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A GEOLOGIC AND HYDROLOGIC RECONNAISSANCE OF LAVA BEDS NATIONAL MONUMENT AND VICINITY CALIFORNIA

By

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Prepared in cooperation with the
National Park Service

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ABSTRACT

Lava Beds National Monument is on the Modoc Plateau in Modoc and Siskiyou Counties. The principal geologic units in the vicinity are volcanic rocks, which in places are highly permeable, and poorly permeable lake sedimentary deposits, all probably post-Oligocene in age. Yields and specific capacities of wells in the unconfined water body within volcanic rocks and lake deposits range widely, but in general are low in the lake deposits and higher in the volcanic rocks. A confined water body, occurring in volcanic rocks underlying the lake deposits yields large quantities of water to three wells in the study area.

Dissolved-solids content of ground water generally increases in proportion to the thickness of lake deposits penetrated and to proximity of the lake deposits. Water from wells drilled in the volcanic rocks several miles from the lake deposits, and from wells penetrating the confined water body in volcanic rocks underlying the lake deposits contains small to moderate quantities of dissolved solids.

Ground-water supplies can be developed almost anywhere in the study area by drilling wells to depths below the water table. In addition, there is a reasonable possibility of developing wells in a confined water body underlying the water-table system.

INTRODUCTION

At the request of the National Park Service, the U.S. Geological Survey made a geologic and hydrologic reconnaissance of Lava Beds National Monument and vicinity (fig. 1). In July 1962 R. H. Dale made a brief survey of the area and proposed a test site for a water well near Captain Jack's Stronghold at the northern boundary of the national monument. In October 1964 C. F. Berkstresser supervised drilling, development, and test pumping of a well at the proposed site.

The area of this investigation encompasses about 560 square miles (fig. 1) on the Modoc Plateau. The Modoc Plateau (Jenkins, 1938) is characterized by thick accumulations of lava flows, tuffaceous beds, small volcanic cones, long north-south faults, occasional lakes and marshes, and sluggish streams. The area is aptly designated "lava beds" on highway maps.

Purpose and Scope

This investigation was made to determine the general hydrologic characteristics of volcanic and sedimentary rocks underlying the study area, and to provide a guide for future development of water supplies for visitor and administrative facilities in the national monument.

Specifically, the scope of this investigation includes: (1) A geologic investigation of Lava Beds National Monument with particular attention to the water-bearing character of the geologic units, and (2) a reconnaissance of the ground-water reservoir to determine the source, occurrence, movement, and chemical quality of ground water.

This report was prepared by the Geological Survey, Water Resources Division, in cooperation with the National Park Service. The fieldwork was done intermittently from October 1965 through June 1966. The study was made under the general supervision of Walter Hofmann and R. Stanley Lord, successive district chiefs in charge of water-resources investigations in California, and under the immediate supervision of W. W. Dean, chief of the Sacramento subdistrict office, and R. E. Evenson, supervisory hydrologist, Sacramento subdistrict.

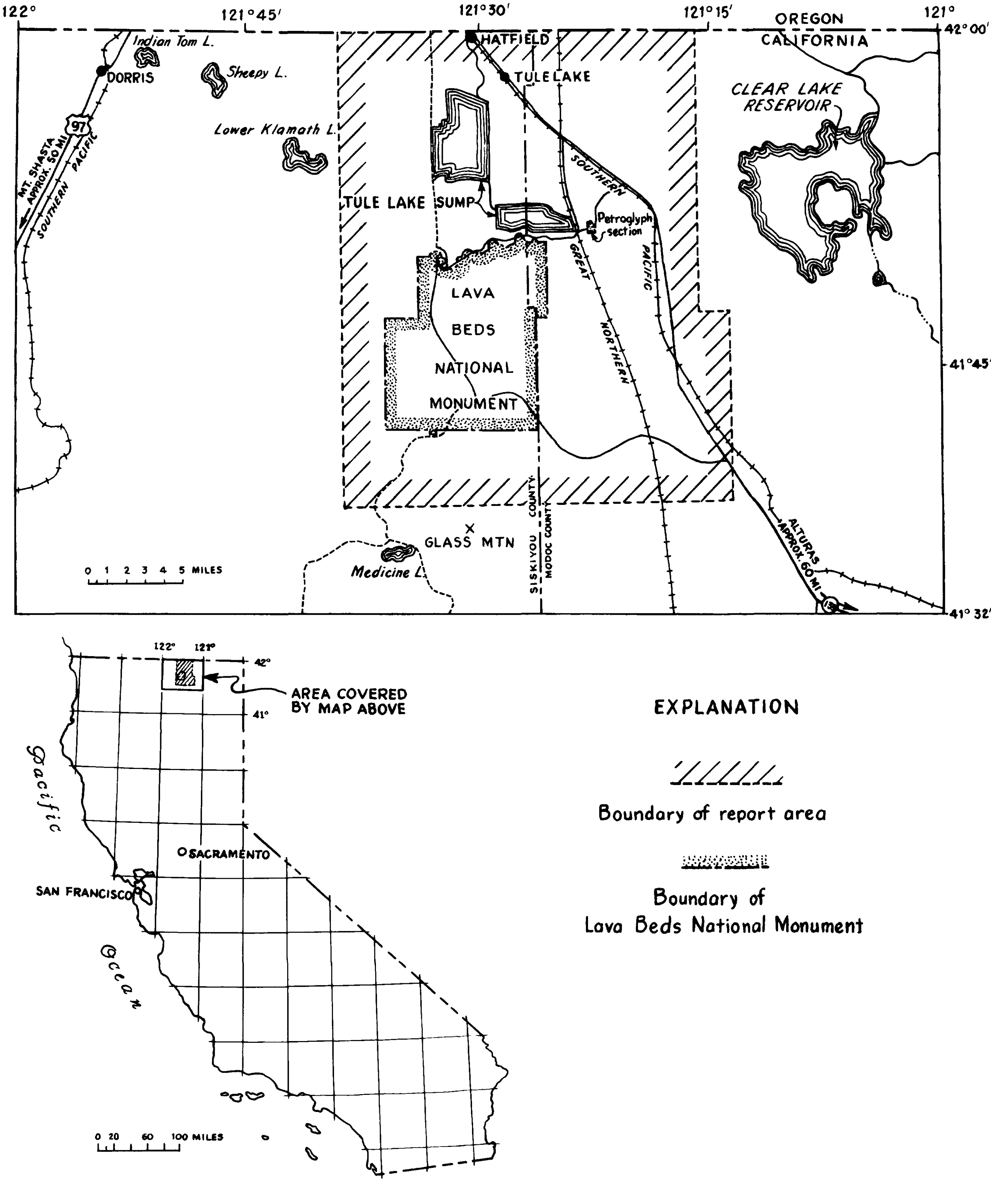
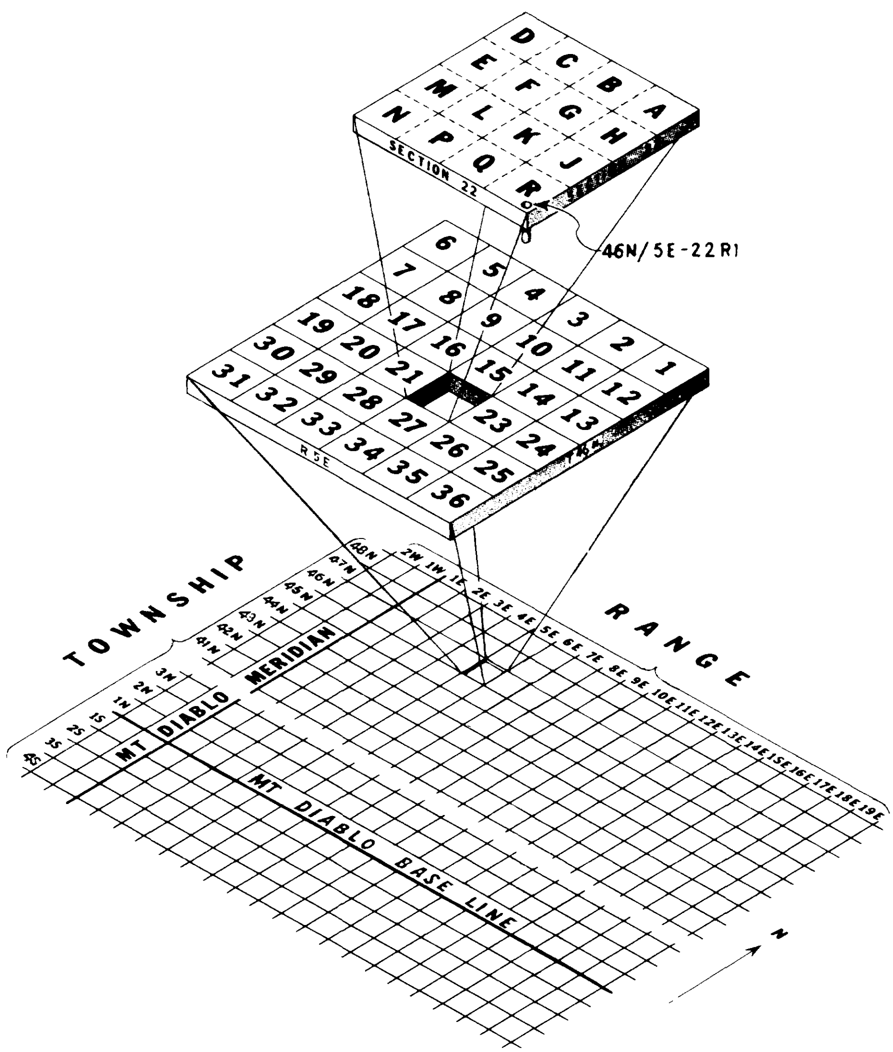


Figure 1.— Index map

Well-Numbering System

The well-numbering system used by the U.S. Geological Survey in California indicates the location of wells according to the rectangular system for the subdivision of public lands. For example, in the number 46N/5E-22R1, which was assigned to a well about $2\frac{1}{2}$ miles south of the Petroglyph Section, the part of the number preceding the slash indicates the township (T. 46 N.); the number following the slash, the range (R. 5 E.). The digits following the hyphen refer to the section (sec. 22); the letter following the section number, to the 40-acre subdivision of the section as shown below.

Within each 40-acre tract, the wells are numbered serially as indicated by the final digit of the well number. Thus, well 46N/5E-22R1 was the first well to be listed in the $SE\frac{1}{4}SE\frac{1}{4}$ sec. 22. The entire area is north and east of the Mount Diablo base line and meridian, therefore, the base line and meridian is not indicated.



GEOLOGY

Geologic units and structural features were examined in the field and have been modified and generalized after the California Division of Mines (1958) in preparing the geologic map for this report. As shown in figure 2, the geologic units of the area are subdivided into two groups--volcanic rocks and sedimentary deposits that range in age from Miocene to Holocene. The volcanic rocks consist of tuffaceous rock and basalt of Miocene and Pliocene age, palagonite tuff and basalt of Pleistocene age, basaltic scoria and ash (cinder cone deposits) of Pleistocene and Holocene age, and basalt of Holocene age. To differentiate the three basalts in figure 2 and in the text, they are referred to as the lower basalt, the intermediate basalt, and the upper basalt. Sedimentary deposits consist of nonmarine deposits of Pliocene age, lake deposits of Pliocene, Pleistocene, and Holocene age, and alluvium of Pleistocene and Holocene age. Older rocks have not been recognized in the study area. However, about 75 miles south of the area, Diller (1895) mapped metamorphic rocks of Jurassic age, marine sedimentary rocks of Cretaceous age, and nonmarine sedimentary deposits of early Tertiary age. These rocks and deposits probably underlie the younger sequence in the study area. To date, no wells have penetrated these older rocks.

Volcanic Rocks

Most of the study area (fig. 2) is underlain by volcanic rocks, with the notable exception of sedimentary deposits in the north-central part of the area. Basalt forms most of the volcanic rocks in the study area. Basalt is not a permeable lithologic unit as a rule, but where there are interconnected spaces and fractures, it can be highly permeable, dependent upon fracturing, and water can easily move through the rocks. The basalt in Lava Beds National Monument and nearby areas contains many examples of interconnected spaces and fractures ranging in size from open passageways and caves, called lava tubes, to those of microscopic size.

Inspection of rocks in the study area indicates that, at the surface, fractures and other openings in the rocks are extensive and commonplace but not uniformly distributed. This situation probably also exists at depth, consequently, the volcanic rocks in the study area can be expected to have highly variable permeability.

A description of the volcanic rocks of Lava Beds National Monument and their water-bearing properties based on field observations, is given in table 1.

Geologic age, system and series, shown in table 1 and in figure 2, are for the most part in agreement with the map compiled by the California Division of Mines (1958). Two exceptions to previously determined ages, although not pertinent to the scope of this report, are included to explain differences with previous work:

Table 1.--Volcanic rocks and their water-bearing properties

System	Series	Geologic unit and map symbol	General description	Water-bearing properties
Quaternary	Holocene	Upper basalt (Qbu)	Vesicular olivine basalt, extremely rough surface, sparsely covered with rhyolite pumice. Fresh, unweathered, still warm appearance. Exposed over much of the southern half of the study area.	Highly permeable due to extensive fractures in most parts of the area but impermeable in the vicinity of Dry Lake. In part above water table and not saturated. Where saturated, readily yields water to wells. Where fractured but not saturated, serves as a conduit to the saturated zone for recharge.
	Pleistocene and Holocene	Basaltic scoria and ash (cinder-cone deposits) (Qs)	Red, brown and black basaltic scoria ash forming cinder cones, mounds, and spatter ramparts. Weathered surface varies from fresh and nearly barren to well-developed soil. Most of the exposures are scattered across the southern part of the study area with a few farther north along the eastern boundary.	Highly permeable but mostly above the water table.
	Pleistocene	Intermediate basalt (Qbi)	Reddish-brown to black, diabasic olivine basalt. Well developed columnar jointing in thin-bedded flows tending to separate into flat sections perpendicular to the joints. Weathered exposures show a subdued, rounded, undulating topographic form. Exposed along eastern and western boundaries of study area.	Highly permeable, water-bearing characteristics are generally indistinguishable from lower or upper basalt. Probably less effective locally as a conduit for recharge because of lack of fractures.
		Palagonite tuff (Qt)	Glass shards, pumice, scoria fragments and brecciated, welded tuff exhibiting the characteristics of underwater volcanic eruption (phreatomagmatic eruption). Rock and mineral grains show hydration and decomposition. Forms wave-eroded remnants of volcanic cones in and near the Petroglyph Section.	Highly permeable, but generally above the water table and has limited areal extent.
Tertiary	Miocene and Pliocene	Lower basalt (Tbl)	Dark green to black, ophitic olivine basalt and gray to black porphyritic basalt with pyroxene phenocrysts. Within the rock, columnar jointing is weakly exhibited and in weathered exposure forms a well-rounded topographic surface. Exposures are seen along eastern, western, and southern boundaries of the study area and near the Petroglyph Section.	Highly permeable, water-bearing characteristics are generally indistinguishable from those of the intermediate and upper basalt.
		Tuffaceous rocks (Tt)	Yellow, light tan, brown, and gray vitric tuff containing fragments of andesitic rock and occasional beds of bentonite. Easily eroded and forms rounded, low-lying hills. Exposed mostly near the western border of the study area with one small exposure noted at Horse Mountain near the eastern boundary.	Probably moderately to highly permeable. Few wells have been drilled.

1. The palogonite tuff has been suggested as representing some of the oldest rocks in the study area (California Division of Mines, 1958). However, fossil clams and snails recovered while drilling test well 46N/5E-3P1 (appendix C) in lake deposits beneath the tuff probably are Pleistocene in age. Identification and dating of the faunal assemblage by Dwight D. Taylor of the U.S. Geological Survey (written commun., 1966) follows:

Freshwater clams:
- *Sphaerium striatinum* (Lamarck)
- *Pisidium nitidum* Jenyns
- *Pisidium ultramontanum* Prime

Freshwater snails:
- *Lithoglyphus* sp.
- *Lanx patelloides* (Lea)
- *Helisoma newberryi* (Lea)
- *Vorticifex effusus* (Lea)

"These species are all still living in the region, but perhaps not in the Tule Lake or Klamath Lake basins. An assemblage composed entirely of living species of freshwater mollusks is not necessarily of Pleistocene age in all cases. In the midcontinent region the late Pliocene faunas are mostly all recent species, for example. In northeastern California and in adjacent Oregon there are a number of late Pliocene assemblages that one can use as a standard. All of them have a high percentage of extinct forms, and some have extinct genera and no living species. Hence it seems to me improbable that this collection can be Pliocene, and I would even favor a mid-Pleistocene or younger age."

2. Powers (1932, p. 272) suggested that the youngest of the basalt flows is not more than 500 years old. However, monument rangers have found rhyolite pumice in crevices and pockets over the entire surface of these flows (oral commun., Garrett A. Smathers, U.S. National Park Service, 1966). The only known local source of rhyolite pumice is at Medicine Lake highlands, 6 miles south of the study area. The youngest pumice from the highlands has a probable age of 1,400 years (Chesterman, 1955, p. 418). Because the pumice in the study area is superposed on the basalt, the youngest basalt probably is more than 1,400 years old.

In addition to the volcanic rocks that crop out in the area shown (table 1 and figure 2), basalt is reported in well logs at depths up to 2,207 feet beneath the surface of the sedimentary deposits at Tulelake. This basalt is highly permeable and readily yields water to wells. Logs of the two wells, 48N/4E-35L1 and 48N/4E-16P3 which penetrate the basalt are presented in Appendix C.

Sedimentary Deposits

The sedimentary deposits are found in several places in the study area (fig. 2). Except for the lake deposits, they are of little significance in terms of their water-bearing potential. All of the sedimentary rocks are permeable in varying degrees though in general much less permeable than many parts of the volcanic succession.

A description of sedimentary rocks in the area and their water-bearing properties based on field observations is given in table 2. The relation between units of the sedimentary and volcanic rocks is shown in figure 2. In the subsurface, nonmarine deposits of Pliocene age overlap volcanic rocks of Miocene and Pliocene age but because wells have not been drilled in the nonmarine deposits, their thickness and relation to adjacent rocks are not known. The relation of the lake deposits to adjacent and underlying volcanic rocks is shown diagrammatically in figure 3. The alluvium of Pleistocene and Holocene age is found along drainage channels and around the margins of the lake deposits. The deposits of alluvium are thin and too small to be shown on the geologic map (fig. 2) except for the area in the southeast near Dry Lake Guard Station where alluvium overlies the intermediate and upper basalt. Water wells shown in the alluvium (fig. 2) were all drilled through the alluvium and yield water from the underlying volcanic rocks.

Faults

North-south faults, in places intersected by local east-west faults, probably are related to block faulting, which was initiated on the Modoc Plateau in the Pliocene Epoch (Powers, 1932, p. 258). The faults are implied basin boundaries on figure 2, but in fact, the water-transmitting properties of the faults are not known. Existing wells drilled in near proximity on both sides of a fault were not found during field data collection, and an attempt to drill a test well to determine the water-level gradient across a fault was unsuccessful. A number of wells adjacent to faults probably intersect fractured volcanic rocks but whether they penetrate an actual fault zone is not known. Fault movements in the study area undoubtedly have caused extensive fracturing in volcanic rocks, thereby improving the water-bearing properties of the rocks.

Table 2.--Sedimentary deposits and their water-bearing properties

System	Series	Geologic unit and map symbol	General description	Water-bearing properties
Quaternary	Pleistocene and Holocene	Alluvium (Qal)	Sand, clay, soil, and loess. Only exposure mapped is in the southeast part of the study area extending northerly from Dry Lake Guard Station. Estimated maximum thickness is about 30 feet.	Moderately permeable but generally above the water table. Probably serves as an infiltration area for recharge from precipitation.
Quaternary and Tertiary	Pliocene, Pleistocene and Holocene	Lake deposits (QTl)	Sand, silt, clay, ash and lenses of diatomaceous earth. Semiconsolidated variably fissile shale and clay containing fossil clams, snails and tules. Interfingers with palagonite tuff and basalt. Exposed in the north-central part of the area, north of the National Monument. Maximum known thickness 2,366 feet.	Very low permeability, mostly saturated but yields only small quantities of water to wells.
Tertiary	Pliocene	Nonmarine deposits (Tn)	Clay, diatomaceous earth, and interbedded fluvial deposits. Exposed in the northwestern part of the area and in the southwest about 2 miles south of Bonita Butte. Thickness unknown.	Probably low to moderate permeability--data not available because wells were not found in this unit.

HYDROLOGY

Surface Water

Surface-water supplies in the area have been regulated since the inception of the Klamath Project in 1903-05. Under present conditions natural runoff in the area is virtually nonexistent. Although historically important, supplemental supplies such as ponded water, springs, and ice caves, are now of little consequence.

Prior to the inception of the Klamath Project, 1903-05, Tule Lake (at one time called Rhett Lake) covered about 98,000 acres in California and Oregon and derived its water from Lost River, which heads in Clear Lake east of the study area. The altitude of the water surface in Tule Lake was about 4,060 feet above sea level (written commun., William G. Ely, U.S. Bureau of Reclamation, 1964). Waterlines at an altitude higher than 4,076 feet at the Petroglyph Section indicate that the lake level fluctuated widely in response to wet and dry climatic periods during prehistoric time. The water level in the lake probably was directly related to the amount of southeastward overflow from the Klamath River. during periods of high flow. At high lake levels, water probably drained southeastward into the Pit River (Cleghorn, 1959, p. 10). Fishes in Medicine Lake and Goose Lake, south and east of the study area, respectively, are similar to present day Pit River fishes. Such similarities indicate the possibility of north-south stream connections across the Modoc Plateau during Pleistocene time (Blackwelder and others, 1948).

Following construction of dams and canals of the Klamath Project, Tule Lake shrank rapidly in size due to evaporation and irrigation diversions until it was diked into its present shape in 1923 and became the Tule Lake sumps (fig. 1). Water that enters and leaves the Tule Lake sumps is completely regulated by engineers of the Klamath Project, a water system which in 1966 encompassed an area of about 9,500 square miles and supplied water to irrigate more than 400,000 acres (oral commun., David E. Bunger, U.S. Bureau of Reclamation, 1966).

Ground Water

Source, Occurrence, and Movement

Infiltration of surface water from the Tule Lake sumps and underflow from adjacent volcanic rocks probably are the principal sources of recharge to ground water in the study area. In addition, precipitation and intermittent streams infiltrate very quickly into fractured or permeable volcanic rocks. Infiltration probably is much slower in the sedimentary deposits, and is virtually zero where unfractured basalt is exposed at the surface as at Dry Lake in the southeast corner of the study area.

The ground-water reservoir in Lava Beds National Monument and vicinity, as controlled by the geologic framework (fig. 3), consists of all volcanic and sedimentary rocks beneath the water table.

For many parts of the area well data are not available, but the geologic and hydrologic evidence suggests that the central part of the area bounded on the east and west sides by north-south faults (figs. 2 and 3), has a continuous water table and probably functions as a single unconfined water body. A water table, which may or may not be continuous with the central part of the area, also probably exists across the faults and outside of the area bounded by mapped faults. The volcanic rocks beneath the lake deposits that underlie the Tule Lake sumps contain a confined water body. The northern and southern boundaries of the ground-water reservoir are outside of the area of this investigation, and the basement rock forming the bottom of the reservoir has not been penetrated by wells.

In general, where volcanic rocks are exposed at the surface (figs. 2 and 3) the area probably is underlain by an unconfined water body. The water table in this water body probably has little change in gradient where crossing from volcanic rocks into sedimentary lake deposits. The lake deposits probably contain water under unconfined, semiconfined, and confined conditions. However, because only a few shallow wells yield water from the lake deposits, the degree of confinement is not clearly known. Beneath the lake deposits a confined water body is contained in the volcanic rocks, locally more than 2,000 feet below land surface. As indicated in figure 3, the water level in wells penetrating the confined water body is the same, or nearly the same, as the water level in wells penetrating the lake deposits. The water-level contours (fig. 2) are interpretive and present only one of several possible alternatives. However, almost any interpretation will indicate that ground-water movement is generally from the north to the south.

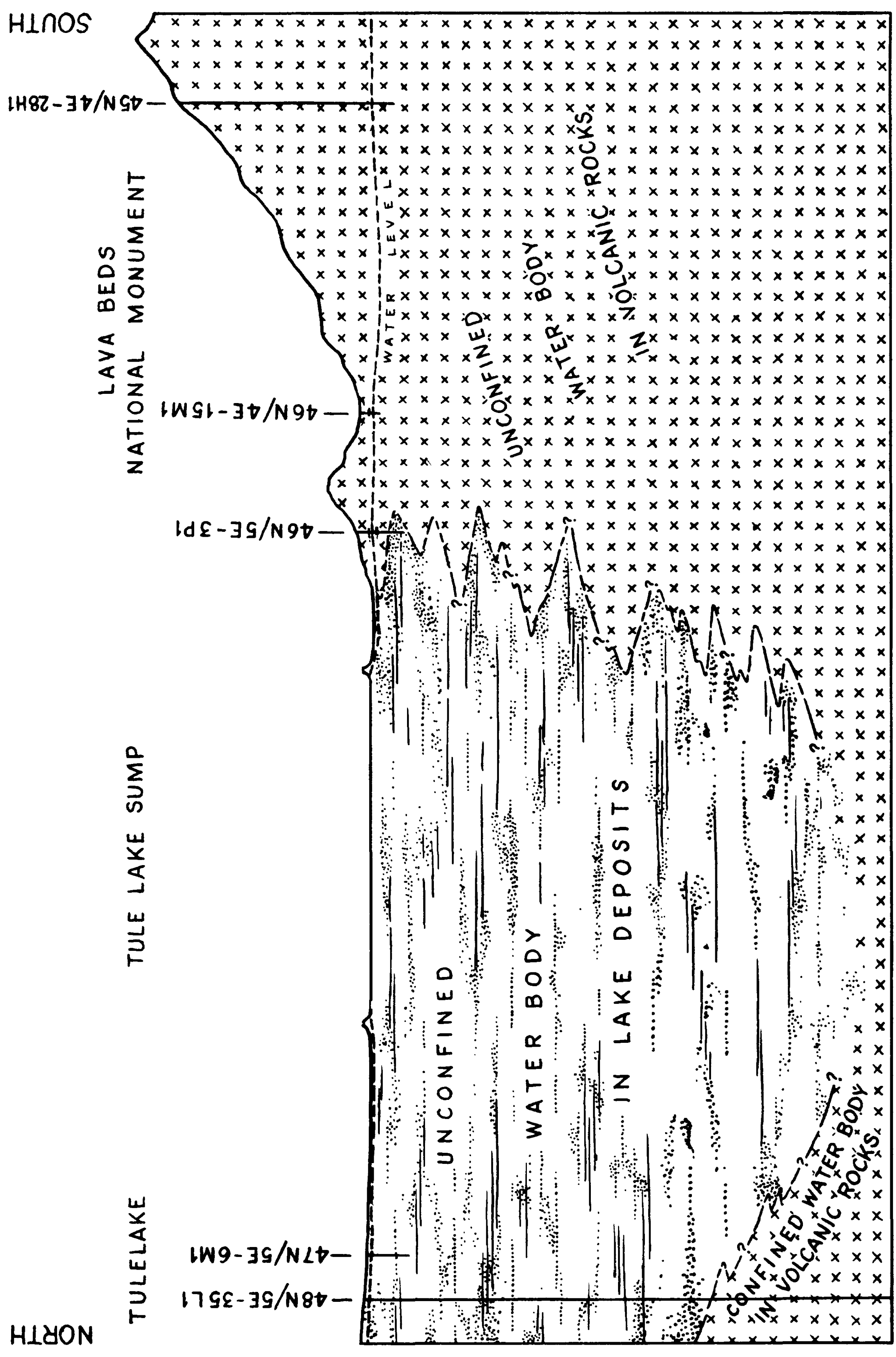


Figure 3._Diagrammatic cross section showing water bodies and wells.

Yields of Wells

Yields of wells are described in this report by the measured or reported rate of discharge, in gallons per minute, and by specific capacity. Specific capacity is the rate of discharge per unit of drawdown (Meinzer, 1923, p. 62). To obtain reasonably accurate information on both yield and specific capacity, the yield and drawdown must be nearly constant. Most of the data reported here were obtained from drillers records or reported by owners; the circumstances of the tests are not known, and the accuracy of the results not verified. Even though these data probably were obtained from a variety of testing sequences, they do indicate some notable differences in yield and specific capacity between wells drilled in the several aquifers of the area. Descriptions of all wells canvassed during this study are given in appendix A.

Most of the wells penetrating the unconfined aquifer in the volcanic rocks (fig. 3) yield moderate to large quantities of water. For example, well 46N/6E-5L1, 190 feet deep, is reported to yield 4,000 gpm with a specific capacity of 250 gpm/ft (gallons per minute per foot of drawdown). Another well, 45N/6E-17Q1, 282 feet deep, yields 2,100 gpm with a specific capacity of 52. A notable exception is well 45N/4E-28H1 at monument headquarters. This well is 758 feet deep and yields 11.5 gpm with a specific capacity of 0.3.

These examples emphasize the speculative aspect of drilling wells in volcanic rocks. Success or failure is dependent entirely on encountering fractures or interconnected spaces in the rock which contain a sufficient quantity of water to supply a well. Although the volcanic rock in the study area is extensively fractured, at any given site, openings in the rock may not be found at depth, if found they may not contain water, or if they contain water they may not be interconnected to a volume of water large enough to supply a well. In general, wells drilled along the east side of the area, near the faults shown on figure 2, yield notably larger quantities of water than those elsewhere in the unconfined aquifer in volcanic rocks.

Wells drilled into the lake deposits commonly yield small quantities of water. These wells usually are less than 150 feet deep. The lake deposits are more than 2,000 feet thick at Tulelake, consequently, yield information is available only from a veneer near the surface. Reported data indicate average yield from wells penetrating the lake deposits is 30 gpm and average specific capacity is 2.

Along the contact between the lake deposits and volcanic rocks (fig. 2), a number of wells have been drilled in an area where lake deposits and volcanic rocks interfinger (fig. 3). There, yield and specific capacity vary widely from well to well, usually showing a crude correlation with the total thickness of volcanic rock penetrated.

Three wells were found during the field investigation for this study which have been drilled through the lake deposits into the underlying confined water body in volcanic rocks (figs. 3 and 4). Two of these wells, 48N/3E-35L1 and 35L2, are at Tulelake. Each is 2,676 feet deep and penetrates the volcanic rocks at 2,207 feet below land surface. These two wells each are reported to yield 1,200 gpm with specific capacities about 16. A third well 48N/4E-16P3, at Hatfield, is 1,200 feet deep, penetrated the top of the volcanic rocks at about 1,000 feet, and yields 2,650 gpm with a specific capacity of about 62.

CHEMICAL QUALITY OF WATER

Ground water derives most of its dissolved solids from the soils, rocks, and minerals through which it moves. As water infiltrates into the earth it dissolves and reacts with surrounding materials, altering the chemical character of the solution.

In this report, the chemical character of the water is identified in chemical analyses by the major cations and anions determined from percentage reacting values (percentage of total milliequivalents per liter of cations and anions, respectively). For example, if the water in a sample is described as sodium bicarbonate in character, sodium is the predominant ion among the cations and bicarbonate is the predominant anion.

Chemical analyses of surface-water samples from the Tule Lake sumps indicate the water is sodium bicarbonate sulfate type containing more than 700 mg/l (milligrams per liter) dissolved solids. Surface-water inflow to the sumps usually contains more than 600 mg/l dissolved solids (D. E. Bunger, U.S. Bureau Reclamation, oral commun., 1966).

Chemical analyses available for water from two wells (45N/4E-28H1 and 45N/6E-28M1) indicate that the water in the unconfined water body within the volcanic rocks, several miles south of the southern contact between the lake deposits and volcanic rocks (fig. 2), is a sodium bicarbonate water containing 150 and 266 mg/l dissolved solids. Other wells in the same water body but closer to the southern margin of the lake deposits yield water containing more than 600 mg/l dissolved solids. Calcium, magnesium, and sodium are present in approximately equal concentrations in this vicinity; bicarbonate is still the predominant anion, but the concentration of sulfate is notably larger than in the samples from farther south.

Analyses of water from wells drilled in the lake deposits show concentrations of dissolved solids higher than elsewhere in the study area. Results from two wells, 48N/4E-16P2 and 35R1, show 962 and 1,300 mg/l dissolved solids. Calcium, magnesium, and sodium are prominent among the cations but none predominate. Among the anions, bicarbonate is predominant.

Water analyses from wells along the east side of the lake deposits are not available, one analysis is available on the west side, and a number along the south side and in the peninsula of volcanic rock extending northward into the lake deposits. These analyses indicate from 400 to 800 mg/l total dissolved solids. The three major cations are about equally represented and the anions are predominently bicarbonate or bicarbonate and sulfate.

Two wells, 48N/4E-16P3 and 35L1, penetrating the confined water body in volcanic rocks underlying the lake deposits have been sampled. The water is sodium bicarbonate type, contains about 200 mg/l total solids and is the best-quality ground water in the study area.

TEST-WELL DRILLING

Test wells were drilled at four sites (fig. 2) in Lava Beds National Monument to obtain geologic and hydrologic information during this study. Test sites were selected in areas of potential future development of visitor and administrative facilities, and in areas where water-well information was not available. The wells were drilled for the Park Service by Geo-Data of Bakersfield, Calif., using a rotary drill.

Test-well 46N/5E-3P1 (appendix C) was drilled in the Petroglyph Section. This well was unique among the four test wells in that drilling was started in volcanic rock and at a depth of 150 feet, penetrated underlying lake deposits. Water from this well, both in quantity and chemical quality (appendix B) is similar to other wells near the Petroglyph Section and those near the southern contact of the lake deposits.

A second test well, 46N/5E-19M1, was drilled to the water table but could not be drilled deeper. Test-well 45N/5E-36K1 was abandoned on the third attempt when the bottom 15 feet of drill stem was sheared off in the hole at a depth of 270 feet and test-well 45N/4E-14J1 was abandoned after encountering repeated caving problems. Neither 36K1 nor 14J1 reached the water table.

Drilling at each test-well site involved problems of caving in layers of various kinds of volcanic ejecta, and of loss of drilling fluid. These problems suggest that cable-tool or down-hole airhammer drilling rigs might be more successful if additional wells are drilled in the volcanic rocks of the study area.

SUGGESTIONS FOR FUTURE DEVELOPMENT OF WATER SUPPLIES

A supply of ground water can be developed at almost any site in the study area between the basin-bounding north-south faults (fig. 2), providing the bottom of the well is below the water table. Wells probably can be developed in those parts of the area outside the basin-bounding faults, perhaps at shallower depth, but few water-level data are available. Wells drilled inside the boundaries of the national monument can be expected to yield small to moderate quantities of water providing that fractured volcanic rock is penetrated below the water table.

In the Petroglyph Section of the monument, wells drilled to depths not more than 200 feet below land surface can be expected to yield up to 50 gpm. However, dissolved minerals in water probably will equal or exceed some of the maximum recommended limits for human consumption (U.S. Public Health Service, 1962).

In the main section of the national monument, roughly southward from an east-west line arbitrarily drawn through Juniper Butte, chemical quality of ground water probably is better suited for human consumption. Only one well, 45N/4E-28H1, is available in this area, and it has low yield and very low specific capacity. The prospective yield of new wells is dependent on the degree of fracturing in the volcanic rock below the water table. Some wells in the study area but outside the monument, drilled to depths less than 300 feet below land surface in fractured volcanic rock, yield very large quantities of water. Unfortunately, information is not available to select sites for similar wells inside the borders of the national monument. The only guide in searching for fractured rock in the monument is the faulting in volcanic rock in the western part of the monument. Rocks in the vicinity of faults often are extensively fractured but because the fault surface can also function as a barrier to ground-water movement, selection of a well site near a fault will not guarantee a high yield.

Wells drilled in or adjacent to the lake deposits north of the national monument probably will yield small quantities of water that will not meet Public Health Service recommendations for chemical quality.

The possibility of developing deep wells yielding large quantities of water of good chemical quality is present in the study area. Two public-supply wells at Tulelake are about 2,700 feet deep, and reportedly yield 1,200 gpm of water of excellent quality from the confined water body in volcanic rocks (p. 14). Another well, at Hatfield, also obtains water from the confined water body. This well is about 1,200 feet deep and reportedly yields about 2,600 gpm. Whether the rocks penetrated by these wells are continuous southward under Lava Beds National Monument is not known, but if they are, a single well could supply all the water requirements of the monument. A well drilled into the confined water body at a site inside the monument boundaries might have to be between 1,500 and 3,000 feet deep. Water from the two public-supply wells at Tulelake is available at a point less than 2 miles north of the Petroglyph Section via a pipeline of the Stronghold Irrigation District. If arrangements could be made to secure a water supply from the public-supply wells at Tulelake and to pipe it to user areas in the monument, the water-supply problems of the monument would be solved without the need for drilling additional wells.

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APPENDIX A.--Data on water wells

Source of data and other numbers: The sources of data are indicated by the following symbols: DWR California Department of Water Resources, FG California Department of Fish and Game, FS U.S. Forest Service, GNRR Great Northern Railroad, GS U.S. Geological Survey, NPS National Park Service, T City of Tulelake, USBWF U.S. Bureau of Wildlife and Fisheries, WSC Western Starch Company.

Date of observation: The date on which the observation was made. In some instances the exact month or day is unknown and the year is the only entry in this column.

Owner or user: Name is that of the apparent owner or user on the indicated date.

Year completed: Completion date of well was obtained from driller's log or reported by owner.

Depth: Well depths to the nearest foot were reported by owners or drillers.

Depth of casing: Depth to which casing extends from the land surface was reported by driller. Most wells were constructed with open bottom; exceptions noted.

Type, diameter: The type of well construction is indicated by the following symbols: C cable tool, D dug, R rotary. The number following the letter is the diameter of the casing or hole, in inches.

Pump type and power: The type of pump is indicated by the following symbols: C centrifugal, J jet, N none, P piston, S submersible, T turbine. The type of power is indicated by the symbols: 3 gasoline engine, 5 electric motor, F gasoline engine through 5 hp, G gasoline engine >5 to 20 hp, S electric motor through 1 hp, T electric motor >1 to 5 hp, U electric motor >5 to 15 hp, V electric motor >15 to 100 hp, W electric motor more than 100 h.p.

Use: The well and water use is indicated by the symbols: F fire protection, H domestic, I irrigation, N industrial, P public supply, S stock supply, U unused, Z destroyed.

Measuring point: The point from which water-level measurements were made is described as follows: Al air line (broken if followed by [b], Ap access pipe, Bnc bottom of notch in casing, Hcc hole in casing cover, Hpb hole in pump base, Ls land surface, Na no access, Pp plug on pump, Tc top of casing.

Altitude of lsd: Altitude is elevation, to the nearest foot, of the land surface datum above mean sea level. Land surface datum is on arbitrary plane that closely approximates land surface at the time of the first measurement and is a fixed plane of reference for all subsequent measurements.

Depth to water below lsd: This is the difference in elevation, to the nearest foot, between lsd and the ground-water surface at the time of the observation.

Other data: Other data available in the files of the U.S. Geological Survey are indicated as follows: L driller's log, C chemical analysis of water, Cp partial chemical analysis of water, H hydrographs, E electric log.

USGS number	Source of data and other numbers	Date of observation	Owner or user	Well data: Year completed	Depth (feet)	Depth of casing (ft)	Type diameter (in.)	Pump type and power	Use	Discharge (gpm)	Drawdown (ft)	Measuring point (feet)	Altitude of lsd (feet)	Water level Depth below lsd (feet)	Temperature °C	Other data
			T. 44 N., R. 5 E.													
24E1	GS	10-26-65	Unknown		471		14		Z				4,315			
			T. 44 N., R. 6 E.													
2N1	GNRR	9- -39	D. O'Conner		600			T V	S			Na	4,180	245		L
3P1	FS	12- 2-65	U.S. Forest Service	1959	471		C 16	T T	H			Al 0.3	4,150	158		L
9B1	GS	12- 2-65	O. Ackley		250		C	P F	S			Na	4,145	132		
16P1	DWR	11- 4-64 5-11-66	E. Hawkins	1964	271	19	C 8	S	H	15	0	Hcc 0	4,220	236 213	13	L
21D1	GS	5-11-66	E. Hawkins				12	T U	H			Tc .5	4,232	227		
			T. 45 N., R. 3 E.													
14J1	NPS	5-29-66	National Park Service	1966	90		R 5	N	Z				4,775			L
			T. 45 N., R. 4 E.													
28H1	NPS	7-26-62 3- 2-66	National Park Service		758			T U	P	11.5	.3	Al .5	4,671	674 653	13	C,L
36K1	NPS	5-19-66	National Park Service	1966	270		R 5	N	Z				4,350			L
			T. 45 N., R. 5 E.													
36C1	GS	12- 1-65	U.S. Forest Service					P 3	F			Tc 0	4,200			
			T. 45 N., R. 6 E.													
17F1	GS	12- 2-65	O. Ackley	1930	300		C	P F	S			Na	4,138			
17Q1	DWR	8-21-63	O. Ackley	1963	250	95	C 16	T W	I	2,100	40	Tc .3	4,145	136	18	L
21N1	GS	1930	O. Ackley	1930	100		D 72	P F	S			Na	4,139	98		
22L1	GS	1939	R. Byrne		300+			P G	H			Na	4,220	181		
28M1	DWR	3-17-61 10-28-65	O. Ackley	1961	385		C 16	T W	I	850	180	Hpb .3	4,140	130 230	18	L C
33G1	GS	12- 2-65	U.S. Forest Service						H			Na	4,156			
			T. 46 N., R. 4 E.													
15M1	NPS	10-29-64 11- 3-64 10-26-65 11- 3-65 12- 2-65	National Park Service	1964	48	34	C 8	N	T	24	10	Tc 1.2	4,059	29 29 27 27 29	11	L,C,H

USGS number	Source of data and other numbers	Date of observation	Owner or user	Well data: Year completed	Well data: Depth (feet)	Well data: Depth of casing (ft)	Well data: Type diameter (in.)	Well data: Pump type and power	Well data: Use	Well data: Discharge (gpm)	Well data: Draw-down (ft)	Measuring point (feet)	Altitude of lsd (feet)	Water level Depth below lsd (feet)	Temperature °C	Other data
			T. 46 N., R. 4 E.--Continued													
18J1	NPS	5-10-35 7-25-62 11-10-65	National Park Service	1935	226	10	R 6	S T	H	12		Hcc 1.0	4,059	67 52 51		L
			T. 46 N., R. 5 E.													
3P1	NPS	5- 8-66	National Park Service	1966	173		R 8	N	T	58	3	Ls	4,055	27	14	L,C,E
3Q1	GS	5- 2-66	E. Parsons				C 8	C S	H			Na	4,060		14	C
9J1	GS	3-20-66	Newell Grain Growers					S 5	N			Na	4,055		15	
9R1	USBWF	10-27-65	U.S. Bureau of Wild-life & Fisheries	1938	155	125	C 12	T T	H			Tc 1.5	4,055	33		L,C
10D1	GS	11-10-65	H. Naylor				C 8	C S	H			Tc 2.0	4,040	27	12	C
15B1	GS	5- 3-66	O. Depuy				C	T U	S			Bnc 0	4,076	68		
15Q1	GS	5-11-66	M. Bradley	1949	60		C	J S	H			Na	4,050			Cp
17M1	GS	5-11-66	M. Ott				C	J S	H			Na	4,040			Cp
17N1	GS	5-11-66	Deserted				C	T 5	H			Na	4,050			
19M1	NPS	5-26-66	National Park Service	1966	120		R 6	N	T			Ls	4,110	100		L,C
20F1	GS	5-11-66	W. Davis	1958	45		C	S S	H			Tc .5	4,060	28	14	C
20K1	GS	5-11-66	D. Johnson				C	J S	H			Ap 1.5	4,035	7		
22R1	GS	5-11-66	L. Ablard	1952	30	22	C	5	H			Na	4,045			
23G1	GS	5-11-66	N. Hall	1949	70	10	C	T S	H			Na	4,045			L
28L1	GS	5-11-66	R. Falconer	1949	56	23	C	5	H				4,035			L
29A1	GS	5-11-66	R. Schirman	1960	58	20	C 6	T T	H			Na	4,045			L
29H1	GS	5-11-66	R. Schirman				C 6	T 5	H			Tc 1.0	4,038	15	13	Cp
			T. 46 N., R. 6 E.													
5L1	DWR	1-18-65	D. McAuliffe	1965	190	19	C 16	T V	I	4,000	16	Na	4,060	46	14	L
8E1	DWR	12- 2-65	C. Huffman	1958	215	24	C 16	T V	I	2,200	16	Pp .2	4,092	79	12	L
8F1	GS	12- 2-65	D. McAuliffe				C 16	T V	I			Na	4,090			

			<u>T. 47 N., R. 4 E.</u>																
6F1	DWR	5- 1-37	U.S. Bureau of Wild-life & Fisheries	1937	220	123	C	6	T	T	H	30		Na		4,075	50		L,C
			<u>T. 47 N., R. 5 E.</u>																
IH1	DWR	1-20-66	W. Dalton, Jr.	1955	1,000	20	C	12	P	F	S	20	30	Tc	1.0	4,078	35		L
IK1	DWR	10-17-63 1-20-66	W. Dalton, Jr.	1963	119	54	C	10	T	V	I	500	66	Al	1.0	4,075	26 25	12	L
1K2	DWR	2-19-65	W. Dalton, Jr.	1965	131	70	C	10	T	V	I	1,050	53	Al	1.0	4,075	26	12	L
6M1	GS	5-11-66	W. Edwards	1948	145		C	8	N		U			Tc	.6	4,034	5		
26L1	GS	10-27-65	Newell City Water District	1942	360		R	16	T	V	U			Tc	1.1	4,048	18		
26N1	GS	10-28-65	U.S. Bureau of Reclamation	1942	320		R	16	N		U			Tc	1.0	4,074	59		
26Q1	GS	10-27-65	U.S. Bureau of Reclamation	1943	340		R	16	N		U			Tc	1.5	4,055	23		
27J1	GS	10-28-65	Newell City Water District	1942	185		R	16	T	V	P			Hpb	1.5	4,078	48		
27R1	GS	10-28-65	Newell City Water District	1942	350		R	16	T	V	P			Hpb	1.1	4,088	58		
27R2	GS	11- 3-65	U.S. Bureau of Reclamation	1942			R	16	N		U			Tc	1.0	4,079	50		H
27R3	FG	12- 1-65	California Dept. Fish & Game		162			8	T	S	H			Tc	.4	4,080	50		C
33Q1	GS	5- 2-66	L. Nash	1950	36		C	6	T	S	H			Na		4,055		13	C
35D1	GS	10-28-65	U.S. Bureau of Reclamation	1943			R	16	N		Z			Na		4,085			
			<u>T. 47 N., R. 6 E.</u>																
6C1	DWR	1-20-54 1-20-66	R. Halousek	1954	450	90	C	14	T	V	I	1,200	14	Al	.5	4,135	137 130	21	L
6F1	DWR	4- 8-64	S. Johnson	1964	711	74	C	16	T	W	I	2,000	54	Na		4,120	105	23	L
7G1	DWR	4-23-65	P. Tschirky	1965	594	15	C	14	T	V	I	1,150	128	Na		4,070	22	14	L
30B1	DWR	6-13-64	R. Byrne	1964	117	24	C	8	N		T	1,000	0	Na		4,120	89	11	L
30C1	DWR	7-31-64	R. Byrne	1964	140	80	C	14	T	5	I	3,500	3	Al		4,110	87	13	L
30K1	DWR	10- 9-58	R. Byrne	1958	61	22	C	8	S	5	S	25	9	Tc	0	4,070	36	14	L
30L1	DWR	8-31-64	R. Byrne	1964	275		C	14	T	5	I	40	3	Na		4,075	55	13	L
			<u>T. 48 N., R. 3 E.</u>																
25J1	GS	1937	U.S. Bureau Wild-life & Fisheries	1937	89				T	T	H			Na		4,060	24		

USGS number	Source of data and other number	Date of observa-	Owner or user	Well data: Year com-pleted	Depth (feet)	Depth of casing (ft)	Type diam-eter (in.)	Pump type and power	Use	Discharge (gpm)	Draw-down (ft)	Measuring point (feet)	Altitude of lsd (feet)	Water level Depth below lsd (feet)	Temper-ature °C	Other data
			T. 48 N., R. 4 E.													
16P1	GS	5-17-66	Western Starch Co.						U				4,040	12		
16P2	GS	5-17-66	Western Starch Co.					T U	N			Na	4,040			C
16P3	WSC	10-29-65	Western Starch Co.	1965	1,200	1,148	C 12	T V	N	2,650	43	Na	4,047	10	23	L,C
18L1	GS	5-17-66	P. Comstock		75		C 8	T 5	H			Tc 0	4,062	14		
35L1	T	4- -53	City of Tulelake	1953	2,676	2,665	C 12	T 5	P	1,200	76	Na	4,035	8		L,C
35L2	T	4- -53	City of Tulelake	1953	2,676	2,665	C 12	T 5	P	1,200	76	Na	4,035	8		L,C
35R1	GS	5-11-66	P. McGinley	1952	160		C 8	J T	I			Tc .4	4,034	5	10	C
			T. 48 N., R. 5 E.													
14Q1	DWR	10-19-62	R. Byrne	1962	155	55	C 6	T 3	S	30	8	Na	4,058	4	13	L
33A1	DWR	4-27-65	J. Smith	1965	33		C 6	S 5	H	50	4	Na	4,038	6	10	L,C
36H1	DWR	10-10-58	W. Dalton, Jr.	1958	110	5	C 8	P 3	S	10	30	Tc 0	4,100	18		L
36K1	DWR	7-16-59	R. Byrne	1959	66	21	C 8	T 5	S	30	0	Tc 0	4,062	53	14	L
			T. 48 N., R. 6 E.													
31L1	DWR	9-15-62	W. Dalton, Jr.	1962	251	62	C 8	T 5	H	30	0		4,190	162	22	L
31M1	DWR	3-20-55 1-20-66	R. Byrne	1955	438	80	C 14	T V	I	1,200	44	Al .5	4,160	156 148	24	L

APPENDIX B.--Chemical analyses of water

The dissolved solids are the sum of the constituents analyzed except for bicarbonate which is divided by 2.03 (Collins, 1928, p. 253). GS, U.S. Geological Survey; LA, The Permutit Company; LTL, Laucks Testing Laboratory; NBS, National Bureau of Standards; PH, State of California, Department of Public Health.

Number above line, milligrams per liter (mg/l); Number below line, milliequivalents per liter (me/l). Values shown as mg/l / me/l.

Well number	Date of collection	Depth of well (feet)	Water temperature (°C)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Specific conductance (micromhos at 25°C)	pH	Laboratory and sample number
U.S. Public Health Service drinking-water standards (1962)					0.3							250	250		45		500						
45N/4E-28H1	7-26-62	725		44		7.3 / .36	4.0 / .33	25 / 1.09	1.8 / .05	90 / 1.48	0.0 / .00	2.0 / .04	12 / .34	0.1 / .01	0.9 / .01	0.3	141	34	0	60	182	7.7	GS 40781
45N/4E-28H1	8- 9-65	725			0.23	5.9 / .29	4.5 / .37	25.3 / 1.10	2.4 / .06	71.8 / 1.18	.0 / .00	.3 / .01	13.2 / .37	.4 / .02	.3 / .00		c156	33.5				8.2	PH 3516
45N/4E-28H1	3- 2-66	725	13	49	.0	3.0 / .65	.9 / .07	26 / 1.13	1.8 / .05	89 / 1.46	.0 / .00	3.0 / .06	11 / .31	.3 / .02	.6 / .01	.3	150	36	0	59	185	7.8	GS 52108
45N/6E-28M1	11- 2-65	365	18	49	.0	23 / 1.15	10 / .85	45 / 1.96	7.7 / .20	216 / 3.54	.0 / .00	10 / .21	14 / .39	.3 / .02	.7 / .01	.0	266	100	0	47	396	8.1	GS 52113
46N/4E-15M1	10-29-64	47.6	11	62	a7.6	72 / 3.59	48 / 3.93	101 / 4.39	14 / .36	324 / 5.31	8 / .27	246 / 5.12	34 / .96	.2 / .01	24 / .39	.1	c800	376	97	36	1,190	8.4	GS 47778
46N/4E-18J1	7-26-62	225.7		56	.23	64 / 3.19	45 / 3.68	62 / 2.70	12 / .31	424 / 6.95	.0 / .00	97 / 2.02	4.4 / .12	.2 / .01	12 / .19	.1	562	344	0	27	868	7.2	GS 40782
46N/4E-18J1	10-30-64	225.7		56	a1.5	72 / 3.59	50 / 4.09	60 / 2.61	9.1 / .23	450 / 7.28	.0 / .00	113 / 2.35	26 / .73	.2 / .01	14 / .23	.1	c638	384	15	25	976	8.2	GS 47779
46N/4E-18J1	8-20-65	225.7			1.24	66.6 / 3.31	50.3 / 4.14	53.0 / 2.31	14.5 / .37	357 / 5.85	.0 / .00	99.9 / 2.08	29.8 / .84	.3 / .02	15.7 / .25		c632	372				7.4	PH 3515
46N/4E-18J1	6- 7-66	225.7		50	a.12	74 / 3.69	47 / 3.83	61 / 2.65	13 / .33	438 / 7.18	.0	109 / 2.27	24 / .68	.4 / .02	15 / .24	.0	609	376	17	25	915	7.8	GS 53349
46N/5E-3P1	5- 6-66	48	13	15	.17	41 / 2.05	29 / 2.35	158 / 6.87	12 / .31	476 / 7.80	.0	158 / 2.89	14 / .39	.6 / .03	.8 / .01	.4	644	220	0	59	1,010	8.0	GS 52837

See footnotes at end of appendix.

Well number	Date	Depth	°C	SiO_2	Fe	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	Dissolved solids	Hardness	Noncarbonate	%Na	Spec. cond.	pH	Lab. and number
46N/5E-3P1	5- 8-66	136	14	23	b0.55	46/2.30	50/4.14	91/3.96	11/.38	544/8.92	0/.0	65/1.35	18/.51	0.4/.02	0.01	0.0	573	322	0	37	921	8.2	GS 52838
46N/5E-3P1	5- 9-66	172	14	21	a.20	30/1.50	46/3.82	119/5.18	10/.26	464/7.60	22/.73	69/1.44	16/.45	.4/.02	1.0	.0	562	266	0	48	896	8.6	GS 52836
46N/5E-3Q1	5- 2-66		14	45	a.16	13/.65	15/1.23	120/5.22	12/.31	328/5.38	0/.0	73/1.52	10/.28	1.4/.07	.7/.01	.4	452	94	0	70	665	7.8	GS 52840
46N/5E-9R1	5-12-66	155		27	b1.5	58/2.89	48/3.91	88/3.83	15/.38	464/7.60	0/.0	120/2.50	18/.51	.4/.02	.5/.01	.2	604	340	0	35	942	7.8	GS 52844
46N/5E-10D1	11-10-65		12	26	.0	46/2.30	27/2.22	66/2.87	13/.33	368/6.03	0/.0	43/.90	15/.42	.3/.02	140/.23	.0	431	226	0	37	700	7.8	GS 52110
46N/5E-19M1	5-27-66	107		32	a.20	67/3.34	49/4.02	99/4.31	11/.28	414/6.79	0/.0	206/4.29	26/.73	.5/.03	.1/.00	.0	695	368	29	36	1,030	8.0	GS 53348
46N/5E-20F1	5-11-66	45	13	44	b.35	70/3.49	35/2.91	86/3.74	15/.38	372/6.10	0/.0	190/3.96	21/.59	.4/.02	11/.18	.0	655	320	15	36	988	7.6	GS 52842
47N/4E-6F1	6-12-39					64/3.19	51.8/4.28	98.1/4.27		519.7/8.50	0/.0	116.8/2.43	27/.76				877.4+	372				8.1	A.M.Beters Co.
47N/4E-6F1	2-28-40				.2					484/7.93		94/1.96	205/5.78					398				7.7	LA 2681
47N/5E-27R1	3- 2-66	350	13	29	.01	50/2.50	60/4.94	101/4.39	13/.33	496/8.13	.0/.00	160/3.33	26/.73	.3/.02	.5/.01	.1	684	372	0	36	1,070	8.0	GS 52111
47N/5E-27R3	3- 2-66	162		30	.0	62/3.09	58/4.75	120/5.22	12/.31	560/9.18	0/.00	170/3.54	24/.68	4/.02	.9/.01	.1	753	392	0	39	1,160	8.0	GS 52112
47N/5E-33Q1	5- 2-66	36	13	29	a.04	44/2.20	30/2.44	66/2.87	11/.28	360/5.90	0/.00	75/1.56	10/.28	.5/.03	.5/.01	.0	443	232	0	37	738	7.9	GS 52839
48N/4E-16P2	3-11-64	80		54	.08	76/3.79	63.5/5.22	173/7.52	17.5/.45	650/10.64	.0/.00	155.2/3.23	26.5/.75	.0/.00	.6/.01		c962	451	0			7.9	LTL 35452
48N/4E-16P3	10-27-65			36	.24	13.6/.68	6.1/.50	38.9/1.69	5.2/.13	116/1.90	6.0/.20	12.2/.25	12.2/.34	.0/.00	.6/.01		c197	59	0			8.4	LTL 38100
48N/4E-35L1,2	3- 2-66	2,700	14	44	.04	9.2/.46	1.7/.14	54/2.35	4.0/.10	146/2.39	.0/.00	15/.31	11/.31	.3/.02	.7/.01	.0	212	30	0	77	292	8.1	GS 52109

See footnotes at end of appendix.

Well number	Date	Depth	°C	SiO_2	Fe	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	Dissolved solids	Hardness	Non-carbonate	%Na	Spec. cond.	pH	Lab. and number
48N/4E-35R1	5-11-66	160	10	48	[b]0.6	196 / 9.78	100 / 8.22	130 / 5.66	16 / .41	1240 / 20.32	.0 / .00	127 / 2.64	27 / .76	0.6 / .03	40 / .65	0.1	1,300	900	0	24	1,940	7.6	GS 52841
Surface water																							
43N/3E-11G	7-27-62			1.7		2.1 / .10	10 / .00	1.2 / .05	.6 / .02	8 / .13	.0 / .00	.0 / .00	2.0 / .06	.0 / .00	.5 / .01	.0	12	5	0	29	17	6.7	GS 40780
46N/5E-9C	5- 2-66		25	12	[a].13	29 / 1.45	40 / 3.27	163 / 7.09	17 / .43	340 / 5.57	.0 / .00	262 / 5.45	24 / .68	.7 / .04	8.4 / .14	.7	724	236	0	58	1,140	8.0	GS 52843
47N/4E-5B	5-19-39					57 / 2.84	67 / 5.51	216 / 9.40		592 / 9.71	.0 / .00	140 / 2.91	184 / 5.19		<.2 / <1.13		[c]1,000	417	0		1,600	7.95	NBS 523h/275

a. Filtered sample.
b. Field analyzed with Hach Direct Reading-Engineer's Laboratory (Model DR-EL)
c. Residue on evaporation at 180°C.

Test well 46N/5E-3P1

Test well 46N/5E-3P1 was begun on May 4, 1966, to test the feasibility of obtaining a water supply for a new monument headquarters to be located in the vicinity. The well was drilled to a depth of 173 feet using the hydraulic rotary method. The well casing was perforated from 10 to 88.8 feet below land-surface datum. On May 8, 1966, standing water level in the well was 26.88 feet below land-surface datum.

	Thickness (feet)	Depth (feet)
Soil cover. Rhyolite pumice fragments, 8-9 inches thick; caliche, 3-4 inches thick; silt, red-brown clayey, 12 inches thick----------------------------	2	2
Olivine basalt, fine vesicular fragments with phenocrysts of sodic plagioclase and weathered ferromagnesian minerals (pyroxene and olivine) 5-10 percent of sample------------------------------	8	10
Basalt, massive, few phenocrysts, weathered ferromagnesian minerals uncommon--------------------	5	15
Olivine basalt, finely crystalline to microcrystalline with scattered plagioclase phenocrysts and olivine--	13	28
Basalt with highly weathered ferromagnesian phenocrysts	3	31
Olivine basalt with 3-6 mm plagioclase phenocrysts----	4	35
Basalt, massive with ferromagnesian and plagioclase phenocrysts--	5	40
Basalt porphyry and rock-flour drill cuttings show rock breakage along mineral grains------------------	5	45
Olivine basalt with intergrown olivine and plagioclase, weathered drill cuttings show presence of calcite stringers--	7	52
Basalt and porphyritic basalt with diabasic texture----	3	55

	Thickness (feet)	Depth (feet)
Olivine basalt with grains or blebs of olivine larger than plagioclase laths but less common; pumice, tuff, and rounded tuffaceous aggregates to make up less than 20 percent of sample--------------------	6	61
Basalt, highly oxidized, and scoriaceous basaltic ash and vesicular glass and glass shards-------------	4	65
Basalt, dense to finely vesicular and no discernible olivine, 90 percent of sample; scoriaceous basalt and tuff, 10 percent of sample-----------------------	5	70
Basalt as above, with large and elongated vesicles, 90 percent of sample; scoriaceous basalt and tuff, 10 percent of sample---------------------------	5	75
Basalt, diabasic or ophitic, vesicular, 90 percent of sample; scoriaceous basalt and tuff, 10 percent of sample---	5	80
Basalt as above, 75 percent of sample; scoriaceous basalt and tuff, 25 percent of sample----------------	5	85
Basalt as above, 85-90 percent of sample, scoriaceous basalt and tuff, 10-15 percent of sample-------------	5	90
Basalt as above, 95 percent of sample; rounded opaque calcite fragments, 5 percent of sample--------	5	95
Basalt as above, 95 percent of sample; pumice <1 percent, calcite <1 percent, vitric tuff 3-4 percent----------	10	105
Palagonite tuff, containing subangular to rounded feldspar, glass shards and aggregates of weathered tuff, 80 percent of sample; basalt, as above, 20 percent of sample----------------------------------	5	110
Palagonite tuff, with ferruginous cement containing calcite, glass shards, weathered feldspars and ash----	5	115
Palagonite tuff, >98 percent of sample; basalt <1 percent; banded gray argillite <1 percent---------	5	120

	Thickness (feet)	Depth (feet)
Palagonite tuff, feldspathic, containing many glass shards, rounded tuff aggregates and feldspars suggests stream transport, 90 percent of sample; argillite, gray banded, 10 percent of sample--------------------	5	125
Palagonite tuff, feldspathic, containing fragments of glass, welded tuff. Pumice and tuff aggregates to 1 cm in diameter, 95 percent of sample; gray banded argillite and siltstone, 5 percent of sample--	10	135
Palagonite tuff, ash and water-laid tuff, welded tuff not discernible, >99 percent of sample; argillite and siltstone <1 percent of sample--------------	10	145
Palagonite tuff, containing glass shards and rounded aggregates, 85 percent of sample; argillite and semiconsolidated silt, 15 percent of sample----------	5	150
Argillite, gray banded, semiconsolidated silt and clay and micro-crossbedding, 75 percent of sample; tuff, palagonite with pumice fragments >1 cm in diameter, 25 percent of sample-----------------------	5	155
Silt and clay, semiconsolidated and variably fissile with foul odor, 95 percent of sample; tuff, palagonite, 3 percent of sample; argillite, gray banded, 2 percent of sample---------------------	5	160
Silt and clay, organic, lacustrine with approximately 10-foot stratum of nonmarine fossil clams and snails[1] overlying 3 feet of lake sediment, as above------------------------------------	13	173

1. For identification see section on volcanic rocks in the text.

Drillers log of municipal well 48N/4E-35L1

This well was drilled by the N. C. Jannsen Drilling Co. of Seattle, Washington, for the city of Tulelake in November 1953. The well is 2,676 feet deep, the casing is cemented in at 2,325 feet below land surface and perforated from 2,365 to 2,665 feet. On December 1, 1963, water level in the well was reported at 8 feet below land surface datum. The log of well 48N/4E-35L2 reportedly is identical to the log listed below.

	Thickness (feet)	Depth (feet)
Lake-bottom mud	283	283
Pumice and shells	8	291
Lake-bottom mud	534	825
Mud-shale streaks and sand	280	1,105
Shale	150	1,255
Hard sand	4	1,259
Mud	66	1,325
Hard shale	11	1,336
Soft shale	231	1,567
Sand streaks and shale	30	1,597
Shale	13	1,610
Rock	63	1,673
Clay and shale	6	1,679
Rock, abrasive	46	1,725
Lava rock, hard	140	1,865
Shale, tough	5	1,870
Rock	47	1,917
Shale, tough	5	1,922
Green shale, sand streaks	59	1,981
Soft lava rock, clay streaks	148	2,129
Soft clay	43	2,172
Rock, sand streaks	28	2,200
Rock	7	2,207
Lava rock, soft	41	2,248
Lava rock	143	2,391
Lava rock, lime streaks	53	2,444
Soft lava rock	10	2,454
Broken lava rock	26	2,480
Hard rock	23	2,503
Sandy lava rock	45	2,548
Soft lava rock, shale breaks	18	2,566
Firm lava rock	16	2,582
Broken lava rock	18	2,600
Firm rock	7	2,607
Lava cinders	58	2,665
Hard black rock	11	2,676

Drillers log of industrial well 48N/4E-16P3

This well was drilled by E. E. Storey of Klamath Falls, Oregon, for Western Starch Company, Inc., at Hatfield, California, in 1965. The well is 1,200 feet deep, cased to 1,148 feet below land surface and cemented in from the surface to 420 feet. On November 11, 1965, the water level in the well was reported at 10 feet below land surface datum.

	Thickness (feet)	Depth (feet)
Top soil	2	2
Clay and sand	11	13
Quicksand	2	15
Yellow clay	30	45
Blue clay	10	55
Green clay	95	150
Green shale	95	245
Gray shale	355	600
Green shale	293	893
Black lava	63	956
Black lava, layers of shale	49	1,005
Black lava	15	1,020
Black basalt	2	1,022
(not legible)	4	1,026
Black lava	16	1,042
Gray basalt	13	1,055
Black decomposed lava	113	1,168
Black lava with red lava streaks	17	1,185
Black decomposed lava	15	1,200

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