	215	1,370	2,730	1,830	583	255	188	8,240
1965	217	221	512	383	339	458	1,850	2,040	1,170	584	382	320	8,480
1966	225	592	343	260	218	1,010	1,840	1,620	599	244	177	158	7,290
1967	177	183	241	201	220	645	996	3,340	2,080	612	273	203	9,170
1968	209	203	202	217	339	697	1,010	1,580	1,300	424	298	211	6,690
1969	274	245	228	980	369	576	3,250	3,600	1,200	560	257	198	11,750
1970	239	204	199	248	266	471	862	2,400	1,570	469	244	197	7,370

During the irrigation season, only a very small portion of the river is diverted for irrigation. There is only one diversion canal along the Middle Fork and during 1970 the total amount of irrigation diversion was about 450 acre-feet.

North Fork Ogden River near Eden

The North Fork Ogden River enters Ogden Valley from north and flows southward, along the long axis of the valley, into Pineview Reservoir. During the periods of heavy precipitation and the melting of snow, the flow is large enough to support the irrigation-water requirements of Liberty and Eden. For the remainder of the year very little water flows within the channel, probably only surplus irrigation water.

Monthly and annual runoff of the North Fork Ogden River is tabulated in table 4 for the period 1964-70. The monthly flow of the river for the same period is also shown by a hydrograph in figure 8. The maximum annual discharge, 11,750 acre-feet, was during the water year of 1969. The mean annual discharge for the 7-year period was about 8,500 acre-feet. The maximum monthly discharge corresponds to the month of May of each year. This is the month during which the contributions from precipitation and also the snow melt are maximum. During the period of 1964-70, the maximum discharge, 156 cubic feet per second, was in January 21, 1969 and the minimum, 0.8 cubic feet per second, was in January 23, 1964.

Three major irrigation canals divert most of the water from North Fork Ogden River. During 1970, the amount of diversions was about 11,800 acre-feet.

Pineview Dam and Reservoir

Hydraulic Characteristics

Pineview Dam, in Ogden Canyon about seven miles east of Ogden, was constructed by the Bureau of Reclamation as part of the Ogden River Project during 1934-37. The dam is a zoned earth-fill structure. It was originally constructed to a height of 103 feet, creating a reservoir of 44,170 acre-feet capacity. Under the Weber Basin Project the dam was enlarged to a height of 132 feet during 1955-57, which increased the reservoir capacity to 110,200 acre-feet. The width of the dam at the top is 30 feet and the maximum width at the base is 480 feet. The length of the crest is 600 feet.

The overflow, channel-type spillway, with a capacity of 10,000 cubic feet per second, is controlled by two radial gates. The maximum discharge capacity of the outlet works is 2,300 cubic feet per second from the spillway located in a concrete-lined tunnel in the right abutment. It consists of two pipes: A 72-inch pipe leads into the 75-inch Ogden Canyon conduit, and a 60-inch pipe discharges into the spillway stilling basin.

Pineview Reservoir, when filled to capacity, occupies an area of 2,900 acres. It is separated from the underlying artesian reservoir by a clay confining bed which is essentially impervious. Forty-six artesian wells of the City of Ogden's domestic water supply system are submerged by the Pineview Reservoir.

Pineview Reservoir provides supplemental irrigation to 22,867 acres of land and municipal water within the Ogden River Project. The water supply has improved economic conditions in the area and has brought fertile land under cultivation.

Changes in Pineview Reservoir Capacity

Ever since the Pineview Dam was completed in 1936, the reservoir level has been recorded daily at 8:00 a.m. and the contents at that hour are computed from the capacity table for the reservoir. The storage data for the Pineview Reservoir are available in the Office of State Engineer for the period 1937-70.

The storage of Pineview Reservoir for the period 1937-70 is shown in figure 9. During 1957, the reservoir was drained for the first time to increase its capacity by increasing the height of the dam. Again in November 1970 the reservoir was drained to construct a new pipe line for the new artesian wells at the Camp Browning area on the north side of the reservoir.

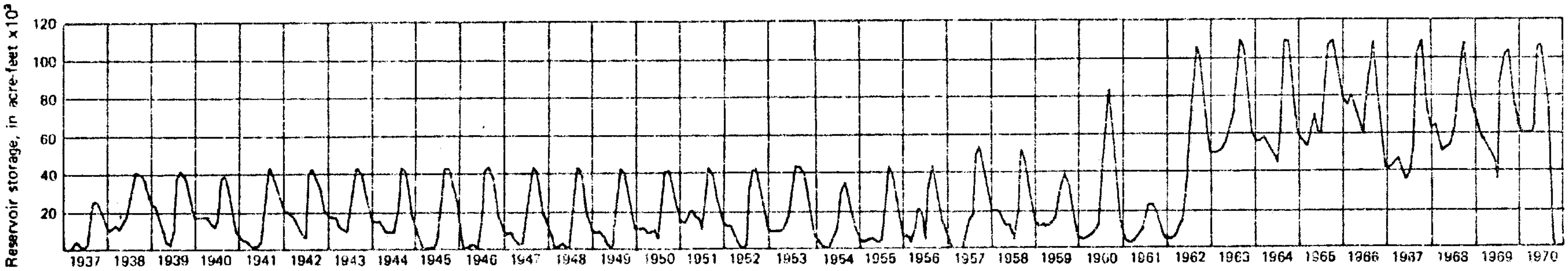

Figure 9. Monthly storage of Pineview Reservoir for the period
1937-70.

Throughout 1961, the storage of Pineview Reservoir was at an all-time low when it stayed within the range of 1,010 acre-feet and 25,090 acre-feet. During the same year the inflow of South Fork Ogden River was also at its minimum. Further comparison of the long-term storage data with the inflow of South Fork supports the idea that South Fork Ogden River is the most important contributor to the storage of Pineview Reservoir.

Starting in 1962, the runoff of South Fork Ogden River increased due to greater precipitation, and the available dead storage in the reservoir was also increased to an average of 48,000 acre-feet for the period 1963-70. For the same period, the maximum storage was about 110,100 acre-feet.

GROUND-WATER RESOURCES

Occurrence

Ground water in Ogden Valley occurs under both artesian and nonartesian conditions (see glossary) in the gravel, sand, silt, and clay of the valley fill to known depths of 400 feet and probably deeper. The artesian aquifer underlies the valley south of Eden and in the vicinity of Huntsville, and extends westward toward the head of Ogden Canyon. It is now partly overlain by Pineview Reservoir. The artesian aquifer is the most important source of ground water in Ogden Valley. Ground water is confined in the pore spaces of the gravel, sand, and silt of the valley fill by overlying clay and silt confining beds, and by underlying Tertiary tuffs.

The clay and silt confining beds underlie an area of approximately 10 square miles. Most of the 46 wells in operation in Artesian Park terminate in a sand and gravel sequence immediately beneath the confining beds. Although several lenses of confining silt and clay also are encountered within the thickness of gravel and sand, these lenses are not of wide extent, and the entire system behaves hydraulically much as a single aquifer (Lofgren, 1955, p. 80).

In the recharge areas of the artesian aquifer, north, northeast, east, and southeast of the outer edge of the clay confining bed, ground water occurs under water-table conditions. The water-table aquifer is really an extension of the artesian aquifer beyond the limits of the confining bed. The water table aquifer may be several hundred feet thick, but its thickness remains uncertain because most wells were drilled into the aquifer only to the depth needed to produce water in the quantity desired. About 23 percent of the wells that tap the water-table aquifer are less than 50 feet deep, 50 percent from 50 to 100 feet deep, 14 percent from 100 to 150 feet deep, and the remaining 13 percent are 150 feet and deeper.

Local bodies of perched water occur. These are generally the zones of saturation which exist at some level above the main water table where an impervious stratum within the zone of aeration interrupts percolation and causes ground water to accumulate in a limited area above that stratum.

Movement

Contours of the water table (plate 2) indicate that the general slope and therefore the direction of flow of the ground water is from the north, northeast, east, and southeast toward the head of Ogden Canyon, and it is approximately parallel to the general slope of the land surface.

The map of plate 2 was prepared on the basis of water-level measurements from wells that tap the water-table aquifer. The surface elevations were measured by an altimeter. Since most of the wells in the Artesian Park area, where the ground water is under artesian conditions, were inaccessible, no measurements were taken from the artesian wells. It is, however, logical to assume that the direction of movement of ground water under artesian conditions is toward the head of Ogden Canyon where most flowing wells are concentrated. These wells are discharging water continually and thus, they create an area of low pressure toward which water flows from the surrounding aquifer.

The most significant feature of the map is the shape of the water-table contours. The contours are relatively widely spaced in the east and southeast of the area suggesting that the aquifer materials are more permeable, whereas in the north, the water-table contours show a steep gradient. The steepness may result from the slow movement of water through the relatively less permeable materials that underlie the area.

In the northern part of Ogden Valley contours showing the surface of the water-table aquifer bend toward the mountain. This suggests that North Fork Ogden River supplies less recharge to the ground-water aquifer. Whereas in the eastern and southeastern parts of the valley the water-table contours bend toward the head of Ogden Canyon indicating more recharge from Middle Fork and South Fork Ogden Rivers.

The slope of the water table is generally greater near the mountains. The maximum gradient is about 80 feet per mile near Liberty; the minimum gradient is about 25 feet per mile near Eden.

Contours of the water table may indicate that there is not much recharge to the ground-water reservoirs by subsurface flow directly from the consolidated rocks of the bordering mountains. In most places the contours are more or less perpendicular to the valley boundary. The only exception to this is the eastern border of the valley where there may be some subsurface recharge from the fan gravels.

Recharge

Sources of Recharge

The ultimate source of recharge to the ground-water reservoir in Ogden Valley is precipitation which falls mostly in the form of snow on the drainage basin. Some of this precipitation falls upon the permeable deposits of the valley fill and infiltrates directly to the water-table aquifer. (See area of recharge on Plate 2.) Because of the hydraulic connection between the water-table and the artesian aquifer,most of this recharge water reaches the artesian aquifer due to a gravitational flow along the pore spaces of the valley fill. That portion of the precipitation which falls upon the permeable deposits above the confining layer forms local bodies of perched water.

Some of the runoff from this precipitation reaches the surface streams. The principal recharge to the ground-water reservoir is from seepage along the major stream channels and from canals and irrigated lands.

The three forks of Ogden River contribute substantial amounts of water to the ground-water reservoirs. Seepage from irrigated land and delivery canals also contribute some recharge to the ground-water reservoirs. This seepage takes place during the irrigation season.

An unknown but probably small quantity of water may be recharged to the ground-water aquifer by subsurface flow directly from the consolidated rocks of the bordering mountains. The soluble and fractured rocks in the mountains absorb part of the precipitation that falls upon them. Part of the absorbed water is consumed by evapotranspiration, part seeps into surface streams in the mountains, and part remains in the subsurface until it eventually percolates directly into the valley fill. The quantity of water that recharges the ground-water reservoirs in Ogden Valley in this manner is not known.

The minimum total recharge in 1970 was estimated to be 34,300 acre-feet (table 5).

Table 5. Ground-water recharge in 1970.

	Acre-feet
Seepage from waterways and irrigated land	29,000
Infiltration of precipitation	5,300
Subsurface inflow	Unknown
Total (rounded)	34,300

Seepage from waterways and irrigated land

The Ogden River system is the most important source of recharge to the ground-water reservoir in Ogden Valley. The estimated seepage to the ground-water reservoir in 1970 from waterways (perennial streams, and canals and ditches that distribute water from perennial streams) and irrigated land was about 29,000 acre-feet.

No work was done during this investigation to establish the amount of water lost by seepage from waterways. However, a series of measurements of seepage losses was made in the channel of South Fork Ogden River during the summer of 1924 by H.W. Browning, of the Office of the State Engineer.

> On July 20, all the water in the South Fork was being diverted at the mouth of South Fork Canyon for irrigation, and the channel of the stream was dry for a distance of more than 2 miles below the diversion. Water began to flow in the channel again at a point about half a mile southeast of Huntsville. On that day about 34 second-feet of the flow at the mouth of the canyon was turned back into the dry creek channel. Two days later the water had reached a point only about a mile below the place of diversion, and more than a mile of the channel still remained dry. On July 23, 1925, 43 second-feet was flowing in the stream channel just below the point of diversion at the mouth of the canyon, but the flow at a point approximately 1 mile farther down the channel was only about 25 second-feet, showing a loss of about 18 second-feet in 1 mile of channel (Leggette and Taylor, 1937, p. 132).

Further tests along the same stream channel showed that the seepage loss was about 39 second-feet through the 2-mile section of the channel. These tests indicate a seepage loss of about 42 percent along one mile section of the stream channel, a loss much higher than one should normally expect. In order to come up with more reliable seepage figures, references were made to other ground-water basins in Utah. With the information obtained from the already published reports of Weber Delta District, Northern Utah Valley, and Southern Utah Valley, the author made the following assumptions: (1) seepage loss from the channels of major streams is about 20 percent of the total discharge, (2) seepage loss from the canals is about 20 percent of the water diverted for irrigation, and

(3) diversions from the perennial streams were made only during the irrigation season.

Most of the seepage from perennial streams takes place during late spring and early summer when the flow is maximum. The three forks of Ogden River flow across the highly permeable recharge areas of Ogden Valley. The total runoff from the three forks of Ogden River during the nonirrigation season of 1970 was about 27, 600 acre-feet. Probably about 20 percent of this runoff recharges the aquifers. Thus, during the nonirrigation season of 1970 the total amount of recharge was about 5,500 acre-feet.

During the irrigation season, the channel of North Fork was more or less dry since most of the water is diverted into irrigation canals. The flow of South Fork and Middle Fork Ogden Rivers, however, was about 52,000 acre-feet. Thus, the seepage from the channels of these streams was about 10,400 acre-feet.

Water is diverted from the three forks into unlined irrigation canals which cross the principal recharge areas of Ogden Valley. These canals divert about 30,000 acre-feet of water during the irrigation season, and they undoubtedly lose water to the recharge areas. The loss from these canals is estimated to be about 20 percent of the water diverted; thus, the recharge from these unlined canals was about 6,000 acre-feet. The remaining 24,000 acre-feet of water is applied for irrigation. If 30 percent of the water infiltrates to the ground-water reservoir, then the amount of recharge from this source is about 7,200 acre-feet.

In Ogden Valley there are only two irrigation wells. Most of the wells were used for household purposes. Therefore, the recharge from such sources was assumed to be negligible.

Infiltration of Precipitation

Some of the precipitation that falls on the more permeable surfaces of Ogden Valley infiltrates downward toward the aquifers. The amount of infiltration of precipitation varies with the slope of the land. The steeper the slope, the larger the amount of runoff in a given period of time. On uneven surfaces, however, there may be considerable surface storage of water. A greater proportion of water enters the soil during periods of steady rains than during heavy downpours. The more open and porous the soil cover, the better able it is to absorb water and prevent it from running off immediately.

The use of water by vegetation and the time of the year are interrelated factors. During the growing season, vegetation intercepts and consumes large amounts of water before it reaches the water table, especially from June through September. As a result of consumptive use of water by plants, the water table declines gradually throughout the summer and fall months, and usually is lowest in the late fall. Lower temperatures, long steady rain, and no transpiration losses favor the recharge of ground water. In the presence of dense vegetation the rate of flow of surface water is appreciably retarded.

The surface materials in Ogden Valley, especially those in the recharge areas, are quite permeable. This favors a direct infiltration of precipitation. Some of the precipitation that falls on the surrounding mountains also drains into the valley fill.

The only precipitation station in Ogden Valley is at Pineview Dam, in Ogden Canyon about a mile below the lower end of Ogden Valley. The record began in January 1935 and during the period 1935-70 the average annual precipitation was 28.49 inches. An earlier record at Huntsville in the southeast part of Ogden Valley covered 30 years of the period 1895 to 1930, during which the average annual precipitation was 20.4 inches. Absence of overlap makes the correlation of these two records impossible, but it appears that the Pineview Dam station receives about 40 percent more precipitation than the Huntsville station, because of the orographic influence of the Wasatch Range.

The amount of recharge from precipitation during 1970 was estimated by making the following assumptions: (1) only 70 percent of the precipitation at Pineview Dam is representative of precipitation in Ogden Valley; (2) none of the precipitation that falls on the clay confining layer recharges ground-water reservoir; (3) only 25 percent of the precipitation that falls on the more permeable sediments infiltrates to the ground-water reservoir; and (4) only the precipitation during the months of January-May and October-December infiltrates to the water table and none of the precipitation during June-September infiltrates.

The monthly precipitation in Ogden Valley for the year 1970 is given in table 6.

Table 6. Monthly precipitation in Ogden Valley for the year 1970. Record of station located at Pineview Dam.

	Precipitation (inches)
January	4.57
February	1.20
March	2.64
April	3.82
May	3.55
June	2.65
July	.41
August	.29
September	3.19
October	4.36
November	5.69
December	4.35
Annual	36.72

The precipitation during the periods of January-May and October-December 1970 was 30.18 inches (2.51 feet) at Pineview Dam. The recharge area (the area between the boundary of the valley fill and the upper limit of the clay confining bed, plate 2) is about 12,000 acres in Ogden Valley. If 25 percent of this precipitation infiltrates to the ground-water reservoir, the amount of recharge is:

$$0.25 \times 2.51 \times 12,000 \times .70 \cong 5,300 \text{ acre-feet.}$$

Some parts of Ogden Valley have reasonably permeable materials at the surface, but they are underlain at depth by clay that is less permeable than the surface materials. Some of the clay, being only slightly permeable, supports perched water bodies. Such situations may be seen in the vicinity of Huntsville. Here, several dug wells discharge water from perched water bodies.

Subsurface Inflow

The consolidated and poorly consolidated rocks that crop out along the Wasatch Mountains bordering Ogden Valley are capable of absorbing and transmitting part of the precipitation that falls upon them. Part of the melt water from snow probably seeps along the joints, fractures, and other openings and may reach into the valley fill. However, the contribution to recharge from such sources is probably small. The rocks that crop out along the eastern boundary of the valley dip away from the valley and recharge from these rocks will be negligible. The Norwood Tuff probably constitutes the large part of the bedrock of Ogden Valley. Because of its low permeability it acts as an underlying confining bed. Some of the water percolating through the rocks along the western boundary of the valley will be largely intercepted by this confining bed and will not reach to the groundwater aquifers in the Quaternary deposits.

Discharge

Ground water is discharged in Ogden Valley both artificially and naturally. Artificial discharge occurs as withdrawals from both flowing and pumped wells. Natural discharge includes evapotranspiration, discharge from springs, and subsurface outflow. As will be discussed further in this report, the subsurface outflow was greatly reduced by building of Pineview Dam and it is now negligible.

The minimum total discharge in 1970 was estimated to be 34,000 acre-feet (table 7).

Table 7. Ground-water discharge in 1970.

	Acre-feet
Wells	
Flowing	12,600
Non-flowing	100
Evapotranspiration	20,000
Springs	1,300
Subsurface outflow	Negligible
Total (rounded)	34,000

Wells

In Ogden Valley there are 46 artesian wells (flowing) and 160 non-flowing wells. The City of Ogden obtains all but a small part of its municipal water supply from a group of artesian wells in Ogden Valley, and these withdrawals constitute the greatest part of the discharge from artesian wells in the valley.

In 1914, the City of Ogden began developing artesian water near the junction of the three forks of Ogden River, and the drilling of wells by the city continued at irregular intervals until 1933. Altogether, 51 wells were drilled by the City of Ogden in the so-called "Artesian Park" area (now covered by the reservoir). These wells range in depth from 85 to 600 feet. Five of these wells were poor producers and they were plugged and abandoned in 1936. Of the 46 wells now in use, 43 range in depth from 85 to 215 feet and the others are 246, 475, and 600 feet deep.

Prior to the completion of Pineview Reservoir, 48 wells were connected to a collecting system and the rate of withdrawals from these wells was regulated by controlling works at the wells.

> About 19 of the wells are individually equipped with valves by which they can be closed or opened. Twenty-five wells are equipped with concrete catch basins around the well casings and can be made to flow into the catch basins over the tops of the casings, four or five feet above the surface. The catch basins drained by gravity into the collecting system (Leggette and Taylor, 1937, p. 140).

In preparation for the inundation of Artesian Park by Pineview Reservoir, the casings of 46 of the wells were cut down as much as 10 feet and connected to a 3-foot-diameter steel conduit. By lowering the point of discharge, the maximum discharge with all wells flowing free was increased 20 percent above the previous maximum.

Until 1951 these artesian wells supplied water of good quality to the City of Ogden. However, in 1951 the first iron bacteria problem in the artesian well supply was recorded, and in 1964 there was a sudden large increase in the iron bacteria content of the water from the wells. When further tests made in 1967 confirmed the increasing amounts of iron bacteria, the City of Ogden decided to drill new replacement wells. Replacing the existing wells with the new wells would provide water free from iron bacteria and would further provide an opportunity to arrange for simple treatment of the wells with chlorine if bacterial problems should develop in the future. These new wells were then drilled on the land surface at the Camp Browning area. Altogether eight wells were drilled during the period 1969-71 but three of them were poor producers and abandoned. The five wells which are going to supply water for the City of Ogden are 20 inches in diameter and their depths range from 240 feet to 278 feet (see drillers' logs in appendix III). Each well is provided with 20-inch-diameter multiple sections of well screens and 18-inch casing was installed between sections of screens. A new 3-foot-diameter steel conduit has been constructed and the water from these new wells will be pumped into this conduit. As soon as the new wells are put into operation, the old wells will be plugged and abandoned.

Prior to 1937 most of the non-flowing wells in Ogden Valley were dug wells. They were limited in depth to the first water encountered, and usually to relatively shallow depths (less than 50 feet). During 1940-70, about 110 wells were drilled by cable-tool percussion method and 16 wells were drilled by hydraulic rotary drilling.

Table 8 gives the classification of non-flowing wells in Ogden Valley in 1970 according to use, depth, and diameter.

Table 8. Classification of non-flowing wells in Ogden Valley in 1970.

(Based on applications, claims, and drillers' reports filed with the Utah State Engineer).

Use:	Number of wells
Domestic (D)	128
Irrigation (I)	2
Stock (S)	9
Combined (D,I,S)	21
Total reported	160
Depth (feet):	
Less than 50	34
50-100	78
100-150	23
150 and more	25
Total reported	160
Diameter (inches):	
Less than 4	3
4	42
6	77
8	22
More than 8	7
Dug	9
Total reported	160

Discharge From Artesian Wells

The withdrawals from the artesian reservoir by means of 46 Ogden City wells constitute the largest artificial discharge. Since 1936, the discharge from these wells has been measured by a venturimeter. Monthly and annual discharge from artesian wells in Ogden Valley is shown in table 9.

The monthly discharge from artesian wells for the period 1931-70 is shown in figure 10. The discharge from these wells is not constant but changes from season to season and from year to year. In general the lowest withdrawals are in the autumn and winter seasons, and the highest withdrawals are in June of each year. For several years compressed air was forced into the wells to increase the flow during the summer. The average discharge from these 46 wells for the period 1931-70 was about 12,800 acre-feet a year. The maximum discharge for the same period, 18,146 acre-feet, was in 1952, and the minimum discharge, 9,449 acre-feet, was in 1964. During 1970 the total discharge from the artesian wells was about 12,600 acre-feet.

Discharge From Non-flowing Wells

The discharge from non-flowing wells for domestic use was determined by multiplying an average annual discharge (about 0.7 acre-feet) per well used for domestic purposes by the total number of domestic wells (128). The average annual discharge of a domestic well was obtained from the information on rural-family and stock use by Criddle and others

Table 9. Monthly and annual discharge of Artesian Park Wells, in acre-feet.

Sources: Records 1931-1951 from H.E. Thomas (1953) and 1951-56 and 1960-70 from J.F. Barnett's Annual Report Ogden River System.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1931	780	760	790	830	880	1,300	1,230	1,120	930	830	800	800	11,100
1932	740	650	680	650	650	930	1,190	1,180	910	750	610	680	9,800
1933	870	790	870	875	915	1,000	1,115	1,155	1,100	910	835	860	11,300
1934	860	775	910	965	970	1,010	1,160	1,200	1,090	900	860	920	11,600
1935	920	800	870	840	875	915	1,005	1,130	1,095	1,000	900	930	11,700
1936	1,000	920	1,005	1,015	1,000	1,050	1,340	1,265	1,190	1,160	895	940	12,800
1937	1,000	930	985	965	1,125	985	1,245	1,390	1,295	1,195	845	750	12,700
1938	755	685	730	665	695	890	1,300	1,215	1,065	945	755	730	10,400
1939	750	670	735	620	910	1,005	1,383	1,340	970	785	855	820	10,800
1940	790	665	755	695	1,095	1,265	1,445	1,395	875	920	775	795	11,500
1941	790	680	630	550	910	1,000	980	1,070	1,090	790	690	710	9,900
1942	770	730	790	840	1,030	1,070	1,130	1,380	1,250	1,170	860	890	11,900
1943	900	810	860	1,040	1,250	1,020	1,280	1,480	1,380	1,180	900	900	13,000
1944	960	930	930	780	990	960	1,460	1,590	1,300	1,350	1,120	1,350	13,700
1945	1,350	1,020	1,030	870	1,030	900	1,310	1,380	1,370	1,330	1,200	1,260	14,000

Table 9 – Continued

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1946	1,270	1,050	990	860	1,300	1,300	1,650	1,700	1,360	1,270	1,210	1,210	15,200
1947	1,280	1,060	1,150	1,070	1,250	1,180	1,580	1,470	1,370	1,260	1,160	1,270	15,100
1948	1,140	1,110	1,170	1,120	1,350	1,560	1,600	1,410	1,300	1,220	1,160	1,210	15,300
1949	1,310	1,170	1,220	1,210	1,250	1,410	1,560	1,560	1,560	1,250	1,240	1,240	15,800
1950	1,100	1,100	1,350	1,050	1,360	1,480	1,740	1,540	1,730	1,260	1,400	1,400	16,500
1951	1,300	1,060	1,270	1,390	1,430	1,660	1,680	1,490	1,460	1,400	1,300	1,280	16,700
1952	1,828	1,200	1,130	1,520	1,580	1,450	1,830	1,530	1,780	1,380	1,330	1,580	18,146
1953	1,267	1,260	1,520	1,235	1,300	1,850	1,550	1,435	1,660	1,340	1,180	1,490	17,087
1954	1,170	1,240	1,520	1,300	1,660	1,150	1,430	1,700	1,240	1,120	1,450	1,030	16,010
1955	1,360	1,240	1,190	1,230	1,680	1,320	1,430	1,740	1,220	1,180	1,290	1,060	15,940
1956	1,270	1,050	1,000	1,080	1,470	1,270	1,770	1,363	1,170	1,320	1,060	1,060	14,883
1957	–	–	–	–	–	–	–	–	–	–	–	–	–
1958	–	–	–	–	–	–	–	–	–	–	–	–	–
1959	–	–	–	–	–	–	–	–	–	–	–	–	–
1960	756	736	820	870	1,195	1,474	1,180	725	680	840	820	840	10,936
1961	740	670	720	780	1,160	1,300	780	666	535	707	740	715	9,513
1962	758	635	690	815	905	1,195	1,565	1,340	675	1,095	915	990	11,578
1963	990	770	890	835	1,126	880	980	950	850	885	680	795	10,631
1964	830	767	670	615	979	626	860	920	860	920	670	735	9,449
1965	595	600	600	620	1,260	1,630	1,045	670	660	645	640	660	9,625
1966	648	560	614	1,127	1,458	1,234	1,200	1,255	1,123	1,102	876	825	12,022
1967	816	714	721	1,338	1,533	1,479	1,364	1,210	1,074	941	570	554	12,316
1968	540	506	915	1,375	1,487	1,428	1,414	1,324	1,265	1,010	747	568	12,580
1969	553	501	558	1,316	1,426	1,333	1,333	1,288	974	894	847	893	11,917
1970	806	273	490	823	1,420	1,601	1,695	1,692	1,353	1,041	776	682	12,652

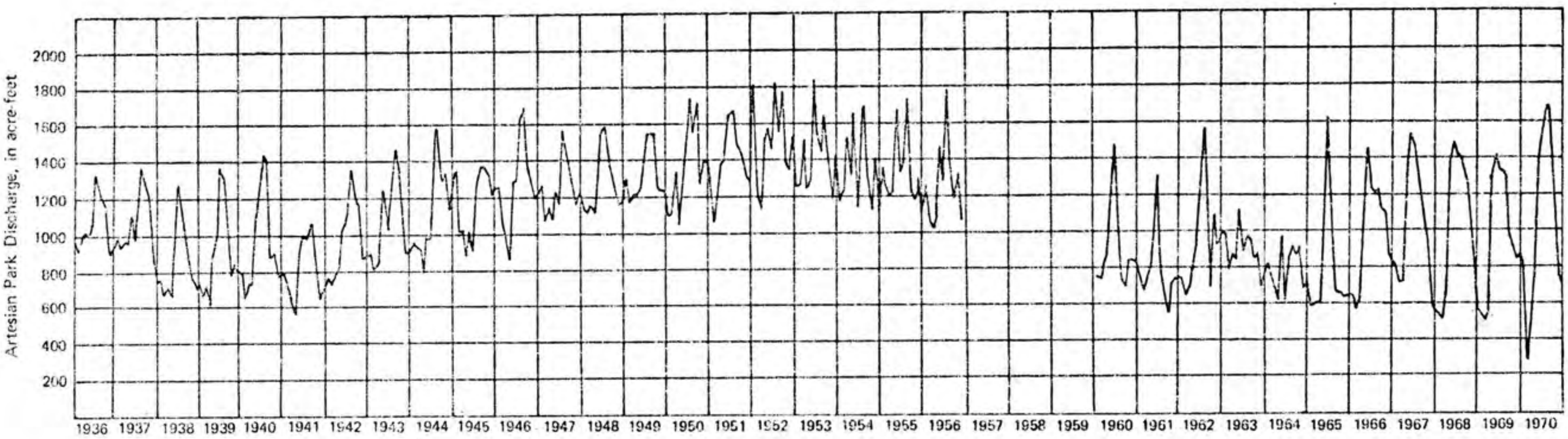

Figure 10. Monthly discharge from artesian wells for the period 1936-70.

(1962, p. 23). During 1970, the total discharge from non-flowing wells in Ogden Valley was about 100 acre-feet.

Evapotranspiration

Method of Study

The field work was done in July 1971. At the beginning of the field work a rapid reconnaissance was made to identify the principal types of plants, their characteristic associations, and their location. Then, areas occupied by each plant type were mapped on aerial photographs, taken in the fall of 1965, on a scale of 1:20,000. Plate 3 represents the types, areal extent, and location of different plant groups in Ogden Valley.

Each parcel of land was inspected to identify the plant types, assemblages, and their relative percentages. At the end of the field work the author came up with a long list of plant species. Since it was not possible to plot the areal extent of each plant species on a map, the author attempted to group the plants into nine categories (see plate 3). Each category represents plants of similar growth habits. In general, climate, depth to water, and quality of ground water are the most important factors which exert a controlling influence on the occurrence and growth of plants. Since there are no drastic changes in the climate and the quality of ground water in Ogden Valley, the depth to water is probably the most important factor which determines the typical plant associations. Therefore, the grouping of different plant species was based on the availability and the relative position of the ground water.

The areal density of growth is defined by Mower and Nace (1957, p. 6) as the ratio of the area occupied by plants to the total area in a given parcel of land. An areal density of 100 percent is a spacing of plants so closely that the addition of one new plant theoretically would crowd out an old plant of the same size. Field observations indicate that 100 percent density has nowhere been achieved. The areal density of growth, on the average, is about 75 percent.

In order to compare the amount of vegetation in different parcels of land, the net area occupied by plants, and the amount of water consumed in each parcel, it is useful to adjust the density to 100 percent. This method, which was developed by Gatewood and others (1952), might lead to more consistency in the results of consumptive-use studies.

Table 10 lists the most common vegetations in Ogden Valley with common and scientific names.

Specific Characteristics and Associations

There are many varieties of water-loving plants in Ogden Valley. The growth habits for some of the most common plants with plant associations, usefulness of types, and the depth to which each sends roots to obtain water are described below. More complete descriptions may be obtained from Robinson (1958), Meinzer (1923), and Hitchcock (1950).

Alfalfa: is one of the most important hay and forage crops in Ogden Valley. Alfalfa grows best on deep loams and it has a wide range of climatic

Table 10. Common types of vegetation in Ogden Valley.

Common or local name	Scientific name
Alfalfa	*Medicago sativa* Linnaeus
American manno-grass	*Glyceria grandis* S. Wats.
Big sagebrush	*Artemisia tridentata* Nutt. ssp.
Bigtooth maple	*Acer grandidentatum* Nutt.
Black mustard	*Brassica nigra* (L.) Koch
Blue wildrye	*Elymus glaucus* Buckl. var.
Boxelder	*Acer negunda* L. var.
Cattail	*Typha domingensis* Pers.
Cattail	*Typha latifolia* L.
Common dandelion	*Taraxacum officinale* Weber
Cottonwood	*Populus* L.
Crested wheatgrass	*Agropyron cristatum* (L.) Goertn.
Curly dock	*Rumex crispus* L.
Elk thistle	*Cirsium* c.f. *undulatum* (Nutt.) Spreng.
Gambel scrub oak	*Quercus gambelii* Nutt.
Giant wildrye	*Elymus condensatus* Presl. var.
Hairy chess (Brome)	*Bromus commutatus* Schrod. var.
Hound's tongue	*Cynoglossum officinale* L.
Intermediate wheatgrass	*Agropyron* c.f. *intermedium* (Host) Beauv.
Kentucky bluegrass	*Poa pratensis* L.
Mule ears	*Wyethia amplexicalus* (Nutt.) Nutt.
Mustard	*Brassica* L.
Oats	*Avena sativa* L.
Orchard grass	*Dactylis glomerata* L.
Quaking aspen	*Populus tremuloides* L.
Redtop bentgrass	*Agrostis alba* L.
Rye	*Secala cereale* L.
Slender wheatgrass	*Agropyron caninum* (L.) Beauv.
Smooth brome	*Bromus inermis* Leyss.
Timothy	*Phleum pratense* L.
Willow	*Salix* L.
Wiregrass	*Juncus balticus* L.
Yarrow	*Achillea millefolium* L. ssp.
Yellow sweet clover	*Melilotus officinalis* (L.) Lam.

tolerance. As a rule it does not thrive in acid soils (McKee, 1948, p. 715). Alfalfa is a deep-rooted plant and will send its roots to great depths in search of ground water. Meinzer (1927, p. 54) cites three reports of the roots of older plants being traced at depths of 65, 66, and 129 feet.

In Ogden Valley a very characteristic association of alfalfa is yellow sweet clover.

Bluegrasses: The bluegrasses are of great importance because of their forage value. The most important species is Poa pratensis, commonly known as Kentucky bluegrass.

With very few exceptions the bluegrasses are palatable and nutritious and are the second most important forage grasses in Ogden Valley. Their growth habits are very similar to those of alfalfa.

In Ogden Valley the bluegrasses are commonly associated with orchard grass, timothy, crested wheatgrass, and smooth brome. Slender wheatgrass and redtop bentgrass are also associated with bluegrasses.

Oats: The most important species of the genus is Avera sativa, the familiar cultivated oat. In Ogden Valley, oat is utilized for hay. It is the least abundant cultivated plant and is present in about 11 acres. It grows mostly around Eden and Huntsville.

Pasture grasses: The most common grasses used for permanent pasture are: Kentucky bluegrass, redtop bentgrass, orchard grass, smooth brome, clovers, elk thistle, meadow foxtail, wiregrass, giant wildrye, and shepherds' purse.

Pasture grasses occupy an area of approximately 2,200 acres in Ogden Valley. They grow in areas of high water table and along the flood plains of surface streams and Pineview Reservoir.

Dry-land crops, grasses, and shrubs: Dry-land crops, grasses, and shrubs depend on precipitation for growth and they probably use practically all the precipitation that falls on areas in which they grow. Although the soil at most times absorbs all moisture as it falls, some precipitation may be lost by surface runoff. This possible loss by surface runoff is probably balanced by the use of a small amount of ground water by the vegetation.

Typical plants of this category include big sagebrush, mule ears, curly dock, common dandelion, mustards, shepherds' purse, slender wheatgrass, yellow sweet clover, black mustard, and gamble scrub oak.

Along the western boundary of the valley, gambel scrub oak is more abundant whereas the eastern boundary of the valley is rather barren.

Trees: The most common trees, in Ogden Valley, include willow and cottonwood. Willow is generally found along the streambanks and are commonly associated with cottonwood, cattails, bluegrasses, and wheatgrasses. The willow growth on the flood plains of the three forks of Ogden River is particularly outstanding. Because of the many species of _Salix_ and the difficulty of distinguishing among them, generic reference will be made here.

Most species of willow are believed to be phreatophytes, for they are nearly always associated with moist situations. According to Robinson (1958, p. 64) most of the willow growth occurs where the depth to water table is less than 15 feet. Most willows prefer water of good quality and deep fertile soils. They have a low tolerance for alkaline or saline conditions.

Willows are important in erosion control, through stabilizing the soil on the banks of streams and gullies. They also form an important browse plant.

The genus Populus includes aspens, poplars, and cottonwoods. In Ogden Valley, cottonwood is by far the most abundant. They are commonly found along the streambanks in association with willow and cattails. They also grow at places where the ground water is generally at shallow depth and readily available.

Cottonwoods are considered as phreatophytes. Information as to the depth that cottonwood will send its roots to the water table is scanty. Meinzer (1927, p. 58) quotes reports of cottonwoods growing where the depth to water table was 20 feet.

Cottonwoods prefer a water of good quality, although they tolerate a water of moderate salinity. They furnish browse for livestock when the leaves are within reach.

Water-loving Plants in Relation to Water Supply

In Ogden Valley, large tracts of land are occupied by certain distinctive groups of plants which grow only where ground water occurs at shallow depth. These plants were named "phreatophytes" (Meinzer, 1923, p. 55). Phreatophytes extend their roots to the water table, or to the capillary fringe above it. Other types of water-loving plants grow where the water table is very close to the land surface, or where water is ponded to shallow depth. These plants, which grow under water or have their roots under water, are called "hydrophytes". Phreatophytes and hydrophytes may be referred to collectively as hydrophilic (water-loving) plants.

During the irrigation season almost all of the irrigation water is diverted from surface streams by canals and ditches. Although sprinkle irrigation system is applied at some places, most of the area is still irrigated by flooding of large tracts of land. Overirrigation is a common practice in Ogden Valley, especially during the early parts of the irrigation season. As a result, large areas are oversaturated and where such areas are underlain by impermeable soils or soils of low permeability, natural drainage will be very slow and the ponds will form. Because of overirrigation and the nature of soils some good land is waterlogged, usable only for pasture.

Consumptive Use of Water by Crops in Ogden Valley

During this investigation no direct measurements have been made of the amount of water consumed by crops in Ogden Valley. However, some data were obtained from U.S. Department of Agriculture Soil Conservation Service in Ogden. The results of their investigations are shown in table 11.

Table 11. Annual consumptive use of water by various crops in Ogden Valley.

(Source: U.S. Department of Agriculture Soil Conservation Service)

Crop	Peak Use Month	Peak Use Use (inches)	Growing Season Start	Growing Season End	Growing Season Length (days)	Growing Season Total use (inches)
Alfalfa	July	7.0	5/1	9/30	152	27.8
Spring grain	June	5.9	4/12	8/20	130	18.5
Pasture	July	5.8	4/12	10/21	192	24.1
Corn (silage)	July	6.1	5/27	8/30	95	17.5

Rates of evapotranspiration for areas occupied by plants that are not listed in the table are obtained from available information on specific plant types. Feth and others (1966, p. 69) included the willow and cottonwood trees in the same group with cattails since they have similar evapotranspiration rates. Cattails selected for the tank experiments indicate that the evapotranspiration rate of the cattails is nearly the average for this vegetation group. The results of evapotranspiration studies at Ogden Bay Bird Refuge for the 1955 growing season show that cattails growing in water 2 inches above the surface of the ground had an evapotranspiration rate of 60.42 inches. Therefore, Feth and others (1966, p. 69) estimated that the cattails grown under natural conditions would have an evapotranspiration rate of 61.5 inches (5.125 feet) for the entire year.

The growth habits of pasture grasses and bluegrasses are rather similar. The majority of the plant species associated in each group are common. These groups must have similar evapotranspiration rates. It is, thus, assumed that an annual evapotranspiration rate for pasture grasses, 24.1 inches, may also apply to bluegrasses.

The gross areas of each type of plant group were measured by planimeter from the aerial photographs. The net area occupied by each plant group is adjusted to 100-percent density (table 12).

Table 12. Areas occupied by plants in Ogden Valley.

Plant type	Gross area (acres)	Net area adjusted to 100-percent density (acres, rounded)
Alfalfa	4,608	3,500
Bluegrasses	2,253	1,700
Spring grains (wheat and barley)	1,200	900
Oats	11.5	9
Corn (silage)	120	90
Pasture	2,240	1,700
Trees	1,420	710

Knowing the net area adjusted to 100-percent density and the evapotranspiration rate of each plant or group of plants, the total consumptive use may be calculated. Table 13 shows the estimated consumption of water by plants in Ogden Valley.

Table 13. Estimated consumption of water by plants in Ogden Valley.

Plant	Rate of evapotranspiration (feet/year)	Net area adjusted to 100-percent density (acres)	Total consumptive use. (acre-feet/year)
Alfalfa	2.32	3,500	8,100
Bluegrasses	2.008	1,700	3,400
Spring grains (wheat and barley)	1.54	900	1,400
Oats	1.54	9	13
Corn (silage)	1.46	90	130
Pasture	2.008	1,700	3,400
Trees	5.125	710	3,600
Total (rounded)			20,000

Springs

Discharge by springs constitutes a very small part of the total discharge of ground water in Ogden Valley. Several small springs were located along the edge of the valley fill but because of their small yields they are not significant.

Three major springs discharge ground water in Ogden Valley. The total discharge from these springs in 1970 was estimated to be about 1,300 acre-feet. The largest discharge comes from Bennett spring, which is located in (A-6-2) 26 ccc. It supplies water both to the town of Huntsville and to the Monastery. The discharge from the spring is extremely variable. These variations are mostly seasonal. The maximum discharge observed during the spring freshet was about 4 second-feet (Barnett, Ogden River Commissioner, oral commun., 1970). However, during most of the summer, the discharge is generally less than 1 second-foot. When the discharge drops down to 1 second-foot or less, 0.4 second-foot goes to the town of Huntsville and the rest to the Monastery.

The Bennett spring discharges a water of good quality from the Knight Formation. The annual discharge from this spring is estimated to be about 860 acre-feet.

Patio springs, (A-7-1) 22 caa, discharges about 220 acre-feet of water per year. Some of the water is used for the swimming pool in the Patio Springs lodge and the rest is diverted for irrigation.

The springs emerge from the unconsolidated sediments of the valley fill. The water samples obtained from the Patio springs were analyzed by U.S. Geological Survey in September 16, 1952. The analyses indicate that the water is of good quality.

Burnett springs, (A-7-1) 22 acb, also discharge about 220 acre-feet of water per year. Most of the water is used by the town of Eden. It is, however, reported that the actual discharge from the springs is a little larger than the figure given above. Since the actual discharge has never been measured, the minimum discharge, which is the recorded amount used by the town of Eden, is shown in this report.

Burnett springs issue from the unconsolidated sediments of the valley fill about 1/4 mile southeast of Patio springs. The water is of good quality and it does not require pretreatment before use.

Subsurface Outflow

Prior to the completion of Pineview Dam, the natural discharge by seepage from the artesian reservoir was studied by Leggette and Taylor (1937). Their investigations indicated that the seepage into the Ogden Canyon was of the order of 2,100 acre-feet. With the construction of the Pineview Dam, seepage from artesian reservoir into Ogden Canyon has been practically eliminated. Pineview Dam has been provided with a steel sheet pile which extends to the bedrock. Likely there is now little or no seepage underneath the dam.

The amount of water lost from the artesian reservoir by upward movement through the clay confining bed is very small. Tests of permeability on clay samples indicate that the clay is essentially impervious (Leggette and Taylor, 1937, p. 120).

Ground-Water Budget of Ogden Valley

For the effective utilization of a limited ground-water supply, a general inventory of supply and demand should be made. This provides the basis for making the best use of the supply through regulation of surface-water and ground-water storage and withdrawals, and also provides a logical basis for planning for future water requirements. Ground-water inventories are made by determining the various items of recharge, discharge, and change in storage, and balancing them on an annual basis in accordance with the simple hydrologic equation:

$$\text{Recharge} = \text{Discharge} \pm \text{Change in storage}$$

In Ogden Valley there are only two irrigation wells. Most of the water for irrigation is supplied by surface streams. The water for domestic use is supplied by several springs and by wells that tap the water-table aquifer. The discharge from 46 artesian wells in the Artesian Park area is exported to the City of Ogden.

Table 14 shows the ground-water budget of Ogden Valley for 1970.

Table 14. Ground-water budget of Ogden Valley for 1970.

<u>Recharge</u>	Acre-feet
Seepage from waterways and irrigated land	29,000
Infiltration of precipitation	5,300
Subsurface inflow	Unknown
Total	34,300
<u>Discharge</u>	
Wells	
Flowing	12,600
Non-flowing	100
Evapotranspiration	20,000
Springs	1,300
Subsurface outflow	Negligible
Total	34,000

The difference of 300 acre-feet between recharge and discharge may be due to the assumptions made for various items of the hydrologic equation.

Water-Level Fluctuations

Water levels in Ogden Valley are changing continually for many reasons. They rise with a net addition of water to the ground-water reservoir, and they decline with a net subtraction. The causes of fluctuations of water levels in the artesian wells may be classified into four groups: (1) recharge to the artesian reservoir by means of direct infiltration of precipitation, seepage from irrigated areas, canals, and surface streams; (2) changing atmospheric pressure; (3) changes in the rate of discharge from the artesian wells; and (4) loading by Pineview Reservoir. The various influences may operate singly or in combination and may be long term, seasonal, daily, or brief. Only long-term and seasonal fluctuations will be discussed in this report.

Water levels were measured by monthly intervals in twenty-three wells during the period July 1970-June 1971 (table 15), and hydrographs of these wells are shown in figure 11. A steel tape was used for depth-to-water measurements. A permanent measurement point, usually the collar of the well, was established. Long term records were obtained from U.S. Geological Survey for the three observation wells that are equipped with automatic water-level recorders. The hydrographs for these wells are shown in figures 12, 13, and 14.

Thomas (1953) indicated that the water level in the test well, (A-6-1) 11 cab-1, rises by 1.2 feet for each inch of precipitation during autumn period. The water levels in few artesian wells located in Ogden Valley have been shown to correlate closely with changes in atmospheric pressure. "... 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..." Thomas (1945, p. 22). He assumed a barometric efficiency of 22 percent for the test well,

Table 15. Water levels, in feet below land-surface datum, from twenty-three representative wells in Ogden Valley for the period July 1970–June 1971.

Coordinate Number	Altitude above mean sea level (Ft.)	July 6	Aug. 4	Sept. 7	Oct. 18	Nov. 8	Dec. 7	Jan. 16	Feb. 8	Mar. 7	Apr. 17	May 9	June 8
(A-6-1) 1 aaa	4,921	11.45	11.85	11.43	17.22	18.19	16.14	14.82	13.02	13.81	13.45	14.19	12.12
(A-6-1) 2 aab-1	4,916	7.45	7.80	9.05	10.33	11.35	10.21	11.72	10.79	12.06	9.33	10.87	8.57
(A-6-1) 2 aab-2	4,902	12.11	10.91	12.89	14.05	17.14	14.12	16.01	15.42	13.07	15.58	15.15	12.75
(A-6-1) 2 dbd	4,913	8.75	8.51	9.29	13.19	14.22	14.82	14.37	14.18	14.51	13.19	14.13	9.02
(A-6-2) 5 bbc	4,981	14.21	18.20	16.72	16.69	16.01	14.66	16.21	14.57	17.69	15.85	16.02	13.94
(A-6-2) 6 bbb	4,929	9.51	12.92	10.31	16.74	18.03	13.35	12.55	9.61	10.37	11.11	12.01	13.33
(A-6-2) 6 ddc	4,957	1.85	5.55	4.11	7.62	7.53	6.68	8.01	6.99	7.96	4.61	7.67	2.19
(A-6-2)16 acc	4,987	18.11	24.75	28.69	32.66	32.20	33.42	26.69	25.14	30.89	25.31	21.25	10.16
(A-6-2)16 cbb	4,971	8.02	12.55	14.21	19.68	20.48	17.98	13.45	10.76	13.81	10.77	9.34	4.46
(A-6-2)16 daa	5,005	–	34.42	39.08	41.85	43.88	29.86	22.31	28.05	34.81	23.26	22.47	14.94
(A-6-2)16 dad	5,012	28.31	31.62	34.65	40.06	43.26	25.55	13.51	20.91	26.96	15.52	17.31	12.33
(A-6-2)17 aac	4,964	5.31	6.41	8.03	11.79	12.36	11.88	12.12	7.61	8.75	7.69	6.77	3.58
(A-6-2)18 aba	4,196	11.51	11.60	12.73	15.55	16.14	15.95	15.55	16.14	15.61	15.17	16.23	14.06
(A-6-2)18 bab	4,907	16.01	21.28	–	15.55	16.09	–	29.82	26.13	25.43	12.77	20.89	15.89
(A-6-2)18 bad	4,907	14.41	14.15	34.45	31.54	32.42	17.49	16.93	17.56	17.78	17.15	20.02	14.79
(A-6-2)18 dbb	4,919	12.91	14.41	13.03	15.85	16.22	15.99	15.53	16.11	15.48	15.69	15.92	14.19
(A-6-2)21 cbb	4,998	4.23	7.53	10.05	12.85	13.31	11.17	6.54	7.07	7.04	4.31	4.68	15.49
(A-7-1) 8 ccb	5,203	18.81	29.01	36.69	33.51	18.83	12.65	12.45	13.26	17.87	18.98	12.64	42.43
(A-7-1)20 aaa-1	5,076	13.07	17.45	29.96	36.98	35.81	17.43	16.55	13.58	13.46	10.81	10.91	11.82
(A-7-1)20 aaa-2	5,066	39.81	46.51	57.58	66.99	66.82	54.38	48.87	45.22	45.67	43.55	41.21	42.61
(A-7-1)20 aad	5,071	28.21	33.65	43.32	–	52.05	42.99	38.77	35.37	35.19	30.72	30.36	32.16
(A-7-1)21 bbc	5,061	1.61	7.27	15.51	21.29	22.25	14.48	5.22	2.48	2.66	0.68	0.69	1.43
(A-7-1)35 cdd	4,917	7.05	4.55	8.69	13.03	14.69	15.56	17.34	15.89	15.82	12.86	13.82	12.28

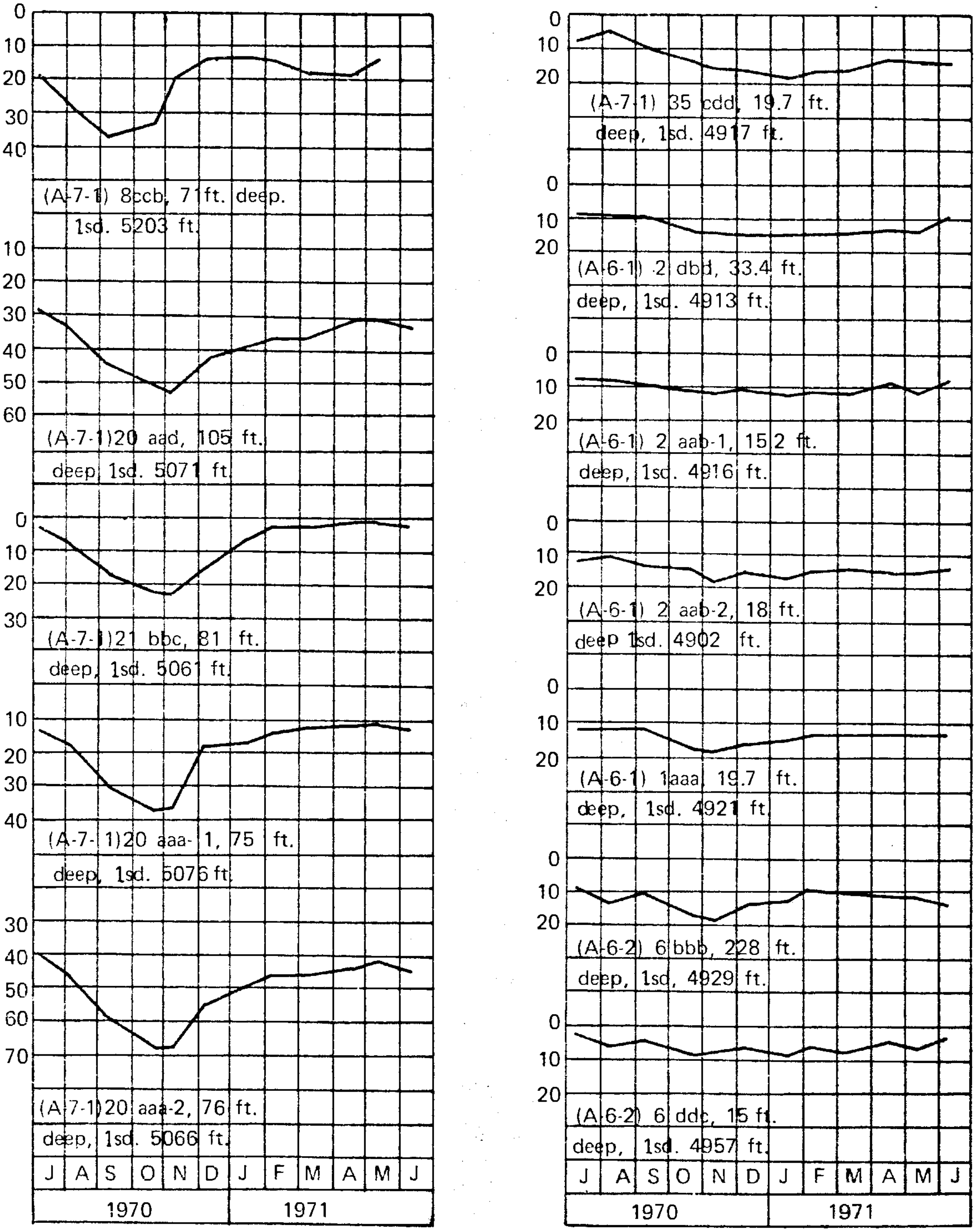

Figure 11. Hydrographs of selected wells, in Ogden Valley, for the period July 1970-June 1971.

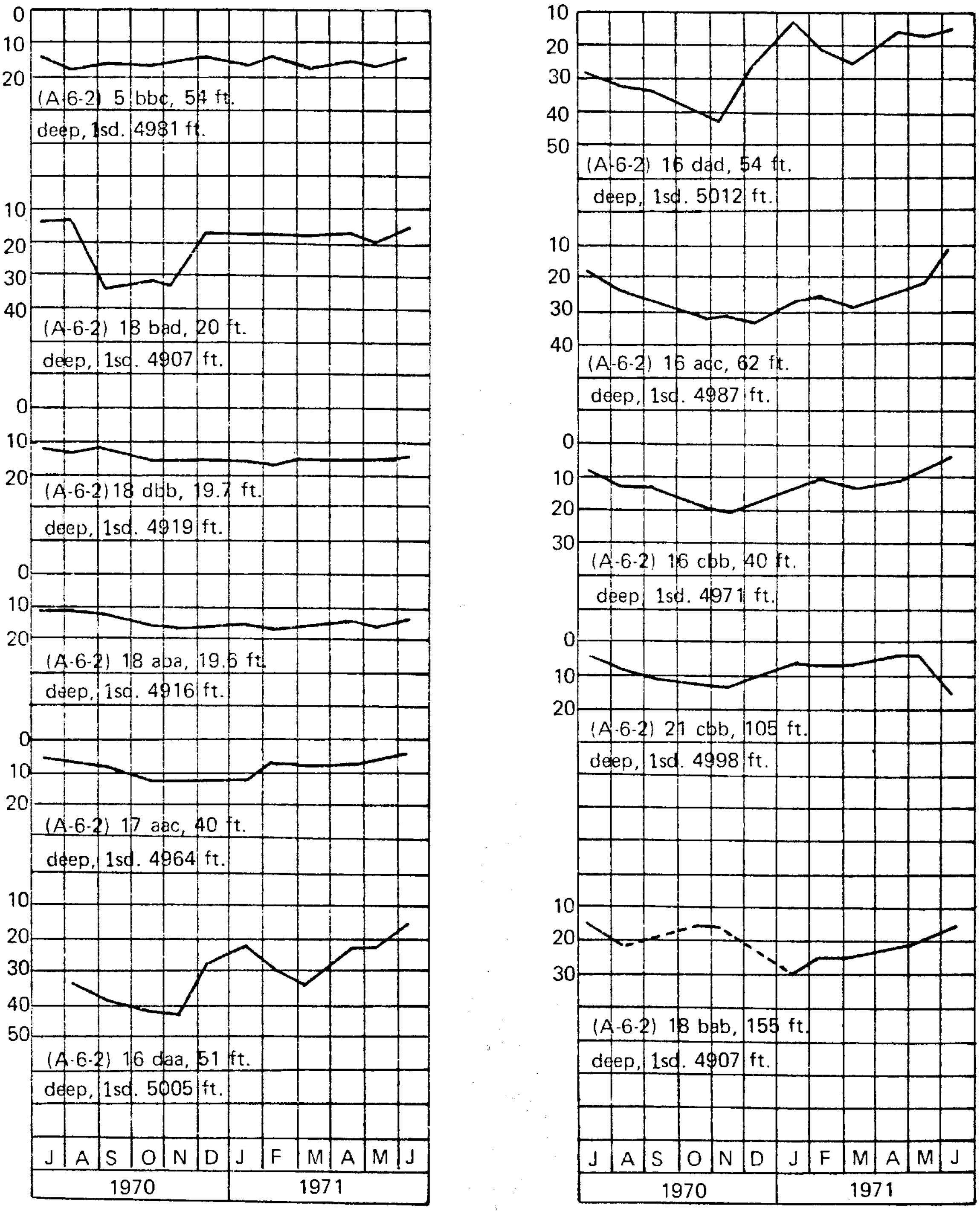

Figure 11. Continued.

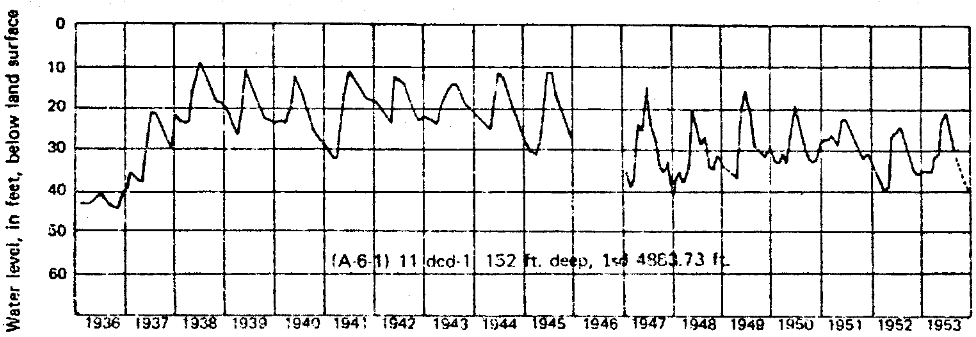

Figure 12. Hydrograph of the test well, (A-6-1) 11 dcd-1, for the period 1936-53.

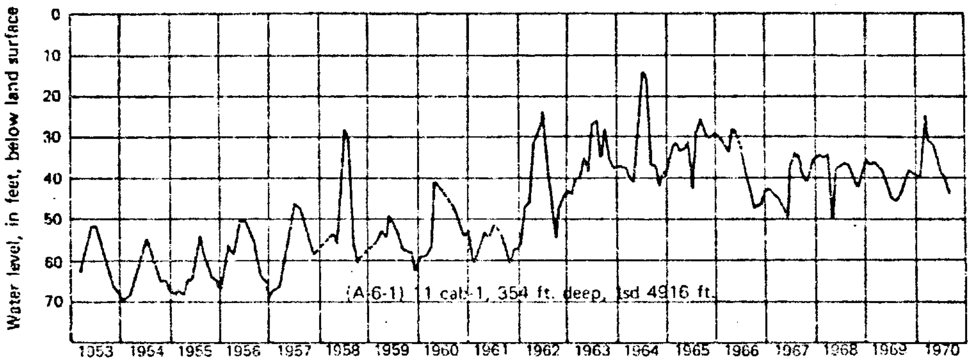

Figure 13. Hydrograph of the test well, (A-6-1) 11 cab-1, for the period 1953-70.

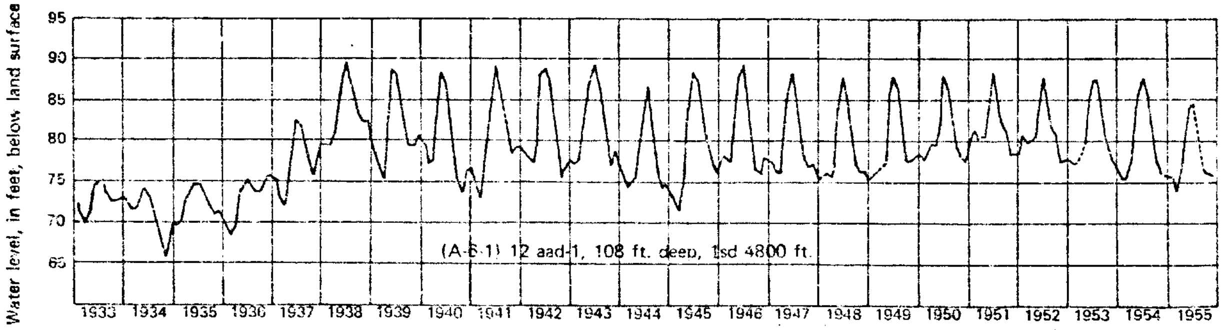

Figure 14. Hydrograph of the test well, (A-6-1) 12 aad-1, for the period 1933-55.

(A-6-1) 11 cab-1. The effects of changing atmospheric pressure on the fluctuations of water level are very small in comparison with the effects of changing artesian discharge and loading by Pineview Reservoir.

There is always some discharge from the artesian wells in Ogden Valley. This discharge is not constant but changes from season to season and from year to year. As a result, the water levels in the nearby wells fluctuate. Thomas (1945), using the records for the test well, (A-6-2) 12 aad-1, prior to construction of Pineview Dam, indicates that "...the change of water level ranged from 0.05 to 0.10 foot per each second-foot change in discharge".

Continuous withdrawal of water from an artesian reservoir produces reduction of pressure around the well and the water in the vicinity of the well starts to move toward the well. Movement of water toward the well develops a pressure gradient in the aquifer directly proportional to the velocity of percolation and inversely to the permeability of the water-bearing material. This effect extends radially from the well and is limited to the areal extent of the conduit furnishing water to the well. The depression in the pressure surface caused by large quantities of withdrawals is known as "the cone of pressure relief", and the areal extent of this depression is "the area of influence". The water levels in all wells reaching the conduit tapped by the pumping wells are lowered within the area of influence.

The shape and position of the cone of pressure relief is determined by the nature of withdrawals from the reservoir and by the nature of the aquifer material, itself. When the withdrawals change from season to season, a similar change will take place in the cone of pressure relief; thus, the water level in the wells will show seasonal fluctuations.

If the rate of discharge from an artesian aquifer has been more rapid than the rate of recharge to the same aquifer, some of the water discharged must have been derived from storage in the water-bearing material underlying the area. The withdrawal from storage requires a reduction in the interstitial space occupied by water. As a result of this the aquifer undergoes a certain amount of compaction in which its total interstitial space will decrease by a volume approximately equal to the volume of the discharged water.

Correlation between artesian discharge and the fluctuations of water level in the test well, (A-6-1) 11cab-1, is done for the period 1960-69. During the month of June of each year, the storage of Pineview Reservoir reaches its maximum and remains more or less constant. Thus, the loading effect of Pineview storage for this month is approximately constant. Accordingly, an attempt is made to correlate artesian discharge with the fluctuations of water level in the test well for the June measurements. In general no good correlation exists except for the years 1963, 1965, and 1968. For the years indicated, 0.1 foot change in water level corresponds to one second-foot change in discharge.

The long term hydrographs for the observation wells, (A-6-1) 11 dcd-1 and (A-6-1) 12 aad-1, indicate that the fluctuations of water levels in these wells strongly correlate with the changes in storage of Pineview Reservoir. Ever since November 1936, the filling of Pineview Reservoir created a unique situation by adding a load on the underlying artesian aquifer. Thus, with the rise of reservoir level, the artesian aquifer compressed and the water level in the wells started to rise. This subject will be discussed further under the section of loading by Pineview Reservoir.

Seasonal fluctuations of water levels in the wells are shown by the hydrographs in figure 11. All the wells tap the water-table aquifer. The water level is highest in late spring because of recharge from winter and spring precipitation. The water level declines during summer mainly because of heavy pumpage.

The long-term fluctuations of water levels in Ogden Valley are illustrated in figure 12, 13, and 14. For the period 1937-63 the water levels do not show any significant amount of change. A rise of water level in the test well, (A-6-1) 11 cab-1, corresponds to January 1963. This is due to a higher than normal precipitation at this year. The continued fluctuations of water levels in response to variation of precipitation in Ogden Valley indicates that on a long-term basis total discharge does not exceed recharge.

Quality of Water

The chemical quality of ground water is determined from the water samples of eleven representative wells in Ogden Valley. Some additional chemical quality data are obtained from U.S. Geological Survey Water Resources Division. The bacteriological analyses are done by Utah Division of Health. The surface-water quality data for the major streams and Pineview Reservoir are obtained from Hahl and Mitchell, 1963. The results of chemical analyses of the water samples from wells, springs, and surface waters in Ogden Valley are shown in table 16. The location of sampling sites and graphical presentation of chemical analyses are shown on plate 4.

Quality in Relation to Use

The purpose of water quality study is to determine if the water is satisfactory for a proposed use. Accordingly, the subject of water-analysis interpretation must often include some considerations of standards and tolerances that have been established for water that is to be used for various purposes. Standards for water to be used for drinking and other domestic uses have been established by U.S. Public Health Service. According to the 1962 standards, the following substances should not be present in amounts greater than those shown:

Substance	Concentration (mg/l)
Iron (Fe)	0.3
Manganese (Mn)	0.05
Magnesium (Mg)	125
Chloride (Cl)	250
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Total dissolved solids	500

Standards for water quality established by the Public Health Service drinking water standards of 1962 specify an upper limit of permissible fluoride concentration of 2.4 mg/l for areas where the annual average of maximum daily air temperature is in the range of 50.0 F to 53.7 F. Limits for warmer climates are lower, ranging down to a recommended limit of 0.8 mg/l with a maximum permissible limit of 1.4 mg/l where average maximum daily temperatures are 79.3 F to 90.5 F.

Water that contains less than 150 mg/l of chloride is satisfactory for most purposes. A chloride content of more than 250 mg/l is generally objectionable for municipal water supply. Water containing more than 350 mg/l is objectionable for most irrigation and industrial uses. Water containing as much as 500 mg/l of chloride frequently has a disagreeable taste.

Nitrate in concentrations greater than 45 mg/l is undesirable in water used for domestic purposes because of the possible toxic effect that it may have on infants. This effect is known as cyanosis (blue-baby disease).

Table 16. Chemical analyses of waters from wells, springs, and surface waters in Ogden Valley. (Analyses were made by the author unless otherwise indicated)

Coordinate Number	Date Collected	Temperature °F	MILLIGRAMS PER LITER												Specific conductance at 25° C	pH	Remarks
			Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved Solids (evaporated at 105° C)			
Samples from wells																	
Artesian Park wells	Dec. 15, 1952	–	12	.06	47	11	8.4	.7	186	11	10	.1	3.7	197	339	7.3	Composite sample (1)
(A-6-1) 2aab	Feb. 16, 1971	50	5.9	–	57	12	7.7	2.1	180	10	16	–	13.5	255	350	7.7	Water-table well, 15 ft deep
(A-6-1)11cab-1	Dec. 15, 1952	–	12	.06	47	11	8.4	.7	186	11	10	.1	3.7	197	339	7.3	Artesian well (1)
(A-6-1)11dcd-1	Nov. 4, 1955	48	10	0	55	17	6.3	1.2	233	12	12	.1	2.7	224	413	7.3	Artesian well (1)
(A-6-2) 5bcc	Feb. 16, 1971	41	2.9	–	23	4.9	4.9	1.7	72	6.9	11	–	9.5	127	174	7.2	Water-table well, 50 ft deep
(A-6-2) 7aab	Feb. 16, 1971	38	6.2	–	42	12	9.2	1.3	160	10	14	–	8.1	201	317	7.4	Water-table well, 89 ft deep
(A-6-2)16acc	Feb. 16, 1971	52	3.4	–	53	14	5.9	1.0	198	9.1	13	–	1.9	219	360	7.5	Water-table well, 62 ft deep
(A-6-2)16dad	Feb. 16, 1971	43	1.7	–	45	13	6.7	.9	172	8.1	14	–	.2	199	323	7.8	Water-table well, 43 ft deep
(A-6-2)18bab-1	Nov. 30, 1955	50	17	.01	54	15	13	1.0	242	6.9	14	.1	2.0	236	413	7.5	Artesian well, 155 ft deep (1)
(A-6-2)21bbb	Feb. 16, 1971	41	1.8	–	51	15	6.2	.8	196	7.3	15	–	3.6	208	350	7.9	Water-table well, 81 ft deep
(A-6-2)21cbd	Feb. 16, 1971	–	8.8	–	35	10	13	1.7	142	13	20	–	.9	202	313	7.6	Water-table well, 110 ft deep
(A-7-1)20aaa	Feb. 16, 1971	43	1.9	–	16	5.7	3.8	.5	58	8.8	11	–	2.8	93	148	7.3	Water-table well, 76 ft deep
(A-7-1)22ccd	Feb. 16, 1971	50	5.1	–	41	12	11	1.5	125	22	33	–	1.6	269	382	6.9	Water-table well, 45 ft deep
(A-7-1)29ada	Feb. 16, 1971	47	7.5	–	23	8.5	11	.6	79	12	27	–	14	129	189	7.3	Water-table well, 80 ft deep
(A-7-1)34bba	Feb. 16, 1971	43	4.2	–	26	9.5	5.6	.9	102	14	12	–	.7	166	207	6.9	Water-table well, 75 ft deep
(A-7-1)36cab	Sept. 16, 1952	–	25	–	22	8.2	–	–	76	9.9	30	–	1.1	–	233	6.9	Water-table well (1)
Samples from sources other than wells																	
Patio springs	Sept. 16, 1952	–	11	–	32	8	7.4		135	9.5	5.5	–	.6	–	247	8.1	1000 ft below spring outlet (1)
Bennett springs	Sept. 16, 1952	48	12	–	58	17	–	–	254	8.6	10	–	2.4	–	422	8.2	From concrete diversion (1)
Hawkins spring	Sept. 27, 1950	–	16.7	0	58	17	13.7		247	17	16	.3	.2	266	–	8.6	
South Fork	Jan. 12, 1961	–	6.1	–	65	15	5.8	.9	242	13	10	–	1.2	238	417	8.2	Sec. 13,T.6 N., R.1 E. (2)
North Branch of South Fork	Apr. 6, 1961	–	5.3	.02	55	14	6.5	1.3	215	14	10	–	1.9	209	372	8.1	Sec. 13, T.6 N., R.1 E., (2)
South Branch of South Fork	Jan. 12, 1961	–	7.9	–	63	16	9.2	1.0	238	15	20	–	2.1	250	436	8.0	Sec. 13, T.6 N, R.1 E. (2)
North Fork	Apr. 6, 1961	–	6.9	.02	31	6.3	4.9	.8	102	15	9.0	–	5.3	127	225	7.7	Sec. 3, T.6 N., R.1 E. (2)
Middle Fork	Apr. 6, 1961	–	9.2	.07	71	20	13	1.3	302	15	17	–	3.2	292	521	8.0	Sec. 1, T.6 N., R.1 E. (2)
Pineview Reservoir	Oct. 14, 1960	–	8.5	–	46	11	6.0	1.6	176	14	10	–	8.7	192	329	7.4	Sec. 16, T.6 N., R.1 E. (2)
Geertsen Creek	Apr. 6, 1961	–	6.3	.08	19	3.4	3.7	1.5	60	11	6.5	–	2.5	87	138	7.5	Sec. 1, T.6 N., R.1 E. (2)

(1) Analyses of U.S. Geological Survey Water Resources Division.
(2) Analyses obtained from Hahl and Mitchell, 1963.

A sulfate concentration of about 300 mg/l will impart a bitter taste to the water and the water may act as a laxative for people not accustomed to drinking it.

Iron and manganese leave stains of oxide on fabrics and on plumbing fixtures.

A water that is safe for drinking on the basis of its chemical composition may not be safe bacteriologically. Besides being chemically safe for human consumption, water to be used in the home should be free from undesirable physical properties such as color or turbidity and have no unpleasant taste or odor. Harmful microorganisms should be virtually absent. The presence of harmful microorganisms is a very important consideration.

The standard test for bacteriological quality is the determination of coliform bacteria concentration. The common species Escherichio coli occurs in greater numbers in the intestinal tracts of warm-blooded animals, and the presence of these and related bacteria in water is generally considered an index of fecal pollution.

In May 1970, the Utah Division of Health began bacteriological examinations by membrane filter. By this method, coliform colonies filtered from each 50 ml sample are counted. Water that contains more than one coliform colony per 100 ml (one colony in two 50 ml samples) is unsatisfactory.

Domestic Use

The ground water in Ogden Valley is bicarbonate in type except near the town of Liberty (plate 4). The principal sources of calcium, magnesium, and carbonates are limestones and dolomites. In Ogden Valley, most of the Paleozoic rocks consist of limestones and dolomites. These rocks contribute substantial amounts of carbonate to South Fork Ogden River. The increasing bicarbonate content in wells southeast of Huntsville may be explained by direct recharge of the seepage waters from South Fork Ogden River.

Most of the water has a fairly low concentration of dissolved solids, and it is suitable for most uses without treatment.

Nitrate is derived principally from the decay of organic matters, from the animal wastes, and from nitrate fertilizers. The high nitrate content in the well, (A-7-1) 29 ada, may be derived from either one of these sources. The wells, (A-6-1) 2 aab, (A-6-2) 5 bcc, and (A-6-2) 7 aab, contain relatively high concentrations of nitrate and also coliform bacteria (table 17). This may indicate that both nitrate and coliform bacteria are derived from the similar sources. These sources may include privies, cesspools, or barnyards. A positive result from a bacteriological analysis does not necessarily indicate a permanent pollution. More tests, preferably at monthly intervals, are required to reach a more definite conclusion.

In general, the ground water in Ogden Valley is chemically safe and would meet most requirements for domestic purposes without treatment.

Table 17. Results of bacteriological analysis of water samples from wells in Ogden Valley.

(Analyses were made by Utah Division of Health)

Well Location	Date of Collection	Coliform colonies in sample	Rating
(A-6-1) 2aab	3-28-1971	10	U
(A-6-2) 5bcc	3-28-1971	10	U
(A-6-2) 7aab	3-28-1971	1	U
(A-6-2)16acc	3-28-1971	0	S
(A-6-2)16dad	3-28-1971	0	S
(A-6-2)21bbb	3-28-1971	0	S
(A-7-1)20aaa	3-28-1971	0	S
(A-7-1)22ccd	3-28-1971	36	U
(A-7-1)29ada	3-28-1971	0	S
(A-7-1)34bba	3-28-1971	0	S

U = unsatisfactory; S = satisfactory

Agricultural Use

Water required for nondomestic purposes on farms and ranches includes that consumed by livestock and that used for irrigation. Water to be used by stock is subject to quality limitations of the same type as those relating to quality of drinking water for human consumption. Most animals, however, are able to use water that is considerably higher in dissolved-solids concentration than that which is considered satisfactory for humans.

The chemical quality of water is an important factor to be considered in evaluating its usefulness for irrigation. Whether a particular water can be used successfully for irrigation, however, depends on many factors not directly associated with water composition. A discussion of these factors is beyond the scope of this report.

A diagram widely used for evaluating waters for irrigation, published by the U.S. Salinity Laboratory (1954), is adopted in figure 15. The conductivity, as an index of dissolved-solids concentration, is plotted on one axis and sodium-absorption-ratio on the other. The sodium-absorption-ratio (SAR) is defined by the relation:

$$\mathrm{SAR} = \frac{(\mathrm{Na}^{+})}{\sqrt{\dfrac{(\mathrm{Ca}^{++}) + (\mathrm{Mg}^{++})}{2}}}$$

where ion concentrations are expressed in milliequivalents per liter (U.S. Salinity Laboratory staff, 1954).

For Ogden Valley, the water from eleven wells and four streams fits

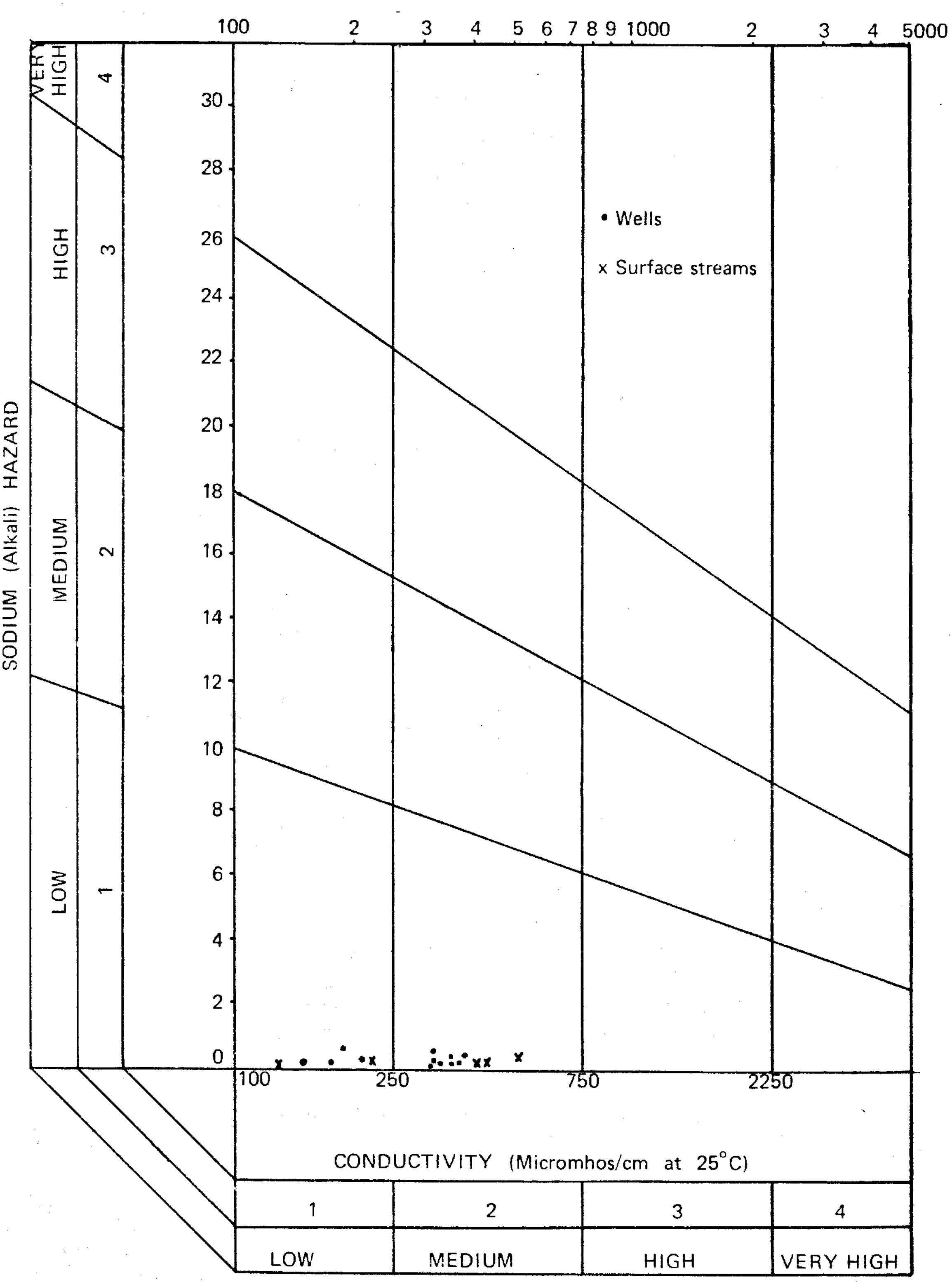

Figure 15. Diagram showing relation between sodium-absorption-ratio and conductivity of water from wells and surface streams in Ogden Valley, Utah.

mostly in the low-sodium hazard class (fig. 15). Low-sodium hazard water is usable on nearly all soils without the development of harmful amounts of exchangeable sodium.

Iron Bacteria Problems in Ogden Valley

Iron bacteria, when present in noticeable quantity, may cause discoloration and turbidity which result in taste and odor problems. They may also form slime and iron oxide accumulations in wells and pipes. They may also indirectly contribute corrosion problems. When present in wells, they may seriously restrict perforations, well screens, and casings and reduce the quantity of water available from the source.

Some forms of iron bacteria are *Gallionella ferruginea*, *Crenothrix polyspora*, and *Leptothrix ochracea*. *Gallionella* occurs as twisted bands of ferric hydroxide and *Crenothrix* and *Leptothrix* are long filament-like tubes containing the organisms which secrete or precipitate iron hydroxide in the sheath of the tube. Previous investigations have indicated that the organisms obtain their necessary energy from the oxidation of ferrous iron to ferric iron and of carbon from carbonates or carbon dioxide in the water. The same organisms can also oxidize dissolved manganese with a resulting precipitate of manganese hydroxide in the sheath.

The first iron oxide problem in the artesian well supply to the City of Ogden was reported in about 1951. A large increase was then noticed quite suddenly in 1964.

> This sudden increase in the problem appeared to coincide with rapid changes in the withdrawal rate from the well field and was probably the result of dislodging large amounts of the bacterial growth which had accumulated either in the well casings or in the pipe collection system between the well field and Pineview Dam (Anderson and Kelly, 1968, p. 15).

Anderson and Kelly collected a total of fifteen water samples in 1967 for analysis to determine the presence or absence of iron bacteria. Samples were collected from the artesian wells (composite samples) at various flow rates, from Pineview Reservoir at various depths, and also from other wells at the periphery of Pineview Reservoir. The samples were then sent to the Federal Water Pollution Control Administration, Department of the Interior, at Cincinnati, Ohio. A summary of the iron bacteriological analyses is given in table 18. The results of these analyses confirm the presence of iron bacteria in both the water of Pineview Reservoir and the discharge from the artesian wells but indicates that iron bacteria contamination is essentially absent from other wells in the basin.

The bacteria Crenothrix polyspora and Gallionella ferruginea are typical of deposits that occur and grow in well waters. The bacterial form Leptothrix ochracea, however, can develop in waters that are well aerated such as the reservoir water; they use organic matter present in the reservoir water to obtain energy for growth.

The occurrences of Leptothrix in the discharge from artesian wells indicate that the contamination probably took place after the filling of Pineview Reservoir due to leakage into the pipe collection system. Since the

Table 18. Iron bacteriological analyses.

(Source: Anderson and Kelly, Consultants in Engineering and Geology, Boise, Idaho, 1968)

Source	Description
Artesian Wells Composite 9/1/67 at Filter Platn Basement	Some groups of *Leptothrix ochracea*.
Artesian Wells Composite 9/2/67 at Filter Plant Basement	*Lepthothrix ochracea* or old empty *Crenothrix polyspora* sheaths.
Artesian Wells Composite at 18.5 cfs 9/11/67 at Blackpoint mainline	Heavy growth of *Crenothrix polyspora* and some *Gallionella*.
Artesian Wells Composite at 6 cfs 9/11/67 at Blackpoint mainline	*Crenothrix polyspora* and *Gallionella ferruginea*.
Artesian Wells Composite at 27 cfs 9/11/67 at Blackpoint mainline	Very extensive growth of *Crenothrix polyspora*.
Artesian Wells Composite at 26 cfs 9/11/67 at Filter Plant Basement	Profuse growth of *Crenothrix polyspora*.
Artesian Wells Composite at 26 cfs 9/11/67 at Blackpoint mainline	*Crenothrix polyspora*, *Gallionella* and a few *Leptothrix ochra*.
Artesian Wells Composite at 18.2 cfs 9/12/67 at Filter Plant Basement	*Crenothrix polyspora* and a few strands of *Gallionella ferruginea*.
Pineview Reservoir at 10' depth 9/11/67	A few *Gallionella* and *Crenothrix*.
Pineview Reservoir at 60' depth (bottom) 9/11/67	*Gallionella ferruginea* and some *Crenothrix polyspora*.
Surface water inlet to treatment plant 9/11/67	A few *Gallionella* - extensive precipitate of iron.
Treatment plant discharge 9/11/67	Very few iron bacteria.
U.S.G.S. Well (A-6-1) 11 cab-1	Many diatoms (algal forms).

Table 18 - continued.

U.S. Forest Service Well (A-6-1) 13 dcc 9/12/67	Broken fragments of *Crenothrix* or algal material.
U.S. Forest Service Well (A-6-1) 10 ddb 9/12/67	No iron bacteria in sample.

confining layer separating the artesian reservoir and Pineview Reservoir is essentially impervious, the downward leakage from the surface reservoir into the artesian reservoir is unlikely.

Correction of iron bacteria problems such as in the artesian wells of Ogden Valley may be accomplished with one of the following methods: (1) treatment of existing wells with some means of disinfection to prevent the bacterial growth; (2) removal of bacterial deposits by filtration or other treatment prior to placing the water into the Ogden City distribution system; and (3) abandoning the contaminated wells and drilling new wells. The first method was rather impractical because of the inaccessibility of the artesian wells under Pineview Reservoir. The filtration or the other means of removal of bacterial growth from the water at the Ogden City treatment plant were possible. The remaining useful life of the existing wells, however, was considered to be short. Replacing the existing wells with new wells would provide water free from the iron bacteria problem. The new wells were then drilled at the Camp Browning area. As soon as the new wells are put into operation, the old wells will be plugged and abandoned.

Quality in Relation to Geology

The ultimate source of most dissolved ions is the mineral assemblage in rocks. The importance of rock composition, however, is only part of the story. The purity and crystal size of minerals, the rock texture and porosity, the regional structure, the degree of fissuring, and a good number of other factors might influence the composition of water passing over and through the rock. In rocks of relatively low permeability, the movement of water is slow and there is a considerable time available for completion of slow chemical reactions.

The northwestern extension of Ogden Valley is largely surrounded by Precambrian quartzites. These rocks generally consist of insoluble minerals (mostly quartz) and are strongly fractured and jointed. The lack of solubility of minerals and fast movement of water through fractures and joints prevent contribution of dissolved ions from the rocks. The North Fork Ogden River and its tributary streams pass over these rocks and dissolve very small amounts of ions. The wells located within the area recharged from North Fork also contain very small amounts of dissolved solids.

Most of the soluble rocks are exposed along the eastern and southeastern parts of Ogden Valley where the Paleozoic limestones and dolomites crop out. These rocks provide a major source of bicarbonate to South Fork Ogden River. The major source of recharge to the water-table aquifer in the southeastern part of Ogden Valley and also to the artesian aquifer is the seepage waters of South Fork Ogden River. Plate 4 shows that the wells located within the area of recharge from South Fork show relatively high concentrations of dissolved solids.

LOADING BY PINEVIEW RESERVOIR

In November 1936, the filling of Pineview Reservoir created a unique situation by adding a load on the underlying artesian aquifer. Thus, with the rise of reservoir level, the artesian aquifer compressed and the water levels in the wells started to rise. Since the original filling, the reservoir has been emptied to permit enlarging the dam, refilled to a higher level, and in 1970 emptied again to permit construction of a steel conduit to collect the water from the new replacement wells.

In the history of the artesian aquifer, in Ogden Valley, we can distinguish five different phases. These phases include: (1) the conditions before the construction of Pineview Dam; (2) the conditions during 1937-56 when the maximum storage capacity of Pineview Reservoir was 44,170 acre-feet; (3) the draining of the surface reservoir in 1957 for the purpose of enlarging its capacity; (4) the filling of the enlarged reservoir to a maximum capacity of 110,100 acre-feet during 1957-70; and (5) the draining of the surface reservoir for the second time in November 1970. In order to show the effects of loading by Pineview Reservoir during the early stages of the artesian aquifer history, we will refer to the Tower well, (A-6-1) 12 aad-1. The Tower well was constructed in 1932 and the water levels in this well was recorded by a float-type automatic water-level recorder until 1955.

During 1933, 1935, and 1936 the water level in the Tower well reached a maximum stage of about 4,875 feet above sea level (fig. 14). Prior to 1937, there was no external load on top of the artesian aquifer except the weight of the overlying sediments.

In November 1936 a new phase started in the history of the artesian aquifer. When Pineview Dam started to impound water, an external pressure was gradually applied to the underlying artesian aquifer. The maximum pressure was reached when the reservoir was filled to its total capacity of 44,170 acre-feet in 1938. Part of the additional pressure exerted on the artesian aquifer was borne by the structural skeleton of the aquifer and the rest was borne by the confined water. The sand, however, is incompetent to support even a slight additional load without compression. During compression, the water is forced to escape from the voids of the sediments, and some particles are forced into new positions thus reducing the porosity of the aquifer material. The compression of the aquifer causes a rise in water level in the well that reaches a maximum when the external load is maximum. The net result of this phenomenon may be observed in figure 14. When the surface reservoir reached its maximum capacity in 1938, the water level in the Tower well reached a maximum stage of 4,889 feet above sea level. This is 14 feet higher than the previous maximum stage recorded in 1933, 1935, and 1936. Thomas (1953), using the records of the Tower well, determined the loading effect of Pineview Reservoir on the artesian aquifer during this phase of the aquifer history. He found out that, on the average, an increase in surface reservoir storage amounting to 3,000 acre-feet will cause the water level in the Tower well to rise one foot.

Early in 1957, the surface reservoir was drained to increase the height of the dam and thus the capacity of the reservoir. When the load on an artesian aquifer is reduced to zero, the soil particles will tend to return to their former positions. This releases pore space that can now be reoccupied by water moving into the part of the formation that was influenced by the previous compression. This expansion of the aquifer is accompanied by a decline of the water level in the well. Figure 13 shows that the water level in the test well, (A-6-1) 11 cab-1, reached a minimum stage of 4,846 feet (70 feet below datum of 4,916 feet) above sea level in early 1957.

As soon as the enlargement work was completed in 1957, the dam started to impound water. However, the surface reservoir did not reach to its maximum storage capacity of 110,100 acre-feet until 1962. As this maximum was reached, the water level in the test well, (A-6-1) 11 cab-1, began to rise (fig. 13).

The loading effect of Pineview Reservoir on the underlying artesian aquifer may be best illustrated with reference to the test well, (A-6-1) 11 cab-1 . The records for both Pineview storage and water level in the test well are available for the period 1960-69. In order to establish the most reliable correlation between the two, the measurements taken on the same day will be considered. Since the storage of Pineview Reservoir does not change within a short period, the lag will be negligible.

In the following analysis, a statistical technique, regression method, will be used. A linear relationship between the reservoir storage and the water level in the test well does exist. The regression equation will be obtained using the model $Y = a + bX$. The dependent variable, Y, will denote the water level observations in the test well and the independent variable, X, will denote the storage of Pineview Reservoir. The line obtained by plotting Y-values against X-values will be characterized by its intercept, a, and slope, b. From the slope of the line, we can establish the desired relationship between the reservoir storage and the fluctuations of water level in the well.

The result of computations is shown in figure 16. The position of the regression line is obtained with the aid of computer, which gives a greater degree of accuracy. The line thus determined is defined by the following equation:

$$Y = 4853.42 + .21\ X$$

Where 4853.42 is altitude of water in well and .21 is slope of the line. The slope of the line may be defined as $\Delta Y/\Delta X$, where:

ΔY = change in water level in the test well, in feet

ΔX = change in reservoir storage, in acre-feet

since

$$\Delta Y/\Delta X = .21$$

therefore, a rise of water level in the test well by one foot corresponds to an increase of reservoir storage by 4,800 acre-feet. This is, however, greater than what Thomas (1953) found (3,000 acre-feet). The absence of

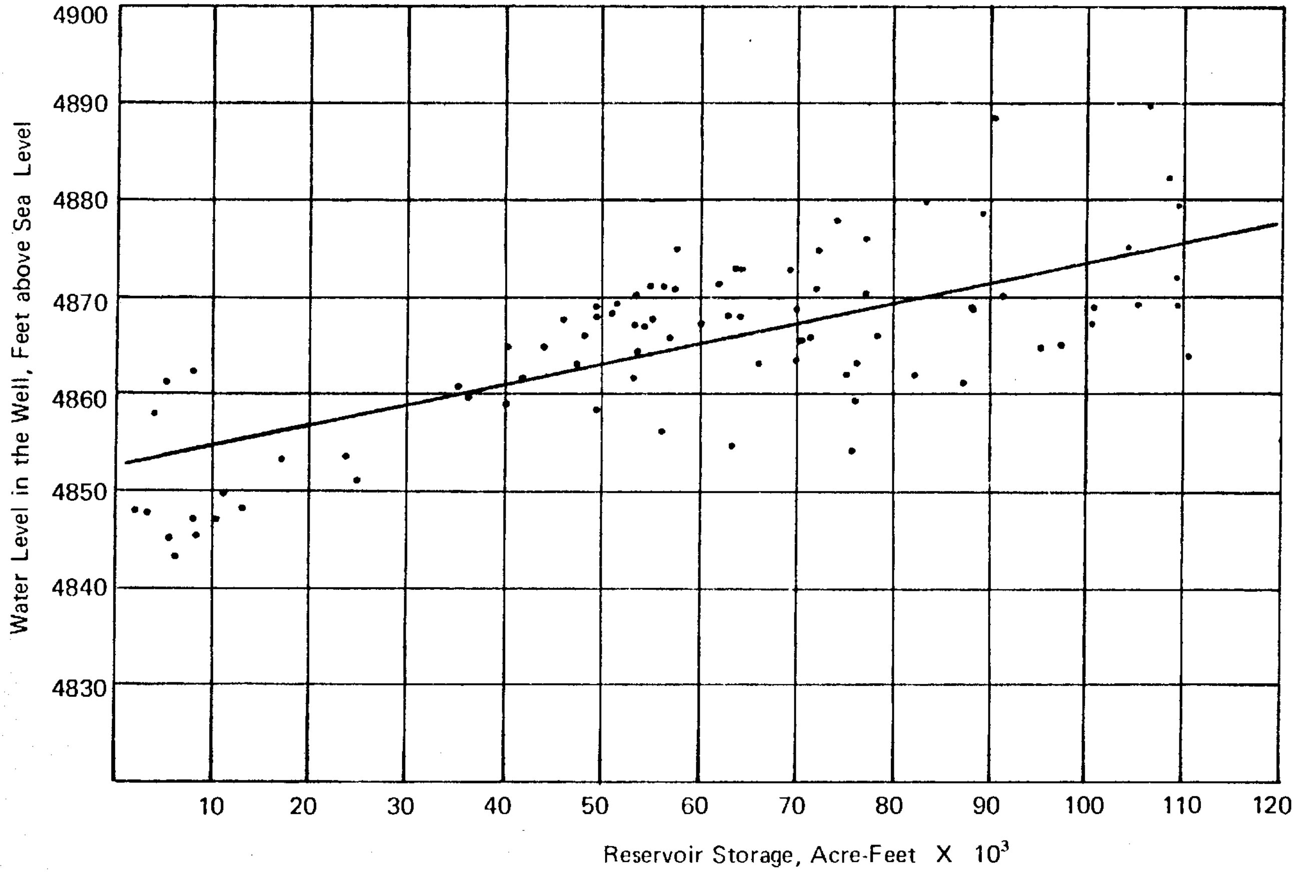

Figure 16. Relation of water level in the test well, (A-6-1) 11 cab-1, to storage in Pineview Reservoir.

correspondence is probably caused by the effect of withdrawals from the artesian wells. The Tower well is sufficiently distant from the Artesian Park area and it is less affected by the discharge from the artesian wells. Whereas the test well, (A-6-1) 11 cab-1, is closer to the Artesian Park area and more load will be required to overcome the decline caused by the artesian wells.

Toward the end of October 1970, Pineview Reservoir was drained for the purpose of installing a new pipe line for the new replacement wells at the Camp Browning area. Before the storage began, the author, with the help of U.S. Geological Survey, installed a recorder on the test well, (A-6-2) 18 bab-1, at Huntsville in order to record the changes of the water level in the test well during the filling of the reservoir. The attempt was only partially successful for the recorder obtained records for parts of January, February, and March but did not record the changes in most of April and May.

When the available records of water levels were plotted against the reservoir storage (fig. 17) a good linear relationship was observed. This linear relationship is defined by a straight line whose equation was:

$$Y = 4876.75 + .208\,X$$

Since the slope of the line is the same as the slope of the line in figure 16, it is, therefore, obvious that both wells react similarly to loading by Pineview Reservoir.

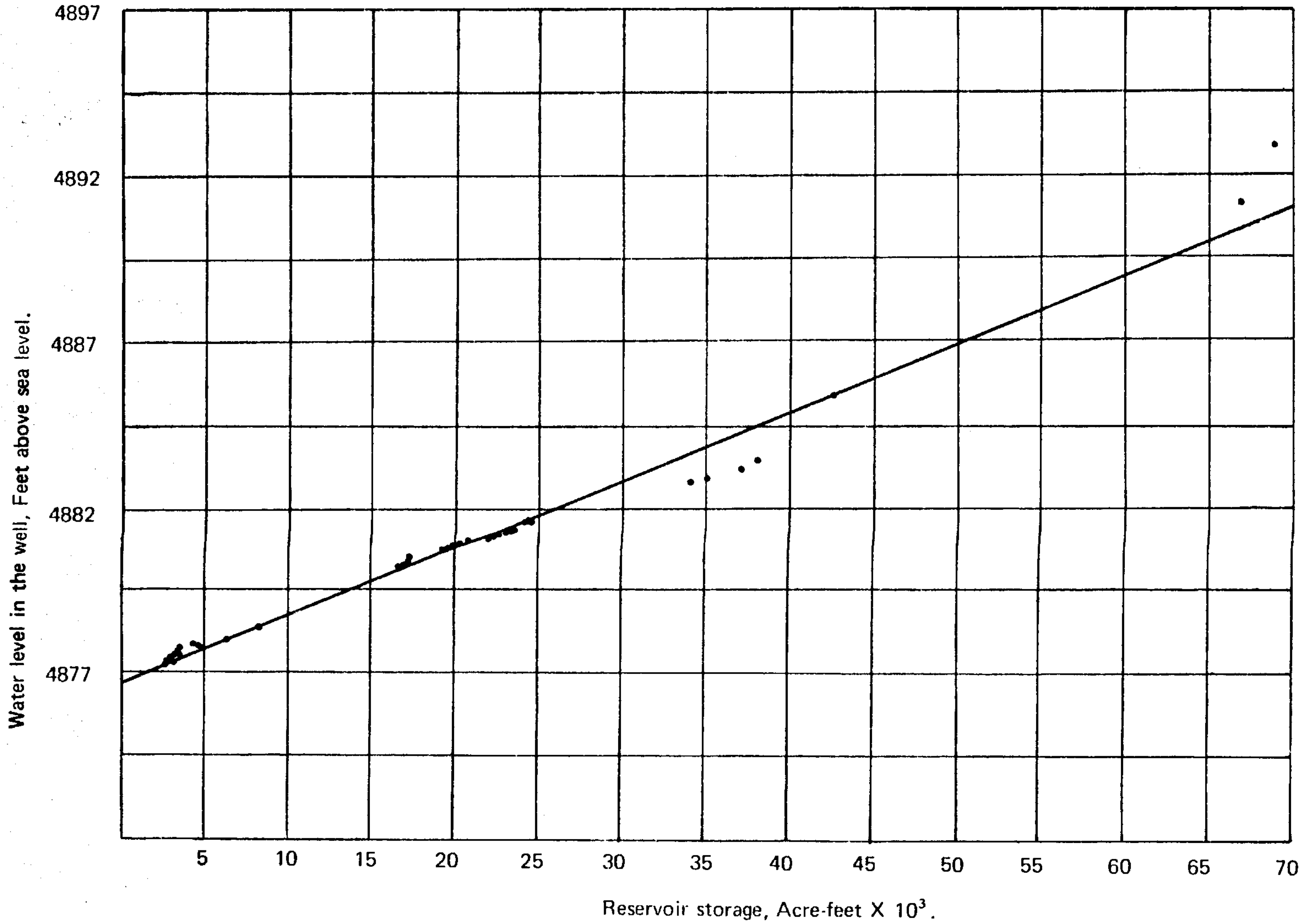

Figure 17. Relation of water level in the test well, (A-6-2) 18 bab-1, to storage in Pineview Reservoir.

Some of the conclusions drawn from these studies may be summarized as follows:

1. The application of varying loads on an artesian aquifer causes a certain amount of compression of the water-bearing material and the confining layer. As a result, there will be a slight reduction in the porosity and, thus, the permeability of the aquifer material.

2. The clay confining layer undergoes more compression than sand or gravel. This compression greatly reduces upward seepage from the artesian aquifer to the surface reservoir.

3. During each unloading there will be an accompanied expansion in the artesian aquifer.

4. The water level rise in the artesian wells is but a reflection of the increased pressure head in the aquifer caused by loading of Pineview Reservoir.

5. The loading by Pineview Reservoir is not applied uniformly but is greater where the depth of the water is greater. As a result, some parts of the artesian aquifer receive more loads than other parts. The greatest depth and thus the loading of the surface reservoir near the head of Ogden Canyon causes the greatest rise in the water levels in the wells. This rise, however, is partly compensated for by the greater decline caused by discharging wells located in this area.

6. The additional loading since 1962 caused further rise in the water levels in the artesian wells.

7. The loading may cause a slight reduction in the yield of the artesian wells.

CONCLUSIONS

The surface water resources of Ogden Valley include three major rivers and a surface reservoir. Pineview Reservoir regulates the flow of Ogden River and the storage capacity in the reservoir provides supplemental irrigation to 22,867 acres of land and municipal water within the Ogden River Project.

The unconsolidated deposits of the Quaternary age include two main aquifers- a water-table aquifer and an artesian aquifer- which supply water both for Ogden Valley and for the City of Ogden. The two aquifers are connected hydraulically. The artesian aquifer in Ogden Valley probably could be developed further if the present users would be willing to accept a reduction in pressure in exchange for the additional water.

The discharge from wells that tap the water-table aquifer constitutes a very small part of the total discharge. Each year, considerable recharge takes place to the ground-water aquifers. During the years of excessive recharge some of the water will be rejected and move to Pineview Reservoir. This loss to the aquifer may be reduced by developing the water-table aquifer. The water-table aquifer probably could be developed five times as much as it is now (discharge is about 100 acre-feet/year). If this were done the new wells would increase the discharge and make it possible for the aquifer to take in more recharge than it does now. The increased discharge might make it necessary to deepen some existing wells and the increase in recharge would result in less water going to Pineview Reservoir.

Recharge to the aquifers in 1970 was estimated to be about 34,300 acre-feet. The Ogden River system is the most important source of recharge to the ground-water reservoir in Ogden Valley. Seepage from waterways and irrigated land contribute about 84 percent of the total recharge and the rest is derived from direct infiltration of the precipitation.

Ground water is discharged both artificially and naturally. Artificial discharge occurs as withdrawals from wells, and the natural discharge includes evapotranspiration and discharge from springs. Withdrawals from artesian wells constitute the greatest part of the artificial discharge. The estimated total discharge in 1970 was about 34,000 acre-feet and the estimated discharge by evapotranspiration, alone, constitutes about 59 percent of the total discharge.

The long-term trends in water-level fluctuations in Ogden Valley indicate that discharge has not exceeded recharge. The water levels rise in late spring because of recharge from winter and spring precipitation and decline during summer because of greater discharge from the artesian wells.

The ground water in Ogden Valley is of good quality. The chemical analyses of the water samples indicate that the water is suitable for household purposes as well as for agricultural purposes. The results of bacteriological analyses imply that the water in four wells around Eden are contaminated. However, further tests are required to reach a more definite conclusion.

The ground water in Ogden Valley is bicarbonate in type. The increasing bicarbonate content in the wells may be explained by direct recharge of the seepage waters from the surface streams which contain more bicarbonate.

The Ogden Valley artesian reservoir is a complex hydraulic system. Some of the complexities are the result of continuous discharge from a group of artesian wells and changes in load resting upon the artesian reservoir.

An increase in storage of Pineview Reservoir is an indication of an increase in loading upon the artesian reservoir. The ultimate result of this loading is the compaction of the artesian aquifer and the subsequent reduction in the porosity of the aquifer material. Continuous withdrawal of water from the artesian reservoir produces reduction of pressure around the discharging wells. As a result of this the aquifer undergoes a certain amount of compression in which its total interstitial space will decrease by a volume approximately equal to the volume of the discharged water. During the recharge season, however, there will be an expansion to compensate the previous compression.

The fluctuations of water level in the test wells, (A-6-1) 11 cab-1 and (A-6-2) 18 bab-1, indicate changing stress conditions within the artesian aquifer. We can, therefore, relate these fluctuations to the factors which cause such stress changes. The loading by Pineview Reservoir, regardless of its magnitude, will always tend to raise the water levels in the test wells. On the other hand, the discharge from the artesian reservoir will always tend to lower the water levels in the wells. The hydrograph of the test well, (A-6-1) 11 cab-1, which is in the area of influence of the discharging wells, indicates that in spite of the continuous withdrawals from the artesian wells the water level in the well rises with an increase of the storage of Pineview Reservoir.

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APPENDIX I

WELL-NUMBERING SYSTEM USED IN UTAH

The well numbers used in this report indicate the well location by land subdivision according to a numbering system that was devised cooperatively by the Utah State Engineer and the U.S. Geological Survey about 1935. The system is illustrated in figure 18. The complete well number comprises letters and numbers that designate consecutively the quadrant and township (shown together in parentheses by a capital letter designating the quadrant in relation to the base point of the Salt Lake base and meridian, and numbers designating the township and range); the number of the section; the quarter section (designated by a letter); the quarter of the quarter section; the quarter of the quarter-quarter section; and, finally, the particular well within the 10-acre tract (designated by a number). By this system the letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quadrants of the standard base and meridian system of the Bureau of Land Management, and the letters a, b, c, and d designate the northeast, northwest, southeast, and southwest quarters of the section, of the quarter section, and of the quarter-quarter section. Thus, the number (B-2-2) 12 dcd-2 designates well 2 in the SE¼SW¼SE¼ sec.12, T.2N., R.2W., the letter B showing that the township is north of the Salt Lake base line and the range is west of the Salt Lake meridian; and the number (D-3-2) 34 bca-1 designates well 1 in the NE¼SW¼NW¼ sec. 34, T.3S., R.2E., in the southeast quadrant of the standard base and meridian system.

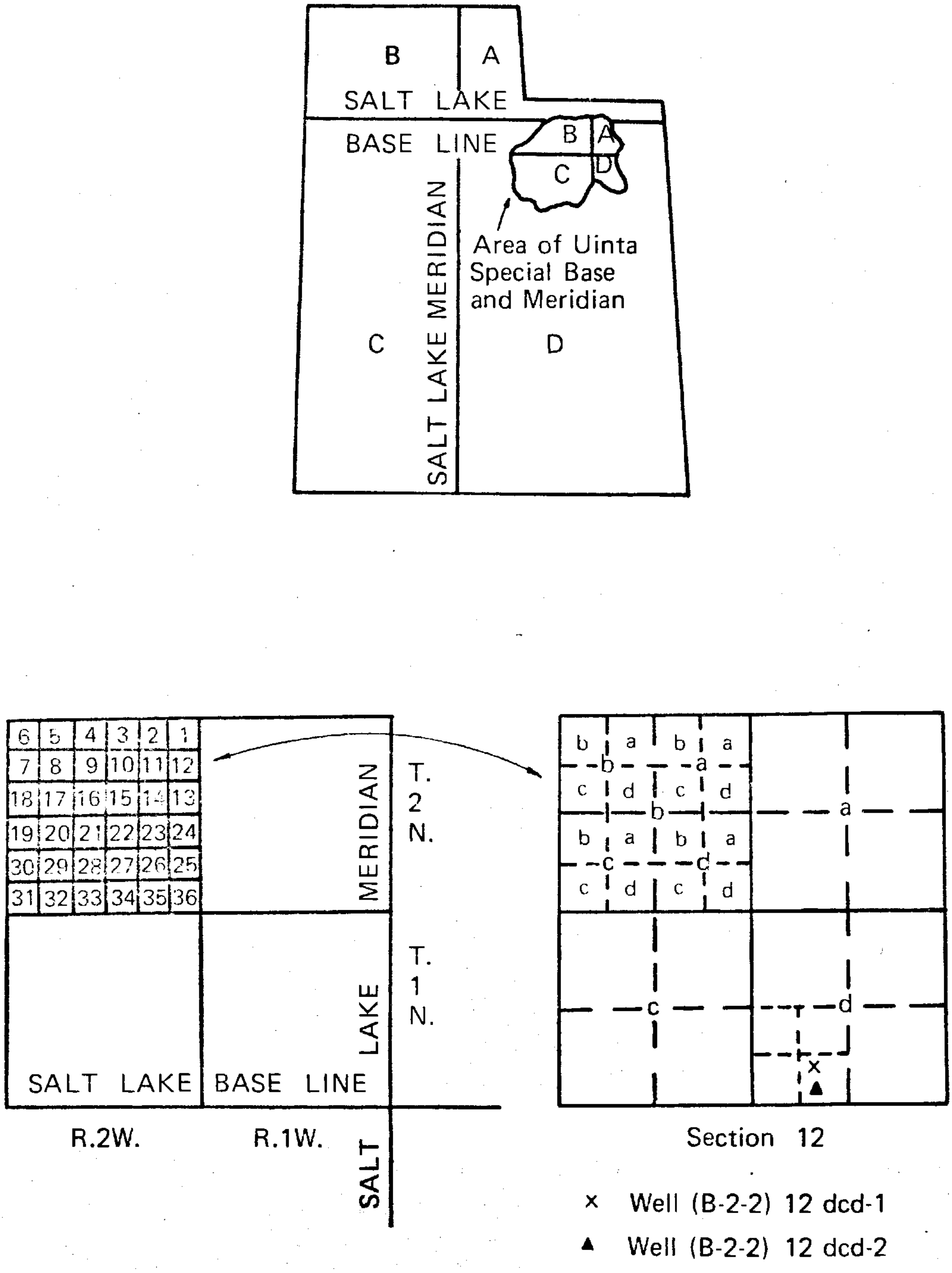

Figure 18. Well-numbering system used in Utah.

APPENDIX II

GLOSSARY OF SELECTED TERMS

Meinzer (Water-Supply Paper 494, p. 2) stated that a scientific term is a symbol that represents a scientific concept. It has the same significance as the definition of the concept; it is neither more nor less precise. However, there should be general agreement regarding it. Meinzer's definitions in Water-Supply Paper 494, on the whole, are still the most precise definitions of ground-water terms available, thus the definitions that follow are taken from that publication.

acre-ft: acre-foot; a unit of volume commonly used where large quantities of water are being expressed. It is the volume of water that could cover one acre to a depth of one foot. It equals 43,600 cubic feet or 325,850 gallons.

Aquifer; is a formation, group of formations, or part of a formation that is water-bearing.

Artesian water; is ground water that has artesian pressure because it is confined by material that is less permeable than the materials of the aquifer. Artesian water is under sufficient pressure to rise above the base of the confining bed. An artesian aquifer is one that contains artesian water.

Cone of influence; is the depression produced in the water or other piezometric surface by the withdrawal of the water.

Confining bed; of an aquifer is one which, because of its position and its impermeability or low permeability relative to that of the aquifer, gives the water in the aquifer either artesian or subnormal head.

cfs; (cubic foot per second or second-foot) a unit of flow or discharge commonly used to express the flow of streams but also used for large discharge rates from wells. It is the rate of flow where one cubic foot of water passes a given point in one second. It equals 724 acre-ft per year or 448.8 gallons per minute.

Drainage basin; a part of the surface of the land that is occupied by a drainage system or contributes surface water to that system.

Drainage system; consists of a surface stream or a body of impounded surface water, together with all surface streams and bodies of impounded surface water that are tributary to it.

Evaporation; is vaporization that takes place at a temperature below the boiling point.

Ground water; water in the zone of saturation.

Perched aquifer; an aquifer separated from an underlying body of ground water by unsaturated rocks. Its water table is a perched water table.

Phreatophyte; is a plant that habitually obtains its water supply from the zone of saturation, either directly or through the capillary fringe.

Piezometric surface; of an aquifer is an imaginary surface that everywhere coincides with the static level of the water in the aquifer.

Run-off; the discharge of water through surface streams.

Safe yield; the rate at which water can be withdrawn from an aquifer without depleting the supply to such an extent that withdrawal at this rate is harmful to the aquifer itself, or to the quantity of water, or is no longer feasible.

Seepage; is the percolation of water through the land surface or through the walls of large openings in the near-surface rocks such as caves or artificial excavations.

Static water level; is the level at which water stands in a well when no water is being taken from the aquifer by the well either by pumping or by free flow.

Transpiration; is the process by which the water taken into the roots of the plants directly from the zone of saturation or from the capillary fringe is discharged.

Water table; is the upper surface of a zone of saturation except where that surface is formed by an impermeable body.

Well; is an artificial excavation that derives some fluid from the interstices of the rocks or soil which it penetrates, except that the term is not applied to ditches or tunnels that lead ground water to the surface by gravity.

Zone of saturation; the zone in which the rocks are saturated with water under hydrostatic pressure. Does not include any saturated portion of the capillary fringe, as the water in the fringe is not under hydrostatic pressure.

APPENDIX III

LOGS OF NEW OGDEN CITY WELLS

Log of well (A-6-1) 11 cab-2

Date: Started April 5, 1971; completed April 14, 1971.

Screen schedule: 20"- #150 slot at 169'-172'; #100 slot at 176'-181'; #50 slot at 181'-185'; #100 slot at 185'-191'; #50 slot at 194'-204'; #80 slot at 204'-209'; #100 slot at 222'-227'; 18" casing installed from 167' to 169', between sections of screens, and from 227' to 240'.

Material	Thickness (feet)	Depth to bottom (feet)	Water conditions
Top soil	2	2	Dry
Clay with some sand	130	132	Confining layer
Sand and gravel	4	136	Contains water
Clay, sand, and gravel	32	168	Relatively impermeable
Cobbles, gravels, and coarse sand	5	173	Contains water
Clay	2	175	
Gravel with medium-to-coarse sand	16	191	Water
Clay	2	193	
Gravel with coarse and fine sand	16	209	Water
Clay, sand, and gravel	13	222	Contains some water
Gravel and coarse sand	4	226	Water
Clay, sand, and gravel	14	240	Some water

Log of well (A-6-1) 11 cab-3

Date: started November 17, 1970; completed December 11, 1970.

Screen schedule: 20"-#80 slot at 190'-195'; #70 slot at 203'-215'; #100 slot at 236'-241'; #50 slot at 241'-256'; 18" casing installed from 188' to 190' between sections of screens, and as tail pipe from 256' to 266'. Hole backfilled from 266' to 278'.

Material	Thickness (feet)	Depth to bottom (feet)	Water conditions
Top soil	2	2	Dry
Clay, sand, and gravel	24	26	
Clay with alternating layers of sand	103	129	Relatively impermeable. Confining layer.
Gravel and sand	1	130	Contains water
Clay, sand, and gravel	24	154	Contains water
Mostly gravel with some clay	21	175	Water
Clay, sand, and gravel	9	184	Water
Clay	1	185	
Gravel and sand	3	188	Contains water
Clay with sand	1	189	
Gravel and sand	7	196	Water
Clay with alternating layers of sand and gravel	5	201	
Gravel and coarse sand	13	214	Water

Log of well (A-6-1) 11 cab-3 continuted

Material	Thickness (feet)	Depth to bottom (feet)	Water conditions
Clay with small sand	21	235	Relatively impermeable
Gravel with coarse and fine sand	28	263	Contains water
Gravel with alternating layers of clay	4	267	
Gravel, sand and clay	5	272	
Clay	6	278	

Log of well (A-6-1) 11 cab-4

Date: started March 19, 1971; completed April 14, 1971.

Screen schedule: 20"- #50 slot at 190'-196'; #60 slot at 201'-216'; #150 slot at 243'-249'; #100 slot at 255'-262'; 18" diameter casing installed from 188' to 190', between sections of screens, and as tail pipe from 262' to 274'.

Material	Thickness (feet)	Depth to bottom (feet)	Water conditions
Top soil	3	3	Dry
Mostly sand with some clay	36	39	
Clay and silt	98	134	Confining layer
Clay with some sand and gravel	17	151	Relatively impermeable
Clay	3	154	
Clay, sand, and gravel	9	163	Water table at 50 feet below land surface.
Clay and silt	8	171	
Gravel	2	173	Contains water
Mostly gravel with alternating thin layers of sand and clay	43	216	Water table dropping
Clay	11	227	
Mixture of hard clay and gravel	11	238	
Gravel	1	239	Contains water
Gravel with clay	3	242	

Log of well (A-6-1) 11 cab-4 continued

Material	Thickness (feet)	Depth to bottom (feet)	Water conditions
Very clean gravel	8	250	Contains water
Hard clay with gravel and cobble size material	7	257	
Hard pan	17	274	

Log of well (A-6-1) 11 cab-5

Date: started March 14, 1971; completed April 2, 1971.

Screen schedule: 20"-#80 slot at 176'-186'; #50 slot at 191'-199'; #80 slot at 204'-219'; 18" casing installed from 174' to 176', between sections of screens and as tail pipe from 219' to 229'. Hole drilled below 229' is backfilled.

Material	Thickness (feet)	Depth to bottom (feet)	Water conditions
Top soil	4	4	Dry
Sand	5	9	
Clay	18	27	Impermeable
Sand and clay	7	34	
Sand	4	38	Contains water
Mostly clay with alternating layers of sand and gravel	119	157	Relatively impermeable
Gravel and coarse sand	5	162	Confined
Clay with alternating layers of sand and gravel	13	175	Relatively impermeable
Gravel and fine sand	9	184	Contains water
Clay mixed with sand and gravel	6	190	
Gravel with fine and coarse sand	12	202	Contains water
Clay with alternating layers of gravel and coarse sand	17	219	Relatively impermeable

Log of well (A-6-1) 11 cab-5 continued

Material	Thickness (feet)	Depth to bottom (feet)	Water conditions
Gravel with coarse and fine sand	10	229	Contains water
Mostly clay with alternating layers of sand and gravel	38	267	Hard. Relatively impermeable.

Log of well (A-6-1) 11 cab-6

Date: started February 19, 1969; completed April 30, 1969.

Casing schedule: 20" casing from 0 to 202 ft.
20" screen from 202 ft to 230 ft.
18" casing from 230 ft to 240 ft.

Material	Thickness (feet)	Depth to bottom (feet)	Water conditions
Top soil	5	5	Dry
Clay, sand, and gravel	45	50	Relatively impermeable
Clay	35	85	Impermeable
Mostly clay with some sand and gravel	84	169	
Gravel	5	174	Contains water
Clay	2	176	
Gravel	1	177	
Clay, sand, and gravel	1	178	
Gravel	4	182	Contains water
Clay, sand, and gravel	3	185	
Cobble and gravel	10	195	
Clay, sand, and gravel	3	198	
Gravel	33	231	Water
Clay	9	240	

APPENDIX IV

RECORDS OF WELLS LOCATED IN OGDEN VALLEY

Well No.: See appendix I for description of well-numbering system.
Method of construction: C, cable tool; D, dug; H, hydraulic rotary; J, jetted.
Casing: Finish - O. open end; P, perforations; S. screen.
Altitude above mean sea level: Altitudes interpolated from topographic maps.
Water level: Levels reported by driller.
Method of lift: F, flows; J, jet pump; S, submersible pump; T, turbine pump.
Yield: Flow rate of flowing well or pumping rate of nonflowing well, reported.
Use of water: H, domestic; I, irrigation; O, water-level observation; S, stock; U, unused.
Temperature: Reported unless indicated by M, measured.
Remarks and other data available: B, bacteriologic analysis in table 17; C, chemical analysis in table 16; H, hydrograph of water levels in figure 11;
W, water-level measurements in table 15. The wells are finished in water-table aquifer unless otherwise indicated.

Well No.	Owner or user	Year constructed	Method of construction	Depth of well (feet)	Casing			Altitude above mean sea level	Water level		Method of lift	Yield		Use of water	Temperature (°F)	Remarks and other data available
					Diameter (inches)	Depth (feet)	Finish		Above(+) or below(-) land-surface datum (feet)	Date of measurement		Rate (gpm)	Date of measurement			
(A-6-1)																
1aaa	J. S. Eggleston	1932	D	19.7	D	–	–	4,935	-16.9	8-17-32	J	–	–	H	–	H,W.
1bba	A. L. Murray	1968	C	105	6	105	O	4,916	-17	4-19-68	S	10	4-19-68	H	51	
1bbb	M. J. Rasley	1970	C	94	6	93	P 80-87	4,906	+4	7-5-70	F	20	7-5-70	H,I,S	–	
2aab-1	M. Fuller	1932	D	15.2	D	–	–	4,925	-9	8-18-32	J	–	–	U	–	H,W
2aab-2	Lloyd	1960	D	18	D	--	–	4,918	–	–	–	4	–	H	50M	B,C,H,W
2dbd	H. B. Stalling	1932	D	33.4	D	–	–	4,926	-25.9	8-18-32	--	–	–	U	–	H,W
3abc	W. F. Johnson	1967	C	187	4,6	187	6" 0-80	4,915	-28	6-20-67	–	10	6-20-67	H	–	
3bab	U. S. Forest Service	1961	H	75	8	75	P 53-75	5,120	0	7-5-61	–	70	7-5-61	H,I	50	
3dbc-1	H. M. Gerber	1963	C	120	6	120	O	4,970	-47	4-20-63	–	10	4-20-63	H	–	
3dbc-2	W. F. Johnson	1967	C	187	6,4	187	P 140-170	4,995	-28	6-20-67	–	10	6-20-67	H	–	
10aac	Pineview Yatch Club	1951	C	155	6	155	P 70-101	4,945	-51	June, 51	–	30	June, 51	–	–	
10aca	G. Wood	1963	C	350	6	350	P 22-53	4,948	-12	6-4-63	–	30	6-4-63	H	–	
10dac	U. S. Forest Service	1963	H	172	8	169	P 114-169	4,940	-32	11-29-63	–	–	–	H,I	–	
10dbc	E. L. Rodford	1969	H	142	8	142	P 124-142	4,942	-38	9-10-69	–	15	9-10-69	H	–	
10dbd	E. L. Rodford	1969	H	130	8	130	P 114-130	4,948	-30	9-19-69	–	20	9-19-69	H	–	
11acb	H. R. Fuller	1968	C	151	6	151	O	4,918	-47	5-10-68	–	10	5-10-68	H	51	Finished in artesian aquifer
11bdc-1	Realty Insurance Co.	1954	C	224	8	224	P 170-191	4,920	-69	11-8-54	–	75	11-8-54	–	–	do
11cab	U. S. G. S.	1952	C	354	8	354	P 0-333	4,916	-79	12-11-52	–	250	12-11-52	O	–	do,C
11cba	Ogden City Corp.	1969	C	237	20-18	237	20", 0-205 20" 205-230 18" 230-237	4,895	-30	4-29-69	–	–	–	Test Well	–	do
11dcd	Bureau of Recla.	1955	–	190	8	190	P 170-187	4,915	-70	10-29 55	–	180	10-29-55	–	48	do,C
11dda-2	Ogden Pineview Yatch	1947	–	130	3½	130		4,910	-18	–	–	–	–	–	60	–
12ccb	O. G. Yeaton	1950	–	135	4	135	O	4,905	-8	5-15-50		6.5	5-15-50	H	–	do
12dcd	A. Lancaster	1960	C	145	4	145	P 138-144	4,920	-42	10-21-60	–	8	10-21-60	H	–	do
13ccd	Pineview Lodge & Resort	1960	–	500	10-8	500	P 400-500	4,925	0	4-6-60	–	175	4-6-60	–	56	do
13dcc	U. S. Forest Service	1961	H	133	8	133	P 110-133	4,921	-26	7-1-61	–	60	7-1-61	N	50	do

Well No.	Owner or user	Year constructed	Method of construction	Depth of well (feet)	Casing			Altitude above mean sea level	Water level		Method of lift	Yield		Use of water	Temperature (°F)	Remarks and other data available
					Diameter (inches)	Depth (feet)	Finish		Above(+) or below(-) land-surface datum (feet)	Date of measurement		Rate (gpm)	Date of measurement			
24aba	Valley Lake Corp.	1969	C	198	8	197	P 130-150	4,916	-29	7-17-69	S	100	7-17-69	H,I	–	do
(A-6-2)																
5bab	K. Jensen	1953	C	164	12	125	P 70-125	5,075	-24	9-12-53	J	–	–	H	–	
5bbc	R. Glantz	1964	C	54	8	56	P 40-54	4,997	-30	12-15-64	J	–	–	H	41M	B,C,H,W
5bcc	K. Jensen	1952	C	50	8	50	P 30-45	4,995	-20	10-16-52	J	25	10-16-52	H	–	
6bbb	R. H. Hinckley	1965	C	228	8-6	227	P 181-227	4,940	-8	2-15-65	S	20	–	H,S	–	H,W
6dad	C. L. Davey	1967	C	55	8	55	P 50-55	4,978	-15	1-17-67	–	–	–	H	–	
6ddc	U. S. G. S.	–	–	12	–	–	–	4,962	–	–	–	–	–	O	–	H,W
7aab-1	F. Allen	1964	C	84	6	84	O	4,935	-38	8-2-64	–	10	8-2-64	H	51	
7aab-2	J. Skeen	1968	C	92	6	92	O	4,932	-21	7-30-68	S	8	7-30-68	H	51	B,C
7aac	B. O. Wilcox	1965	C	100	6	100	P 72-100	4,932	-11	7-8-65	–	10	7-8-65	H	51	
7aba	G. W. Downs	1956	C	78	8	78	P 60-75	4,925	-25	7-21-56	–	10	7-21-56	H	–	
7bbb-1	Keisel Bldg. Ogden	1957	C	111	8	105	P 85-105	4,920	-45	12-30-57	S	20	12-30-57	–	–	
7bbb-2	J. V. Stoker	1960	C	88	4	88	P 60-67	4,923	-28	7-27-60	S	4	7-27-60	H	51	
7bcc	S. I. Quist	1965	C	102	6	100	O	4,935	-18	10-26-65	S	6	10-26-65	H	–	
7dab	E. W. Crezee	1962	C	63	4	63	O	4,935	-11	6-13-62	J	5	6-13-62	H	50	
7dbd	E. J. Carroe	1968	C	84	6,4	84	4", 74-84	4,920	-39	6-28-68	–	5	6-28-68	H	51	
8ddb	Paul and Margret Ann Smith	1970	C	160	8	160	P 100-150	4,963	-15	5-21-70	–	30	5-21-70	H	–	
12caa	Cosec and Co.	1970	C	30	6	30	O	5,115	-4	4-18-70	–	10	4-18-70	H	–	Replacement Well
14bac	Farternal Order of Eagles	1958	C	70	6	70	O	5,112	–	–	–	20	7-14-58	H	–	
14bad-1	A. K. Cross	1964	C	22	6	22	O	5,115	-5	4-12-64	–	10	4-12-64	H	50	
14bad-2	T. F. Miller	1963	C	23	6	23	O	5,115	-8	3-27-63	–	5	3-27-63	H	50	
14bad-3	D. Hutchins	1958	C	23	6	23	O	5,115	–	–	–	20	7-17-58	H	–	
14bad-4	D. F. Morrin	1961	C	21	6	21	O	5,115	-5	4-7-61	–	5	4-7-61	H	42	
15baa	L. Garner	1960	C	72	4	72	O	5,117	-32	8-11-60	–	5	8-11-60	H	51	
15bab	H. W. Jacobs Co.	1957	C	61	4	61	–	5,119	-31	8-6-57	–	5	8-6-57	H	52	
15bcd	L. Mumford	1950	C	56	6	56	P 47-56	5,032	-24	3-28-50	–	5	3-28-50	H	–	
15cbb	W. J. Poulter	1957	C	52	4	52	O	5,038	-20	6-21-57	J	6	6-21-57	H	52	
16abc	C. Lund	1960	C	56	4	56	O	5,003	-26	8-3-60	–	5	8-3-60	H	52	Deepened
16abd	L. Stoker	1959	C	54	4	54	P 21-54	5,005	-21	6-22-59	–	5	6-22-59	H	52	
16abd	J. H. Noorlander	1964	C	81	6 5/8	81	P 40-75	5,005	-35	3-12-64	–	20	3-12-64	H	–	
16acc	D. W. Smuin	1965	C	62	6	62	O	5,012	-34	4-26-65	J	10	4-26-65	H	51	B,C,H,W
16acd	R. L. Thompson	1968	C	78	6	78	O	5,005	-17	7-12-68	–	10	7-12-68	H	51	
16ada	Realty Insurance Co.	1954	H	242	12	236	P 84-170,196-236	5,020	-38	12-17-54	T	150	12-17-54	–	–	
16bac	F. Layton	1960	C	58	4	58	O	4,992	-9	6-4-60	–	5	6-4-60	H	52	
16bac	N. W. Beckstead	1959	H	49	4	49	P 7-49	4,990	-7	6-9-59	–	5	6-9-59	H,I,S	52	
16bad	L. Malkos	1963	C	62	6	62	O	4,988	-17	10-25-63	S	9	10-25-63	H	–	
16bbc	C. A. Clark	1960	C	54	4	54	P 25-54	4,982	-22	4-2-60	S	5	4-2-60	H,I	52	
16caa	G. A. Donnelsen, Jr.	1970	C	91	6	91	O	5,005	-28	10-15-70	–	10	10-15-70	H	–	
16cad	B. Thomsen	1969	C	95	6	95	P 85-95	4,995	-11	5-11-69	S	35	5-11-69	H,I	–	
16cba	A. P. Haney	1970	J	40	4	40	O	4,978	-12	4-6-70	S	25	4-6-70	H,S	–	

Well No.	Owner or user	Year constructed	Method of construction	Depth of well (feet)	Casing			Altitude above mean sea level	Water level		Method of lift	Yield		Use of water	Temperature (°F)	Remarks and other data available
					Diameter (inches)	Depth (feet)	Finish		Above(+) or below(-) land-surface datum (feet)	Date of measurement		Rate (gpm)	Date of measurement			
16cbb	G. Smith	1970	C	40	4	40	O	4,982	–	–	J	25	1970	H	–	H,W
16cbd	E. L. Brown	1954	C	53	4	53	P 47-53	4,987	-16	12-4-54	–	10	12-4-54	–	–	
16daa-1	W. J. Hart	1951	C	51	4	48	O	5,028	-32	7-29-51	J	–	–	–	–	H,W
16daa-2	R. Lindsey	1970	C	57	6	57	P 39-55	5,022	-13	5-27-70	S	20	5-27-70	H	–	
16dad-1	E. Royer	1960	C	54	4	54	O	5,028	-37	10-18-60	J	5	10-18-60	H	44	B,C,H,W
16dad-2	M. Ford	1943	C	43	2½	43	P 10-43	5,010	-33	6-30-43	–	–	–	H		
16dba	C. Rasmussen	1969	C	79	6	79	O	5,007	-14	5-12-69	T	10	5-12-69	H	–	
16dba	C. H. Shannon	1942	C	48	6	48	O	5,007	-32	1942	T	--	–	–	–	
16dbb	L. Melly	1913	D	35	D	35	–	5,010		–	J	5	1913	H	–	
16dbc-2	E. L. Brown	1956	C	52	6	52	P 42-52	5,002	-22	8-7-56	J	–	–	–	–	
16dbc-1	F. G. Brown	1942	–	49	3	49	–	5,006	–	–	S	–	–	–	–	
16dbd	D. E. King	1968	C	82	6	82	O	5,007	-26	8-20-68	–	10	8-20-68	H	50	
16ddd-1	A. King	1960	C	67	4	67	O	5,025	-22	6-21-60	J	5	6-21-60	H	49	
16ddd-2	G. W. Prior	1961	C	53	4	53	O	5,023	-34	8-4-61	–	5	8-4-61	H	42	
16ddd-3	R. Sparks	1962	C	53	4	53	O	5,022	-21	4-3-62	–	5	4-3-62	H	44	
17aaa	W. L. Stokes	1958	C	44	4	44	P 9-44	4,971	-9	5-1-58	–	5	5-1-58	H	50	
17aac	R. E. Toyn	1958	C	42	6	42	P 37-42	4,972	-11	11-10-58	S	–	–	H,I	–	H,W
17bbc-1	O. K. Knight	1956	C	40	4	40	P 35-40	4,938	2lb.	8-9-56	F	20	8-9-56	H		
17bbd	L. L. Fielding	1962	C	41	4	41	O	4,942	+1.5	5-11-62	J	4	5-11-62	H,S	41	Artesian well
17cac	A. G. Mumford	1961	C	67	4	67	O	4,955	-8	6-16-61	–	5	6-16-61	H	51	
17cbd	C. H. Smith	1968	C	88	6	88	O	4,935	-9	9-6-68	S	10	9-6-68	H	50	
17cca	M. F. Schade	1970	C	128	6	128	P 86-94	4,932	-37	5-6-70	S	25	5-6-70	H,S	–	
17dcb	L. R. Felt	1963	C	65	6	65	O	4,932	-1	4-15-63	–	10	4-15-63	H	50	
17dda	C. H. Holmes	1963	C	64	6	64	O	4,970	-9	3-8-63	S	5	3-8-63	H	50	
17ddd-1	B. Allen	1963	C	50	6	50	O	4,965	-3	5-28-63	–	10	5-28-63	H	50	
17ddd-2	G. H. Pope	1962	C	52	4	52	O	4,963	+1	5-4-62	–	4	5-4-62	S,H,I	52	Abandoned
18aab	J. A. McKay	1968	H	120	6	97	P 87-97	4,917	-1	8-2-68	S	5	8-2-68	H,I	39	
18aba	T. McKay	1932	D	19.6	D	–	–	4,931	-14.3	8-17-32	–	–	–	H,I	–	H,W
18bab	J. M. Peterson	1955	C	155	8	155	P 105-115, 125-155	4,924	–	–	–	60	10-29-55	H	50	Not used, C,H,W
18bad	A. A. Berlin	1961	D	20	24	–	–	4,924	-9	8-23-61	J	60	8-23-61	I		H,W
18dad	R. W. Gredille	1969	C	94	6	94	O	4,938	-18	4-25-69	S	10	4-25-69	H	51	
18dbb	L. Brunker	1932	D	19.7	D	–	–	4,934	-16.9	8-17-32	–	–	–	H	–	H,W
18dda	D. D. Smith	1966	C	85	6	85	O	4,935	-13	7-15-66	–	10	7-15-66	H	51	
19aac	D. K. Low	1962	C	85	4	85	O	4,915	-49	5-25-62	–	5	5-25-62	H	50	
19abb	U. S. Forest Service	1961	H	69	8	51	P 26-51	4,912	-1	7-4-61	–	60	7-4-61	N	50	
19bca	R. C. Johnson	1967	C	85	6	85	P 80-85	4,938	+10	9-10-67	J	15	9-10-67	H,S	–	Artesian well
19bda-1	R. J. Penton	1960	C	71	4	71	O	4,958	-49	9-20-60	–	4	9-20-60	H,I	51	
19bda-2	U. C. Bowen	1964	C	75	4	75	O	4,960	-4	7-6-64	–	5	7-6-64	H	51	
19bdb	C. L. Peterson	1961	C	90	4	90	O	4,970	-50	9-1-61	–	5	9-1-61	H,I	48	
20baa	Froerer Corp.	1965	C	84	6	84	O	4,960	-12	8-20-65	–	10	8-20-65	H,S	–	
20bab	M. G. Froerer	1969	C	86	6	86	O	4,962	-4	5-2-69	–	10	5-2-69	H	–	
21aba	Marshall Issacson	1970	C	107	6	107	P 96-104	5,002	-37	6-30-70	S	15	7-1-70	I	–	
21ada	T. Fuller	1942	C	36	4	36	O	5,005	-36	9-29-42	T	–	–	H	–	

Well No.	Owner or user	Year constructed	Method of construction	Depth of well (feet)	Casing			Altitude above mean sea level	Water level		Method of lift	Yield		Use of water	Temperature (°F)	Remarks and other data available
					Diameter (inches)	Depth (feet)	Finish		Above(+) or below(-) land-surface datum (feet)	Date of measurement		Rate (gpm)	Date of measurement			
21adc	R. Birch	1942	C	37	4	37	O	5,004	-24	9-26-42	T	–	–	H	–	
21bbb	S. C. Wangsgard	1956	C	81	6 5/8	81	P 72-81	5.001	-15	12-10-56	J	25	12-10-56	H	41M	B,C
21bca	A. Patterson Jr.	1965	C	76	6	76	U-76	5,003	-8	6-4-65	S	10	6-4-65	H	51	
21cba-1	A. J. Shupe	1957	C	30	4	30	O	5,004	-9	9-29-42	–	–	–	–	–	
21cbb	G. Messerly	1970	C	105	6-4	105	P 38-110	5,003	-12	5-28-70	T	10	5-28-70	H	–	C,H,W
21cbd	L. G. Merill	1963	C	44	6	44	O	4,986	-9	9-24-63	J	9	9-24-63	H	51	
28aad	J. C. Jones	1962	C	92	6	92	P 40-87	5,022	-40	9-11-62	S	10	9-11-62	H	–	
28aba	E. S. Price	1970	C	118	6	117	P 96-115	5,025	–	–	S	15	7-27-70	H	–	Replacement Well
(A-7-1)																
6ccb	L. S. Pierce	1962	C	33	6	33	O	5.372	-9	10-6-62	–	5	10-6-62	H	50	
7abc	Valley Rehab. and Recreation Co.	1970	C	47	6	47	O	5,200	-8	9-3-70		15	9-3-70	H	–	
7dda	W. D. Brown	1964	C	50	8	50	P 38-50	5,210	-30	9-5-64	J	5	9-5-64	H	50	
7ddb	C. F. Blake	1965	C	70	6	70	P 52-67	5,242	-25	2-1-65	–	15	2-1-65	H	–	
7ddd	P. H. Meyer	1970	C	59	6	59	O	5,210	-34	8-20-70	–	10	8-20-70	H	–	
8cbb	W. Pendleton	1967	C	135	14,10	120	P 57-117	5,244	-45	7-25-67	J	–	–	H,I	–	
8cbd	D. K. Roberts	1961	C	20	6	20	O	5,236	–	–	J	–	–	–	–	
8ccb	E. L. Warren	1964	C	71	8	71	O	5,203	-35	10-29-64	J	–	–	S	–	H,W
17bbd	R. F. Mackay	1969	C	82	6	82	O	5,202	-43	8-6-69	S	10	8-6-69	H		
17bca	D. S. Tanner	1965	C	85	6	85	O	5,178	-31	6-10-65	–	9	6-10-65	H	–	
17cac-1	K. Jordan	1963	H	92	4	92	P 81-92	5,162	-67	5-17-63	–	–	–	H	–	
17cac-2	M. G. Jones	1963	H	204	6	204	P 187-202	5,160	-67	12-18-63	–	35	12-18-63	H	58	
17cbb	N. E. Wadsworth	1964	C	75	6	75		5,168	-49	8-27-64	–	10	8-27-64	H	50	
18ada	R. M. Richins	1969	C	83	6	80	P 80-83	5,202	–	–	S	15	1969	S,H,I	–	
18adc	W. Bailey	1958	C	132	6 5/8	132	P 88-91, 122-132	5.275	-80	9-15-58		15	9-15-58	H	–	
18add	E. L. Hadley	1970	C	122	6	122	P 102-118	5,205	-68	7-10-70	S	25	7-10-70	H,I	–	
18dba	W. L. Bailey	1963	C	152	6	150	P 60-150	5.278	-35	6-10-63	–	10	6-10-63	H	–	
19aad	G. B. Handy	1962	H	90	6	90	P 27-90	5,158	+5	7-12-62	J	10	7-12-62	H,I,S	–	Artesian well
20aaa-1	L. L. Braithwaite	1969	C	75	6	105	O	5.027	-13	7-9-69	J	8	7-9-69	H	–	H,W
20aaa-2	D. Tuck	1969	C	76	6	76	–	5,110	-39	6-13-69	S	7	6-13-69	H	43M	B,C,H,W
20aad-3	J. W. McFarland	1970	C	71	6	71	O	5,074	-29	11-6-70	–	10	11-6-70	H	–	
20aad-1	R. Rasmussen	1969	C	87	6	87	O	5,080	-47	8-29-69	–	10	8-29-69	H	–	H,W
20aad-2	R. J. Jones	1965	C	105	6	105	P 63-92	5,102	-45	8-10-65	J	25	8-10-65	H	–	
21bbb	B. F. Euertsen	1970	C	92	6	92	P 85-92	5,078	-8	6-26-70	–	10	6-26-70	H	–	
21bbc	R. L. Warren	1969	C	81	6	81	O	5,062	-18	7-18-69	–	8	7-18-69	H	–	H,W
22ccc	J. D. Aplegarth	1963	H	140	4	140	P 70-100, 120-130	5,080	-40	6-25-63	–	2	6-25-63	H	–	
22ccd	H. Haldeman	1954	C	45	4	45	O	5,088	-19	11-22-54	J	10	11-22-54	H	50M	B,C
27baa	S. Hayes	1963	H	395	4-3	395	P 180-395	5,080	-40	7-3-63	–	–	–	H	–	
28dac	J. C. Lewis	1962	C	75	4	75	O	4,987	-39	9-10-62	S	5	9-10-62	H	50	
28bad	Larry King	1970	C	280	6	280	P 255-275	5,020	42	9-15-70	S	15	9-15-70	H,I,S		
28dbb	B. K. Storey	1970	C	89	6	89	O	5,002	-24	9-25-70	–	10	9-25-70	H	–	

Well No.	Owner or user	Year constructed	Method of construction	Depth of well (feet)	Casing			Altitude above mean sea level	Water level		Method of lift	Yield		Use of water	Temperature (°F)	Remarks and other data available
					Diameter (inches)	Depth (feet)	Finish		Above(+) or below(-) land-surface datum (feet)	Date of measurement		Rate (gpm)	Date of measurement			
28dda	A. B. Malan	1957	–	75	4	75	O	4,982	-26	7-23-57	S	20	7-23-57	H	–	
29ada	H. L. Storey	1964	C	80	6	80	O	5,074		6-13-64	S	5	6-13-64	H	51	B,C
29abd	E. N. Storey	1963	C	82	6	82	O	5,088	-18	8-8-63	S	10	8-8-63	S,H	51	
29baa-1	R. C. Shaw	1949	C	65	6	65	O	5,122	-22	11-28-49	–	30	11-28-49	H	–	
29baa-2	L. J. Chard	1962	H	105	4	105	P 65-105	5,135	-38	9-3-62	J	15	9-3-62	H,S	–	
29cad	G. P. Henderson	1962	H	126	4	126	P 63-126	5,334	-36	11-5-62	–	20	11-5-62	H,S	–	
32dba	Arthur Christiansen	1966	C	193	10	193	P 50-170	5,610	–	–	–	150	12-31-66	H	–	
32dcd	Arthur Christiansen	1963	C	264	12	264	P 40-255	5,980	–	–	–	200	7-20-63	H	45	
34aba	R. G. Jordon	1965	C	118	6	118	P 100-117	4,970	-15	3-10-65	–	25	3-10-65	H	–	
34bba	R. Clark	1949	C	75	6	75	P 65-75	4,983	-35	7-13-69	J	–	–	–	43M	B,C
35cdd	C. Fuller	1932	D	19.7	D	–	–	4,930	-12.5	8-18-32	–	–	–	H	–	H,W
36bdd	Bar. B. Co.	1949	–	95	6	95	P 65-95	4,945	-45	7-5-49	T	20	–	H	–	

VITA

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Birthplace	Aydin, Turkey
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Elementary School	Cumhuriyet Ilkokulu Aydin, Turkey
College	Aydin Lisesi Aydin, Turkey 1955-1961
University	Middle East Technical University (METU) Ankara, Turkey 1961-1965
Degrees	B.S., METU Ankara, Turkey, 1965 M.S., METU Ankara, Turkey, 1967
Professional Organizations	American Institute of Mining, Metallurgical, and Petroleum Engineers
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