Ground Water at Grant Village Site Yellowstone National Park Wyoming

By ELLIS D. GORDON, RICHARD A. Mc CULLOUGH, *and* EDWIN P. WEEKS

HYDROLOGY OF THE PUBLIC DOMAIN

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GROUND WATER AT GRANT VILLAGE SITE, YELLOWSTONE NATIONAL PARK, WYOMING

By Ellis D. Gordon, Richard A. McCullough, and Edwin P. Weeks

ABSTRACT

On behalf of the National Park Service, the U.S. Geological Survey during the summer of 1959 made a study of ground-water conditions in the area of the Grant Village site, along the shore of the West Thumb of Yellowstone Lake, 1 to 2 miles south of the present facilities at West Thumb. The water supply for the present development at West Thumb is obtained from Duck Lake, but the quantity of water available from this source probably will be inadequate for the planned development at Grant Village.

During the investigation, 11 auger holes were bored and 6 test wells were drilled. Aquifer tests by pumping and bailing methods were made at two of the test wells. All material penetrated in the auger holes and test wells is of Quaternary age except the welded tuff of possible Pliocene age that was penetrated in the lower part of test well 4.

Small to moderate quantities of water were obtained from the test wells in the area. Test well 2 yielded 35 gpm (gallons per minute) at a temperature of nearly 100°F. Test well 6 yielded about 15 gpm at a temperature of 48°F. The yield of this well might be increased by perforation of additional sections of casing , followed by further development of the well. Water from the other four test wells was of inadequate quantity, too highly mineralized, or too warm to be effectively utilized.

Most of the ground water sampled had high concentrations of silica and iron, and part of the water was excessively high in fluoride content. Otherwise, the ground water was of generally suitable quality for most uses.

The most favorable area for obtaining water supplies from wells is near the lakeshore, where a large part of the water pumped would be ground-water flow diverted from its normal discharge into the lake. Moderate quantities of relatively cool water of fairly good quality may be available near the lakeshore between test wells 5 and 6 and immediately east of test well 6.

INTRODUCTION

As a part of the Department of the Interior's Mission 66 program for the improvement and development of the National Park system, the National Park Service plans to construct additional facilities for accommodation of the general public in the vicinity of West Thumb, Yellowstone National Park. The proposed new development, known as the Grant Village site, lies along the shore of the West Thumb of Yellowstone Lake, 1 to 2 miles south of the present facilities at West Thumb.

On behalf of the National Park Service, the U.S. Geological Survey during the summer of 1959 made a study of the ground-water conditions in the area bordering Yellowstone Lake at the Grant Village site. The general geographic features and the area covered by the investigation are shown on figure 28.

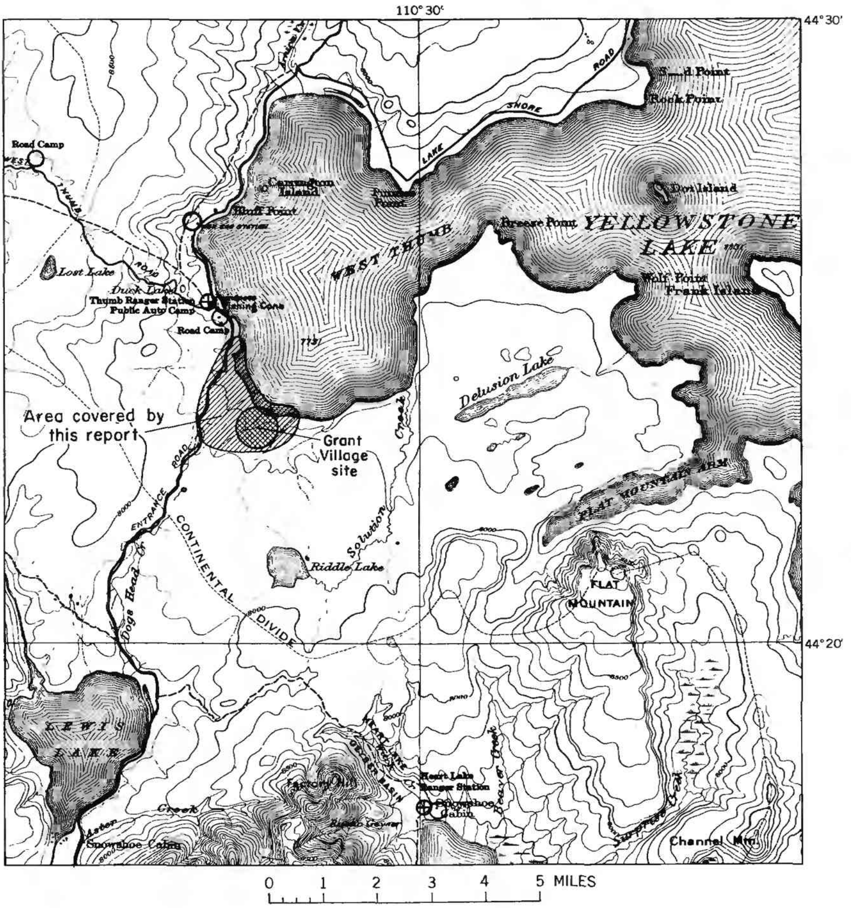

FIGURE 28.—Map of a part of Yellowstone National Park, Wyo., showing general features in the vicinity of the Grant Village site and location of the report area.

The water supply for the present development at West Thumb is obtained from Duck Lake, a small lake about half a mile northwest of the ranger station at West Thumb. The quantity of water available from this source, however, probably will be inadequate for the planned development at Grant Village.

This investigation was made to provide information regarding the occurrence, availability, and quality of ground water in the vicinity of the Grant Village site. The data obtained provide the basis for a decision regarding the relative feasibility of surface water and ground water as a source of supply for the proposed development at Grant Village.

Field investigations made during May through August 1959 included a brief reconnaissance of the geology of the area, boring of 11 test holes with a power auger, supervision of a test-drilling contract under which 6 test wells were drilled, and aquifer testing by pumping and bailing methods. The test wells were drilled by the percussion method under a National Park Service contract, and the test holes were bored with a power auger by the Geological Survey. The installation of temporary casing in five of the auger holes allowed their utilization as observation wells during the aquifer tests.

Many individuals assisted during the investigation: J. D. Love, geologist, U.S. Geological Survey, discussed the geology of the area with the senior author, loaned him a set of aerial photographs of the area, and examined drill cuttings from some test wells; Lloyd Hoener, park ranger at West Thumb, accompanied the authors on a reconnaissance of the area and was helpful in many other ways; Gary Rowe, park engineer, and Thomas Hyde, assistant park engineer, provided information regarding the area and arranged for construction of access roads to the drill sites; Theodore Wirth, project supervisor, and E. J. Axline, engineer, National Park Service, exercised general supervision for the National Park Service drilling contract and provided other technical assistance during the investigation.

TOPOGRAPHY AND DRAINAGE

The Grant Village area is one of moderate relief. The land surface slopes generally northeastward from the Continental Divide toward Yellowstone Lake. The area is drained by the lower part of Thumb Creek and by several small unnamed intermittent streams, all of which discharge directly into the West Thumb of Yellowstone Lake. All the streams are well incised, and have cut rather deep V-shaped valleys into the sediments bordering the lake. The general topography of the Grant Village site is shown in figure 29.

The Grant Village development will be located near the lakeshore, where surface gradients are rather gentle. Along much of the lakeshore the land surface slopes rather evenly toward the shoreline, and

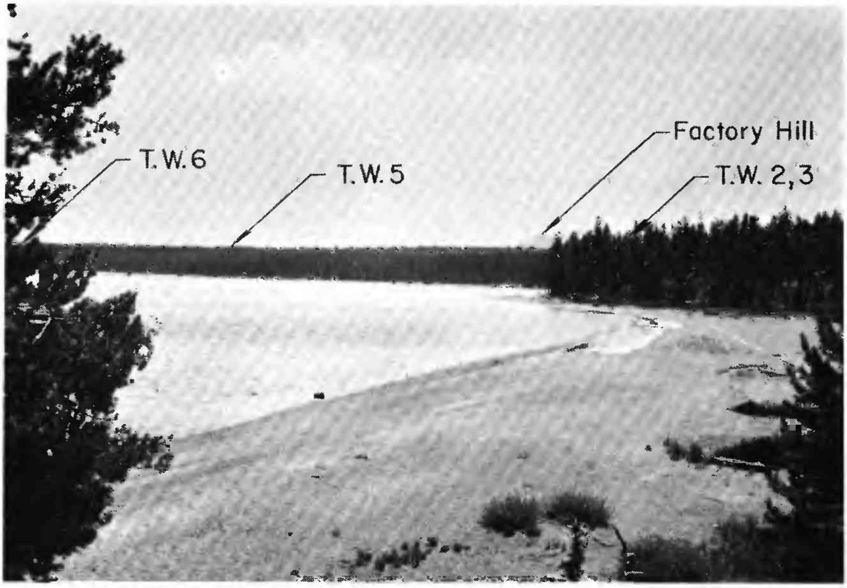

FIGURE 29.—View southward along the shore of the West Thumb of Yellowstone Lake toward the Grant Village site. The mouth of Thumb Creek is at right. Approximate locations of test wells 2, 3, 5, and 6 are indicated. Photograph by Ellis D. Gordon.

sandy beaches have formed. Several offshore bars have developed in the vicinity of the stream inlets. In a few localities, as in the vicinity of test wells 2 and 3, wave action of the lake has cut a steep bank about 15 feet high, leaving only a narrow beach.

SUMMARY OF GEOLOGY

Geologic studies were made in Yellowstone National Park by the U.S. Geological Survey many years ago. Although many separate studies have since been made in different parts of the area, no comprehensive reexamination of the entire area has been made in recent years.

Hague (1896) prepared geologic maps of Yellowstone Park at a scale of 1:125,000, and a map of the geology about the periphery of Yellowstone Lake (1904, pl. 27) at an approximate scale of three-fourths of an inch per mile. Hague and others (1899) described the geology of the entire park in detail. The geologic maps indicate that the Grant Village area is underlain by rhyolite, glacial drift, and lacustrine deposits. Examination of well cuttings from test well 4, drilled during the present investigation, indicates that the igneous intrusive rocks mapped as rhyolite may also include welded tuffs.

The extent, character, and water-bearing properties of the rocks are briefly summarized below. For a more detailed discussion of the geology, the references cited in the previous paragraphs and listed at the end of this report may be consulted.

EXTRUSIVE IGNEOUS ROCKS

Extrusive igneous rocks probably underlie the entire area at depth, but they are exposed in only a few small localities near the southern boundary. Extrusive rocks in the form of welded tuffs of the rhyolitic obsidian variety were found in test well 4 at a depth of 55 feet; they are dark gray, somewhat pumiceous, brittle, and slightly porous. The tuffs seem to be interbedded with sedimentary strata, as some thin beds of claystone were penetrated in the interval between 112 and 125 feet. No extrusive rocks were penetrated in the other test wells.

Extrusive rocks exposed in the vicinity of Duck Lake, immediately north of the area, were described by Iddings (in Hague and others, 1899, p. 383) as light- and dark-gray pumice and brecciated flows of perlite. He described exposures in the vicinity of Riddle Lake, just south of the Grant Village area, as lithoidal purplish-gray banded rhyolite accompanied by spherulitic obsidian.

The water-bearing properties of the igneous extrusive rocks have not been extensively tested. However, the welded tuff penetrated in test well 4 yielded only a small quantity of water.

GLACIAL DRIFT

Glacial drift was mapped in the Grant Village area by Hague (1896; 1904, pl. 27). During the present investigation, no materials that could be definitely identified as being of glacial origin were penetrated in any of the test wells or auger holes. Therefore, no direct information is available regarding the water-bearing properties of the glacial drift. However, the drift, according to Hague and others (1899, pl. 34), consists of gravel, sand, and clay. These materials are commonly admixed in glacial drift, and generally do not yield substantial quantities of water.

LACUSTRINE DEPOSITS

Lake sediments underlie most of the Grant Village area, and they were identified in most of the auger holes and in all the test wells. Test well 4 penetrated the lake sediments to a depth of 55 feet, where extrusive igneous rocks were reached. All the other test wells ended in the lake sediments. Individual beds in the lake sediments were not

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correlated between test holes, but in general the lowest beds penetrated were sand, sandstone, and conglomeratic gravel. The sand commonly is composed of quartz and obsidian and is fine to coarse grained, angular to subrounded, and generally has a salt-and-pepper appearance. The sandstone is commonly green, brown, or white, medium to coarse grained, and poorly to well cemented. The conglomerate is composed of obsidian, quartz, and rhyolite granules and pebbles in a matrix of subangular obsidian and quartz sand and is poorly to well cemented. The conglomeratic gravel is similar in composition.

The basal beds are commonly overlain by clay which shows a large range in sorting from true clay through silty clay to sandy clay. These beds in turn are overlain by angular to subangular fine- to coarse-grained sand composed principally of quartz and obsidian; the sand is mixed with much clay and silt.

The principal water-bearing strata in the lacustrine deposits are the sand, sandstone, and conglomeratic gravel which in most wells were penetrated beneath the clay and silty clay. The temperature of the water in many of the test wells increased rapidy with depth; water from some of the test wells would have to be cooled before it could be used for drinking. The temperature gradients in 5 test wells and 1 auger hole are showin in figure 30.

GROUND WATER

Ground water in the Grant Village area originates from infiltration of precipitation through the pore spaces of the soil and underlying rocks to the zone of saturation (the zone in which water is under hydrostatic pressure). The upper surface of the zone of saturation, if not confined, is known as the water table. A saturated section of rock that will yield water to wells is known as an aquifer. If water in an aquifer is between less permeable beds, confined or artesian conditions exist and water in wells will rise above the level at which it is reached. Such conditions were found in test well 1. The piezometric surface of a confined aquifer is an imaginary surface that everywhere coincides with the static level of the water in the aquifer and, therefore, is the surface to which water in an aquifer will rise under its full pressure head.

MOVEMENT OF GROUND WATER

Ground water moves in the direction of the gradient of the water table or piezometric surface from points of recharge to points of discharge such as streams, springs, and lakes. The gradient of the water table or piezometric surface generally follows the slope of the topographic surface, but is not so irregular.

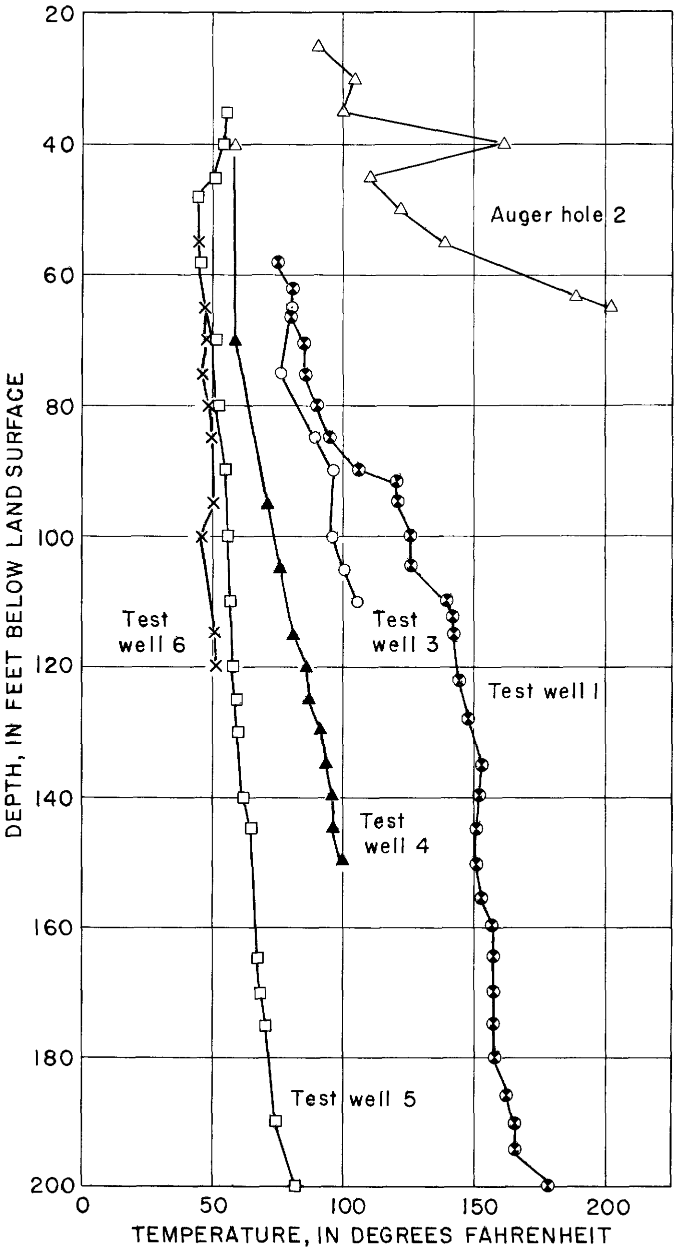

FIGURE 30.—Temperature gradients in test wells and auger hole at Grant Village site.

Ground water in the Grant Village area generally is moving from the topographically high area near the Continental Divide northeastward toward Yellowstone Lake. The hydraulic gradient in the area under investigation, as indicated by the altitudes of water levels in the test wells and auger holes, is about 90 feet per mile. This gradient, which is relatively steep compared to gradients in many other areas, suggests that the aquifer will not readily transmit large quantities of water to wells.

TEST-DRILLING PROGRAM

During the summer of 1959, six test holes were drilled by the percussion (cable-tool) method in the Grant Village area under a National Park Service contract with the Van Dyken Drilling Co., Bozeman, Mont. Initial plans provided for test drilling to begin in middle to late May, but adverse weather and deep snow in parts of the area required postponement of drilling until late June. The contractor began drilling test well 1 on June 23, 1959. Logs of the six test wells drilled are given in table 1.

TABLE 1.—*Logs of test wells and auger holes, Grant Village area, Yellowstone National Park, Wyo.*

[All material penetrated in the test wells and auger holes is of Quaternary age, with the possible exception of the welded tuff penetrated at 55 to 150 feet in test well 4, which may be of Pliocene age]

Material	*Thickness (feet)*	*Depth (feet)*
Test well 1		
Obsidian sand, dark-gray, fine to coarse, silty; some clay in lower part	15	15
Clay, silty	3	18
Silt, sandy, some obsidian granules	22	40
Obsidian pebble gravel, rounded to angular; silty sand matrix	18	58
Obsidian sand, silty to clayey, gray; contains a few pebbles	32	90
Sandstone, porous	2	92
Obsidian sand, black, medium to coarse	8	100
Quartz and obsidian sand, gray, very fine to medium, angular to subangular	12. 5	112. 5
Claystone, light-gray, silty; contains some imbedded quartz grains	6	118. 5
Claystone, same as unit above, interbedded with siltstone, light-greenish-gray, pumiceous	6. 5	125
Obsidian sand, dark-gray, fine to medium, subrounded to subangular, interbedded with light-gray silty sandstone	15	140
Obsidian sand, same as unit above, interbedded with siltstone, light-greenish-gray, pumiceous, well-cemented	15	155
Siltstone, light-greenish-gray, pumiceous, well-cemented; some quartz and obsidian sand, fine to medium, well-rounded	35	190
Siltstone, same as unit above, interbedded with rhyolite sandstone, gray, fine-grained, well-cemented	10	200
Test well 2		
Soil, brown, sandy	5	5
Sand, brown, fine to medium; some silt and clay	10	15
Obsidian sand, gray, fine to medium, some silt and clay	5	20
Clay, gray; some silt, sand, and a few pebbles	40	60
Gravel, granule to pebble, angular to subangular; composed of quartz, obsidian, and rhyolite; fine to medium sand matrix	5	65
Gravel, same as unit above, and much medium to coarse sand; in part cemented	50	115
Drove casing to 118.5 ft, total depth, in same material as above; no sample obtained	3. 5	118. 5

TABLE 1.—*Logs of test wells and auger holes, Grant Village area, Yellowstone National Park, Wyo.*—Continued

Material	Thickness (feet)	Depth (feet)
Test well 3		
Obsidian granule gravel, black to white; some silt and very coarse sand	37	37
Clay, gray, and silt; some sand and a few pebbles	13	50
Sand, clayey to silty, gray	5	55
Obsidian granule gravel, angular; some fine sand and much silt: some rhyolite pebbles altered to clay	5	60
Obsidian gravel, granule to pebble, angular; and fine to coarse angular sand	25	85
Obsidian and quartz sand, medium to coarse, angular, silty; in part cemented	5	90
Quartz sand, brownish-gray, fine to medium, angular to subangular, silty	10	100
Gravel, granule to pebble, gray, angular; and silty sand, very fine to coarse, angular	10	110
Test well 4		
Silt, sandy, white to tan	5.5	5.5
Obsidian and rhyolite gravel, brownish-gray, granule to pebble, angular to subangular; much silt and sand	4.5	10
Silt and sand, gray; many granules of obsidian, subangular	5	15
Obsidian gravel, gray, granule, angular to subangular; much silt and sand	5	20
Sand, silty, gray, very fine to fine; some granules of obsidian, rhyolite, and reworked conglomerate	10	30
Rhyolite boulder, black to gray, conchoidal fracture	1.5	31.5
Sand and silt, gray; some pebbles and granules; interbedded with clay	13.5	45
Sand, clayey to silty, dark-gray; some granules and pebbles	10	55
Welded tuff, obsidian rhyolite variety, gray, badly weathered	5	60
Welded tuff, rhyolitic obsidian variety, dark-gray, soft, porous	52	112
Welded tuff, gray, interbedded with claystone, green, bentonitic, and pumicite, gray, fine-grained	13	125
Welded tuff, rhyolitic obsidian variety, dark-gray, porous	20	145
Welded tuff, rhyolitic obsidian variety, light-gray, contains rounded chert(?) pebbles	5	150
Test well 5		
Soil, silty, light-brown, clayey	5	5
Obsidian and rhyolite sand, fine to very coarse, silty, angular	10	15
Obsidian sand, gray, fine to coarse, silty	13	28
Sand, gray, coarse to very coarse, angular; less silt, some granules	17	45
Sand, coarse, rounded to subrounded, little silt, water-bearing	3	48
Obsidian sand, very fine to medium, angular, some water	8	56
Obsidian sand, silty, very fine to medium clayey	9	65
Clay, silty, tan	5	70
Obsidian sand, tan, fine to coarse, subrounded; contains silt and clay	5	75
Clay, silt, sand, and fine gravel, admixed	25	100
Obsidian sand, clayey to silty, tan, coarse, angular to subangular	15	115
Sand, very coarse, and granule gravel, subangular; some orange silty clay	5	120
Sand, clayey to silty; some rhyolite and obsidian granules	5	125
Quartz sand, clayey to silty, very coarse to medium, and reworked pink sandstone fragments	30	155
Sand, clayey to silty, buff, medium	10	165
Sand, brown, medium to very coarse, angular to subangular; some clay and silt	25	190
Quartz sand, clayey to silty, fine to medium	10	200

TABLE 1.—*Logs of test wells and auger holes, Grant Village area, Yellowstone National Park, Wyo.*—Continued

Material	*Thickness (feet)*	*Depth (feet)*
Test well 6		
Soil, silty-clay, yellow	5	5
Obsidian sand, medium to very coarse, sharply angular, silty	15	20
Silt, sandy, light-brown, clayey; some obsidian granules and pebbles	10	30
Obsidian sand, silty, coarse to very coarse	5	35
Obsidian sand, silty, fine to medium	5	40
Obsidian rhyolite sand, silty, fine to very coarse, angular	15	55
Obsidian rhyolite sand, fine to very coarse, rounded to subrounded; very little silt	20	75
Obsidian sandstone, silty, and granule conglomerate, angular; interbedded with sandstone, brown, medium, moderately to well-cemented	20	95
Obsidian sandstone, very fine to very coarse, interbedded with quartz sandstone, brown, medium, poorly to moderately cemented	11	106
Sandstone, same as unit above, very well cemented	14	120
Auger hole 1		
Soil; some obsidian pebbles	5	5
Clay, silty, and obsidian sand	5	10
Sand, silty, clay, and medium sand, interbedded; a few pebbles	5	15
Sand, silty, medium to coarse; contains rounded obsidian and quartz pebbles	10	25
Sand, silty to clayey, fine, some obsidian granules	20	45
Clay, sandy, gray	7	52
Silt, sandy, buff	15	67
Clay, silty, a little sand	35	103
Auger hole 2		
Clay, sticky, some obsidian pebbles	5	5
Clay, sandy, some angular obsidian pebbles	2.5	7.5
Gravel	2.5	10
Clay, sticky; some obsidian sand	25	35
Obsidian sand, clayey and silty	20	55
Clay, silty, some obsidian sand	7	62
Conglomerate, well-cemented	1	63
Clay, silty, some obsidian sand	2	65
Conglomerate, well-cemented, at 65 ft; too hard for drill to penetrate; steam emanating from hole.		
Auger hole 3		
Soil, sandy, some pebbles	5	5
Sand, silty, very fine to coarse, some obsidian granules and pebbles	30	35
Sand, clayey to silty, a little fine to coarse sand	30	65
Pebble gravel, subrounded, silty-sand matrix	5	70
Conglomerate, cemented, at 70 ft, drill unable to penetrate.		
Auger hole 4		
Clay, silty, gray, some sand	5	5
Clay, silty, brownish-yellow, some obsidian granules	5	10
Obsidian sand, fine to medium, some buff silty clay	10	20
Obsidian sand, very coarse to granule, a little clay and silt	10	30
Clay, silty, buff, some fine to medium obsidian sand	42	72
Conglomerate, granule to pebble, angular; consists of obsidian and reworked sandstone	3	75
Obsidian sand, fine to medium, much silt and clay	10	85
Clay, silty, gray, a little sand	14	99
Conglomerate (sample not recovered)	4	103

TABLE 1.—*Logs of test wells and auger holes, Grant Village area, Yellowstone National Park, Wyo.*—Continued

Material	*Thickness (feet)*	*Depth (feet)*
Auger hole 5		
Surface soil, some gravel	5	5
Obsidian sand and gravel, very coarse to granule, some silty clay	15	20
Clay, silty, some obsidian granules	5	25
Gravel, granule, angular, and admixed clay and silt; consists of obsidian and reworked sandstone	5	30
Gravel, same as unit above, very little silt, clay	15	45
Clay, sticky (no sample recovered)	5	50
Clay, silty, brown, and obsidian granules	15	65
Obsidian sandstone, clayey to silty, and conglomerate, coarse to granular, cemented	30	95
Obsidian sand, clayey to silty, and very coarse to granular	8	103
Auger hole 6		
Sand, clayey to silty, some medium to coarse	5	5
Sand, very fine to coarse, silty; some gravel	25	30
Sand, very fine to coarse, silty	20	50
Sand, clayey to silty, very fine to coarse, some granules of obsidian	5	55
Sand, very fine to coarse, silty	15	70
Sand, very fine to medium; much silt and some coarse sand	20	90
Sand, very fine to medium, silty	13	103
Auger hole 7		
Sand and gravel, some silt; water at 16 ft	20	20
Sand, silt, and clay, admixed	25	45
Clay, some sand	7	52
Sand, silt, and clay, admixed; fluid	26	78
Clay, green, hard, some sand and silt	12	90
Sample could not be retrieved, material drilled as though it were sandy	13	103
Auger hole 8		
Sand, fine to coarse, some silty clay	35	35
Clay	10	45
Sand and fine gravel, some thin clay beds	26	71
Conglomerate; very hard from 77–80 ft	9	80
Clay, sandy	4	84
Sand and fine gravel, some silty clay	19	103
Auger hole 9		
Surface soil, some granule gravel	5	5
Clay, silty, and obsidian sand	10	15
Obsidian and quartz sand, medium	10	25
Obsidian sand and medium gravel, granule; some medium quartz sand	10	35
Obsidian sand, medium; silty-clay binder; contains well-rounded granule gravel; more gravel than above	5	40
Obsidian sand, medium to coarse, well-rounded	5	45
Obsidian sand, same as unit above; some obsidian granules	5	50
Obsidian sand, same as unit above; some rounded pebbles and granules	20	70
Quartz and obsidian sand, fine to medium; water at 71.5 ft	28	98
Clay	5	103

TABLE 1.—*Logs of test wells and auger holes, Grant Village area, Yellowstone National Park, Wyo.*—Continued

Material	*Thickness (feet)*	*Depth (feet)*
Auger hole 10		
Clay, sandy; some pebble gravel	20	20
Clay, silty to sandy	15	35
Clay, silty to sandy, more clay than above	15	50
Clay, silty to sandy, a few rhyolite granules	5	55
Clay, silty to sandy	23	78
Clay, sticky	3	81
Conglomerate, well-cemented	4	85
Clay, sticky, red	5	90
Conglomerate and sandstone, well-cemented, no sample obtained at 95–97 ft	7	97
Auger hole 11		
Surface loam and coarse obsidian sand	10	10
Obsidian sand, fine to medium, and silty clay	20	30
Clay	6	36
Clay, sandy	4	40
Clay, sandy; more clay than above	5	45
Clay, sticky	5	50
Clay, silty, very little sand	35	85
Clay, silty to sandy	18	103

During July 7–12, 1959, 11 test holes were bored in the Grant Village area with a power auger. The locations of the 6 test wells and the 11 auger holes are shown in figure 31.

The test wells were drilled with bits of sufficient size that 6-inch I.D. (inside-diameter) casing could be installed in the holes. Casing left in place in wells was perforated opposite water-bearing strata by use of a casing perforator which cut vertical slots in the casing walls at selected intervals.

Samples of materials penetrated were taken at 5-foot intervals. The temperature of the cuttings or the water from different strata was measured, and samples of water were collected from the test wells for analysis. Brief bailing tests were made as needed to determine approximate yields of water-bearing strata. Water-level measurements were made as necessary to determine the depth to the water surface of the different water-bearing strata reached.

TEST WELLS

Test well 1 was drilled about 100 yards east of the South Entrance road and about 0.6 mile south of the bridge over Thumb Creek. Water was first tapped at a depth of 92 feet, in a soft sandstone, under slight artesian head. The water rose in the hole to about 83 feet below the land surface. The temperature of the water at 92 feet was 120°F (fig. 30). As drilling progressed, the water temperature increased to 125°F at 100 feet and 142°F at 112.5 feet. At 200 feet, the total depth of the well, the temperature was 180°F.

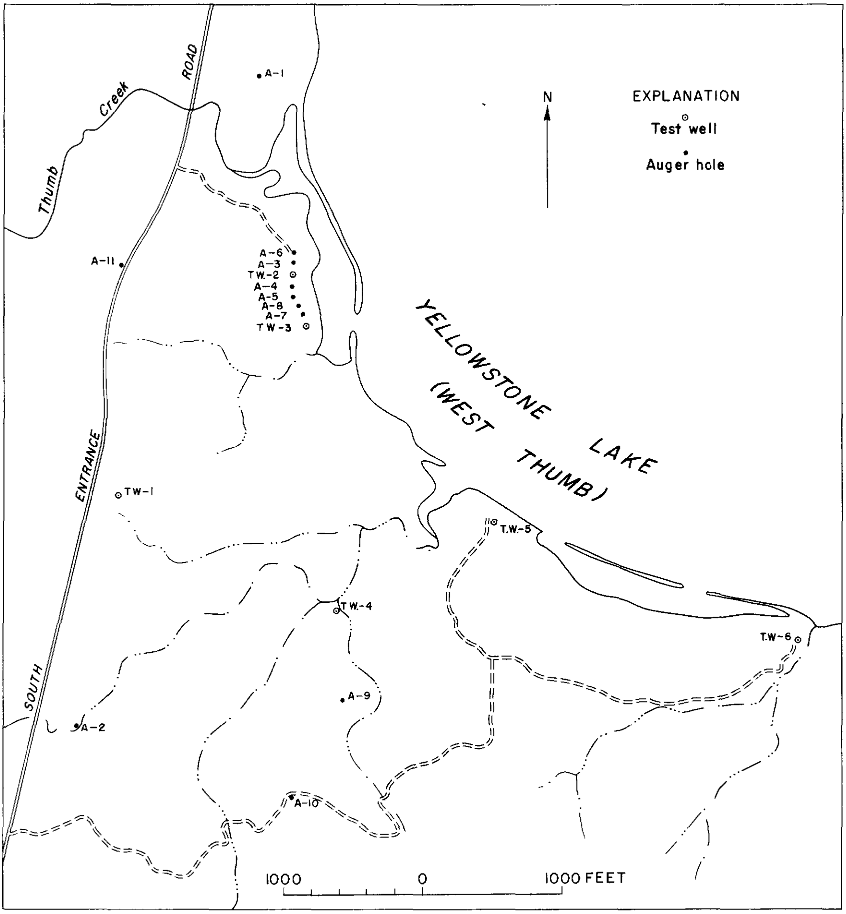

FIGURE 31.—Location of test wells and auger holes, Grant Village area, Yellowstone National Park, Wyo.

A brief bailing test made after completion of the hole indicated that the well was capable of producing water at a rate of about 40 gpm (gallons per minute). The temperature of the water was about 165°F, which indicated a mixture of water from strata at various depths in the hole. Because of the high temperature of the water, the casing was removed and the hole was plugged and abandoned.

Test well 2 was drilled about 125 feet from the lakeshore about 0.1 mile south of the mouth of Thumb Creek. A very small quantity of cool water was found in a mixture of sand and clay at about 15 to 20 feet. The principal water-bearing material, a gravel containing medium- to coarse-grained sand and some silt, was reached at 60 feet.

The temperature of the water was 96° at a depth of 100 feet; at 118.5 feet, the bottom of the hole, it was about 100°F. As preliminary bailing tests indicated that the well would yield a moderate quantity of water, the casing was perforated from a depth of 70 to 118 feet.

Two aquifer tests, of 10- and 48-hour duration, were made at test well 2; results of the tests are discussed on pages 189–194. The water temperature initially was about 96°F but increased slightly during the tests. At the end of the 48-hour test, the temperature apparently had stabilized at about 100°F. The increase in temperature probably was the result of pumping action in the test well which removed some fine sand from the lower part of the aquifer; this allowed a proportionately greater amount of water to move into the well from the lower part of the aquifer in the later stages of the test. Vigorous development by earlier bailing had developed the upper part of the aquifer.

Because of the relatively large yield of test well 2, the casing was left in place. A grout seal was placed around the casing from the surface to a depth of about 10 feet, and a steel plate was welded to the top of the casing. The steel plate can be removed easily if the well is to be utilized for water supply.

Test well 3 was drilled about 100 feet from the lakeshore, 0.2 mile south of the mouth of Thumb Creek and 500 feet south of test well 2. A small quantity of water was found in angular silty sand and gravel in the interval between 18 and 37 feet. However, the material was so angular and so poorly sorted that it would yield very little water to the well. Angular silty sand and gravel was again penetrated from 55 to the bottom of the well, but this zone also was low in permeability. The well was completed at a total depth of 110 feet. A bailing test made at this depth indicated that the well would have a maximum sustained yield of about 5 gpm. The temperature of the water in the well rose from 76°F at 75 feet to 106°F at 110 feet. As water at greater depths probably would be too warm to drink, the well was plugged and abandoned.

Test well 4 was drilled about 1,000 feet south of the lakeshore, just south of the intersection of two unnamed intermittent streams and about 0.4 mile east of the South Entrance highway (fig. 31). The well was drilled through silty sand and gravel to a depth of 55 feet. A small quantity of water was obtained from the interval between 35 and 55 feet. At 55 feet a bed of welded tuff was reached, and the well was completed in the welded tuff at a depth of 150 feet. Temporary casing was installed to a depth of 58 feet below the land surface. A 20-minute bailing test obtained a yield of 2.6 gpm from the uncased section in the welded tuff at 58 to 150 feet. The temperature of the water in the well ranged from 58°F at 40 feet to 99°F at 150 feet.

Because the yield of the well was small, the casing was pulled and the hole was plugged and abandoned.

Test well 5 was drilled about 100 feet from the lakeshore, about 400 feet east of a bay formed by the inlet of an intermittent stream, and about 0.6 mile east of the South Entrance highway (fig. 31). A moderate quantity of water was found in sand at a depth of 45 to 56 feet. A well screen was placed at the interval between 45 and 50 feet and a brief bailing test was made. The well yielded about 10 gpm of water at a temperature of 44°F. The screen was removed and the well was drilled and cased to 120 feet, at which depth the well was again tested by bailing. As the well yielded very little water at this depth, it was drilled and cased to a total depth of 200 feet. The casing was not perforated. The water temperature gradually increased from 44°F at 50 feet to 81°F at 200 feet. The well yielded very little water during the final bailing test, and therefore the casing was removed and the well was abandoned.

Test well 6 was drilled about 150 feet from the lakeshore, about 100 feet west of the inlet of an unnamed intermittent stream, about 0.6 mile south-southeast of test well 5, and about 1.0 mile east of the South Entrance highway (fig. 31). The well was drilled to a depth of 75 feet and was cased to a depth of 55 feet. The interval from 55 to 75 feet was bailed at 45 to 50 gpm for 15 minutes, but the yield diminished on further bailing. Therefore, the well was deepened and cased to a total depth of 120 feet. The casing was perforated from 77 to 111 feet, the well was developed by bailing and surging, and a 3-hour bailing test was made. The test indicated that the well should have a sustained yield of at least 15 gpm. The water temperature was about 50°F.

The casing for test well 6 was sealed in place with a cement grout and a steel plate was welded to the top of the casing. If the well is later used for water supply, the yield might be increased appreciably by perforating the upper part of the casing and further developing the well.

AUGER HOLES

The auger holes, which were 4 inches in diameter, ranged from 65 to 103 feet in depth. Some of the holes were bored to provide stratigraphic information as a guide in selecting favorable sites for the test wells; others were bored near test wells 2 and 3 and were equipped with temporary casing in order that they might be used for water-level observations during aquifer tests. Logs for the auger holes are given in table 1.

Auger hole 1, which was drilled near the lake just north of Thumb Creek, was cased with 1¼-inch pipe and completed as an observation well at a depth of 103 feet. The water temperature at the bottom of the hole was 105°F. The water level in the hole was about 32 feet below the land surface. The fine-grained character of the sediments that were penetrated indicated that only small quantities of water could be obtained at this site.

Auger hole 2 was bored about 100 yards east of the South Entrance road and about 1.0 mile south of the bridge over Thumb Creek, on a small valley flat adjacent to a small stream. The temperature of the water in the hole increased rapidly with depth (fig. 30); it increased from 90°F at 25 feet to 162°F at 40 feet, then declined to 110°F at 45 feet. The temperature then increased at a fairly uniform rate to 188°F at 62 feet, and to 202°F at 65 feet, the bottom of the hole, where the auger reached a well-cemented conglomerate which it could not penetrate. Steam under low pressure was emanating from the hole upon completion of drilling. Upon withdrawal of the auger the hole caved, thus shutting off the steam.

The abnormally high temperature gradient in the auger hole probably indicates the presence of a cooling mass of intrusive rock at shallow depth in the vicinity of the test hole, or the upward movement of superheated water or steam from a considerable depth through fractures in the rock. The abnormal temperature increase at a depth of 40 feet may be due to lateral movement of hot water through the obsidian sand which was penetrated at that depth.

Auger holes 3 through 8 were bored in the immediate vicinity of test wells 2 and 3. Auger hole 3 was drilled to a depth of 70 feet; the others were completed at 103 feet. Each of these holes was cased temporarily with 1- or 1¼-inch pipe having a screen attached to the bottom. Auger holes 3 through 6 were used as observation wells during the aquifer tests at test well 2. Auger holes 7 and 8 provided information regarding stratigraphic conditions near test well 3.

Auger holes 9 and 10 were completed at depths of 103 and 97 feet, respectively. Both holes penetrated a thick sequence of permeable sand, but much of the section was above the water table. This information was used in the selection of the site for test well 4.

Auger hole 11 was completed at a depth of 103 feet. Most of the material penetrated consisted of clay and silt of low permeability, indicating that little water could be obtained from a well in that locality.

AQUIFER TESTS

As a part of the test-drilling program, a series of aquifer tests by pumping and bailing were made to evaluate the feasibility of the estabishment of a well, or series of wells, that would furnish a sufficient water supply at the proposed new development of Grant Village.

Two aquifer tests were made at test well 2. The first test, of 10 hours' duration, was made to ascertain whether the aquifer at that location would yield water for an appreciable period and to determine the most suitable pumping rate for the second test.

In the first of the aquifer tests, made on July 11, 1959, test well 2 was pumped at a nearly constant rate of 45 gpm. Changes in water levels were measured in observation wells A–6 and A–3, which were north of the pumped well, and observation wells A–4 and A–5 south of the pumped well, as shown in figure 31. The depths of the observation wells were about 103 feet, exception well A–3 which was about 70 feet deep. Well A-3 had 1¼-inch casing; the rest had 1-inch casing. The pumped well, test well 2, was about 118 feet deep and was cased to the bottom with 6-inch steel casing, which was perforated from 70 to 118 feet. Pumping was discontinued after a 10-hour period at which time the drawdown of the water levels in observation wells A–3, A–4, A–5, and A–6 were 4.99, 5.00, 3.55, and 10.05 feet, respectively. Drawdown readings were erratic in wells A–3 and A–4. The wells had been flushed out before the start of the test but the water levels had not yet reached a static position. The recovery of the water levels in all wells was measured for 10 hours.

A second aquifer test was made on July 28, 1959, at these same wells. Test well 2 was pumped at a rate of 40 gpm for the first 10 minutes and at a nearly uniform rate of 36 gpm for the balance of the 48-hour period. The drawdown of the water level was observed in the pumped well and in observation wells A–3, A–4, A–5, and A–6. The drawdowns in the observation wells at the end of the period were 8.86, 6.50, 3.33, and 6.60 feet, respectively; that in the pumped well was 71.4 feet. The rate at which the water level rose after pumping ceased was observed for about 15 hours. The water rose to within 0.52 foot of the static level in the pumped well and 0.28, 0.59, 0.33, and 0.57 foot, respectively, in observation wells A–3, A–4, A–5, and A–6. Normally, the observed period of recovery should be equivalent to the drawdown period, but in this test the measurements indicated that the recovery data were similar to the drawdown data, so the period of observation was shortened. The rate of discharge of test well 2 was measured by filling a 55-gallon barrel and timing the operation with a stopwatch. The water was discharged into Yellowstone Lake. Depths to water in the observation wells were measured manually with a steel tape; the water levels in the pumped wells were measured with an electric measuring device. All measurements were recorded to the nearest 0.01 foot. Graphs of the drawdown and recovery of the water level at each site during the aquifer test are shown in figure 32.

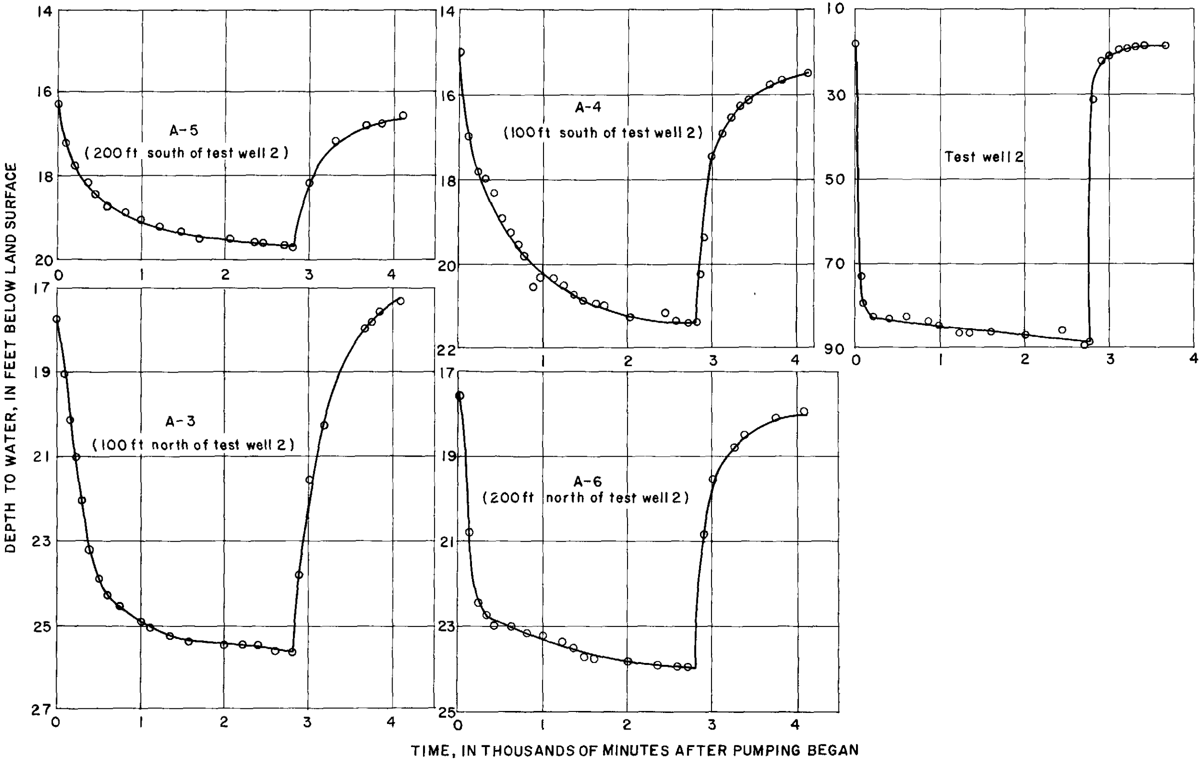

FIGURE 32.—Fluctuation of water levels in observation wells and pumped well during aquifer test of July 28–31, 1959.

A bailing test was made in test well 6 on August 27, 1959. The well was bailed for 3 hours at a nearly constant rate of 18 gpm, and the water level was measured periodically throughout the test. The drawdown of the water level was about 80 feet at the end of the test. After bailing ceased, recovery of the water level was measured for 4 hours and one measurement was made 8 hours 8 minutes after bailing ceased, at which time the water had risen to within 0.13 foot of the original level. Fluctuation of the water level during the test is shown in figure 33.

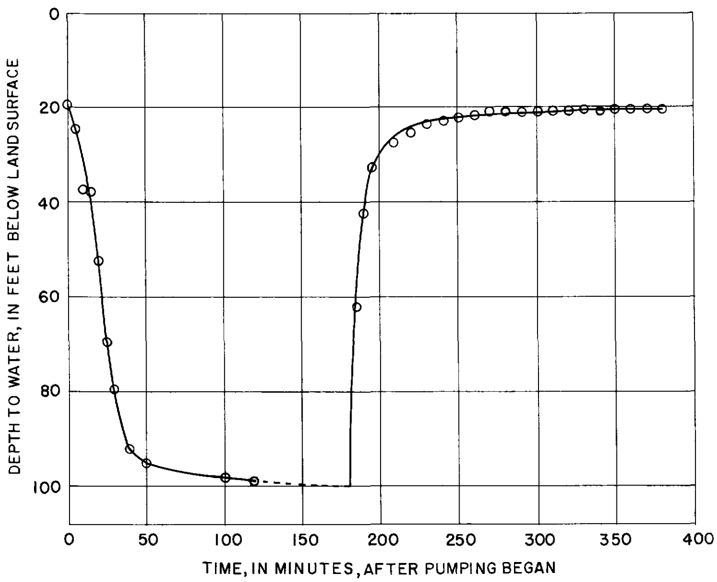

FIGURE 33.—Fluctuation of water level in test well 6 during bailing test of August 27, 1959.

ANALYSIS OF AQUIFER TESTS

Withdrawal of water from any permeable material causes the water level to decline near the point of withdrawal, and the shape of the water table or piezometric surface becomes an inverted cone whose apex is at the point of withdrawal. In some cases the shape of the cone is modified or elongated because of variations in the hydrologic characteristics and areal extent of the aquifer. The overall size, shape, and rate of growth of the cone of depression caused by pumping a well depend on the rate and duration of pumping, the coefficients of transmissibility and storage of the aquifer, the presence of hydrologic and geologic boundaries, and recharge to or leakage from the aquifer. The lowering of the water level at any point within the cone of depression is termed drawdown and depends on the above variables and the distance from the point of withdrawal.

The coefficient of transmissibility, as used by the Geological Survey, may be expressed as the number of gallons of water per day, at the prevailing water temperature, transmitted through a cross section of the aquifer 1 mile wide under a hydraulic gradient of 1 foot per mile. The coefficient of transmissibility is expressed in gallons per day per foot.

The coefficient of storage of an aquifer is the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. Under water-table conditions, this quantity is virtually equal to the specific yield, which is related to the quantity of water that a unit saturated volume of the aquifer will yield by gravity drainage. For artesian conditions, the storage coefficient is related to the unit expansion of the water and unit compression of the aquifer under a unit reduction of pressure. The storage coefficient is a ratio of volumes, and is dimensionless.

Theis (1935, p. 519–524) developed a method for determining the coefficients of transmissibility and storage by observation of the change in drawdown with time in a pumped well and in nearby wells. In developing his method, Theis assumed that the aquifer is homogeneous, isotropic, and of infinite areal extent, that the coefficient of transmissibility remains constant at all places and all times, and that water is released from storage instantaneously with a decline in head.

The aquifer at Grant Village does not fit the assumption of infinite areal extent, as the intersection of the aquifer with the lake forms a hydrologic boundary. This boundary limits the expansion of the cone of depression in the direction of the lake, and in turn the shape and extent of the cone in all directions are altered. Stallman (1952) developed a modification of Theis' method which could be used to analyze data from wells in the vicinity of a boundary to determine the coefficients of transmissibility and storage and the effective distance from the well to the boundary. Stallman's method was used in this report.

The analysis of the aquifer-test data gathered near test well 2 is summarized in the following table.

Summary of aquifer-test data, test well 2 and vicinity

Well	Distance (feet) and direction from pumped well	Coefficient of transmissibility (gpd per ft)	Coefficient of storage	Indicated distance from pumped well to lake (feet)
Test well 2		330	7×10^{-4}	
Auger hole 3	100 N.	550	2×10^{-4}	100
6	200 N.	450	2×10^{-4}	100
4	100 S.	840	2×10^{-3}	100
5	200 S.	1,000	8×10^{-4}	110

This test indicates that the coefficient of transmissibility is fairly constant for at least a few hundred feet north of test well 2, and that it increases immediately to the south of the test well. However, information gained from auger hole 11, about 1,000 feet west of the test well (fig. 31), and test well 3, about 500 feet south of the well, indicates that the coefficient of transmissibility is very low in those areas, and that it changes markedly over relatively short distances.

The computed distance from the pumped well to the lake is only about 100 feet, whereas the measured distance is 125 feet. This difference probably indicates that the coefficient of transmissibility increases significantly toward the lake, and that water moves more freely through that section of the aquifer than it does in the surrounding area described by the cone of depression.

The test indicates that the drawdown in the well is influenced to a marked degree by the nearby lake, and that the water pumped was derived from two sources—ground-water flow diverted from the lake, and ground-water storage.

Theis (1941, p. 734–738) developed a method whereby the amount of ground-water flow diverted from a stream or lake to a nearby pumped well could be determined at any time if the coefficients of transmissibility and storage and the effective distance from the well to the body of water were known. This method was used to determine the quantity of ground-water flow diverted from the lake by the well during this test. The data indicate that after a few days of pumping more than 95 percent of the water pumped would be derived from flow previously directed toward the lake.

Other calculations, based on several assumptions, were made to determine the time required for water now in the lake to reach the well, if the well were pumped continuously at a rate of 40 gpm. These calculations indicate that the water would reach the well after a period of about 50 days, using the effective distance of separation of 100 feet determined from the aquifer test, or about 80 days, using the measured distance of 125 feet. These figures indicate the approximate range in time of pumping before the water in the well would cool appreciably.

Test well 2 could be used to supply 35 to 40 gpm of water at a temperature of 100°F and a drawdown of 70 to 80 feet. Any decrease in temperature would occur only after a few days to a few weeks of pumping, and pumping for several months might be required before appreciably cooler water could be obtained from the well.

An aquifer test made by bailing test well 6 indicated a coefficient of transmissibility at that site of about 50 gpd per foot. This is very low, but because of the proximity of the lake, the well seems to be capable of producing about 15 gpm at a drawdown of about 80 feet. This water has a temperature of about 45°F.

CHEMICAL QUALITY OF WATER

Ground water, in moving through rock strata from recharge areas toward points of discharge, dissolves some of the rock materials with which it comes in contact. All ground water therefore contains mineral matter in solution. The significance of the chemical and physical characteristics of water have been discussed in detail by Hem (1959), the California Water Pollution Control Board (1952, 1954), and many others. The above publications may be consulted for more detailed discussions of the chemical quality of water. Maximum limits of concentration for some of the chemical constituents commonly found in water have been specified by the U.S. Public Health Service (1946) for water used on common carriers in interstate traffic. These drinking-water standards have been accepted by the American Water Works Association as criteria of quality for all public water supplies in the United States.

During the present investigation, 11 samples of ground water were collected from the test wells in the Grant Village area. The analyses of the ground-water samples, together with the analyses of 4 samples of surface water collected from different points in Yellowstone Lake, are shown in table 2. All analyses were made at the Geological Survey laboratory, Lincoln, Nebr.

The analyses show only the dissolved mineral content of the waters, not their sanitary condition. The dissolved mineral constituents are reported in parts per million (ppm). A part per million is a unit weight of a constituent in a million unit weights of water. Results given in parts per million may be converted to grains per U.S. gallon by dividing by 17.12.

Silica (SiO_2) may occur in water as finely divided or colloidal suspended matter. In concentrations commonly found in natural or treated water, silica seems to cause no adverse physiological effects to man, livestock, or fish. It is industrially important, however, because it contributes to the formation of boiler scale, or may help to cement other substances into a hard scale, and may be carried over in the steam of high-pressure boilers to form deposits on turbine blades. Very large concentrations of silica were found in all the samples of ground water from wells in the Grant Village area. Silica concentrations ranged from 172 ppm in test well 1 to 43 ppm in test well 5. The silica content was lowest in water from test wells, 4, 5, and 6, but silica concentrations in all the ground water analyzed were above the recommended limit of 20 ppm for use as feedwater in boilers at pressures of 250 pounds per square inch or less. The silica content of the surface-water samples ranged from 5.6 to 7.4 ppm.

Iron (Fe) is present in small quantities in most natural water. Surface water, unless it is acidic, rarely contains more than a few tenths of a part per million. Much ground water, however, may contain several parts per million of iron. Iron in solution may impart an unpleasant taste to water, and upon precipitating from solution it may cause reddish-brown stains on enamelware and porcelain fixtures and on fabrics washed in the water. Iron in small quantities can be removed from water by aeration and settling or filtration, but water having large concentrations of iron may require other treatment. A considerable amount of iron was present in most of the ground-water samples. The iron content ranged from 0.17 to 1.5 ppm. Only one sample, that from the upper zone in test well 6, contained less than the recommended upper limit of 0.3 ppm for drinking water. The iron content of the surface-water samples ranged from 0.01 to 0.03 ppm.

Fluoride (F) occurs in sedimentary, igneous, and metamorphic rocks in minerals such as fluorite and apatite. Volcanic ash may contain fluoride-bearing minerals, and fluoride is often associated with volcanic or fumarolic gases. In most natural surface water fluoride is present in only small concentrations, whereas in ground water it is present in somewhat larger concentrations—in some water as high as several parts per million. Fluoride in small quantities apparently is beneficial in normal development of teeth, but more than about 1.0 ppm in drinking water may cause permanent mottling of the tooth enamel of children (California Water Pollution Control Board, 1952, p. 257). Ground-water samples high in fluoride were obtained from test well 2 (5.3, 4.6, and 5.1 ppm) and test well 3 (12 ppm). In the

TABLE 2.—*Chemical analyses of ground and*

[Chemical constituents in parts per million]

Test well or location of sample	Depth from which sample was taken (feet)	Date of collection (1959)	Water temperature (°F)	Silica (SiO_2)	Iron (Fe) in solution: When collected	Iron (Fe) in solution: When analyzed	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)
Ground water, vicinity													
Test well 1	92	July 1	120	172	1.5	0.15	42	16	44	8.1	331	0	2.5
2	70–115	11	96	128	.71	.54	3.3	2.9	14	3.3	42	0	8.3
3	84–110	22	107	135	------	.06	5.2	1.0	28	3.6	50	0	7.8
2	70–115	28	96	116	------	------	3.2	3.9	12	2.9	42	0	5.5
2	70–115	30	97	118	.75	.60	3.2	2.9	13	2.9	42	0	5.8
4	150	Aug. 7	99	63	.35	------	2.4	.7	30	2.3	81	0	4.3
5	50	14	45	------	------	------	------	------	4.6	------	43	------	------
5	120	19	58	43	.82	------	7.2	2.2	7.1	1.4	34	0	12
5	200	19	81	------	------	------	------	------	25	------	60	0	------
6	55–71	24	43	69	.17	------	18	2.0	8.2	5.6	19	29	8.5
6	93–120	24	52	48	.54	------	12	4.6	7.3	1.8	78	0	2.5
Surface water,													
Southeast arm	------	July 28	------	7.4	0.03	------	4.5	2.4	8.0	1.8	33	0	8.0
West Thumb	------	28	------	7.2	.01	------	5.0	2.6	9.4	2.0	35	0	8.0
Center of lake	------	28	------	5.6	.02	------	4.9	2.4	9.1	1.5	35	0	9.8
Near outlet	------	28	------	5.7	.02	------	4.5	2.4	8.9	1.7	34	0	7.8

water samples from the other test wells, the fluoride concentration was less than the recommended upper limit of 1.5 ppm for drinking water.

Hydrogen-ion concentration generally is expressed in terms of pH units. The pH range is from 0 to 14; water having a pH of 7.0 is said to be neutral. Progressive values of pH below 7.0 denote increasing acidity, and progressive values above 7.0 denote increasing alkalinity. The pH of all except one of the ground-water samples ranged from 6.8 to 7.6. Water from a depth of 55 to 71 feet in test well 6 had a pH of 9.3; however, the pH may have increased greatly in this sample during the interval before analysis, as a preliminary analysis made with a field kit on the day following collection of the sample indicated a pH of only 6.8. The increase in pH may have occurred as a result of precipitation of silica in the water sample before the laboratory analysis was made.

The hardness of water is commonly recognized by the quantity of soap needed for washing purposes and by the formation of an undesirable curd when soap is used with the water. Calcium and magnesium cause nearly all the hardness of ordinary water. These constituents, together with silica, also are active agents in the formation *surface water, Yellowstone National Park, Wyo.*

[Chemical constituents in parts per million]

Chloride (Cl)	Fluoride (F)	Nitrate (NO$_3$)	Boron (B)	Dissolved solids: Residue on evaporation at 180° C	Dissolved solids: Calculated	Hardness: As CaCO$_3$	Hardness: Noncarbonate	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25° C)	pH	Color	Remarks
of Grant Village													
2.7	0.7	0.3	0.03	457	453	169	0	----	-----	498	7.1	----	Blank casing to bottom.
0	5.3	.1	.01	199	187	20	0	----	-----	117	7.0	5	Collected during 12-hr aquifer test.
3.5	12	.2	.03	309	221	17	0	----	-----	164	7.6	----	Blank casing to 84 ft.
0	4.6	.1	.02	187	170	24	0	----	-----	109	7.1	----	Collected at beginning of 48-hr aquifer test.
0	5.1	.1	.00	187	173	20	0	----	-----	110	7.0	----	Collected at end of 48-hr aquifer test.
3.0	1.0	.3	.01	178	147	9	0	85	4.3	150	7.0	25	From welded tuff of rhyolitic obsidian.
-----	------	-----	------	88	-----	30	0	25	.4	92.0	7.2	----	Temporary well screen at bottom of casing.
.2	.5	.4	.01	106	92	27	0	35	.6	93.7	6.8	24	Blank casing to bottom.
-----	------	-----	------	174	-----	8	0	87	3.8	128	7.6	----	Do.
3.2	.4	.2	.04	164	153	53	0	23	.5	151	9.3	6	Blank casing to 55 ft.
.9	.3	.2	.05	124	116	49	0	24	.5	134	7.4	18	Cased to bottom, perforated 93–120 ft.
Yellowstone Lake													
4.4	.5	0.2	0.08	54	-----	21	0	43	0.8	86.3	6.8	3	
5.6	2.6	.1	.13	57	-----	23	0	44	1.9	96.4	6.8	4	
4.6	.5	.1	.09	55	-----	22	0	45	.8	92.2	6.7	4	
4.8	.5	.1	.10	55	-----	21	0	46	.8	93.2	7.0	4	

of scale in steam boilers and other containers in which water is heated or evaporated. Carbonate hardness refers to the hardness expressed in terms of calcium carbonate equivalent to the carbonate and bicarbonate. Any hardness in excess of this amount is reported as noncarbonate hardness. Water that has a hardness of less than about 50 ppm generally is considered to be soft, and treatment for reduction of the hardness is unnecessary. Hardness between 50 and 150 ppm requires increased use of soap but does not otherwise seriously affect the use of water for most purposes. The carbonate hardness of water from test well 1 was 169 ppm, but that of the other ground-water samples ranged from 9 to 53 ppm. Thus, most of the ground-water samples were moderately soft. Noncarbonate hardness was not present in any of the ground-water samples. Carbonate hardness of the 4 surface-water samples from Yellowstone Lake ranged from 21 to 23 ppm; noncarbonate hardness was not present.

In summary, water from test well 1 is of poor quality because of the very high concentration of silica (172 ppm) and an objectionable amount of iron (1.5 ppm). Water from the other test wells, except for a generally high silica and iron content and high fluoride concentration as indicated in the foregoing discussion, is generally satisfactory for most uses. Surface water from Yellowstone Lake is excellent in quality and is chemically satisfactory for most uses.

POSSIBLE DEVELOPMENT OF GROUND-WATER SUPPLIES

Aquifer tests by bailing and pumping methods indicated that moderate amounts of water could be obtained from test wells 2 and 6. Therefore, the casing was left in place in these two wells, and steel caps were welded over the tops of the casings. If water supplies are needed from these wells, the caps can be removed easily. Test well 2 should yield about 30 to 35 gpm of water at a temperature of nearly 100° F. The fluoride content of the water is very high, and the iron content is higher than the recommended limit for domestic supplies. The water would require treatment to remove the iron and cooling before it would be satisfactory for domestic purposes. About 15 gpm of water having a temperature of about 45 to 50°F could be obtained from test well 6, and the yield possibly could be increased by perforating the casing in the interval from 55 to 77 feet. The water from this well is of relatively good quality, but it may need treatment to remove iron.

Additional ground-water supplies might be located by exploring the area along the lakeshore east of test well 6. Water of moderate temperature and fairly good quality might be obtained from wells drilled near the lakeshore between test wells 5 and 6 and immediately east of test well 6. Larger yields than those obtained from test wells 5 and 6 probably could be obtained from gravel-packed or suitably screened wells of large diameter. The area along the lakeshore between test wells 3 and 5 also might be explored. However, this area does not seem to be too favorable because of the high fluoride content of water obtained from test wells 2 and 3, the very high temperature of the water tapped in test well 1 and auger hole 2, and the low yields of test wells 3 and 4.

CONCLUSIONS

In general, because of the relatively high silt content and the angularity of the grains of the sediments penetrated, only small to moderate supplies of water were found by the test wells drilled in the Grant Village area. The probability of obtaining satisfactory wells is greater near the lakeshore, where a large part of the water pumped would be derived from ground-water flow to the lake.

Ground water in the area is of relatively poor quality as compared to surface water from Yellowstone Lake. The silica content of the ground water is very high. The iron content of the ground water in nearly all samples from the six test wells is above the recommended limits for domestic use as established by the U.S. Public Health Service, although a sample of water from the 55- to 75-foot depth in test hole 6 has an acceptable iron content. However, the water can easily be treated to reduce the iron concentration. Flouride concentrations in water from test wells 2 and 3 are greater than the tolerable limits for drinking water, although the water could be mixed with surface water or water from other wells to reduce the fluoride content. Otherwise, ground water in the area is of generally suitable quality for most uses. Surface water from Yellowstone Lake is excellent in quality and satisfactory for most uses.

Information gathered from the test wells and auger holes indicates that the most favorable areas for obtaining moderate quantities of relatively cool water of fairly good quality probably are along the lakeshore between test wells 5 and 6 and immediately east of test well 6. Larger yields than those obtained from test wells 5 and 6 probably could be obtained from gravel-packed or suitably screened wells of larger diameter. In other areas tested the thermal gradient is steep and warm water is present at relatively shallow depth. Water in these ares is also of generally poorer chemical quality than that near test wells 5 and 6.

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