GL02079

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ROAD LOG - FIELD TRIP 3; STEAMBOAT-MOANA

Distance	Cumulative Mileage	
	0.0	MGM Grand Hotel.
0.3	0.3	Turn left from parking lot on East Second St.
0.5	0.8	Turn left on Kietzke Lane, Virginia Range at 9:00 o'clock, Carson Range (of the Sierra Nevada) at 1:00; near high peak is Mount Rose, farther one is Slide Mountain.
1.4	2.2	Turn right on Plumb Lane.
0.8	3.0	Turn left on South Virginia, Park Lane shopping center on left.
0.2	3.2	Mark Twain Motel on right. This motel has a 930-foot deep well which produces water at 120°F. Water from the well is pumped directly through individual, fan-assisted radiator fixtures in each motel unit for space heating in the winter. The hot water is also supplied to showers and sinks. The equivalent of approximately 100 motel units is heated from this system. The swimming pool is also heated geothermally, by use of a heat exchanger.
0.4	3.6	Peppermill Motel on right. This motel has 110 units, 80 of which are heated geothermally; the remainder have electric heat. The well is about 1000 feet deep. Water at 130°F is pumped from the well, circulated through individual, fan-assisted radiator fixtures in each unit, and disposed of in an irrigation canal. The water circulating in the space-heating system is generally about 117°F. The swimming pool is also heated geothermally, by use of a heat exchanger with a back-up oil-fired boiler. The boiler is usually only used for start-up heating when the pool is filled in the spring. Hot water to showers and sinks is also supplied directly from the well. City water is only used for cold water. The motel plans to build 104 more units; these will also be heated geothermally. The Peppermill Motel is on the periphery of the Moana thermal area, and wells generally need to be drilled deeper here to find hot water, and the temperatures are generally lower. See the map and detailed description of the Moana area in your field trip packet.
0.4	4.0	Turn right on Moana Lane. Sierra Pacific Power Co., main office at 10:00 o'clock.

Distance	Cumulative Mileage	
0.2	4.2	Moana Municipal Pool. In the past this pool was supplied with geothermal well water; the City of Reno recently drilled a well here, approximately 500 feet deep, which may be used to heat water for the swimming pool.
0.5	4.7	Left on Lakeside Drive at Moana West shopping center.
0.2	4.9	Shepherd of the Mountains Lutheran Church, corner of Peckham Lane and Lakeside Drive. This church is heated by a forced-air geothermal system with a down-hole heat exchanger installed when the church was constructed in 1978. The well is 360 feet deep and the water temperature in the well is 179°F.
0.2	5.1	Intersection of Lakeside Drive and Manzanita Lane. Just to the right (west) of here is the largest concentration of single-family homes heated with geothermal water. In this area the wells are generally 100-300 feet deep and water temperatures are 160-185°F. At least 30-40 homes are heated geothermally in this area.
1.5	6.6	Windy Hill. View of Virginia Range to the left. Valley area is the southern end of the Truckee Meadows
0.1	6.7	Turn left on Davis Lane.
0.4	7.1	Turn right on Del Monte Lane.
0.5	7.6	Turn left on Huffaker Lane.
1.1	8.7	Huffaker Elementary School. Turn right on U.S. 395 south.
2.9	11.6	At 10:00 o'clock the light-colored pit on the lower part of the Virginia Range is a light-weight aggregate pit in a rhyolite dome (Steamboat Hills Rhyolite) dated at 1.1-1.5 m.y. and believed to be related to the magmatic heat source for the Steamboat geothermal area.
1.4	13.0	Junction U.S. 395 and Nevada Highway 27. Turn right on Highway 27 (the Mt. Rose Highway). About 10 miles to the east on Highway 27 is famous silver mining camp of Virginia City in the Comstock Mining District. The mines were mainly worked in the late 1800's, and were known for their extremely hot, difficult working conditions. The miners commonly worked in temperatures of 100-125°F. Rock temperatures as high as 167°F were recorded from drill holes on the 3000-foot level of the Yellow Jacket Mine and a considerable amount of 170°F water later flooded that part of the mine.

Distance	Cumulative Mileage	
		Steamboat Hot Springs is located just to the south of the junction of U.S. 395 and Nevada Highway 27. This extensive geothermal area has numerous springs and steam vents, mainly in the main terrace area just west of U.S. Highway 395. The spring deposits of the main terrace are primarily opaline sinter, while older deposits in the vicinity of Pine Basin are mainly chalcedonic sinter. Steamboat Springs is an example of a present-day active epithermal gold-silver hydrothermal system. Thermal water has been encountered in water wells a considerable distance from the springs, but only limited attempts have been made to utilize the geothermal waters for space heating. The Steamboat waters are considerably more corrosive than those of Moana, and this has tended to restrict their use for non-electric purposes. In June of 1979 Phillips Petroleum Co. spudded a major exploratory geothermal well at Steamboat; it is planned to drill the well to several thousand feet.
1.5	14.5	Turn left on dirt road.
0.1	14.6	Take left fork.
0.1	14.7	Abandoned clay pit on right. The clay material (mostly kaolinite) in this pit resulted from alteration of basaltic andesite by acids which formed from hydrogen sulfide gas. The H_2S was released from ascending geothermal fluids as they boiled below the ground surface. Other minerals present include quartz, cristobalite, opal and alunite. Clay from this pit was used by Reno Press Brick Co. from the 1940's to 1963 to manufacture bricks, used mainly in the Reno area.
0.6	15.3	Pine Basin. Old spring sinter deposits here are younger than the surrounding basalt of Steamboat Hills (2.5 m.y.), but old enough to have converted to chalcedony from opaline material. Bedding or lamination in the sinter is quite steep. Painty cinnabar occurs along joints and fractures. A nearby steam well (Nevada Thermal Power Co., Steamboat No. 3) is about 1200 feet deep and has a reported temperature of about 340°F. At the western edge of Pine Basin is a pit where silica was mined in the 1930's for glass; native sulfur and cinnabar occur in highly altered granodiorite and basalt. Most of the altered rock is quartz and opal; the other components having been acid-leached from the rocks by H_2SO_4 formed as H_2S is released in near-surface groundwater. Local areas of warm ground and gases escaping from some shallow drill holes indicate that the thermal activity is continuing. Return to U.S. 395 - Highway 27 junction along same route.

Distance	Cumulative Mileage	
2.2	17.5	U.S. 395 - Highway 27 junction; turn south (right).
1.4	18.9	Turn right; Steamboat Mineral Baths to left.
0.4	19.3	<u>Main Terrace</u>, <u>Steamboat Hot Springs</u>. This terrace is opaline spring sinter. The cracks seen in the Main Terrace appear to be related to north-south trending faults or fractures which have been enlarged by acid waters precipitated from the steam issuing along the cracks. Return north toward Reno.
1.7	21.0	U.S. 395 - Highway 27 junction; continue north on U.S. 395.
10.7	31.7	Return to MGM Grand Hotel via U.S. 395, Kietzke Lane.

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MOANA HOT SPRINGS

The Moana Hot Springs are located in NE/4 S26,T19N,R19E in southwestern Reno. Although surface discharge is at present almost nonexistent, some of the wells drilled in the surrounding area maintain an artesian head. The area of thermal water wells is approximately 4 to 5 square miles centered on the springs. However, cold water wells are also found within this area, and having a well within the area is no guarantee of striking a thermal well at any particular locality.

The Moana Hot Springs were formerly the site of a spa which could be reached from downtown Reno by a streetcar line built in 1907 (Nevada State Journal, January 2, 1977). The swimming pool was also supplied for a long time with heated water from a well in the vicinity, and water was mixed directly with city water to maintain a specified pool temperature. This operation was terminated because of production problems with the well and water quality. Several homes in the area have used the thermal waters for over 40 years, although the number of wells has increased markedly in the past 10 years as the Reno residential area has expanded. Over 30 homes and three commercial establishments now utilize the geothermal waters for space heating; other uses include the heating of domestic hot water and water for swimming pools. Most of the systems use down-hole heat exchangers, and circulate city water through finned-tube baseboard heaters. Thermostatically controlled pumps are installed in most systems. Bateman and Scheibach (1975) discuss the utilization of the Moana geothermal waters in more detail.

Location of the Moana thermal system is thought to be controlled by north-south-trending faults that parallel the front of the Carson Range to the west (Bateman and Scheibach, 1975; Bonham and Bingler, 1973). Several faults in this area cut glacial outwash deposits of Illinoian age (E. C. Bingler, oral communication, 1977). It has also been noted that there is a striking north-south alignment of those wells with artesian head (past and present) and that the alignment may mark a fault trace (Bateman and Scheibach, 1975).

Although thermal ground water has been encountered in wells over an area of several square miles, the highest temperatures, as well as the area of maximum use for space and domestic hot water heating, is concentrated in an area slightly over 2 square miles. The wells in the Sweetwater Drive -- Manzanita Lane area (SE/4 NE/4 S26,T19N,R19E) are usually 100 to 300 feet in depth and many have temperatures of 160° to 185°F. To both the north and west of this area, it has been necessary to drill deeper wells to encounter thermal waters. These hot waters when encountered in drilling are associated with a "blue" clay zone which directly overlies the Tertiary bedrock units here and may be up to 150 feet thick. The hot water is not generally found above this "blue" clay zone (Bateman and Scheibach, 1975). If the water moves upward through faults in the bedrock, this clay zone may act as a relatively impermeable cap, forcing the water to diffuse laterally (and vertically) away from the fault zone. Noticable increases in water temperature were observed when certain wells were drilled through the contact between the clay and underlying bedrock. The existence of an artesian head only in wells drilled along a certain alignment, presumably a fault, may further support this theory of near-surface operation of the system. Wells drilled into or through the clay at some distance from such an input zone would tend not to display artesian conditions due to the hydraulic head loss involved in moving water laterally through the clays and andesite.

Water temperatures encountered at depths in excess of 100 feet range from 167° to 205°F. Deeper wells do not in general have the highest temperatures, suggesting that temperatures deep within the system may not be appreciably greater than those encountered nearer to the surface. Temperature profiles of several wells within the area show a pattern of a leveling off of temperature with depth (Bateman and Scheibach, 1975).

REFERENCES

Bateman, R. I., and Scheibach, R. B. (1975) Evaluation of geothermal activity in the Truckee Meadows, Washoe County, Nevada: Nevada Bur. Mines and Geology Rept. 25.

Bonham, H. F., Jr., and Bingler, E. C. (1973) Geologic map, Reno Folio: Nevada Bur. Mines and Geol.

Map showing locations of shallow thermal wells in southwest Reno that are used for space heating, domestic hot water, and swimming pools (from unpublished map by R. B. Scheibach, 1974).

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STEAMBOAT HOT SPRINGS

Steamboat Hot Springs are located approximately 9 miles south of downtown Reno, just south of the junction of U. S. Highway 395 and State Route 27 (S33,T18N,R20E).

The springs have a long history as a resort and health spa. They were first located in 1860 by Felix Monet. They are so named because, when discovered, escaping steam reportedly produced a noise resembling the puffing of a steamboat. The area had several owners and developments before 1871, when the Virginia and Truckee Railroad was completed to this point and a small town sprang up (Hummel, 1888). A post office was established in 1880 and exists to this day. Some of the resorts have used the names Reno Hot Springs, Mount Rose Hot Springs, or Radium Hot Springs. The deposits of sulfur and cinnabar were first opened up in 1876, and numerous attempts have since been made to mine these deposits (Overton, 1947).

The Steamboat Hot Springs area is the best known and most extensively studied geothermal area in Nevada, and one of the better known thermal areas of the world. The geology and geochemistry have been described in detail by White and others (1964). Other references on the geology of the hot springs area and the surrounding vicinity include: Thompson and White (1964), Bateman and Scheibach (1975), and Tabor and Ellen (1975).

Much of the following geologic description is summarized from White (1968), White and others (1964), Thompson and White (1964), and Bateman and Scheibach (1975). Bonham's (1969) summary of White and others (1964) has also been extensively quoted in the following.

The oldest rocks in the Steamboat Springs area are metamorphosed sedimentary rocks which have been intruded by granodiorite. The sedimentary rocks are largely metamorphosed water-lain volcanic tuffs with intercalated beds of sandstone, conglomerate, and limestone. They are probably Triassic in age. Much of the Steamboat Springs area is underlain by granodiorite of probably Cretaceous age. The granodiorite has been hydrothermally altered over most of the area, and near-surface bleaching is prevalent in and adjacent to the thermal areas.

Flows of soda trachyte, correlated with the Tertiary Alta Formation, crop out at a few localities in the district and have also been recognized in several of the drill holes located within the thermal area. The soda trachyte overlies granodiorite. Two small erosion remnants of an andesite flow are the only rocks of the Kate Peak Formation that crop out in the district. Rocks of the Kate Peak Formation, however, crop out over extensive areas immediately adjacent to the Steamboat Springs district.

Basaltic andesite flows extend over much of the southern and eastern parts of the Steamboat Springs district. The flows overlie granodiorite and alluvial deposits. These pre-basaltic andesite pediment gravels and alluvium are present over much of the district. They rarely crop out, because they are usually concealed beneath younger rocks, but they have been encountered in a number of the drill holes. The oldest deposits of hot-spring sinter are also of prebasaltic andesite age. Several areas of this early hot spring sinter are present in the district.

The Steamboat thermal area lies on a line connecting several rhyolite domes that occur to the southwest and northeast of the thermal area. These rhyolite domes have been named the Steamboat Hills Rhyolite. The emplacement of the large dome that lies southwest of Steamboat Springs was preceded and accompanied by extensive pyroclastic eruptions that mantled much of the adjacent area with a layer of rhyolite pumice. It has been proposed (White and others, 1964) that another rhyolite intrusive may underlie the hot-spring area.

White and others (1964) have differentiated several different types of Quaternary deposits in the Steamboat Springs district, including pre-Lahontan alluvium, post-basaltic andesite sinter, opaline hot-spring sinter, alluvium of Lahontan age, and Recent alluvium and hot-spring deposits. Their detailed mapping of these Quaternary deposits has contributed greatly to an understanding of the history of the Steamboat Springs area.

The hot-springs system formed in the early Pleistocene, prior to the eruption of the basaltic andesite flows in the Steamboat area. The basaltic andesites have been dated at approximately 2.5 m.y., and the rhyolite domes have given K-Ar ages of 1.15 to 1.52 m.y. Also, hydrothermal potassium feldspar which replaces basaltic andesite gave an age of 1 m.y. (Silberman and White, 1975). Thus, the hot-spring system is seen to have been active, possibly intermittently, for over 2.5 m.y. The source of the energy for the thermal convective system is most probably the rhyolitic magma chamber from which the rhyolitic domes were emplaced (Silberman and White, 1975). It has been estimated that about 0.001 km^3 of new magma would have to be provided each year to supply the heat at the present rate of heat loss.

The thermal waters contain small amounts of metals, including mercury, antimony, silver, and gold and have deposited small amounts of stibnite, gold, and silver, and larger amounts of cinnabar in both hot-spring sinter and in the altered wall rocks adjacent to the hot-spring vents.

The thermal waters at Steamboat are high in Na, Cl, HCO_3, and SiO_2, and have a significant Li content. Also, they are anomalous in As, Sb, Hg, Cs, and B. Mercury vapor is commonly detected in the steam from springs and wells. The relative abundance of these highly soluble elements which have a low crustal abundance, coupled with the long life of the geothermal system, creates great problems with maintaining the supply of these elements by rock leaching. White (1974) suggests that the spring waters include a continuing small supply of magmatic water enriched in the previously mentioned constituents. Oxygen isotope data show that there could be no more than 11 percent magmatic water supplied to the hydrothermal system, and it is probably less than 5 percent.

All of the wall rocks in the thermal area have been altered. Near-surface acid bleaching is the most obvious visible effect at the surface, and it has strongly affected the granodiorite and the basaltic rocks. The near-surface acid bleaching extends to depths of 100 feet or more. Below this zone the rocks adjacent to the channelways of migrating thermal waters have been hydrothermally altered. A type of propylitic alteration is prevalent in this zone.

The main terrace at Steamboat Hot Springs is made up of siliceous spring deposits, primarily opaline sinter. It is believed that with time this will change to chalcedonic sinter. A large area of chalcedonic sinter is present in Pine Basin to the southwest of the main terrace and is believed to be the most extensive chalcedonic hot-spring sinter known in the world. It contains disseminated cinnabar. Also, small amounts of siliceous sinter are present about 1.5 miles south of Steamboat Hot Springs in C NE/4 S5,T17N,R20E, and a small deposit of spring travertine is located in SW/4 SW/4 SW/4 S5,T17N,R20E on the southeast flank of Steamboat Hills about 100 feet above the floor of Pleasant Valley (Thompson and White, 1964).

The springs at Steamboat are near boiling, and exploration steam wells have reported temperatures as high as 369°F. One well encountered temperatures of up to 280°F at only 160 feet (White, 1968). The hot water is reported to have 5% to 10% steam flashover (Koenig, 1970). Preferred estimated reservoir temperatures from chemical geothermometers are approximately 400°F (Mariner and others, 1974). Six steam wells, ranging in depth from 716 to 1,830 feet were drilled in the late 1950's and early 1960's by Nevada Thermal Power Co. Also, the U. S. Geological Survey drilled eight core holes for a total of 3,316 feet, and, in the past, several other wells have been drilled in the area for spas. Several years ago the hot water from one steam well was used as a flameless source of heat for the manufacture of plastic explosives.

REFERENCES

Bateman, R. I., and Scheibach, R. B. (1975) Evaluation of geothermal activity in the Truckee Meadows, Washoe County, Nevada: Nevada Bur. Mines and Geology Rept. 25.

Bonham, H. F. Jr. (1969) Geology and mineral deposits of Washoe and Storey Counties, Nevada: Nevada Bur. Mines Bull. 70.

Hummel, N. A. (1888) General history and resources of Washoe County, Nevada Educ. Assoc. (printed by the Reno Evening Gazette).

Koenig, J. B. (1970) Geothermal exploration in the western United States: Geothermics, Spec. Issue 2, v. 2, pt. 1, p. 1-13.

Mariner, R. H., Rapp, J. B., Willey, L. M., and Presser, T. S. (1974) Chemical composition and estimated minimum thermal reservoir temperatures of the principal hot springs of northern and central Nevada: U. S. Geol. Survey open-file report.

Overton, T. D. (1947) Mineral resources of Douglas, Ormsby, and Washoe Counties (Nevada): Nevada Univ. Bull., v. 41, no. 9 (46).

Silberman, M. L., and White, D. E. (1975) Limits on the duration of hydrothermal activity at Steamboat Springs, Nevada, by K-Ar ages of spatially associated altered and unaltered volcanic rocks (abs.): Geol. Soc. America Abstr. with Programs, v. 7, no. 7, p. 1272-1273.

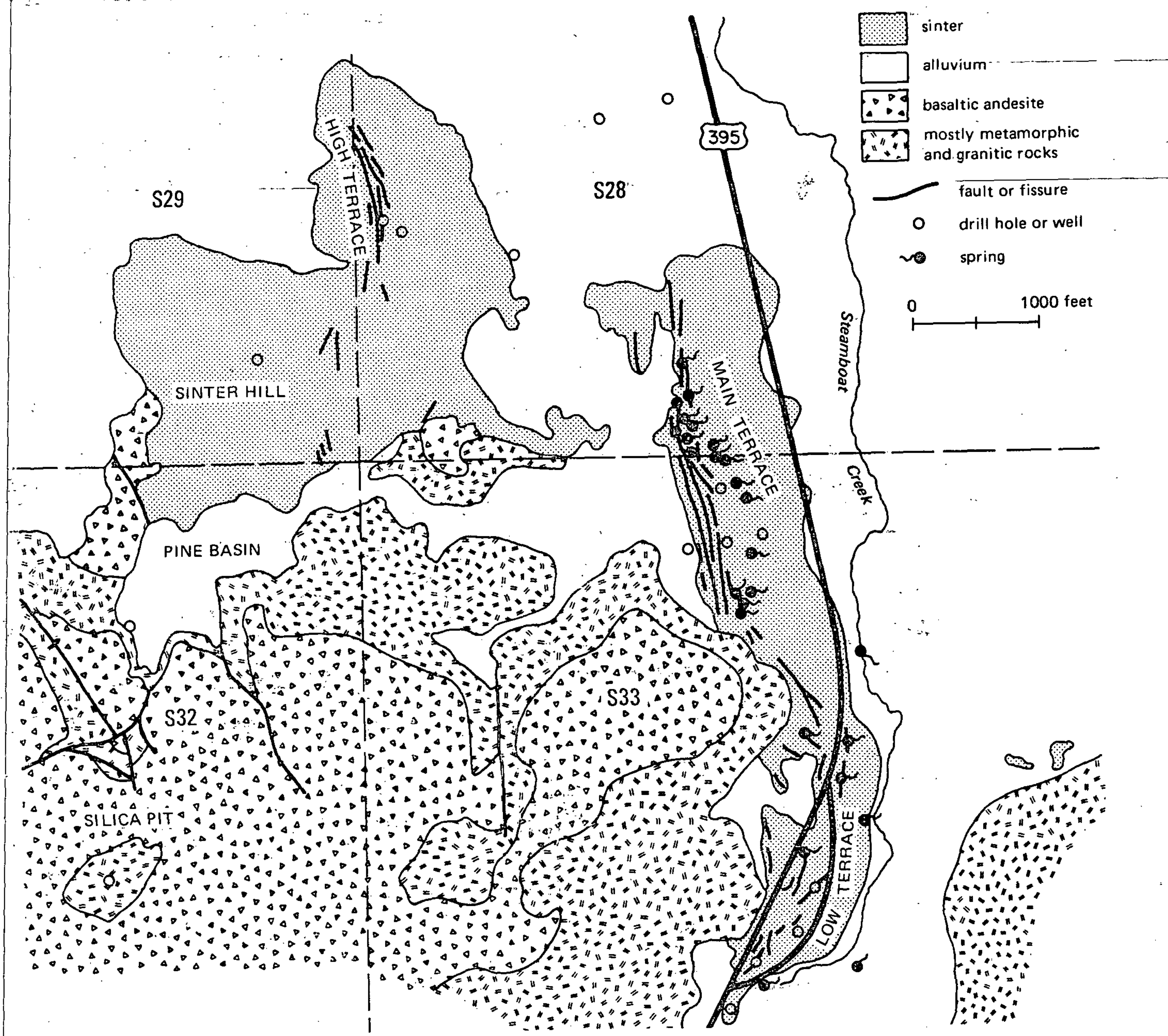
Tabor, R. W., and Ellen, S. (1975) Geologic map, Washoe City Folio: Nevada Bur. Mines and Geol.

Thompson, G. A., and White, D. E. (1964) Regional geology of the Steamboat Springs area, Washoe County, Nevada: U. S. Geol. Survey Prof. Paper 458-A, p. A1-A52.

White, D. E. (1968) Hydrology, activity, and heat flow of the Steamboat Springs thermal system, Washoe County, Nevada, geology and geochemistry of the Steamboat Springs area, Nevada: U. S. Geol. Survey Prof. Paper 458-C.

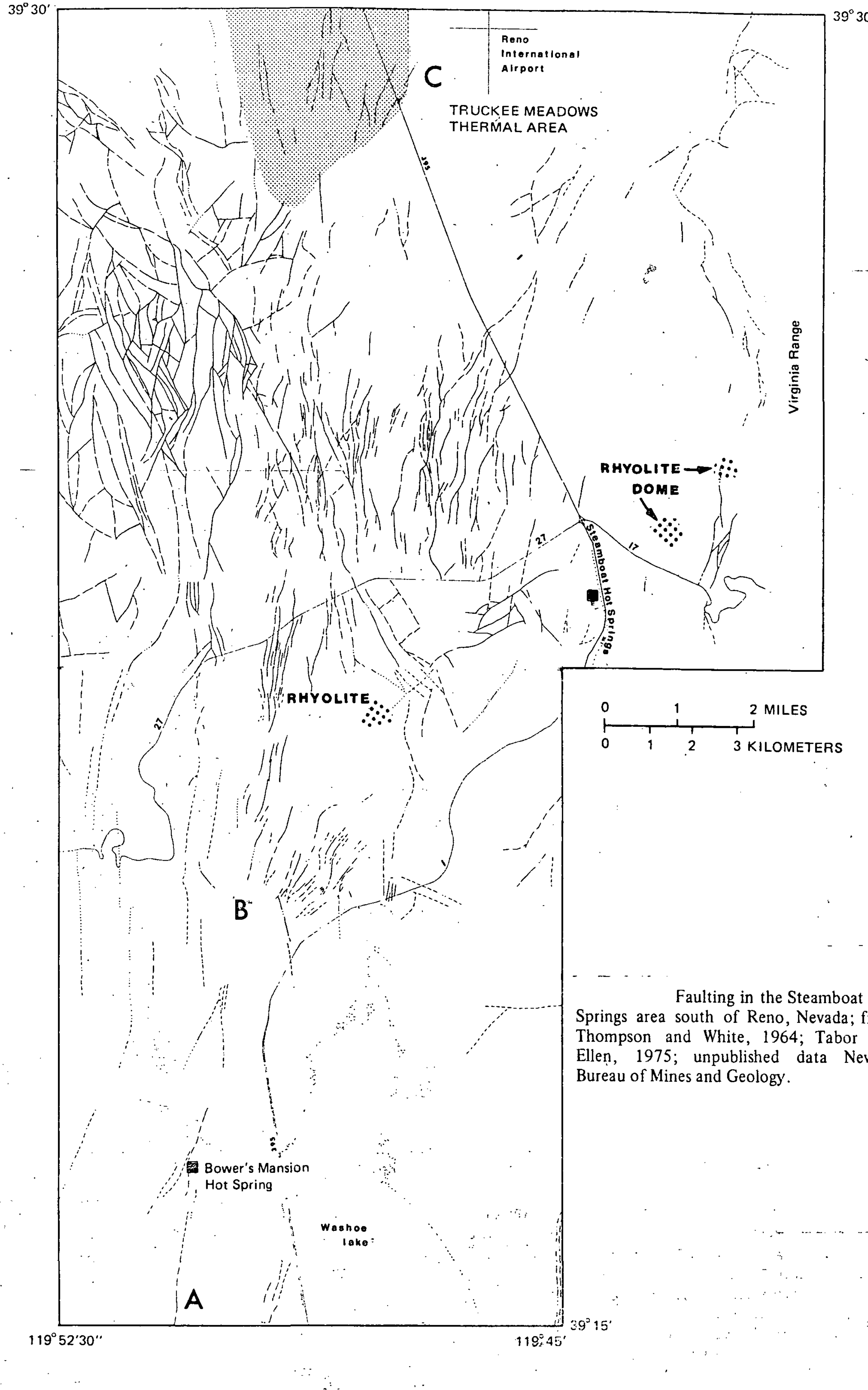
White, D. E., Thompson, G. A., and Sandberg, C. H. (1964) Rocks, structure, and geologic history of Steamboat Springs thermal area, Washoe County, Nevada: U. S. Geol. Survey Prof. Paper 458-B.

Generalized geologic map of Steamboat Springs thermal area, T18N, R20E, Washoe County (modified from White and others, 1964).

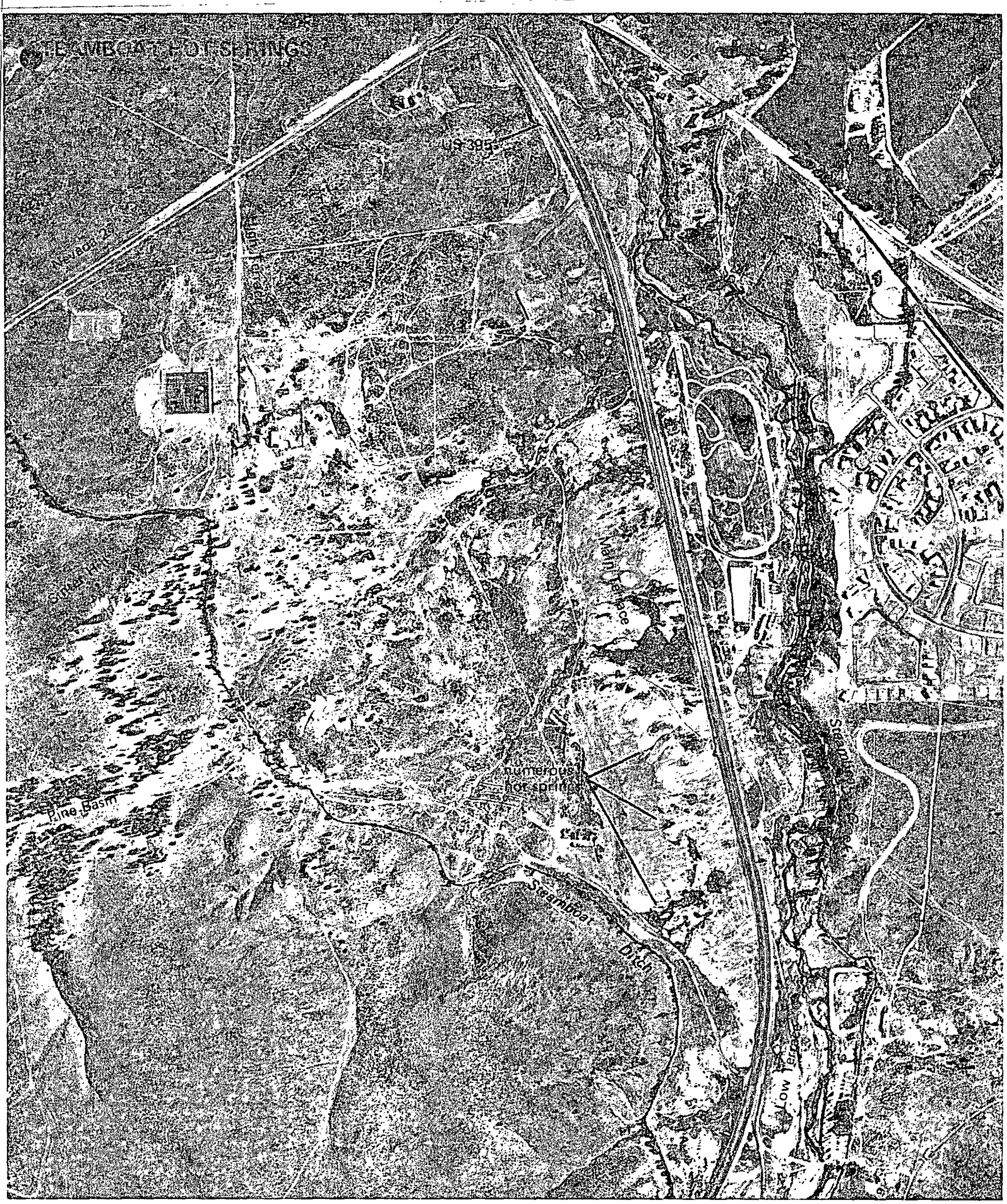


Geothermal wells drilled at Steamboat Hot Springs.

Operator	Name	API No.	Location	Depth, ft	Completion Date	Maximum Temperature (°F)
Nevada Thermal Power Co.	Steamboat No. 1	27-031-90000	NW¼ NE¼ S28,T18N,R20E	1830	1954	
Nevada Thermal Power Co.	Steamboat No. 2	27-031-90001	SE¼ SW¼ S28,T18N,R20E	964	1959	
Nevada Thermal Power Co.	Steamboat No. 3	27-031-90002	NW¼ NE¼ S32,T18N,R20E	1263	1960?	
Nevada Thermal Power Co.	Steamboat No. 4	27-031-90003	NE¼ NW¼ S32,T18N,R20E	520?	1960	367
Nevada Thermal Power Co.	Steamboat No. 5	27-031-90004	NW¼ NW¼ S32,T18N,R20E	826	1961	347
Nevada Thermal Power Co.	Steamboat No. 6	27-031-90005	NW¼ NW¼ S32,T18N,R20E	716	1961	354



Faulting in the Steamboat Hot Springs area south of Reno, Nevada; from Thompson and White, 1964; Tabor and Ellen, 1975; unpublished data Nevada Bureau of Mines and Geology.


STEAMBOAT HOT SPRINGS
US 395
Nevada 22
Main Terrace
numerous hot springs
Pine Basin
Steamboat Ditch
Low Terrace

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BRADY'S HOT SPRINGS

The hot springs along U. S. Highway I-80 about 20 miles northeast of Fernley have been referred to as Hot Springs, or Brady's, Springer's or Fernley Hot Springs, and are the Emigrant Springs of the Forty-Mile Desert. Some early travelers called it the Spring of False Hope. Coming across the desert, the oxen of the wagon trains could smell the moisture before reaching the springs. However, when they rushed forward to drink, they found the water scalding. The emigrants collected water in casks to cool, but pushed on to the Truckee River, as there was no forage at the springs (Works Projects Administration, 1940).

In the 1880's Russell (1885) reported that hot boiling water issued from a number of orifices, and when these became obstructed, the steam escaped with a hissing and roaring sound. During this same period there was an unsuccessful attempt to separate boric acid from the waters. In later years the hot water was used in a bathhouse and swimming pool which were located at a service station along U. S. Highway 40. The concrete pool, built in 1929, is all that remains today. The pool was apparently supplied by hot water directly from the springs. The hot springs do not flow at the surface today.

Brady's Hot Springs are located in NE/4 NE/4 SW/4 S12,T22N,R26E. Thermal ground water is found within an area of 6 to 8 square miles centered on this location. The elongate thermal area is parallel to the "Thermal Fault" mapped by Anctil and others (1960). Areas of hydrothermal alteration are aligned along this fault, and its trace has also been outlined by areas of observed snowmelt, indicating warm ground (Olmsted and others, 1975). This fault has had recent movement, as it cuts spring sinter and the alluvial fan deposits in the spring area and to the north. The fault is normal and dips steeply to the west, with the downthrown side to the west; the amount of displacement is unknown (Olmsted and others, 1975). All successful steam wells were collared in the hanging wall of the Brady Thermal Fault (Anctil and others, 1960).

The rocks exposed in the vicinity of Brady's consist of Tertiary basalt and andesite, Tertiary sedimentary rocks, Pleistocene lake sediments, and Quaternary alluvial deposits and siliceous sinter. None of the wells drilled at Brady's (up to 7,275 ft. deep) penetrated the pre-Tertiary rocks, although they are exposed in the northern Hot Springs Mountains and were found in steam wells near Desert Peak 4 miles to the southeast.

Bailey and Phoenix (1944, p. 51) report the presence of cinnabar and sulfur in S6(?),T22N,R27E about one-quarter mile southeast of U. S. Highway 40 and one-half mile east of the hot springs. The best showings of cinnabar are reported from around an active hot-spring vent. The occurrence is in hydrothermally altered tuff. Soil gas in the vicinity of the main Thermal Fault and around active steam vents at Brady's is anomalous in mercury (John Robbins, Scintrex Limited, written communication, 1973).

The spring sinter at Brady's is predominantly opal, and is quite extensive. It is concentrated along the main Thermal Fault and a small subsidiary fault to the east (Oesterling and Anctil, 1962).

The ground water in Fireball Valley (Hot Springs Flat) to the north probably moves as underflow to Brady's Hot Springs, and other ground water may move as underflow from the Fernley area (Harrill, 1970). Olmsted and others (1975) suggest that the recharge of the thermal area could be outside the local drainage area.

Ground-water discharge from the thermal area is in part by evapotranspiration and in part by lateral subsurface outflow toward the south. Prior to the drilling of geothermal wells in the late 1950's and early 1960's (but after diversion of the flow to a swimming pool) White (written communication, 1974 _in_ Olmsted and others, 1975) estimated a spring flow of about 20.6 gpm. Waring (1965) reported a larger flow (50 gpm), but White believes that this may be too large. The withdrawal of water during drilling may have caused the springs to cease flowing (Harrill, 1970) and at present all discharge is in the subsurface. The original spring was 180°F (Oesterling, 1962). Boiling water reportedly stands at 20 feet below the surface in one well (Willden and Speed, 1974, p. 55).

Twelve major geothermal wells have been drilled at Brady's Hot Springs over the past 20 years, ranging in depth from 341 to 7,275 feet. The temperatures encountered during drilling were up to 418°F, (Koenig, 1970). Following the drilling of Magma Power Co. Brady No. 2 well in 1959 thermal activity spread along the 3-mile portion of the main fault. This activity was probably due to steam escaping through the uncased portions of the wells and into the fault zone. Olmsted and others (1975) describe this activity in more detail from data in a 1960 unpublished report by Allen. Tests on several wells shortly after drilling indicated 170,000 to 700,000 lbs/hr of fluid. The well head pressure was 9.5 to 18.0 lbs/in^2 gage (psig) (Middleton, undated report). The steam flashover is reported to be 5% (Koenig, 1970). Calcite is reported to form rapidly in the well bores during flow, requiring reaming of the wells after a short period of time. However, the amount of scaling is reported to decrease after the wells have been produced for some time (Oesterling, 1962). The thermal water at Brady's is of the sodium chloride type, with total dissolved solids from some steam wells reported to be over 2,400 ppm. The silica concentration from a steam well near C S12,T22N,R26E (Harrill, 1970) indicates a reservoir temperature of about 360°F (Olmsted and others, 1975). This seems somewhat low in view of the 400°F + temperatures reported during drilling. Geothermal Food Processors, Inc. of Reno, Nevada constructed a geothermal food dehydration plant at Brady's in 1978. A Federally guaranteed loan covered 74 percent of the $3.8 million total cost of the project (Nevada State Journal, October 29, 1977).

REFERENCES

Anctil, R. J. (1960) Areal economic geology of T37N,R43E and 44E, M.D.M.: Southern Pacific Co., unpubl. map.

Anctil, R. J., and others (1960) Geology of Brady Hot Springs and vicinity, Churchill County, Nevada: Southern Pacific Co. unpubl. map.

Bailey, E. H., and Phoenix, D. A. (1944) Quicksilver deposits in Nevada: Nevada Univ. Bull., v. 38, no. 5 (41).

Harrill, J. R. (1970) Water-resources appraisal of the Granite Springs Valley area, Pershing, Churchill, and Lyon Counties, Nevada: Nevada Dept. Conserv. and Nat. Resources, Water Resources-Reconn. Ser. Rept. 55.

Middleton, W. M. (undated) Data and comments on geothermal steam wells at Brady Hot Springs, Nevada: Magma Power Co. unpubl. report.

Oesterling, W. A. (1962) Geothermal power potential of northern Nevada: Pacific Southwest Mineral Industry Conf., Am. Inst. Mining, Metallurgical, Petroleum Engrs., San Francisco, unpubl. report.

Oesterling, W. A.,and Anctil, R. J. (1962) Geological and economic appraisal of geothermal steam resources at Brady Hot Springs, Nevada: Southern Pacific Co., unpubl. report.

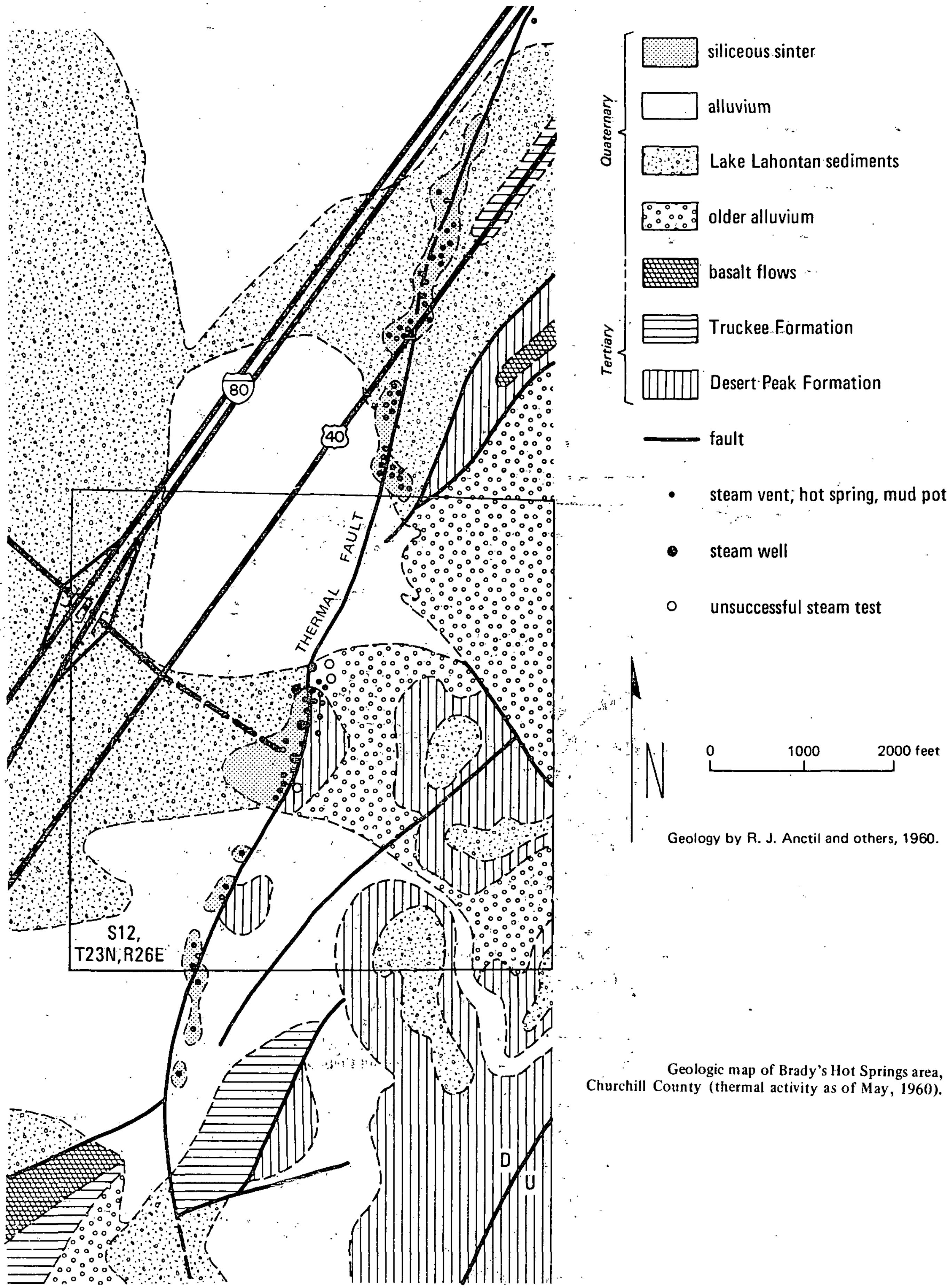
Olmsted, F. H., Glancy, P. A., Harrill, J. R., Rush, F. E., and Van Denburgh, A. S. (1975) Preliminary hydrogeologic appraisal of selected hydrothermal systems in northern and central Nevada: U. S. Geol. Survey open-file report 75-56.

Russell, I. C. (1885) Geological history of Lake Lahontan: U. S. Geol. Survey Mon. 11.

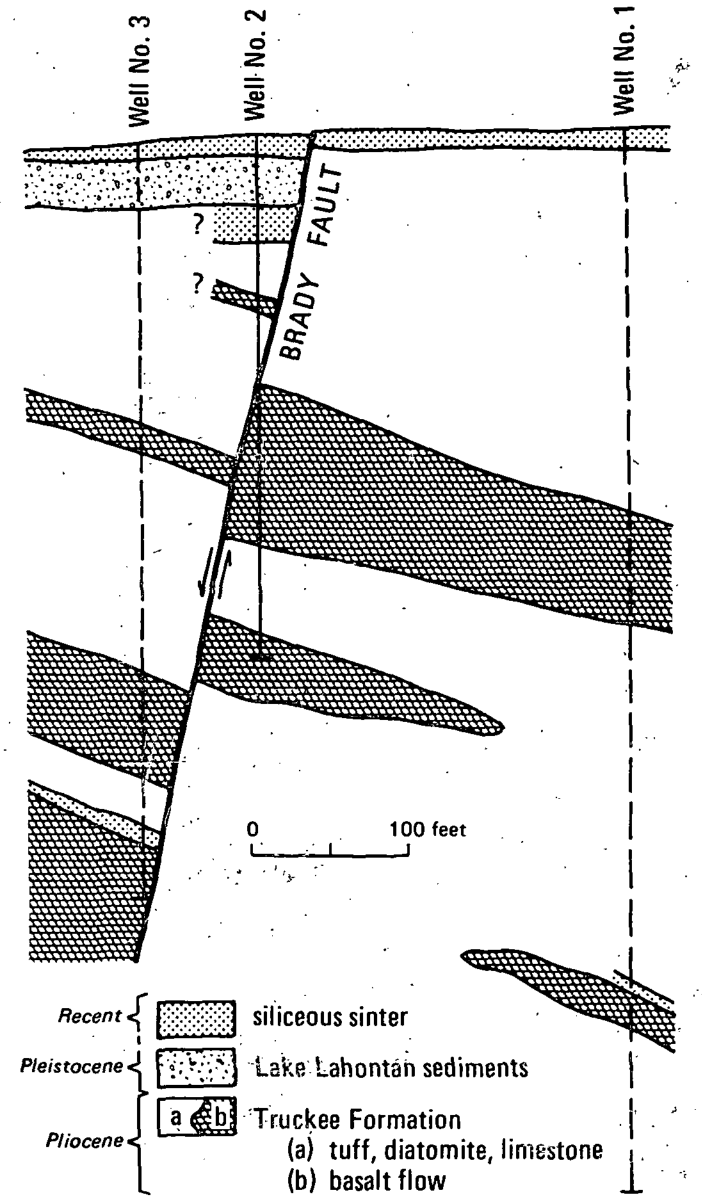
Waring, G. A. (1965) Thermal springs of the United States and other countries of the world: U. S. Geol. Survey Prof. Paper 492.

Willden, Ronald, and Speed, R. C. (1974) Geology and mineral deposits of Churchill County, Nevada: Nevada Bur. Mines and Geol. Bull. 83.

Works Projects Administration (1940) Nevada, a guide to the Silver State: Portland, OR, Binfords and Mort.



Geologic map of Brady's Hot Springs area, Churchill County (thermal activity as of May, 1960).



Cross section (based on driller's logs), looking north-northeast, at Brady's Hot Springs, Churchill County (after Oesterling and Anctil, 1962).

Geothermal wells drilled at Brady's Hot Springs.

Operator	Name	API No.	Location	Depth, ft	Completion Date	Maximum Temperature (°F)
Magma Power Co.	Brady No. 1	27–001–90000	NE¼ NE¼ SW¼ S12,T22N,R26E	700?	1959?	
Magma Power Co.	Brady No. 2	27–001–90001	NE¼ NE¼ SW¼ S12,T22N,R26E	241	1959?	330
Magma Power Co.	Brady No. 3	27–001–90003	SE¼ SE¼NW¼ S12,T22N,R26E	610	1961?	335
Magma Power Co.	Brady No. 4	27–001–90003	SE¼ SE¼ NW¼ S12,T22N,R26E	723	1961?	
Magma Power Co.	Brady No. 5	27–001–90004	NW¼ SW¼ NE¼ S12,T22N,R26E	1800	1961?	340
Magma Power Co.	Brady No. 6	27–001–90005	NW¼ SW¼ NE¼ 212,T22N,R26E	770	?	
Magma Power Co.	Brady No. 7	27–001–90006	NW¼ SW¼ NE¼ S12,T22N,R26E	250	?	
Earth Energy Inc.	R Brady EE No. 1	27–001–90007	S12?,T22N,R26E	5062?	1964	414
Earth Energy Inc.	Brady Pros. No. 1	27–001–90008	S12?,T22N,R26E	1758?	1965?	355
Union Oil Co. of Calif.	SP–Brady No. 1	27–001–90010	NE¼ SW¼ SE¼ S1,T22N,R26E	7275	1974	371
Magma Energy Inc.	SP–Brady No. 2	27–001–90013	NE¼ NW¼ SE¼ S1,T22N,R26E	4446	1975	∿300
Magma Energy Inc.	SP–Brady No. 8	27–001–90014	NE¼ SE¼ NW¼ S12,T22N,R26E	3469	1975	

———20———

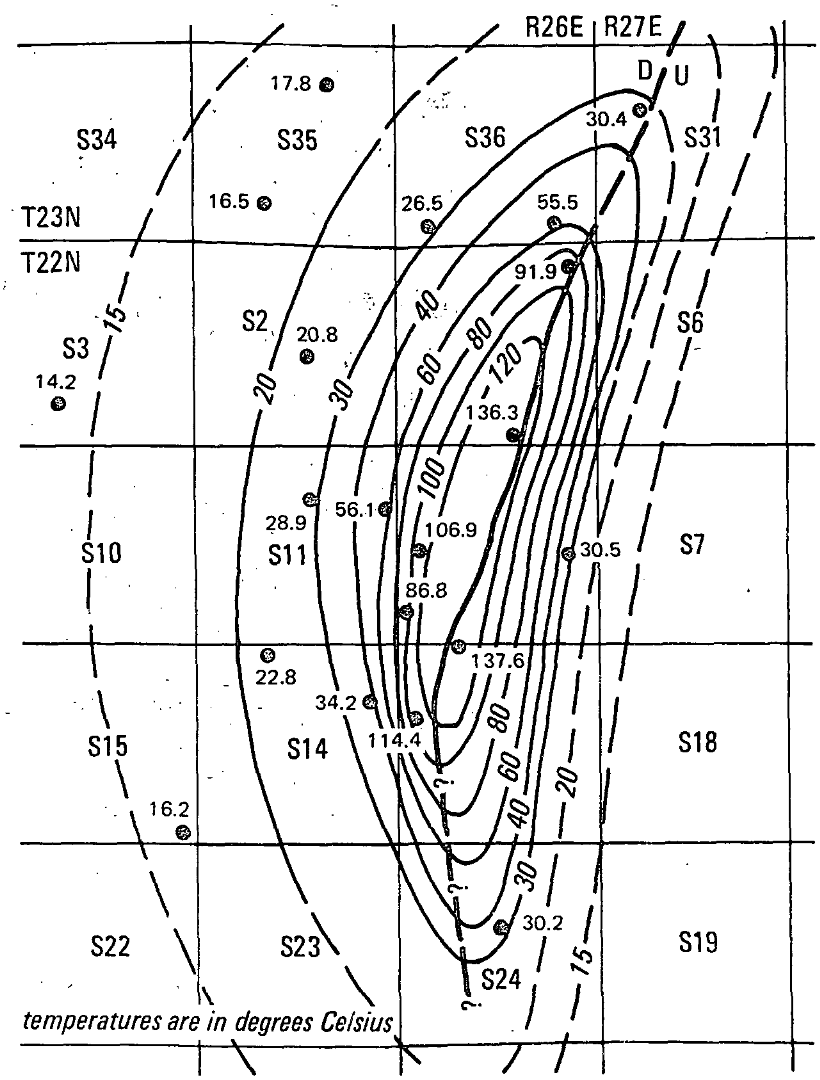
line of equal temperature (°C) at a depth of 30 meters

⊗ 30.2

test hole, number is temperature (°C) at a depth of 30 meters

—— —— ——?——

fault, dashed where concealed, queried where indefinite



Map of Brady's Hot Springs thermal area, Churchill County, showing temperature at depth of 30 meters, 1973 (modified from Olmsted and others, 1975).

NBMG REPT. 25

GEOTHERMAL ACTIVITY IN THE TRUCKEE MEADOWS

BATEMAN

NEVADA BUREAU OF MINES AND GEOLOGY

REPORT 25

EVALUATION OF GEOTHERMAL ACTIVITY IN THE TRUCKEE MEADOWS, WASHOE COUNTY, NEVADA

(Prepared in cooperation with the Center for Water Resources Research, Desert Research Institute, University of Nevada System, Reno, Nevada)

BY RICHARD L. BATEMAN AND R. BRUCE SCHEIBACH

Center for Water Resources Research, Desert Research Institute

A description and discussion of geothermal water in the Reno urban area: the location, extent, and temperature of the hot water; its chemical quality, dispersion, and mixing with non-thermal ground water; and its past, present, and future use for home, and other types of space, heating.

MACKAY SCHOOL OF MINES

UNIVERSITY OF NEVADA • RENO

1975

NEVADA BUREAU OF MINES AND GEOLOGY
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CONTENTS

ILLUSTRATIONS

PAGE

TABLES

FOREWORD

Hopefully the deepening energy crisis has made everyone aware of the need for alternate sources of energy to replace oil and natural gas. Utilizing the earth's heat—geothermal energy—is one of the more interesting possibilities, and has attracted considerable attention. However, much of this interest has focused on using geothermal energy to generate electricity. Geothermal steam is being used to generate electricity in several areas of the world where conditions are particularly favorable, but many complex problems must be solved before most other areas with potential (such as Nevada) can be brought on stream.

Geothermal energy also is being used for heating, but has received much less attention. We at the Nevada Bureau of Mines and Geology have been doing research on, and making appraisals of, Nevada's geothermal resources for a number of years. More and more we feel that home, greenhouse, and other space heating could be as important a use of geothermal energy in Nevada as the generation of electricity, possibly even more important. This is especially true over the short term, while the expensive problems of electric generation are being worked out. Heating requires only small, relatively simple and inexpensive installations that can utilize hot water and require little maintenance.

This study, done as a cooperative project between the Center for Water Resources Research and the Nevada Bureau of Mines and Geology, documents the use of geothermal water for space heating in the Reno area, and hopefully will encourage further utilization.

John H. Schilling
Director
Nevada Bureau of Mines and Geology

ABSTRACT

This study describes occurrences of geothermal activity within Truckee Meadows area of Washoe County, Nevada, and discusses the potential for utilizing geothermal resources for residential heating. Probable effects of thermal waters on overall ground-water conditions under a pattern of increasing development within the basin are estimated. All chemical quality and temperature data for thermal and non-thermal ground waters were assembled and subjected to various forms of analysis. Additional data were developed in areas of inadequate historical coverage. Results were used to precisely delineate areas of geothermal occurrence and assess the probable results of induced mixing of poor-quality thermal and good-quality non-thermal ground waters. Present degradation of non-thermal ground waters was determined to be minimal. Increased mixing of thermal and non-thermal water is a potential problem, especially in regard to trace constituents such as arsenic and fluoride.

Past and present utilization of the local geothermal resource were inventoried and evaluated. The most frequent present use is for single residence heating employing geothermal wells and simple heat-exchanger systems. Approximately 32 dwelling units and 3 commercial buildings are heated in this manner. Detailed analysis of existing heating systems identified several design and system operation improvements which could be made.

This research indicates that space heating is the most practical beneficial use of the geothermal resources in the Truckee Meadows, and that further expansion of this use is feasible under present technology. Development will be restricted to only a portion of the total geothermal area within the Truckee Meadows. However, development of more efficient heat-exchange systems that can function effectively at lower temperature and with more highly mineralized water, will permit greater exploitation of the resource.

ACKNOWLEDGMENTS

This investigation could not have been completed without the cooperation of the numerous residents of the study area who own the thermal wells here under consideration. These people provided access to wells for sampling purposes, and willingly answered questions about design, construction, and operation of their heating systems. For this assistance the authors are extremely grateful.

Mrs. Patricia Harris and staff of the Center for Water Resources Research (CWRR) analytical laboratory performed the chemical analyses of thermal well waters.

The section of this report dealing with the mechanics of domestic-commercial use of thermal waters for heating purposes is primarily the work of Mr. Scott Mansfield of Mansfield Process Engineering, Reno, Nevada. Mr. Mansfield served as a consultant to CWRR, and the authors wish to extend their thanks to him for his contributions to this investigation.

As stated in the Forward, this study has been a cooperative effort between CWRR and the Nevada Bureau of Mines and Geology. Personnel from the Bureau were involved in initial formulation of the study and provided assistance throughout. Deserving of special mention are John Schilling, Director, and Larry Garside and Kenneth Luza of the Bureau staff.

SUMMARY AND CONCLUSIONS

Areas of geothermal occurrence are common within the Truckee Meadows. Warm to hot waters either have been encountered in the subsurface, or discharge naturally at several locations along the margins of the basin. Occurrences are probably related to faulting which has concentrated major geothermal activity at two sites, Steamboat Springs and the Moana area.

Steamboat Springs is a classic geothermal area, exhibiting hot springs, steam, geysers, siliceous terrace deposits, and exotic mineralization. Water temperatures at the surface range from 50°C to approximately 96°C (boiling at site elevation). At Steamboat Springs temperatures in excess of 160°C have been measured at depth. Elsewhere within the Truckee Meadows, surface evidence of geothermal activity is limited to a small number of warm water springs. The Moana area has little if any surface discharge, but temperatures as high as 98°C have been encountered at depths as shallow as 100 feet. Water temperatures of other small-scale geothermal sites do not generally exceed 40°C. Heated water at these sites may occur at shallow or at relatively great depths.

The heat source for the Steamboat Springs system is postulated to be a cooling intrusive body at depth. Quaternary rhyolitic domes found in the vicinity of the springs and in the Virginia Range to the east may be related to this intrusive body. Further evidence for a magmatic heat source is provided by the chemical quality of discharged water which, by its makeup, is suggestive of an approximate 5 to 6 percent contribution of magmatically derived fluids. Although recent volcanic activity is not apparent at Moana or at any of the small dispersed sites, the source of heat for these areas is also presumed to be an intrusive body at depth. Such a heat source need not be different from that supplying Steamboat Springs, although lower temperatures and less mineralized waters do suggest a less direct contact with the heat source.

The most significant problem associated with this extensive geothermal activity is water quality. Thermal waters are of much poorer chemical quality than non-thermal ground waters. Average total dissolved solids (TDS) of thermal and non-thermal ground water are 1130 and 482 milligrams per liter (mg/l), respectively. In addition, most thermal waters contain concentrations of trace constituents such as arsenic and fluoride that are in excess of recommended drinking water standards.

Mixing of poor-quality thermal waters with non-thermal ground water occurs to a limited extent due to existing ground-water flow patterns. A small portion of this mixing may be due to present ground-water pumping. If withdrawals of ground water are significantly increased, more mixing and a resultant decrease in overall ground-water quality will occur. Arsenic concentration may prove to be a limiting factor, because a contribution of less than 10

percent of certain thermal waters could cause the mixed product water to exceed recommended drinking water standards. Other dissolved constituents may exceed recommended standards in a mix containing 30 to 50 percent thermal water. Specific recommendations to help avoid development of this problem are not within the scope of this study, but in general, it may be stated that a detailed study of the hydrogeology of the Truckee Meadows, careful location of large wells, and regular monitoring of ground-water quality would be useful.

Geothermal resources of the Truckee Meadows have not been extensively developed. During the 1950's, feasibility of commercial electric power generation at Steamboat Springs was investigated, but at that time it was found to be impractical because of insufficient temperature and high mineral content of the "wet" steam. Successful historical uses of the resource include spas, mining of mercury, silica and clay formed or deposited by hot springs, explosives manufacturing, and heating of commercial and residential buildings. The latter is the use with most promise for increased application. At present, approximately 35 geothermal heating systems are being operated within the Truckee Meadows. Most of these systems are located in the Moana area, where thermal waters are not excessively mineralized and the temperature of well water ranges from 60 to 90°C.

Development of geothermal heating systems has been on a more or less individual basis, although designs are relatively similar. The present philosophy is to drill an 8-inch well deep enough to encounter at least 70°C water. A 2-inch or smaller diameter copper U-tube (trombone) is then immersed in this water and heat is transferred to water circulating through the tubing. This heated water is then fed through baseboard heaters within the building.

Results of this study suggest that currently employed methods of extracting geothermal heat for space heating can be significantly improved. Studies indicate that well temperature and hot zone length are not the only important considerations. Other important factors are: 1) temperature of the circulating water (baseboard heater or coil bank temperature), 2) heat transfer coefficient from the reservoir to the trombone, 3) heat transfer area of the trombone, and 4) diameter of the trombone tubing.

Other significant conclusions regarding geothermal heating are:

1. Well temperatures as low as 50°C can be exploited if heat flow to the well is adequate.
2. Judicious use of insulation on the trombone can improve performance of a marginal system.
3. A trend toward higher circulating rates is counter productive except in special cases.
4. Eight-inch wells are probably not justified for individual residence systems; 4-inch wells are cheaper, and should perform no differently (the chief function of well diameter is to allow emplacement of the trombone, and a more compact trombone will fit in a smaller well).
5. Well dimensions can be reduced by operating baseboard heaters at lower temperatures.
6. To minimize costs, temperature and heat-flow measurements should be made as well drilling proceeds.
7. Reasonable returns on investment can be expected for 8-inch wells up to 185 feet deep and for 6-inch wells up to 230 feet deep, if water of sufficient temperature is encountered.
8. Using 2-inch copper tubing for the trombone is unnecessary extravagance and may actually hinder heat extraction. Smaller diameter tubing can be used much more effectively.

Further development of the geothermal resource for heating purposes is feasible in the Moana area. Conditions are almost ideal in that heated water is found at relatively shallow depths while surface discharge and associated odor or other esthetic problems are not present. A higher average reservoir temperature would be desirable, but more efficiently designed heating systems should overcome this deficiency.

Attempts at space heating with geothermal wells in the vicinity of Steamboat Springs have generally not been successful due to excessive mineral content of the water and resultant scaling and corrosion problems. This will remain the case unless technological advances are made which can negate these effects. Development of successful heating systems at any of the small, dispersed geothermal areas is tentative at best. Although technically feasible (sufficient temperature) at a few of the identified areas, such development may not be economically feasible because of the high probability that any one well drilled in these small fault controlled areas may not encounter heated water.

Cost may be a major limitation on development of residential geothermal heating. The cost of initial construction and installation of a system as herein described ranges from $5,000 to $8,000 at 1974 prices. Unit costs could be decreased by installing larger wells and systems designed to heat more than one dwelling unit. This certainly would be feasible for apartments or condominiums, but multiple-home heating companies or cooperatives would probably fail because of problems of a non-technical nature.

Increased development of geothermal resources should have little adverse effect on water quality and ground-water conditions in the basin. This statement assumes that future development will be primarily heat exchange rather than extractive systems.

INTRODUCTION

Recent developments in the field of electrical energy production, both in this country and abroad, have caused increased interest in energy sources other than fossil fuels. One of the alternative sources currently being investigated is geothermal activity. Primary research emphasis has been directed toward investigation of the use of large geothermal "fields" for full scale electric energy production. The feasibility of and problems associated with non-power uses of geothermal steam or waters are not being as intensively investigated. Limited use of this natural energy source for heating buildings and greenhouses, heating water, de-icing sidewalks, etc., has long been common in this country and throughout the world. One of the largest users of geothermal heat is Klamath Falls, Ore., where more than 350 wells are used to heat homes and businesses (Koenig, 1970). Other notable uses of this resource are at Boise, Idaho, where over 200 homes are heated, and at Calistoga, Cal. where motels, greenhouses, and homes are heated. Koenig (1970) estimates the total population served in the United States is less than 25,000, most of these living in the states of Oregon, Idaho, Nevada, and California.

Objectives and Scope

The Truckee Meadows, surrounding the cities of Reno and Sparks in northwestern Nevada, is an area of considerable geothermal occurrence. Numerous hot springs are found, especially in the vicinity of Steamboat Springs, and wells which have tapped thermal waters of varying temperature exist at several places throughout the Meadows. While this resource has previously been examined and found to be unsuitable at present for large-scale electric power production, the potential of the area for non-power generation use has not been thoroughly evaluated. Despite the lack of any coordinated activity, several existing thermal wells are being used to heat both domestic and commercial structures. The primary objective of this study was to assess the feasibility of increased utilization of the geothermal resource within the Truckee Meadows.

The Reno-Sparks metropolitan area obtains more than 90 percent of its water for municipal and industrial purposes from the Truckee River, the remainder being obtained from local ground water. Water allotment from the Truckee River to Pyramid Lake, the Newlands Irrigation Project, and other users has recently been subjected to reevaluation both in public discussion and in the courts. Concurrently, upstream development of recreational lands in the Truckee watershed, both in the Lake Tahoe basin and below, has resulted in a potential waste disposal problem that may affect the river. The ultimate solution of these problems may reduce availability and/or desirability of Truckee River water, thereby requiring the Reno-Sparks area to rely more heavily on subsurface supplies. Any such increase in groundwater withdrawal may induce mixing of thermal waters with the normal high quality ground waters. This could eventually cause significant degradation of ground-water quality. A corollary objective of this investigation was to determine the extent and nature of thermal waters within the Truckee Meadows. Such information would permit a reasonable assessment to be made of the type and location of possible future ground-water contamination.

The initial phase of the investigation involved an inventory of existing thermal water users. Information collected included: 1) location of use, 2) depth and lithologic log of the well, 3) temperature, and 4) type of heat extraction system used. In addition, information as to cost of construction and operation of the system was obtained if possible.

The second phase involved a limited water quality sampling program. Fifteen samples were collected from wells at depth and chemically analyzed at the Center for Water Resources Research (CWRR) analytical laboratory in Reno. These data were used in conjunction with existing data to more clearly define areas of geothermal activity or thermal water influence. In addition, the analyses were used to clarify differences between principal areas of geothermal occurrence and for the evaluation of potential chemical effects of increased incursion of thermal waters into existing high quality ground-water areas.

Chemical parameters determined included pH, specific electrical conductance, alkalinity (HCO_3^-; CO_3^{2-}), chloride (Cl^-), sulfate (SO_4^{2-}), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and silica (SiO_2). Total dissolved solids (TDS) were calculated by summation. Abnormal concentrations of boron (B), lithium (Li), arsenic (As), and fluoride (F^-) occur in waters from Steamboat Springs, therefore the majority of collected samples were analyzed for these trace constituents. Hereafter, all dissolved chemical constituents will be denoted by their chemical symbols, valence state omitted.

The final phase considered lithologic and structural factors within the study area. Drillers logs, geologic mapping, and potential distribution maps were evaluated in conjunction with chemical quality differences to ascertain effects of lithology and/or structure on the occurrence and distribution of thermal waters.

Study Area Description

General

The, Truckee Meadows area is located in northwestern Nevada in a basin that includes the cities of Reno and Sparks. This basin is north-south trending, bordered on the west by the Carson Range, a spur of the Sierra Nevada, and on the east by the Virginia Range. The study area as considered in this report includes the topographic basin bordered on the east and west as above, on the north by low volcanic hills related to the major ranges, and on the south by Pleasant Valley (fig. 1).

The Truckee River is the principal drainage within the area. This stream, originating in Lake Tahoe, flows generally eastward through the meadows, and leaves the valley through a deeply incised canyon in the Virginia Range. The major tributary to the Truckee River within the study area is Steamboat Creek. This stream enters the meadows from the south through Pleasant Valley and flows generally northward to its confluence with the Truckee River. Because Steamboat Creek receives the surface outflow of the Steamboat Springs thermal area it is of particular interest to this investigation. Other tributary streams are for the most part ephemeral, maintaining significant discharge only during the spring snowmelt period. The majority of these are located along the east flank of the Carson Range; only one perennial tributary stream, the one in Bailey Canyon, originates in the Virginia Range. These streams and the Truckee River provide most of the groundwater recharge to Truckee Meadows. Recharge occurs both from infiltration along natural stream courses and from infiltration in fields and along ditches and canals of the extensive irrigation system.

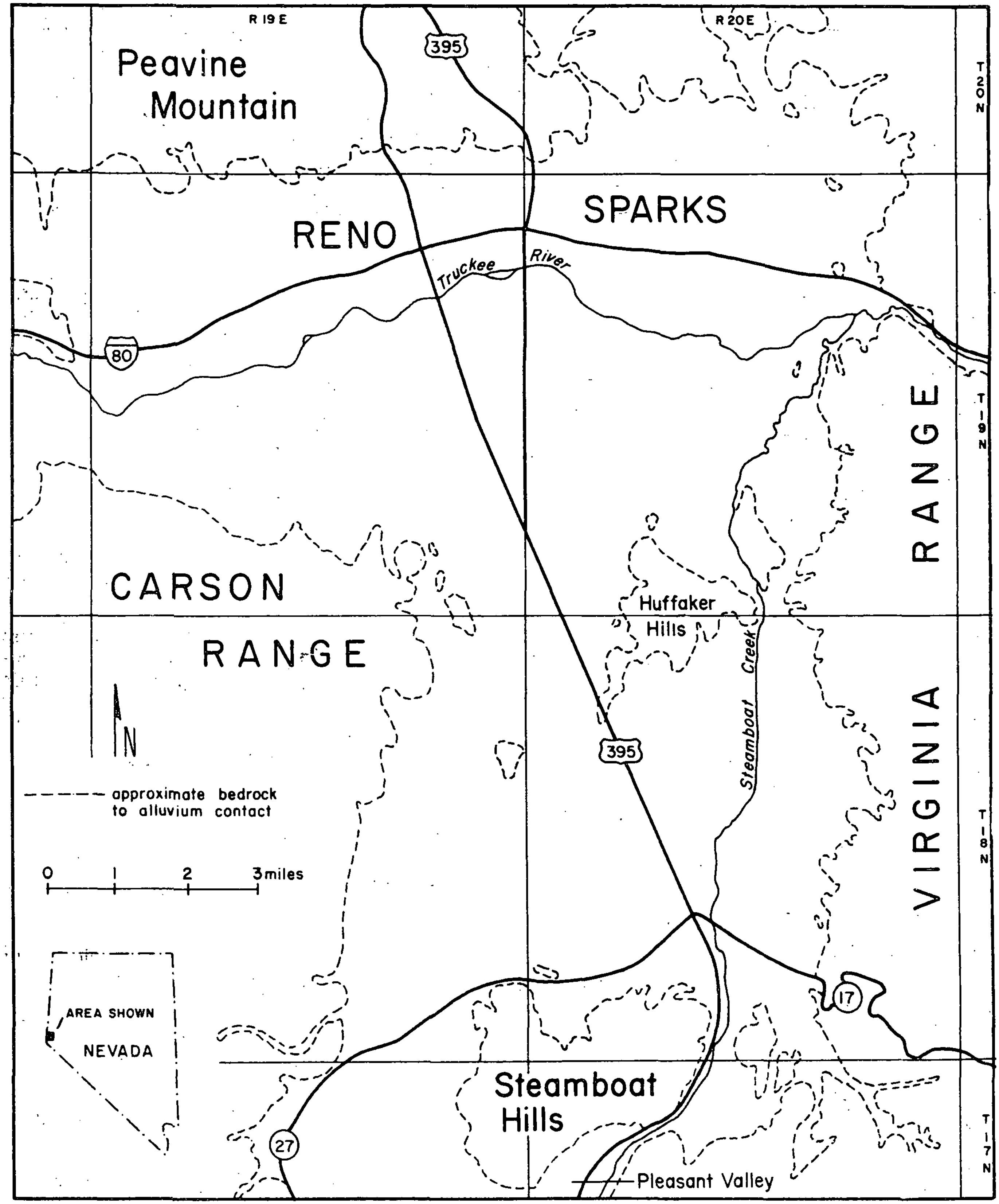


FIGURE 1. Truckee Meadows.

Precipitation is heavily influenced by the Sierra Nevada-Carson Range uplands. With elevations ranging from 8,000 to in excess of 10,000 feet, these mountains produce a strong rain-shadow effect. Annual precipitation, falling primarily as snow, reaches 40 inches in the mountains, but the long-term average in the Truckee Meadows at Reno is only about 7 inches (U.S. Department of Commerce, 1960).

Mean annual air temperature at Reno for the period 1931–1955 was 9.7°C. Mean monthly values range from a high of 20.9°C in July to a low of -0.4°C during January (U.S. Department of Commerce, 1960).

Geology

The ranges surrounding the Truckee Meadows are fault-block mountains with a fairly complex geology. Both ranges are bordered by normal faults, the Truckee Meadows being a structural depression (graben) between the two.

The Carson Range consists primarily of granitic rocks that intruded a diverse assemblage of metavolcanic and metasedimentary rocks. These rocks were subsequently covered to a large extent by thick sequences of Tertiary volcanic flow rock. The foothill belts are composed of complexly faulted and steeply dipping stream and lake deposits which include diatomite, shale, siltstone, conglomerate, and tuff breccia. These deposits are overlain in places by a heterogeneous mixture of floodplain and pediment gravel with intercalated clay lenses. The underlying Tertiary volcanic flow rock ranges in composition from basalt to rhyolite, andesitic flows predominating. The geologic framework of the Virginia Range is similar, but extrusive rocks almost completely cover the granitic core of the range.

A geologic feature of importance to this study because of the probable effect on water chemistry, is the existence of large areas of hydrothermally altered volcanic rocks on the slopes surrounding the Truckee Meadows. Alteration of this type results in formation of secondary minerals such as chlorite, epidote, zeolites, and pyrite. Oxidation of the pyrite forms sulfurous and sulfuric acids which bleach the altered rocks, causing an almost complete breakdown of the silicate minerals to clays. From such geochemically altered areas, surface, and presumably subsurface, runoff is typically high in SO_4 and exhibits a somewhat low (acidic) pH.

Valley fill deposits have been mapped and described by Cohen and Loeltz (1964), Thompson and White (1964), Bonham and Bingler (1973, and unpublished mapping), and Bingler (1975). Based primarily on descriptions given by Bingler (1975) the major types of fill deposits are briefly described below as a means of summarizing their hydrogeologic characteristics.

The oldest fill deposits are beds of unconsolidated to consolidated diatomite, sandstone, and conglomerate of Miocene to late Pliocene age. Outcrops of these are limited to the margins of the basin, occurring primarily along the western border and upstream along the Truckee River. Their existence at depth is postulated but deep wells in central portions of the basin have not encountered material which can be positively correlated. Because of the overall fine-grained nature of these deposits, development of successful producing wells is uncommon. Bonham and Bingler (1973) named these rocks the Sandstone of Hunter Creek; previously these deposits have been correlated with the Truckee Formation.

Major types of Quaternary deposits are: 1) gravel deposits of the Truckee River, 2) alluvial fan deposits around the margins of the Truckee Meadows, and 3) reworked older deposits and relatively fine-grained clastic material deposited throughout the central part of the Truckee Meadows. The lithologies present range from clays and silts to very coarse gravels. The most permeable gravels are genetically related to channel shifts of the Truckee River, and as such are generally restricted to that portion of the basin north of the Huffaker Hills (see fig. 1). Cooley, Fordham, and Westphal (1971) substantiated this general distribution of permeabilities through analysis of lithologic logs. They found permeability to decrease both north and south of the present river course. In addition, another permeability high was indicated in the south-central portion of the basin to the west of Steamboat Creek.

Previous Investigations

The geology of the Truckee Meadows has been described by Anderson (1909), Thompson (1956), Thompson and White (1964), Bonham (1969), Bonham and Bingler (1973), and Bingler (1975). In addition to general geology, Cohen and Loeltz (1964) discuss the hydrogeology and ground-water chemistry. Cooley and others (1971, 1973) provide a quantitative description of the hydrology and hydrogeology of the area. Cohen (1961, 1962) and Stephens (1971) provide additional description of ground-water chemistry. The Steamboat Springs thermal system is discussed in detail by Brannock and others (1948), White and Brannock (1950), White (1957, 1967, 1968), and White and others (1964, 1967).

Literature on the utilization of geothermal resources for space heating or other non-power generation applications is limited. Existing reports generally present inventories and qualitative descriptions of methodologies employed. White and McNitt (1966), Peterson and Groh (1967), and Nichols, Brockway, and Warnick (1972) describe use in the states of California, Oregon, and Idaho respectively. A broader picture of use in the entire western United States is presented by Koenig (1970), and Wells (1971). Descriptions of the more technical aspects of this field are given by Bodvarsson (1964), and Einarsson (1970).

Numbering System for Wells, Springs and Chemical Analyses

Two distinct identification numbers were assigned to sample sites in this report, primarily for ease of record keeping during the data compilation phase.

The first descriptor is a location number consisting of three units. The first unit is the number of the township north of the Mount Diablo Base Line; the second the number of the range east of the Mount Diablo Meridian; the

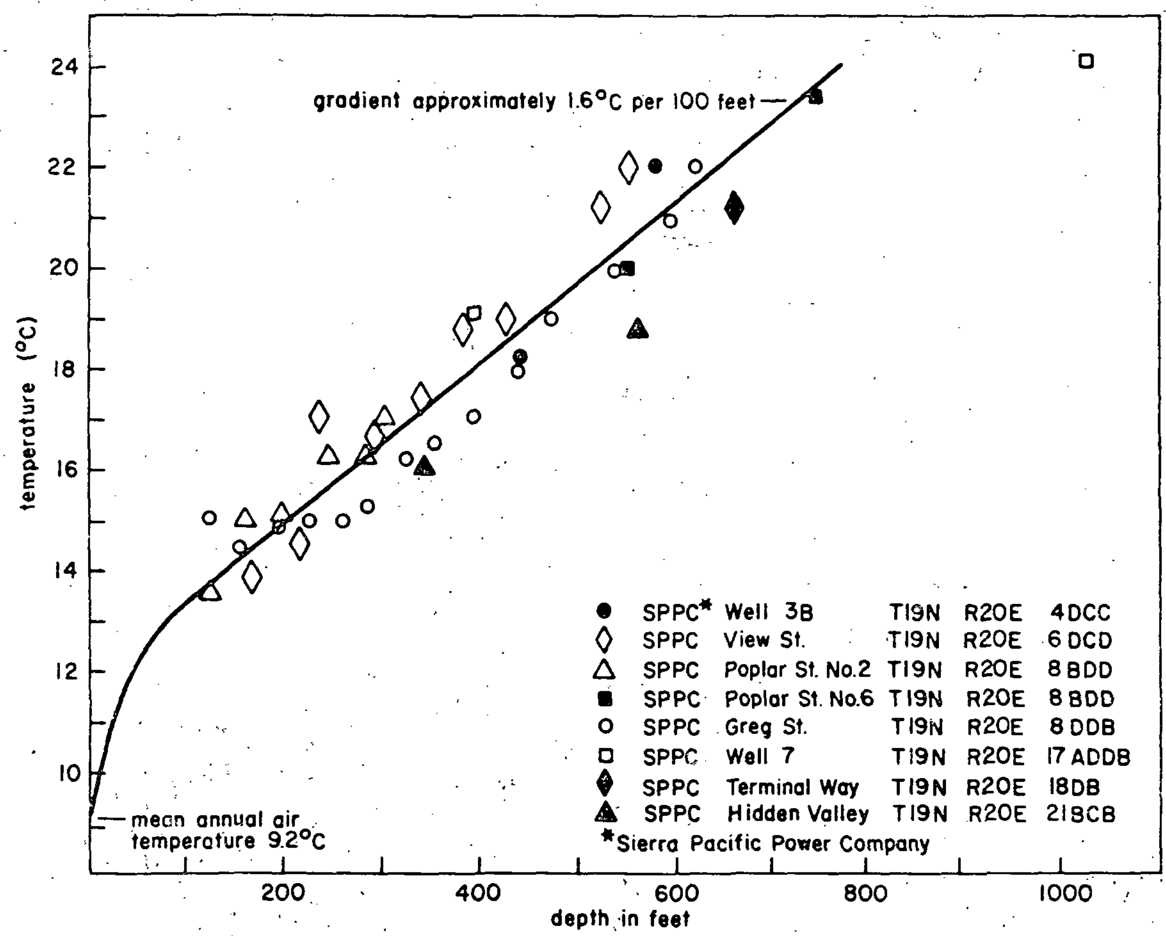


FIGURE 2. Normal thermal gradient in the Truckee Meadows.

third the section number followed by from one to three uppercase letters designating the quarter, quarter-quarter, and quarter-quarter-quarter section. The letters A, B, C, and D are used, A indicating the northeast quarter and proceeding in a counterclockwise direction. For example, site 18N, 20E, 33DBA would be in the NE/4, NW/4, SE/4, sec. 33, T. 18N., R. 20E.

The second descriptor divides the sample and/or data sites into three divisions based on water temperature. These divisions are: 1) ≥30°C, 2) 20 to 30°C, and 3) ≤20°C. To identify each group, the lead numbers 30, 20, and 10 were employed respectively. As data were cataloged, a counter was added to the group number; thus the first site cataloged with water temperature over 30°C was designated 30-1, the second 30-2 and so on for this and the other temperature divisions. At the same time, a location descriptor as previously described was assigned to the site.

LOCATION AND CONTROL OF THERMAL WATER OCCURRENCE

Thermal springs or waters can be loosely defined as those waters whose average temperature is noticeable greater than the mean annual air temperature at the site. Significant variation exists in the numerous attempts to quantify what constitutes a thermal water. Waring (1965) states that only waters whose temperatures are at least 15° Fahrenheit (8.3°C) above local mean annual air temperature should be considered as thermal.

In this study, as previously noted, waters were divided into three temperature groupings rather than being classified simply as thermal or non-thermal. This was done to permit some distinction between relatively "pure" thermal waters (≥30°C), mixed thermal waters (20–30°C), and non-thermal waters (≤20°C). Since the mean annual air temperature for the Truckee Meadows is 9.2°C (U.S. Dept. of Commerce, 1960), the break between non-thermal and mixed waters closely approximates Waring's (1965) definition of thermal water.

General Pattern

To provide a generalized view of ground-water temperature conditions in the Truckee Meadows, a normal thermal gradient and deviations from this gradient throughout the study area were developed (figs. 2, 3). Development of a "normal" thermal gradient obviously required prior knowledge, or at least assumed knowledge, on the part of the authors as to where geothermal influences were not present. All wells chosen for this purpose were located near the

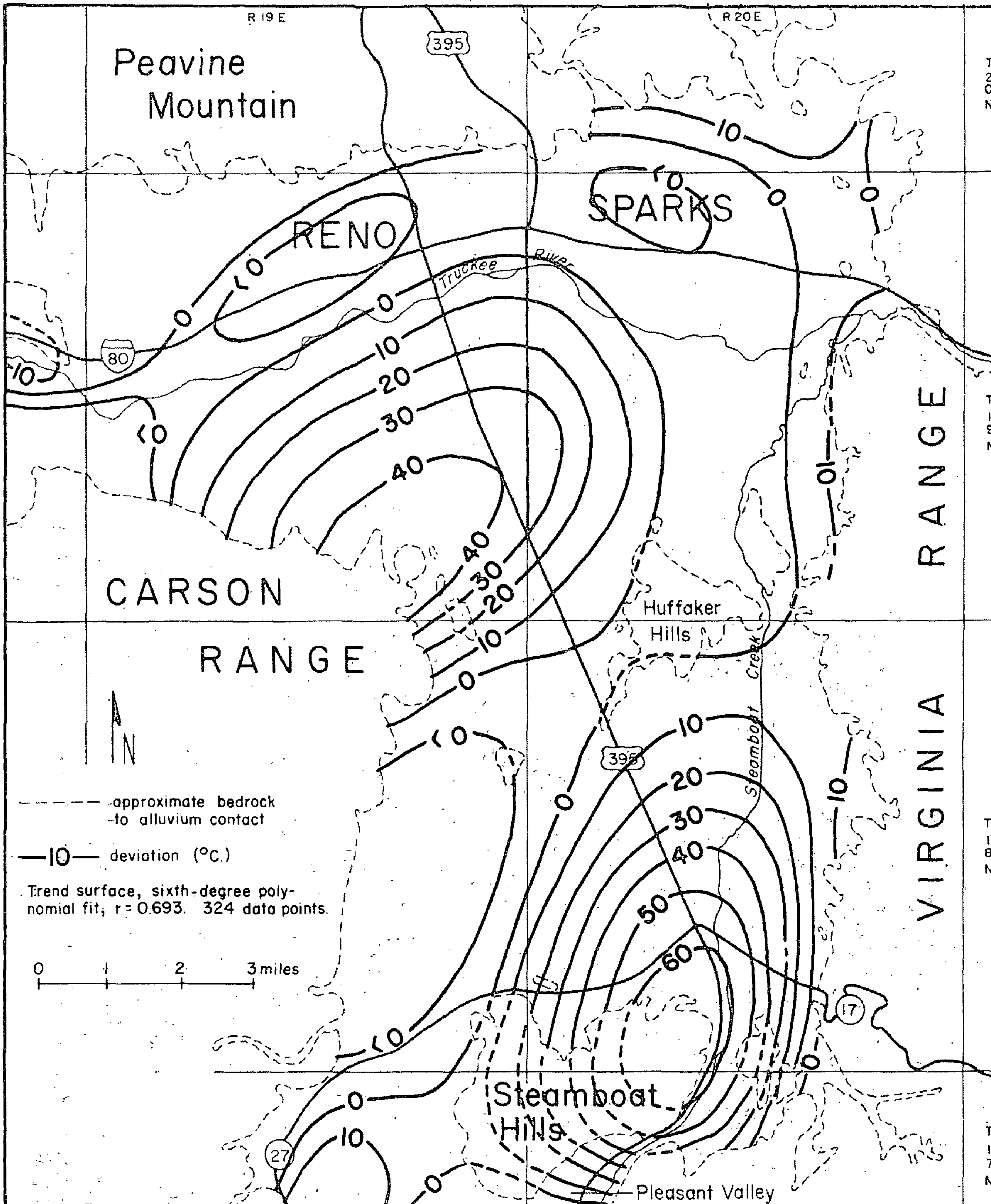


FIGURE 3. Deviation from normal thermal gradient in the Truckee Meadows.

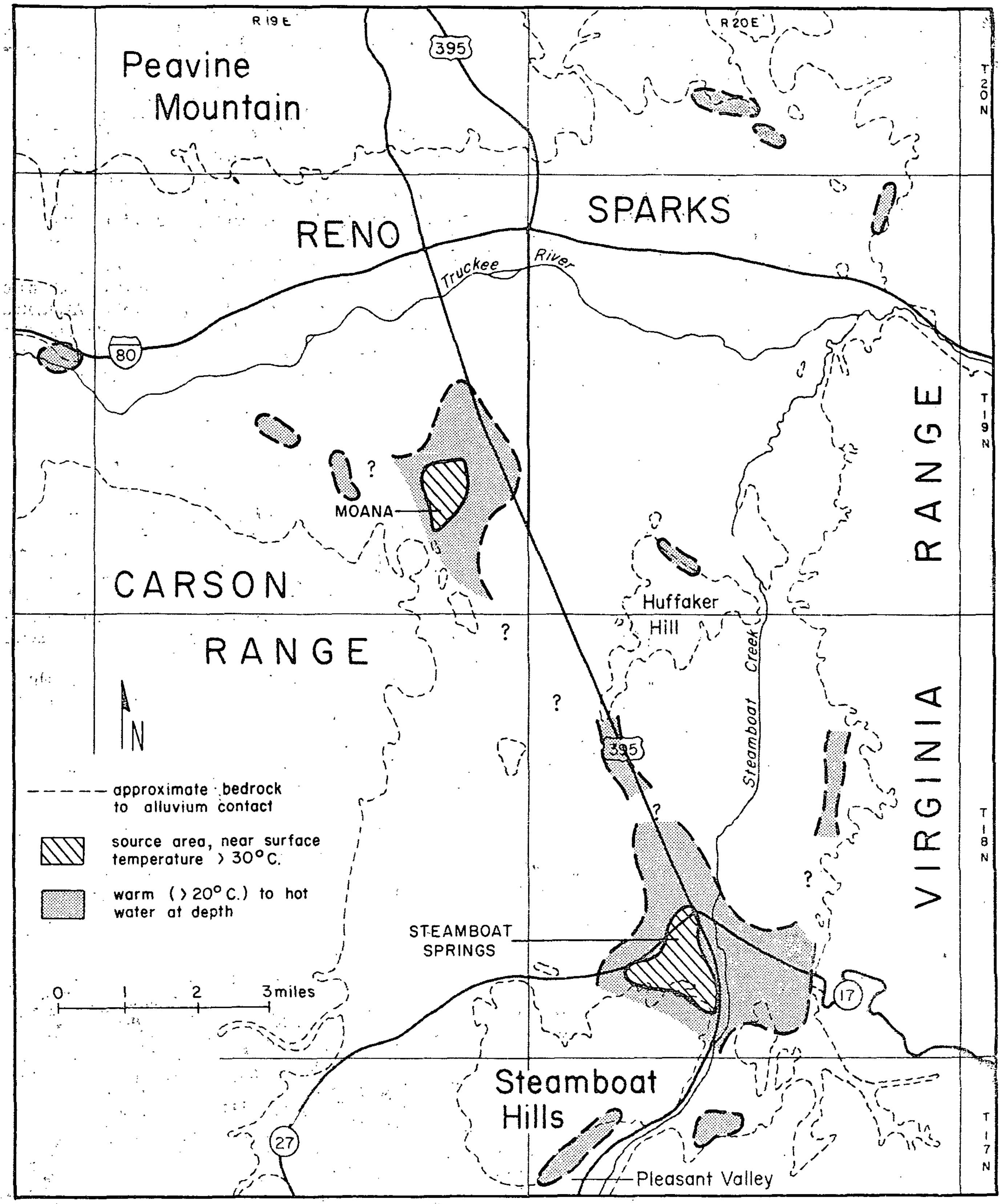


FIGURE 4. Areas of known thermal ground-water occurrence in the Truckee Meadows.

center of the basin and relatively close to the Truckee River. Due to the care taken in choosing input data, the authors believe that the presented gradient of approximately 1.6°C per 100 feet is a reasonable representation of conditions that would be prevalent throughout the basin if geothermal inputs were not present.

Figure 3 shows results of fitting a sixth-degree polynomial surface (O'Leary and others, 1966) to values of deviation from the derived thermal gradient. Depth and water temperature data from 324 wells were used. The areal distribution of data points (wells) was fairly even, therefore results of the trend-surface fitting procedure should be relatively unbiased. The simplified pattern of two major source areas is easily distinguishable. Smaller source areas at various points around the margin of the basin are indicated. Areas showing less than the normal thermal gradient (<0 contour) are perhaps areas of active recharge but most likely represent zones of insufficient data.

Figure 4 shows areas of thermal ground water in the Truckee Meadows as defined by actual water temperature measurements. The zones surrounding the major source areas, shown as having warm to hot water at depth, should not be interpreted as having only thermal water at depth. Both thermal and normal cool ground waters have been encountered in wells drilled there. Additionally, depth does not appear to be the only factor in determining water temperature in wells. The existence of thermal water in these surrounding areas probably is dependent upon minor faulting in the alluvium and/or lithologic contact with the source area. Brief descriptions of these principal source areas follow.

Steamboat Springs

Steamboat Springs, located at the southern end of the Truckee Meadows, is one of the most thoroughly investigated thermal systems in the United States. The published reports annotated in the preceeding section are only a sampling of the total amount of published material.

The active thermal area is situated within the north-south trending graben-like trough between the Carson and Virginia Ranges. Hot springs and other geothermal features occur over an area of about 1 square mile. The exact age of the system is uncertain, but it is thought to have been active over a period of at least 1 million years, and probably for as many as 3 million years (White, 1974). The mid-basin location is controlled by faulting more or less parallel to the major mountain-front faults. The hot springs are on a line of possible weakness that connects three or more Quaternary rhyolite domes. It is generally believed that the heat source for the system is a cooling magmatic body at depth which is also the presumed source of the rhyolite (White and Brannock, 1950).

The amount of water discharged by the system is estimated by White and Brannock (1950) to be in excess of 800 gallons per minute (gpm). This figure matches closely measurements of about 900 gpm made by CWRR while conducting research on Steamboat Creek. White and Brannock (1950) believe that these heated waters are almost entirely of meteoric origin, with perhaps 6 to 16 percent being volcanic in origin. Recharge for the deep circulation system is derived from the high mountains to the east and west. No estimate is available as to size of the contributing recharge area.

Spring discharge temperature ranges from slightly less than 50°C to boiling, which at the prevailing altitude is approximately 96°C. At depth, temperatures upwards of 186°C have been encountered. Relatively shallow wells have also encountered greatly elevated temperatures; one well less than 160 feet deep having a reported bottom temperature of 138°C (Brannock and others, 1948). As would be expected with such high near-surface temperatures, steam and associated geyser activity is common.

Extensive terrace-forming siliceous sinter deposits have been built up around the natural discharge sites. Associated with these deposits are cinnabar, stibnite, pyrite, and other sulfides. Gold, silver, antimony, mercury, and copper are known to occur within the siliceous spring deposits.

Moana

Moana Springs is situated along the western margin of the Truckee Meadows at the southern edge of Reno (fig. 4). Although surface discharge is at present almost nonexistent, some of the wells drilled in the area maintain an artesian head. Records of the discharge history were not found, but it is reasonable to state that the discharge rate was never as great as at Steamboat Springs. Due to the lack of surface discharge, the description presented in the following paragraphs is based solely on information gathered from wells.

Location of the thermal system here is also thought to be controlled by faulting that parallels the front of the Carson Range. Although surface expression of faulting is lacking, a striking north-south alignment of those wells with artesian head (past and present) may mark a fault trace. This alignment can be extended to a visible fault trace slightly to the northeast. Figure 5 is a generalized east-west cross section through the Moana site. The apparent differences in elevation of the andesitic basement may be further evidence of a north-south trending fault. Although recent vulcanism is not evident near Moana, the heat source is again presumed to be a cooling magmatic body at depth. The relationship of this source to the source providing heat to Steamboat Springs is unclear. If a common source is involved, the lower temperatures and lower mineralization of waters at Moana suggest a less direct contact with the heat source than at Steamboat Springs.

Water associated with the system is overwhelmingly if not entirely of meteoric origin, recharge coming from the high mountains to the west. The system probably operates in a manner similar to the mechanism proposed for Steamboat Springs (White and Brannock, 1950). Such a system is simply described as follows: 1) cool water originating in the mountains percolates downward along permeable zones, probably faults or joints, 2) these cool waters are eventually heated by a magmatic heat source at depth

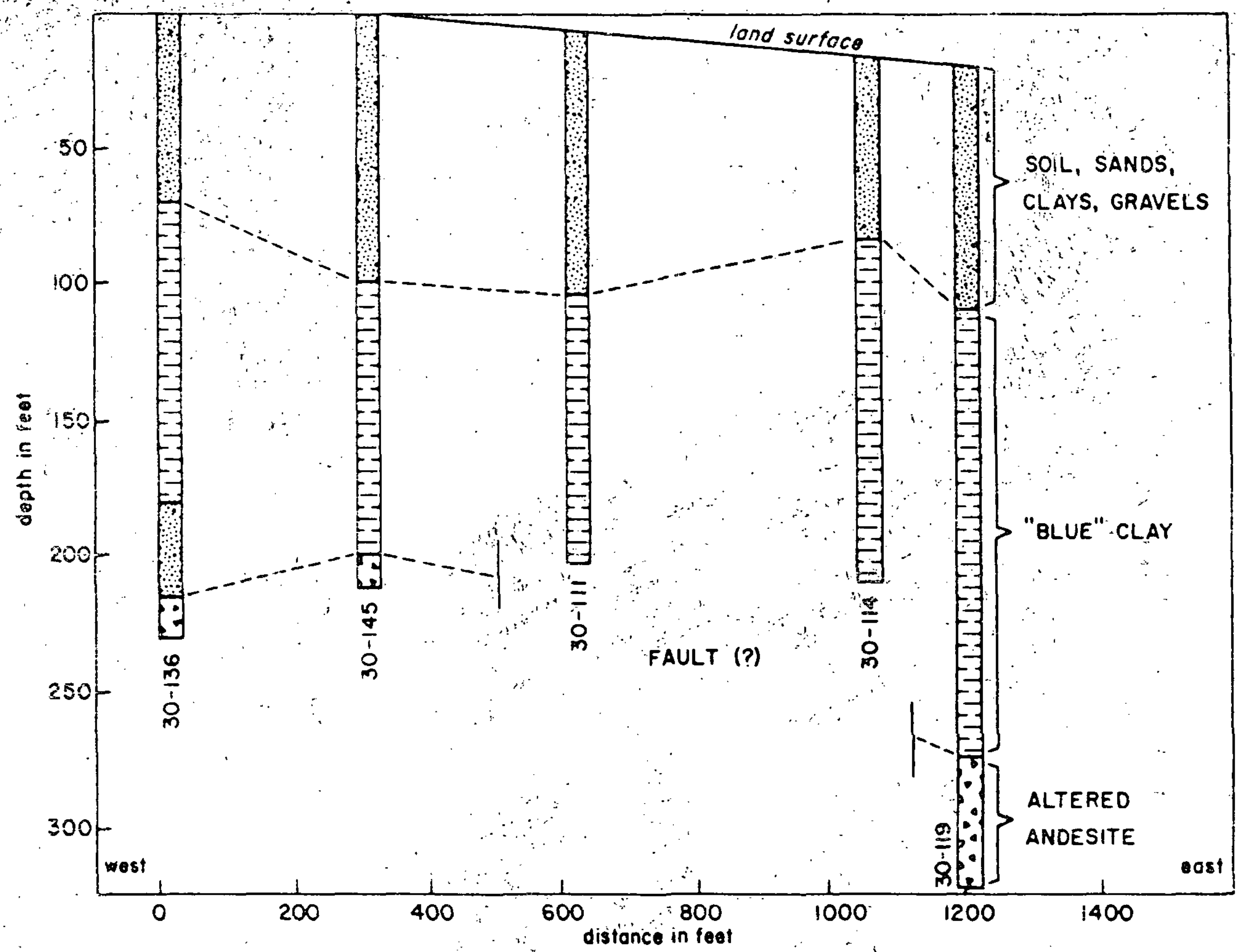


FIGURE 5. Generalized east-west section through the Moana area (the line of section crosses the SE/4, NE/4, sec. 26, T19N, R19E).

(unknown but perhaps several miles) and with the resultant decrease in density are forced upward in a convective system. If the heated waters follow a relatively open path such as a fault to the surface, then upward travel time may be short as compared to total residence time in the system.

Thermal waters when encountered in drilling are associated with a "blue" clay and are not generally found above this zone (fig. 5). If the water moves upward along one or more faults within the andesite, this extensive clay layer may act as a relatively impermeable cap, forcing the water to diffuse laterally (and vertically) away from the fault zone. Noticeable increases in water temperature were observed when certain wells were drilled through the contact between the clay and underlying andesite. The existence of an artesian head only in wells drilled along a certain alignment, presumably a fault, may further support this theory of near-surface operation of the system. Wells drilled into or through the clay at some distance from such an input zone would tend not to display artesian conditions due to the hydraulic head-loss involved in moving water laterally through the clays and andesite.

Water temperatures encountered at depths in excess of 100 feet range from 75 to 96°C. Deeper wells do not in general have the highest temperatures, suggesting that temperatures deep within the system may not be appreciably greater than those encountered nearer to the surface. Figure 6 shows temperature profiles of several wells within the area. Although variable, the pattern of a leveling off of temperature with depth can be clearly observed.

Because of the lower temperature and mineral load, exotic mineralization and spring deposits similar to those at Steamboat Springs do not exist. None of the wells have produced steam nor is there any indication of geyser activity.

Dispersed Areas

As seen on figure 4, several small, isolated areas of thermal activity are found along the western margin of the basin from Pleasant Valley in the south to Lawton's hot spring (T19N, R18E) in the north, and are no doubt related to the major geothermal areas. While none of the areas are known to possess water at the boiling point, some have temperatures upwards of 40°C.

Control by one continuous master fault is improbable; a system of paralleling and related faults following the general "outcrop" pattern of the thermal areas is more likely. Additional heat sources need not be present. The generally lower water temperature and dissolved chemical load are suggestive of a less direct flow path from the zone of heating to the surface. If these assumptions are correct, it is probable that thermal water could be encountered anywhere along this linear zone. Chances of finding thermal water at any specific location may be low, however, as penetration of a fault plane or relatively deep drilling may be required.

The small thermal areas along the eastern and northern margins of the valley may be related to faulting along the front of the Virginia Range. The temperatures encountered, although great enough to allow a thermal classification, may not be high enough to be useful for space heating or other purposes. Heat sources for these areas are not apparent, but there is no eivdence that the heat is derived from sources other than those supplying Steamboat Springs and Moana.

CHEMICAL QUALITY OF GROUND WATER

The chemical quality of thermal and non-thermal ground water in the Truckee Meadows differs greatly, both in total amount and type of dissolved constituents. Table 1 shows typical analyses of water from the two major thermal systems and a Sierra Pacific Power Co. water supply well. A wide range in TDS and the existence of significant concentrations of certain trace elements in the thermal waters is clearly shown.

The chemical quality of thermal and non-thermal waters is discussed separately below. A third section deals with mixing of the various waters and its possible effects on water quality.

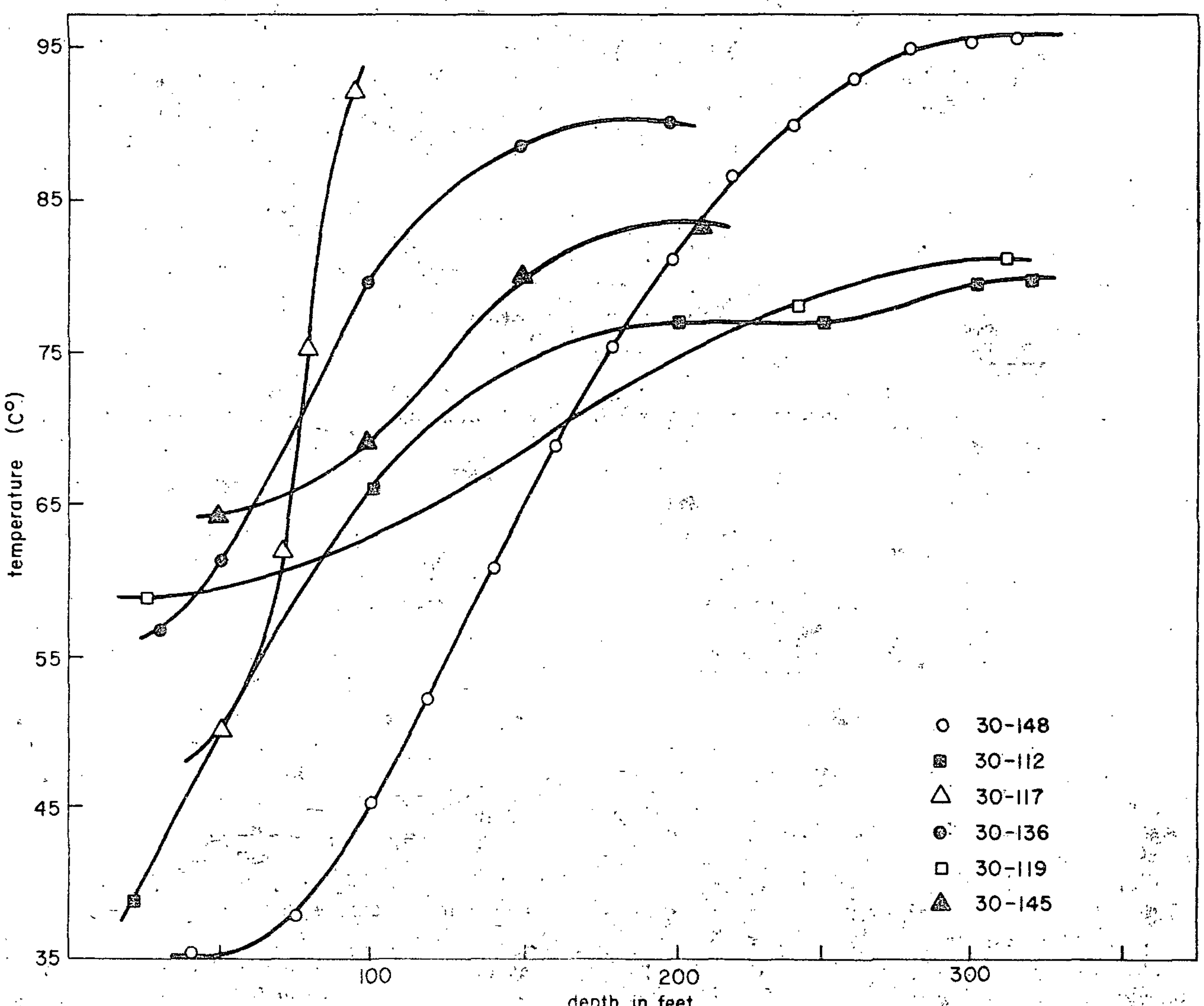


FIGURE 6. Temperature profiles of selected wells in the Moana area.

TABLE 1. Comparison of the chemical quality of Steamboat Springs, Moana, and non-thermal ground waters.

Name	Spring 8, Steamboat Springs		Thermal Well, Moana area		Sierra Pacific Power Co. Well No. 6	
Location	18N 20E 33AB		19N 19E 26ADDD		19N 20E 8BDD	
Sample no.	30-27		30-131		20-31	
Collection date	Aug. 9, 1949[1]		Mar. 27, 1974[2]		Aug. 24, 1959[3]	
	mg/l	epm	mg/l	epm	mg/l	epm
HCO_3	305	5.00	85	1.39	116	1.90
CO_3	0	—	0	—	0	—
Cl	865	24.39	50	1.41	7	0.20
SO_4	100	2.08	457	9.51	57	1.19
F	1.8	0.09	4.8	0.25	0.2	0.01
Br	0.2	—	<0.1	—	—	—
I	0.1	—	0.2	—	—	—
H_2S	4.7	—	0.2	—	—	—
B	49	—	2.0	—	—	—
Total anions	1,326	31.6	599	12.6	180	3.3
Na	653	28.41	243	10.58	43	1.87
K	71	1.82	7.4	0.19	—	—
Ca	5.0	0.25	23	1.15	22	1.10
Mg	0.8	0.06	0.2	0.02	3.9	0.32
Al	0.5	—	<0.04	—	—	—
As	2.7	—	0.10	—	—	—
Fe	0.05	—	0.02	—	0.05	—
Hg	—	—	<0.0005	—	—	—
Li	7.6	1.10	0.19	—	—	—
Mn	0.05	—	0.01	—	0.02	—
Sb	0.4	—	<0.01	—	—	—
Se	—	—	<0.005	—	—	—
Sr	0.5	—	0.5	—	—	—
Total cations	742	31.6	274	11.9	69	3.3
SiO_2	293		102		39	
SEC[4]	3,210		1,367		325	
TDS	2,361		975		288	
pH	7.9		8.3		8.0	
Temp. (°C)	89.2		89.9		23.3	
Depth (ft.)	—		150		752	

[1] Analysis by U.S. Geological Survey
[2] Analysis by Desert Research Institute
[3] Analyst unknown
[4] Specific Electrical Conductance (μmhos/cm @ 25°C)

Non-Thermal Water

Approximately 60 chemical analyses of non-thermal ground waters were obtained from various sources for the present study. These analyses are presented in Appendix A as samples labeled with the prefix 10. Sources of the analyses are also shown.

Data incorporated in this and the following sections were subjected to two principal checks, one on the reported location of the sample sites and the other on the computed ionic balance of the analyses. If a location could not be verified or seemed unreasonable, or if the ionic balance (equivalents per million anions divided by equivalents per million cations) was not within a reasonable tolerance (±5 percent error), the analysis was not incorporated into this study.

Major Chemical Constituents

The predominant dissolved ionic species in non-thermal waters are the anions HCO_3, Cl, and SO_4 and the cations Na, K, Ca, and Mg. Silica, expressed as milligrams per liter (mg/l) SiO_2, is also common. Table 2 shows the average chemical quality of non-thermal ground water in the Truckee Meadows, as calculated from the approximately 60 analyses

TABLE 2. Average chemical quality of non-thermal ground water in the Truckee Meadows.

Parameter	Average Value	Range	Average Ionic Ratio (%)
Temp. (°C)	14.8	9.4 – 19.4	—
pH	7.7	7.0 – 8.8	—
SEC	609.	236. – 3780.	—
TDS (mg/l)	482.	117. – 3278.	—
HCO_3 (mg/l)	180.	68. – 435.	66.
Cl (mg/l)	23.	1.4 – 315.	9.
SO_4 (mg/l)	111.	2.4 – 1680.	25.
Na (mg/l)	51.	6.0 – 400.	34.
K (mg/l)	6.	1.0 – 39.	2.
Ca (mg/l)	48.	7.4 – 354.	40.
Mg (mg/l)	17.	3.0 – 137.	24.
SiO_2 (mg/l)	51.	15. – 101.	—

compiled. The composition of these waters shows minor variations from what one would expect, based on the geology of the surrounding area. The predominance of HCO_3, a ubiquitous component of all naturally occurring surface and ground waters, is common. There is no known significant source of Cl in existing geologic materials to account for the level of concentration observed. Cl within the system is thought to be derived principally from magmatic sources in the geothermal areas and from infiltration of surface water containing Cl from salts applied to sidewalks and highways. The major source of SO_4 is, as described previously, the bleached rock of the surrounding highlands. The relative abundance of the various cations corresponds well with compositions of major minerals in the volcanic and igneous source material. Concentrations of Na and of SiO_2 are great enough to suggest additional input from the geothermal areas.

Minor Chemical Constituents

Trace constituents are not a significant problem in non-thermal waters of the Truckee Meadows. Most of the constituents present at very low levels are no doubt derived from the thermal systems. These include Li, F, As, and B.

Iron and manganese are reported in non-thermal waters, but only in a very limited number of cases were their concentrations great enough to cause problems from use of the water. Nitrates and phosphates derived from surface sources such as animal wastes and fertilizers, are known to be increasing in near-surface water of certain areas. No evidence was found of concentrations reaching problem levels.

Chemical Quality Variation

Figure 7 is a trilinear plot of the percentage of epm for the major anions and cations of the non-thermal waters. Averages of all values presented in table 2, column 3 are also plotted. The pattern indicates two distinctly different influences: 1) mixing with water high in dissolved Cl and Na, and 2) mixing with water high in dissolved SO_4 and Na. In the first case, mixing with water emanating from Steamboat Springs is indicated (see table 1). Because of the source of the increased mineralization, a relationship between temperature and percentage Cl or Na was anticipated, but none was found. Waters high in SO_4 are most prevalent near the margins of the basin because of the exterior source of this constituent. As ground water moves towards the center of the basin, the proportion of SO_4 generally decreases due to mixing. The Moana area, however, is a major within-basin source of SO_4, which alters the general pattern.

Some of the increase in Na is most likely due to ion exchange. As waters move through the system, Na ions on minerals in the flow path are preferentially exchanged for Ca and Mg ions in the water resulting in an increased percentage of Na in the water.

Thermal Water

Approximately 50 chemical analyses of thermal waters were compiled from existing files or were analyzed as a part of this study. These analyses are presented in Appendix A as samples labeled with the prefix 30.

Major Chemical Constituents

The major ionic species are essentially the same as those in non-thermal waters, except that CO_3 is present in approximately 15 percent of the samples due to the somewhat higher pHs encountered. Significant differences exist in the level of concentration and proportions of the various ions. Comparison of tables 3 and 2 shows these differences clearly.

Table 3 shows a wide variation in concentration of the major ions. Waters associated with Steamboat Springs and Moana are internally consistent and the analyses given in

TABLE 3. Average chemical quality of thermal ground water in the Truckee Meadows.

Parameter	Average Value	Range	Average Ionic Ratio (%)
Temp. (°C)	62.2	30. – 145.	—
pH	7.85	6.7 – 9.0	—
SEC	1419.	194. – 3661.	—
TDS (mg/l)	1130.	162. – 3352.	—
HCO_3 (mg/l)	200.	78. – 461.	35. (HCO_3 + CO_3)
CO_3 (mg/l)	6.2	0 – 104.	
Cl (mg/l)	226.	2.6 – 999.	31.
SO_4 (mg/l)	245.	2.3 – 1959.	34.
Na (mg/l)	282.	5.8 – 770.	75. (Na + K)
K (mg/l)	24.	2.6 – 71.	
Ca (mg/l)	34.	1.4 – 336.	17.
Mg (mg/l)	10.	0.1 – 112.	8.
SiO_2 (mg/l)	121.	4.7 – 317.	—

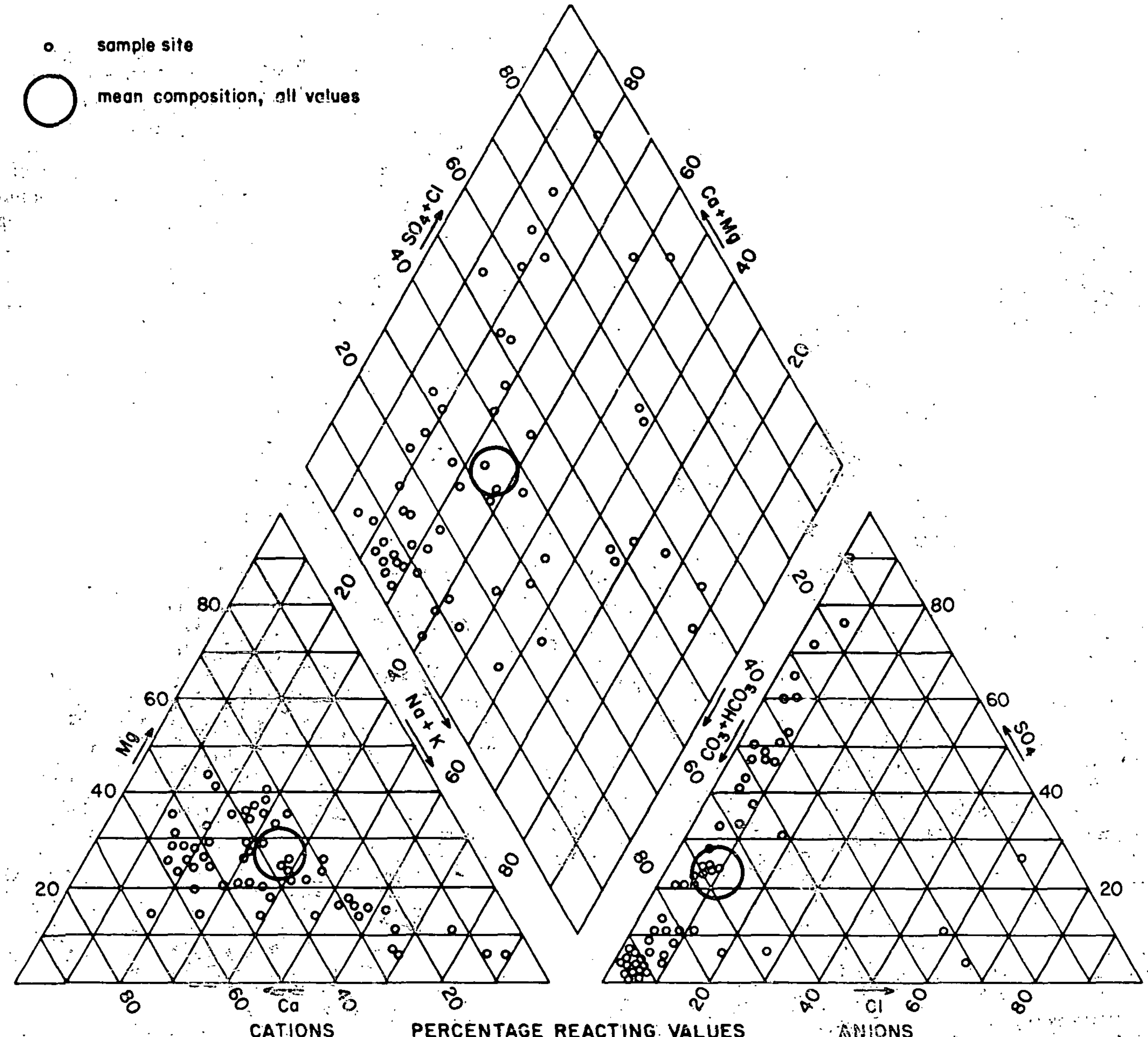


FIGURE 7. Percentage chemical composition of non-thermal (less than 20°C) ground waters in the Truckee Meadows.

table 1 adequately define their average chemical quality. Anomalously low concentrations are caused by near-surface heating of meteoric water by conduction, with little, if any, mixing of water.

Figure 8 is a trilinear plot of thermal ground-water analyses from the Truckee Meadows. Visually estimated average values for Steamboat and Moana waters are included. Waters subjected only to heating are seen to correspond closely to the average composition of non-thermal waters (see fig. 7). The effect of increased mixing is shown by the range of waters which exist between this point and the composition of Steamboat and Moana waters.

White (1957) has divided thermal waters of volcanic origin into several different types based on chemical composition. Water discharged from Steamboat Springs is classified as sodium-chloride. Thermal waters of this type are dominated by Na, Cl, and HCO_3, and are slightly acid to alkaline. Other characteristics include very high SiO_2 content and significant Li concentration. Although these chemical constituents suggest the input of water of direct volcanic origin, the actual contribution, based on isotopic evidence, is only on the order of 5 percent (White, 1957).

White (1957) suggests that the alkalies are transported from the magma as alkali halides dissolved in a very dense vapor. This requires very deep circulation of the meteoric water, perhaps on the order of 2 miles, to condense the vapor and maintain the materials in solution. As this ascending mixture nears the surface, decreases in temperature

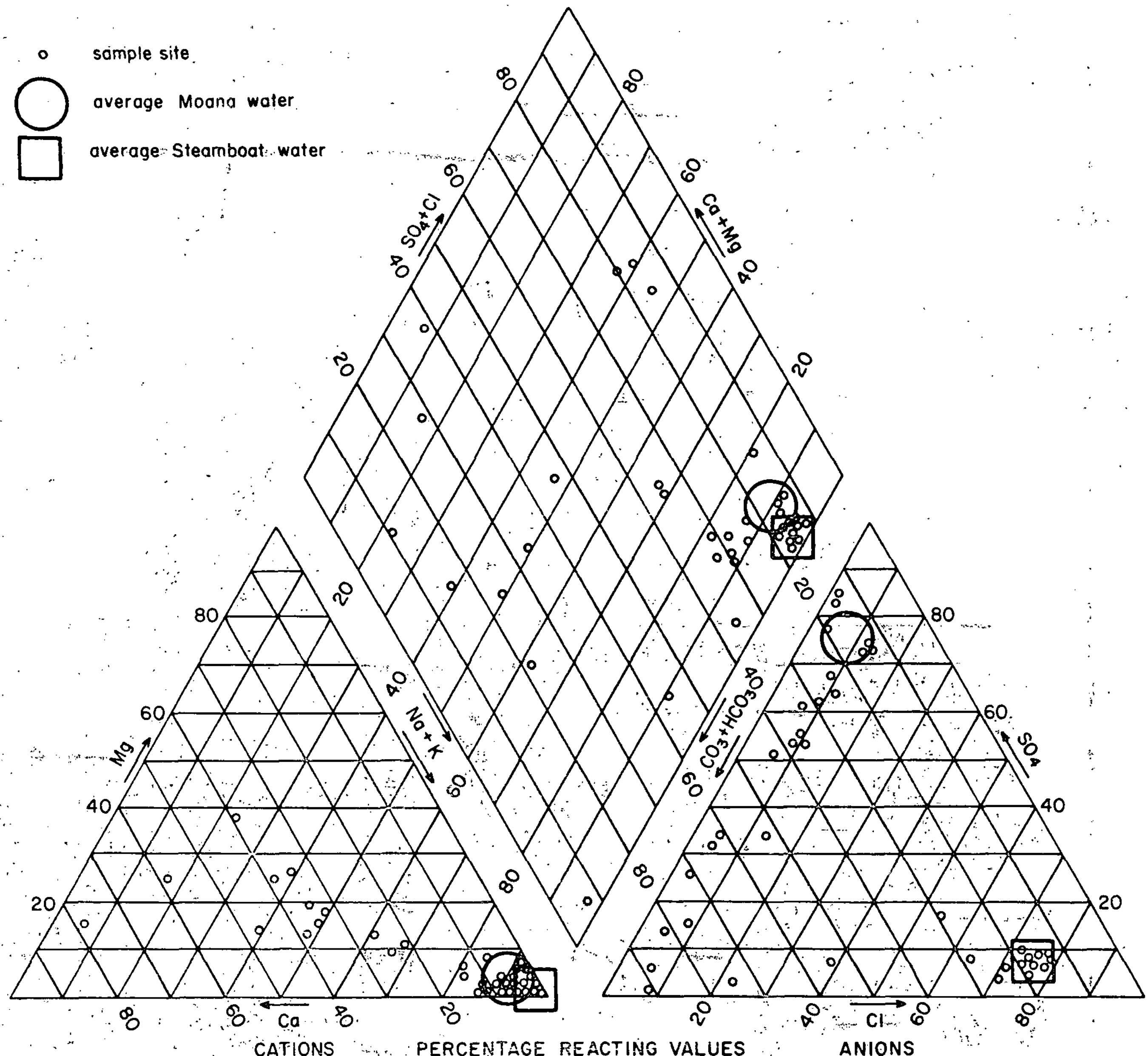


FIGURE 8. Percentage chemical composition of thermal (30°C or greater) ground waters in the Truckee Meadows.

and pressure and reactions with wall rock and other water determine the final chemistry of the surface outflow. Near-surface decreases in temperature and pressure result in extensive siliceous sinter deposits and associated mineralization found around the spring orifices.

Moana water (table 1) is dominated by SO_4, Na, and SiO_2, and as such does not fit within the classification scheme proposed by White (1957). The authors and previous workers in the area (Thompson and White, 1964; Cohen and Loeltz, 1964) believe that this composition is indicative of deep circulation near a heat source, with very little addition of magma-derived fluids. This assumption is based upon: 1) lack of excessive Na and Cl and much lower concentrations of Li and B than at Steamboat Springs, 2) close chemical correspondence between this water and "cool" SO_4-rich waters found around the margins of the valley, and 3) the absence of a significant increase of temperature with depth.

Minor Chemical Constituents

Table 1 showed trace constituent analyses for typical Steamboat and Moana waters. F, B, As, and Li were seen to occur in significant concentrations, other trace constituents being present only at very low levels. Such constituents can be detrimental, however, because minimal concentrations of many of these materials have been shown to be harmful in drinking water supplies and/or irrigation water. The United States Public Health Service (1962) states that

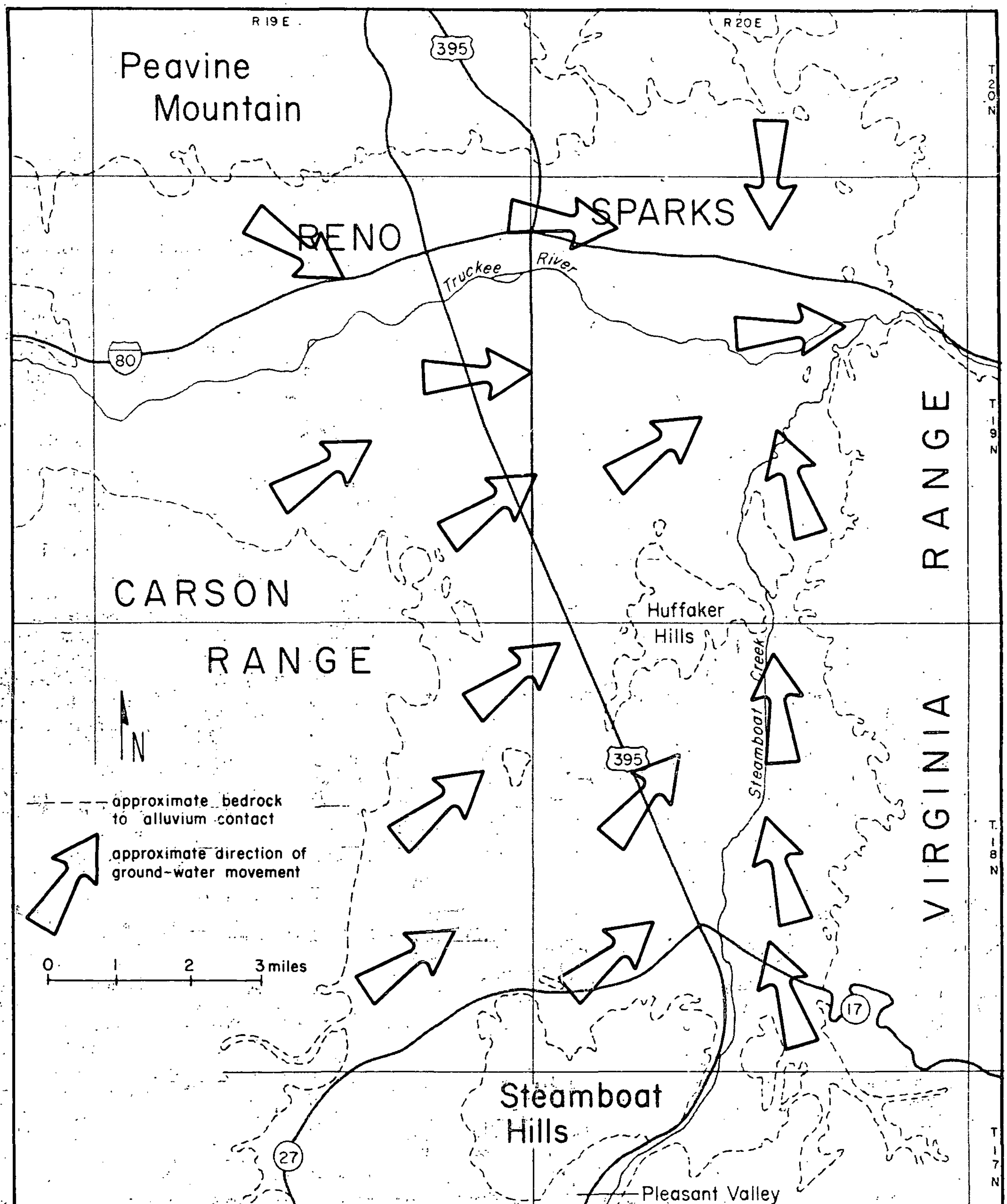


FIGURE 9. General direction of ground-water movement in the Truckee Meadows (modified from Cooley and others, 1971).

the concentration of As in drinking water should not exceed .01 mg/l (.05 mg/l if no alternative supply available). The safe level for F is set between 1.6 and 3.4 mg/l, the site-specific value depending upon the mean maximum daily temperature, which is presumably related to the average amount of water consumed. For the Truckee Meadows the standard is approximately 2 mg/l. Specific standards are not set for B or Li. It is reported (McKee and Wolf, 1963) that concentrations of up to 30 mg/l B are not harmful in drinking water. Several varieties of plants are intolerant of B and should not be irrigated with water containing more than 2 mg/l of this constituent. Limited literature on Li suggests that concentrations observed in thermal waters of the Truckee Meadows would not be a source of concern in a drinking water supply.

Mixing and Degradation

The preceeding sections have documented the wide disparity in chemical quality between thermal and non-thermal ground water in the Truckee Meadows. An obvious question is: what are the chances of increased mixing of these diverse waters, and what are the likely results?

Figure 9 shows the general direction of ground-water movement within the study area. It is apparent water from Steamboat Springs and Moana must move toward the center of the basin. Increased ground-water withdrawals from this central area, where the highest quality water and largest capacity wells now exist, will accelerate such movement.

The extent of migration and mixing of thermal waters to date is noticeable but not excessive. Figures 10, 11, 12, and 13 show locations of wells and springs whose waters currently exceed United States Public Health Service 1962 drinking water standards for TDS, Cl, SO_4, and As respectively. The number of sites shown represent only those sites with available analyses, and should not be considered indicative of the total amount of water which may exceed recommended standards.

Excessive TDS occur down gradient from both thermal source areas. In the south, poorer quality water is encountered in both shallow and deep wells, while down gradient from Moana only deeper wells are affected. Other poor-quality water found near the margins of the valley is due to inflow of cool SO_4-rich water from bleached areas. Waters high in Cl are associated almost exclusively with Steamboat Springs and do not appear to be spreading northward. Apparent containment of Cl is reasonable as the extremely low concentration in non-thermal waters would necessitate that mixing be extensive to produce water with greater than 250 mg/l Cl. Areas of bleached rock are shown on figure 12, and correlation between these areas and sites of excessive SO_4 occurrence is obvious. Movement down gradient from the Moana area at depth is indicated. Data on As presented in figure 13 shows limited dispersal from source areas. This information may be somewhat biased, because determinations are not generally made for this constituent if the sample site is not near an expected source area.

The effect of inflow of poorer quality water on a well centrally located in the basin (19N 20E 8DDB) is shown in figure 14. Water rich in SO_4 and Na exists here in a zone at a depth of 400 feet. A decrease in Ca and Mg corresponding to the increase in Na suggests significant ion exchange in the system. Although it is uncertain whether the degrading water represents input only from Moana or a mix of Moana and "cool" SO_4 water, the well does serve as an excellent example of the type of quality related problems under consideration. It is difficult to predict the precise quantitative changes in general water quality that may occur in central portions of the basin due to increased mixing caused by additional ground-water withdrawal. Effects of chemical reactions, ion exchange, geologic inhomogeneities, and mixing of different waters are too complex to allow exact estimates, but an estimate of the degree of mixing required to exceed a specified concentration can be achieved by assuming the simplest conditions. These ideal conditions are: 1) no chemical reactions occur, results of mixing depend on dilution only, and 2) only two types of water are mixing. Figure 15 shows the effects on concentration of such ideal mixing of a good-quality water from an existing Sierra Pacific Power Co. well with representative water from Steamboat and Moana. The constituents considered are those for which recommended drinking water standards (U.S.P.H.S., 1962) have been set, and these values are shown on the graphs.

Due to the significant chemical quality differences between Steamboat and Moana waters, the proportion of thermal water necessary to exceed the various drinking water standards is extremely variable. The proportion required varies from a low of 2 percent for As and Steamboat water to a high of 50 percent for SO_4 and Moana water. Certain constituents do not exceed standards in unaltered thermal water.

The most significant information gained from these figures is: 1) incursion of low temperature, high SO_4 water may be more detrimental than mixing with thermal water in certain cases, and 2) As is a limiting factor in mixing with either thermal water type; a 2 to 30 percent mix could exceed standards at a particular well.

In summary, it has been shown that incursion of poor quality thermal and high-SO_4 water, although now happening, is not a serious problem at current withdrawal rates. The potential exists for a marked decrease in water quality in central portions of the Truckee Meadows. Extensive quality degradation as regards the major ions would appear to require a substantial increase in ground-water withdrawal. The very low level and critical nature of the As standard will be of more significance.

Estimation of a "safe" annual ground-water withdrawal volume for water quality considerations requires additional research on the hydrogeology of the Truckee Meadows. This problem is complicated by the fact that as ground-water levels are lowered, recharge of higher quality surface waters from the Truckee River and the irrigation systems will increase, thus somewhat lessening the expected effect. Changes in irrigation-recharge conditions as urban areas replace agricultural lands will also be an important factor.

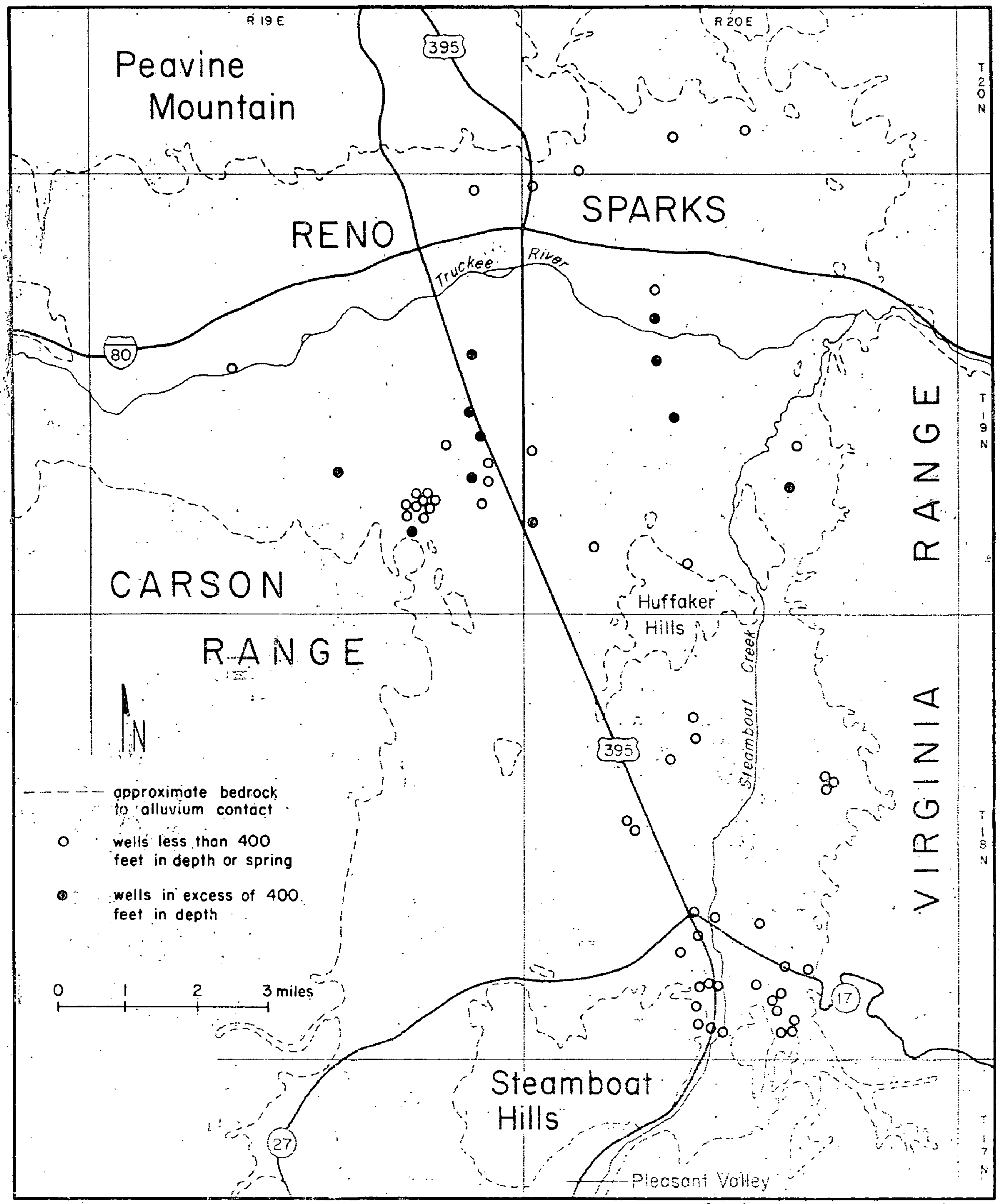


FIGURE 10. Locations of sample sites in the Truckee Meadows with total dissolved solids in excess of U.S. Public Health Service 1962 drinking water standard of 500 mg/l.

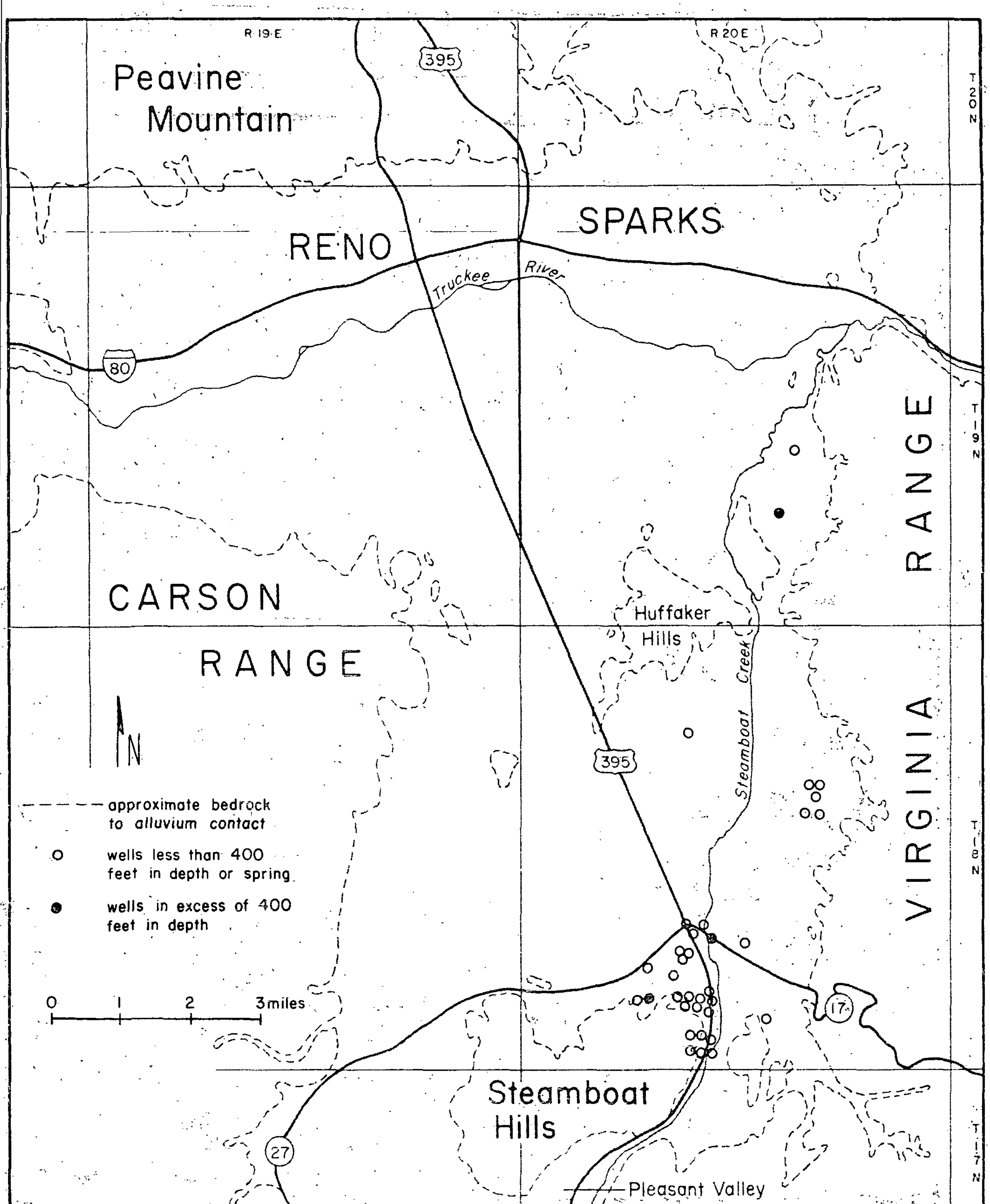


FIGURE 11. Locations of sample sites in the Truckee Meadows with chloride in excess of U.S. Public Health Service 1962 drinking water standard of 250 mg/l.

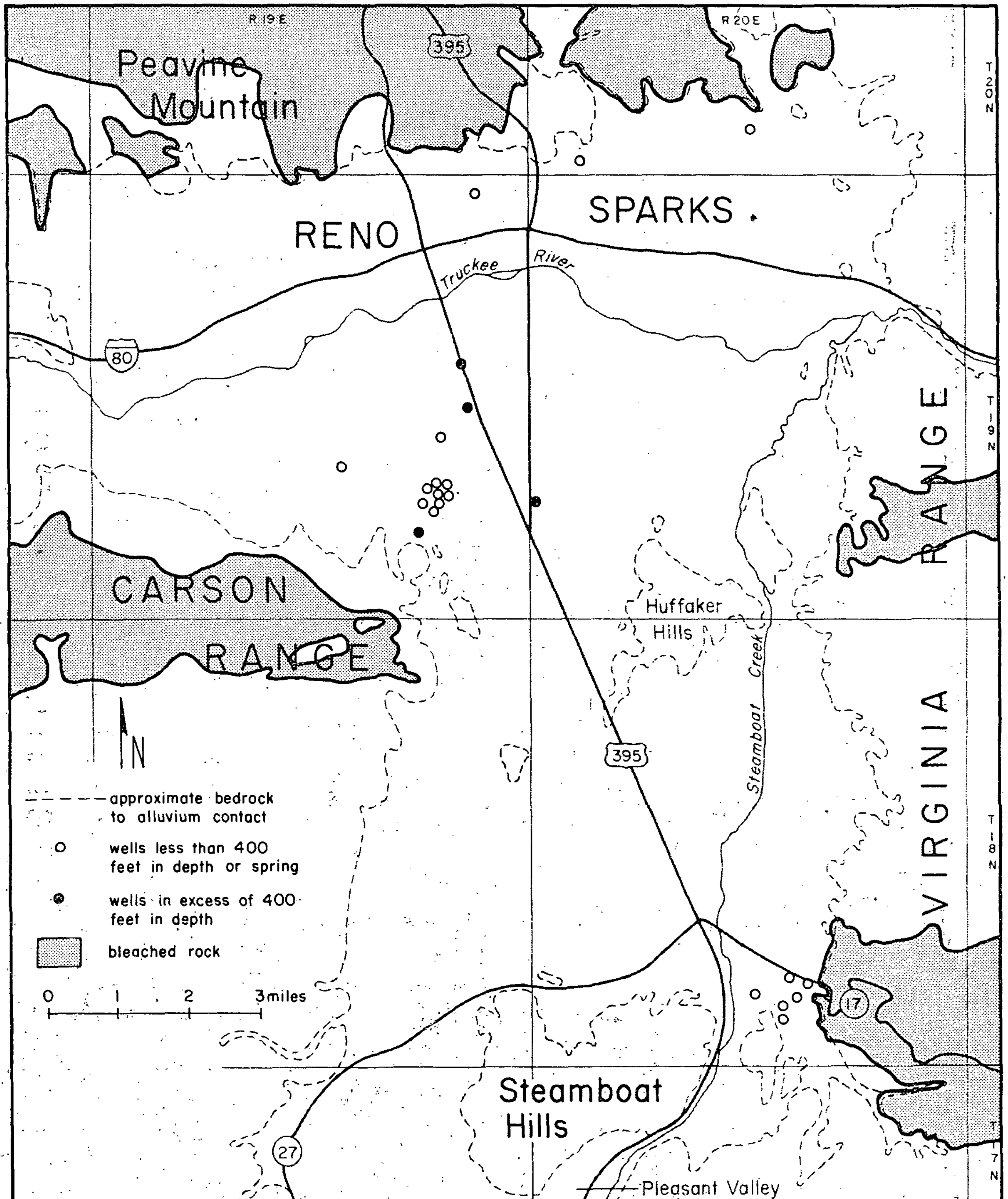


FIGURE 12. Locations of sample sites in the Truckee Meadows with sulfate in excess of U.S. Public Health Service 1962 drinking water standard of 250 mg/l.

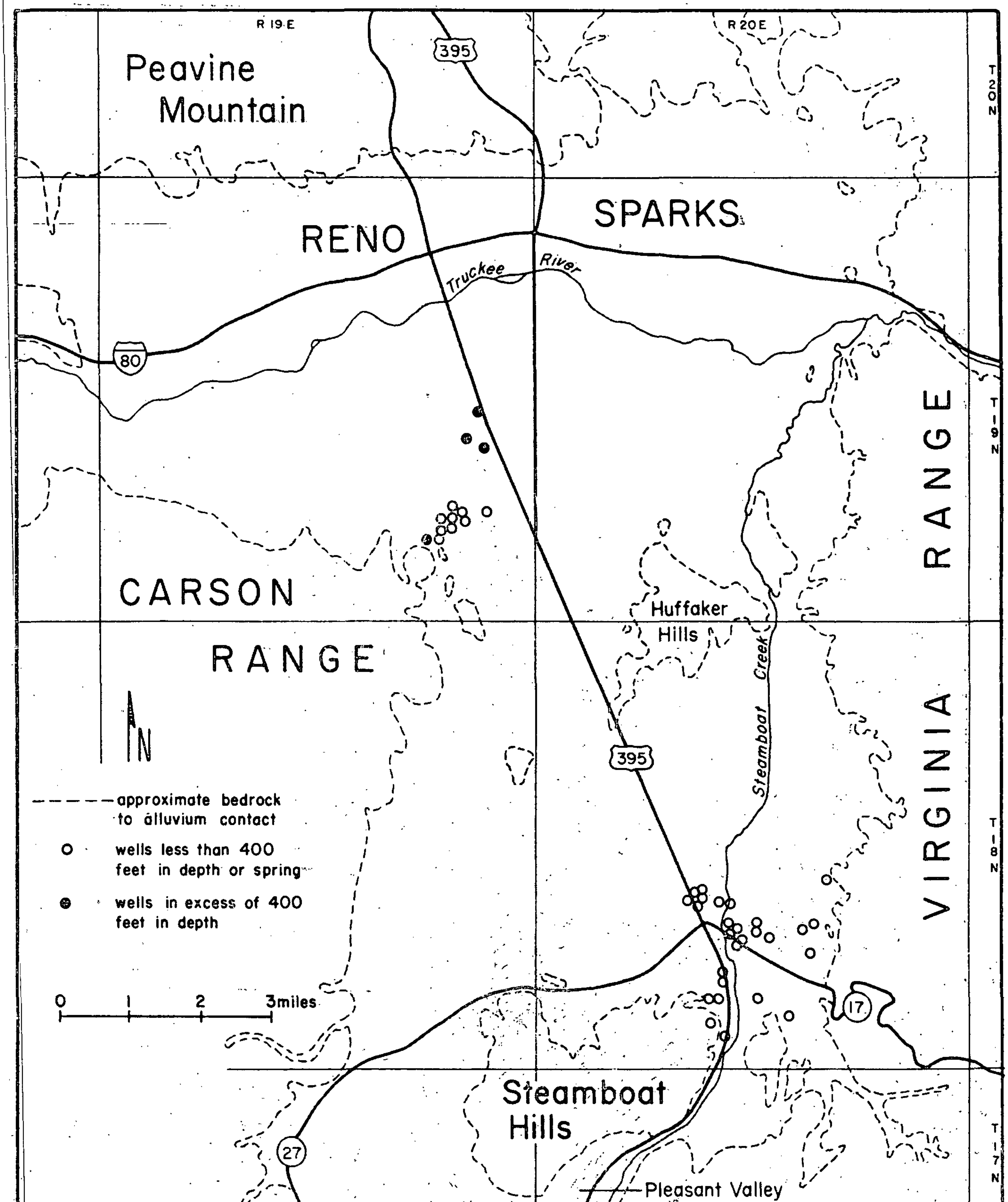


FIGURE 13. Locations of sample sites in the Truckee Meadows with arsenic in excess of U.S. Public Health Service 1962 drinking water standard of .01 mg/l (data on arsenic are scarce or nonexistent in areas other than where its occurrence is known).

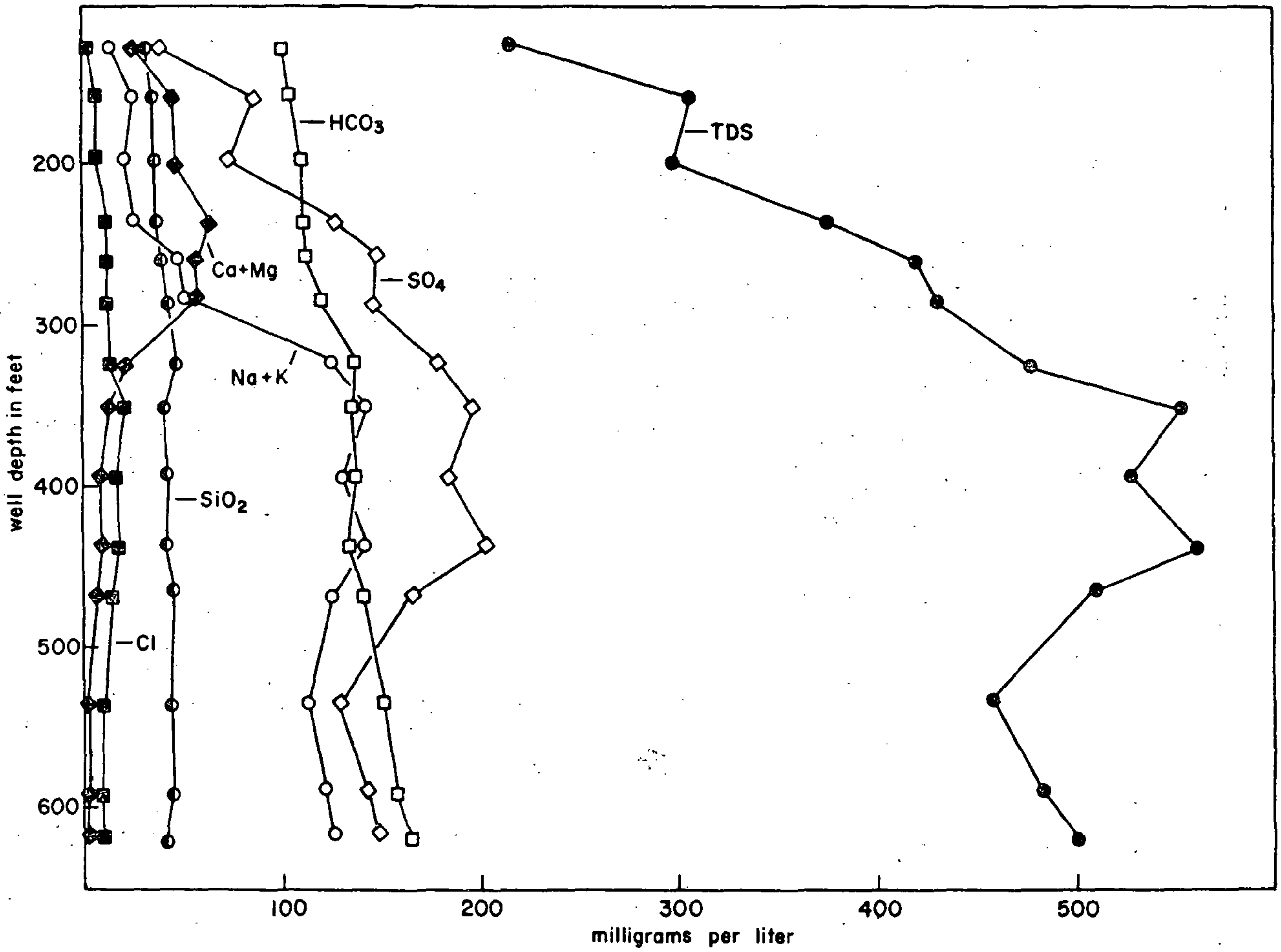


FIGURE 14. Variation of chemical quality of water with depth of well in the central Truckee Meadows (sample site 20-48; T19N, R20E, 8DDB).

UTILIZATION OF GEOTHERMAL RESOURCES

History

Beneficial use of the geothermal resources in the Truckee Meadows, while varied, has not been extensive. At Steamboat Springs major continuing uses have been hot spring-mineral bath resorts and as a site for research on geothermal systems. Mercury, silica, and clay have been mined on a small scale, and an explosives manufacturing firm has used the water as a safe source of heat to maintain the explosives in an easily worked plastic state.

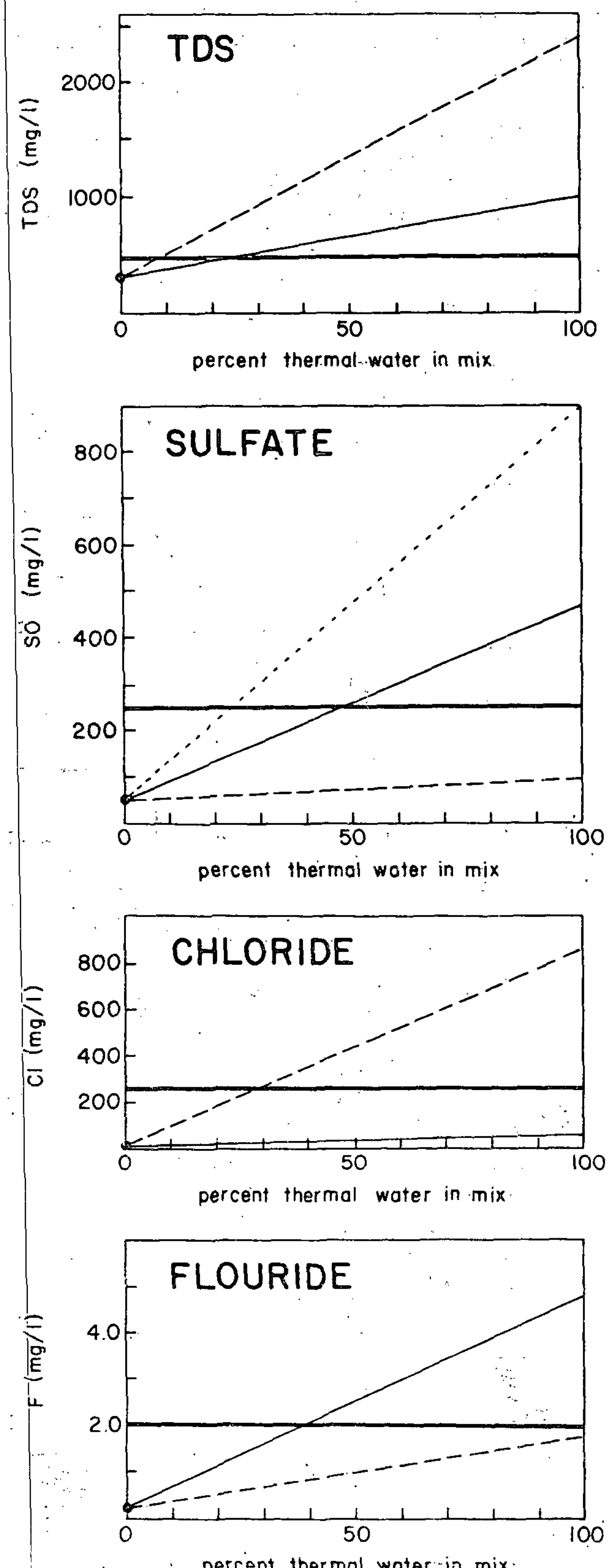
During the 1950's, Nevada Thermal Power Co. conducted investigations of Steamboat Springs as a possible site for geothermal electric power production, but temperatures encountered in test drilling generally fell just short of the minimum 180°C temperature required for successful operation. In addition, all steam produced was "wet" and contained high concentrations of minerals. Utilization of the Steamboat area for power generation purposes may be feasible in the future, depending on successful application of engineering and technology improvements now only in the research stage.

Water from a geothermal well drilled in the Moana area was for a long time used to heat the Moana municipal swimming pool. Water was mixed directly with city water to maintain a specified pool temperature. This operation was terminated because of production problems with the well and water quality considerations.

Development of geothermal wells for heating private homes and commercial buildings began in the Moana area about 1950. Over the past few years a significant increase in this use has occurred.

Current Exploitation

Table 4 lists locations and descriptions of all known geothermal heating systems within the Truckee Meadows. Most of these operational systems are located in the Moana area. Predominant uses are for space heating, heating of water for domestic use, and swimming pool heating. Two distinct types of systems are found, extractive and heat exchange. Both types appear to provide adequate heating for fairly large houses in a climate such as Reno's, where winters are cold but not severe. Some homes have back-up conventional heating systems.



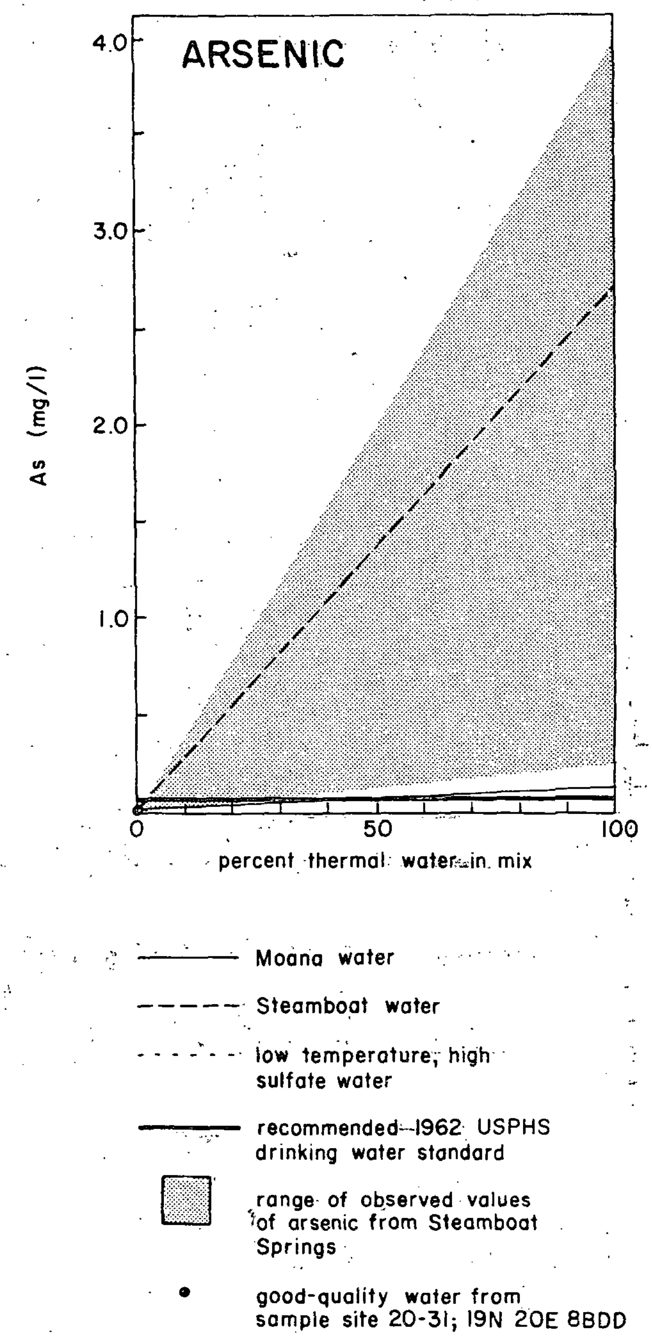


FIGURE 15. Effects of idealized mixing of representative good-quality ground water with Steamboat Springs and Moana waters on concentrations of indicated constituents.

TABLE 4. Utilization of thermal waters in the Truckee Meadows (T19N, R19E).

Location	Temp. (°C)	Depth of Well (feet)	Type of System	Use	Years in Service	Remarks	Chemical Quality Data	Study Number
23DAA	37.	110	(?)	Water heating	≃25	No longer used	Yes	30-51
24BBA	42.	≃950	Extractive (pump)	Motel, water, pool heating	21	Was artesian when drilled in 1953; temperature taken at tap	Yes	30-121
24BCDB	59.	1006	Extractive (pump)	Hot water for apartments	8	Temperature taken at tap	Yes	30-133
24CABA	47.	1000	Extractive (pump)	Motel, water heating	16	Temperature taken at tap	Yes	30-120
25BAAB	45.	≃600	Extractive (pump)	Pool heating	(?)	Used to heat Moana public pool; no longer in service	Yes	30-52
25BDAC	27.	77	—	—	—	Under construction	Yes	30-56
25CBBB	61.	225	Extractive (pump)	Apartment, pool heating	25	Temperature taken at tap	Yes	30-129
26ACC	≃82.	660	Heat exchanger	Home, water heating	12		No	30-137
26ACD	82.	635	Heat exchanger	Home, water heating	12		No	30-110
26ACD	60.	250	Heat exchanger	Home, pool heating	4	Has auxilliary heater for winter use	No	30-144
26ACDA	(?)	(?)	Heat exchanger	Pool heating	6		No	30-138
26ADAA	84.	247	Heat exchanger	Home, water heating	—	Under construction	Yes	30-134
26ADAB	85.	464	Extractive (no pump)	Home heating	≃47	Well is artesian	Yes	30-124
26ADAB	85.	245	Heat exchanger	Home, water heating	—	Under construction	Yes	30-135
26ADBA	≃80.	265	Heat exchanger	Home, water heating	2		No	30-132
26ADBA	82.	201	Heat exchanger	Home, water heating	12		No	30-115
26ADBC	85.	300	Heat exchanger	Pool heating	9		No	30-139
26ADBD	85.	≃200	Heat exchanger	Pool heating	6	Not currently in service due to drop in heat output, plans to redrill soon.	No	30-143
26ADC	≃85.	318	Heat exchanger	Home, water heating	(?)		No	30-112
26ADC	77.	180	Heat exchanger	Home heating	11		No	30-113
26ADCA	85.	204	Heat exchanger	Home, water heating	8		No	30-125
26ADCA	86.	200	Heat exchanger	Home, water heating	10	Well is artesian	No	30-111
26ADCB	85.	360	Heat exchanger	Home, water, pool heating	8	Drilled new well in 1973; currently changing over	No	30-141
26ADCC	90.	230	Heat exchanger, forced air	Home, water heating	1		Yes	30-136
26ADCC	85.	210	Heat exchanger	Home, water heating	—	Under construction	No	30-145
26ADCC	81.	225	Heat exchanger	Home, water heating	—	Under construction	No	30-149
26ADDA	78.	310	Heat exchanger	Home, water heating	1		Yes	30-119
26ADDA	≃80.	≃200	Heat exchanger	Home, water heating	11		No	30-146
26ADDB	≃85.	197	Heat exchanger	Home, water heating	12		No	30-114
26ADDC	≃85.	170	Extractive (no pump)	Home, water heating	≃20	Well is artesian, was used to heat Moana pool, now piped ≃¾ mile to house	No	30-116
26ADDD	90.	≃150	Extractive (no pump)	Home heating	44	Well is artesian	Yes	30-131
26BDCD	≃85.	750	Heat exchanger	Home, water, pool heating	11		No	30-147
26CAAC	93.	360	Heat exchanger	Home, water, pool heating	6	Copper heat exchanger pipe had corroded in 6 years causing a leak	No	30-148
26DABA	80.	198	Heat exchanger	Home heating	1	System not working well	Yes	30-122
26DACB	85.	150	Extractive (no pump)	Home, water heating	45	Well is artesian	Yes	30-128
26DBAD	92.	98	Heat exchanger	Home, water heating	2	Well is artesian	No	30-117
26DBB	≃65.	≃100	Heat exchanger	Home heating	4		No	30-126
27AACC	75.	850	Heat exchanger, forced air	Home heating	14		No	30-118

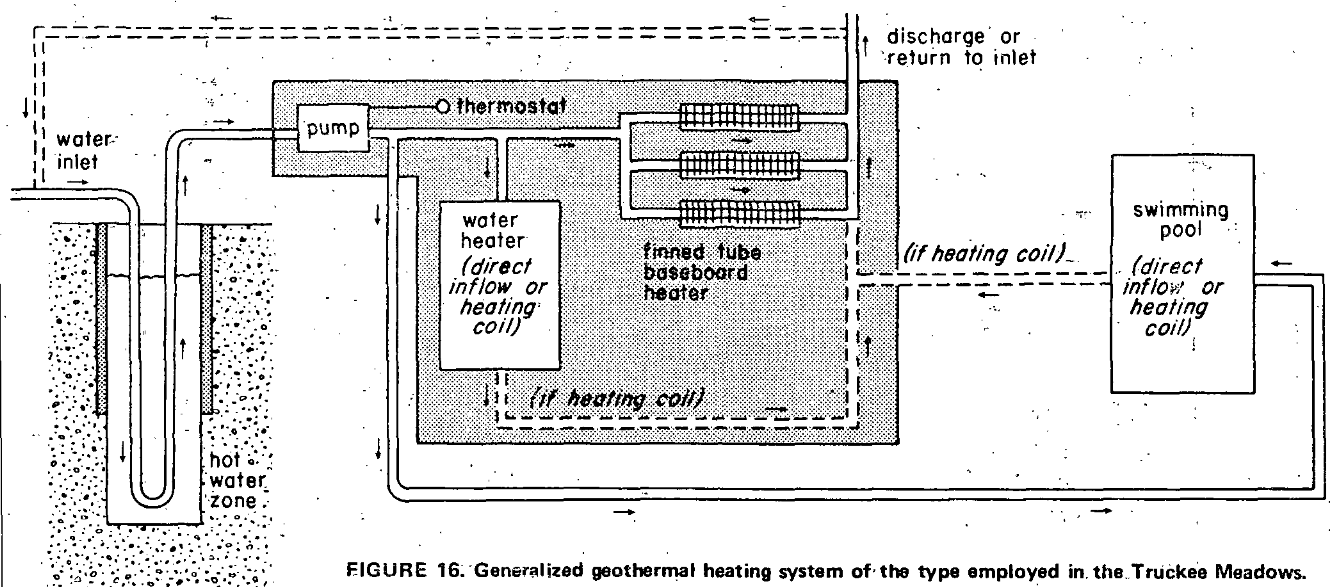


FIGURE 16. Generalized geothermal heating system of the type employed in the Truckee Meadows.

In extractive systems, the raw thermal water is circulated through tubing (baseboard heaters) to provide radiant heating. Thermal water may be used directly as inside hot water and for heated swimming pools. Most of these systems require pumping, but in a few the artesian pressure of the well is sufficient to run the system. Corrosion or scaling, although perhaps anticipated, has not been a problem in systems using Moana thermal water. Due to the rarity and simplicity of these systems, they are not further discussed in this report.

Heat exchanger systems are all of quite similar design. Basic components are: 1) a well of 6- to 8-inch-diameter, cased to the zone where water temperature exceeds approximately 70°C, 2) a heat-exchange device consisting of small diameter (about 1-2 inch) U-shaped copper tubing (trombone heater) which is emplaced in the well, and 3) a thermostatically controlled pump, finned tube baseboard heaters, and other tubing necessary to deliver heated water to the in-house components. Figure 16 shows a generalized system of the type described.

Operation is simple but in most cases effective. Input water (city water, other well water) is fed into the copper tubing and down through the trombone, where heating occurs. Heated water moves upwards out of the well and into the building to provide heat through finned-tube baseboard heaters. Rate of flow through the tubing generally is less than 20 or 50 gpm. The system may be used for generating domestic hot water in one of two ways. Either the heated water is circulated in a coil inside a modified water heater tank or, more commonly, the heated water is bled off the system as input water to a standard water heater. Swimming pools are heated similarly. Thermostatically controlled pumps are installed in most systems. In those without pumps, input water pressure and convection provide the necessary circulation.

Existing systems are of both open and closed types. In closed systems the same water is continually circulated, new water being added only to replace leakage or other losses. In open systems, fresh water is fed into the system and spent water is discharged to the sewer or an outside drain.

Cost and Maintenance

The initial cost of heat exchanger systems is high, ranging from $5,000 to $8,000 depending upon the features desired. This general estimate includes the cost of: 1) drilling and completing well to a depth of 200 to 300 feet, 2) copper tubing, baseboard heaters, and other minor materials, and 3) labor. Drilling and completion of a well is the major cost. Current (1974) rates range from $11.00 per foot for a 6-inch well to $13.50 per foot for an 8-inch well.

Operational costs of systems are minimal if problems do not occur. Electrical power is required simply for the small capacity control pump. The only other basic cost is for the relatively small amount of water (even in an open system) which is circulated through the tubing.

Based on interviews with several owners, maintenance is not a frequent problem. However, when breakdowns do occur they often involve the well and thus are serious and potentially expensive. As an example, a decrease in water temperature has occurred in some wells after an extended period of stable operation. In some cases the temperature drop followed a mild earthquake; for others no cause was apparent. Certain wells have recovered their original temperature, but most have not. Drilling of a new well then may be the only solution.

Other problems most often encountered concern the ability of a well to sustain the temperature of output water under continuous operation; or the ability of the system to maintain and deliver water of well output temperature to in-house components. Explanations of some of these problems, and their possible solutions, will be discussed in following sections of this report.

Hydrologic Effects

Closed heat-exchanger systems should have no detrimental effect on water quality within the basin. Open systems will produce thermally polluted water but because flow rates are quite small (only tens of gpm per unit) the overall effects will be minimal. Extractive systems are potentially most detrimental because the hot, poor quality waters of the thermal system must be disposed of. The current trend toward almost exclusive utilization of heat-exchanger systems suggests the disposal problem will not develop.

The type of development now underway should have only limited effect on ground-water conditions in the immediate Moana vicinity. A gradual lowering of artesian pressure and perhaps of local ground-water temperature can be expected if more and more systems are developed. Distribution and dispersion of thermal water within the basin-wide ground-water system will not be affected by such development.

Theory and Assessment

The following sections deal with the application of geothermal heat to small-scale beneficial uses as those in the Truckee Meadows. Basic theory and design concepts are discussed and suggestions presented for improvement of current technology. All calculations are in English units and degrees Fahrenheit (°F) due to formulation of basic equations. To avoid confusion of double units, corresponding centigrade temperatures are not shown. A temperature conversion table is included as Appendix B.

Basics

Flow of heat from one fluid to another across a solid boundary is described by the following equation:

$$q = U \cdot A \cdot \Delta T \qquad (1)$$

where: q = heat flow (Btu/hr)
U = overall heat transfer coefficient (Btu/hr ft² °F)
A = area through which heat flows (ft²)
ΔT = temperature difference between fluids (°F)

Thus if a horizontal, rectangular tank is divided by a solid partition with a surface area of 4 square feet, with a fluid on one side at 200°F and a fluid on the other side at 150°F, and the heat transfer coefficient is 40 Btu/hr ft² °F, then the heat flow will be:

$$q = 40 \times 4 \times 50 = 8000 \text{ Btu/hr}$$

The overall heat-transfer coefficient has been measured for thousands of gases and liquids. Data and observations from these studies have shown that the overall heat-transfer coefficient can be broken into component parts. Figure 17 is a close-up view of the hypothetical rectangular tank.

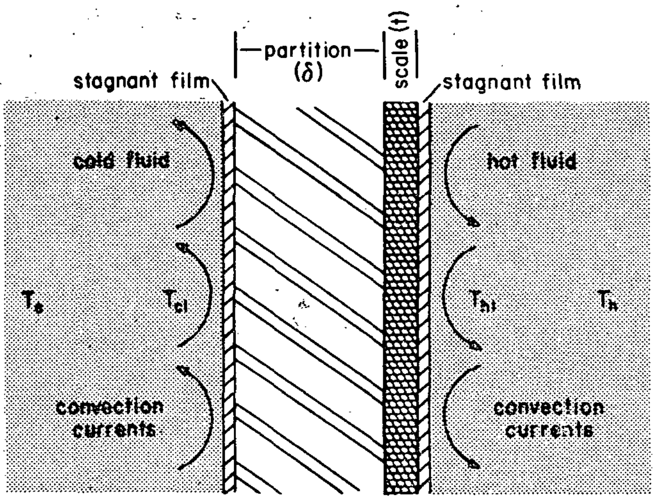


FIGURE 17. Natural convection and stagnant layers near a solid boundary.

First note that the partition has a scale deposit on one side; this will affect the heat-transfer coefficient. Next note that fluids in the vicinity of the wall are moving due to density (ρ) gradients caused by non-uniform temperatures near the partition:

$$T_c < T_{cl} \therefore \rho_c > \rho_{cl}$$

$$T_h > T_{hl} \therefore \rho_h < \rho_{hl}$$

Additionally, the fluid in contact with the partition does not move with convection, there is a stagnant film between the convection currents and the solid surfaces.

In calculating the overall heat transfer coefficient, two solids and the stagnant films are taken as four solids in series and treated by Fourier's theory of conduction, so that:

$$\frac{1}{U} = \frac{1}{h_c} + \frac{\delta}{k_p} + \frac{t}{k_s} + \frac{1}{h_h} \qquad (2)$$

where: h_c = individual cold side coefficient (Btu/hr ft² °F)
h_h = individual hot side coefficient
k_p = partition thermal conductivity (Btu/hr ft² °F/ft)
k_s = scale thermal conductivity and δ, t are defined in figure 19

For the case in which copper tubing is immersed in a geothermal reservoir, the partition is replaced by a pipe wall. Copper thermal conductivity is high and, therefore, $\delta/k_p \approx 0$. Also, since wells examined have shown little sign of scaling, $t/k_s \approx 0$, and:

$$\frac{1}{U} = \frac{1}{h_c} + \frac{1}{h_h} \qquad (3)$$

In the case of the copper tubing, fluid on one side of the wall (the inside) is in rapid motion, being forced through the tubing by a pump or city water pressure. The stagnant film on that side is greatly reduced:

$$\frac{1}{h_c} < \frac{1}{h_h}$$

Thus for trombone heaters placed in geothermal reservoirs, the overall heat-transfer coefficient is a strong function of the hot side (outside) coefficient. It is only a weak function of the cold side (inside) coefficient, but this coefficient cannot be ignored.

In heat transfer between solids and fluids, the individual coefficients are classified according to how fluid motion occurs near the interface: natural convection or forced convection. Natural convection is caused by thermal gradients. Forced convection is caused by mechanical or gravitational means (agitation, pumping).

For the case of turbulent flow inside a pipe, the following equation (Bird, 1960) can be used to calculate the inside coefficient:

$$\frac{h_i D}{k} = 0.026\left(\frac{DV\rho}{\mu}\right)^{0.8}\left(\frac{C_p\mu}{k}\right)^{1/3}\left(\frac{\mu_b}{\mu_w}\right)^{0.14} \qquad (4)$$

where: D = inside diameter
k = fluid thermal conductivity
V = velocity
ρ = fluid density
μ = fluid viscosity (subscript b is for viscosity at the stream temperature, subscript w for viscosity at the wall temperature)
C_p = fluid heat capacity at constant pressure

When natural convection occurs outside long, vertical cylinders under turbulent conditions, equation (5) can be used to calculate the outside coefficient (McAdams, 1954):

$$\frac{h_o L}{k} = 0.13\left[\frac{L^3\rho^2 g\beta\,\Delta T_f}{\mu^2}\left(\frac{C_p\mu}{k}\right)\right]^{1/3} \qquad (5)$$

where: L = vertical dimension
g = local acceleration of gravity
β = coefficient of thermal expansion
T_f = temperature drop across film

Note: This equation applies to natural convection in an unconfined space, a condition which does not exist in a well. Calculated values for h_o will tend to be high. This is acceptable, however, because in a well there is likely to be some flow of reservoir water across the trombone which would raise h_o in a similar manner.

Considering the original heat transfer equation (1), the following observations are worth noting:

$$q = U \cdot A \cdot \Delta T \qquad (1)$$

1. $\underline{q}$ is fixed by the amount of heat that must be supplied to heat a residence on the coldest winter night.
2. $\underline{A}$ is related to dimensions of the well. The larger the well, the more heat-transfer area that can be put in it. However, the larger the well, the more it will cost. $\underline{U}$ and $\underline{\Delta T}$ should be manipulated to minimize $\underline{A}$.
3. $\underline{\Delta T}$ is the difference between thermal reservoir temperature and temperature of fluid in the trombone. At a given reservoir temperature, $\underline{\Delta T}$ can be maximized by using low fluid temperatures in the trombone. This becomes impractical at trombone temperatures near 125°F because the amount of baseboard heaters becomes unduly large.
4. $\underline{U}$ should be raised as high as possible by raising the individual coefficients. This is not appreciated in the present state of the art. $\underline{U}$ will be greatly affected by the presence (or absence) of underground thermal water movement.

Reservoir Testing

It is of great value to determine the thermal reservoir temperature when completing a well to be used for geothermal heating. This is, however, only part of the information needed for installation of a reliable, minimum-cost heating system. Other items requiring definition are the overall heat-transfer coefficient and the heat-flow capability of the well. Such measurements provide an indication of the efficiency of the well and its ability to sustain heat output. Both can be determined quickly and inexpensively.

Equipment needed to make these measurements include three long thermocouples, a 5-foot coiled helix of 5/8-inch copper tubing, several hundred feet of rubber tubing, a galvanometer, and access to city water or some other pressurized water system. Figure 18 shows this equipment set up for test. Rubber tubing is connected to each end of the copper helix. The other end of the tubing attached to the helix is connected to the water source. Two of the thermocouples (TC1-TC2 in fig. 18) are put through the wall of the rubber tubing near where it connects to the helix. The third thermocouple is secured to the helix with its sensitive tip approximately three-quarters of an inch outside the helix envelope.

A sash weight is lowered down the well on a wire. This wire serves to guide the helix and thermocouples to the desired depth in the well. When the helix is in position, wires and tubing are secured to keep from moving the helix while measurements are being made.

After agitation caused by inserting these devices has ceased (detected by monitoring TC3), the water source is turned on and the flow rate determined. Readings are

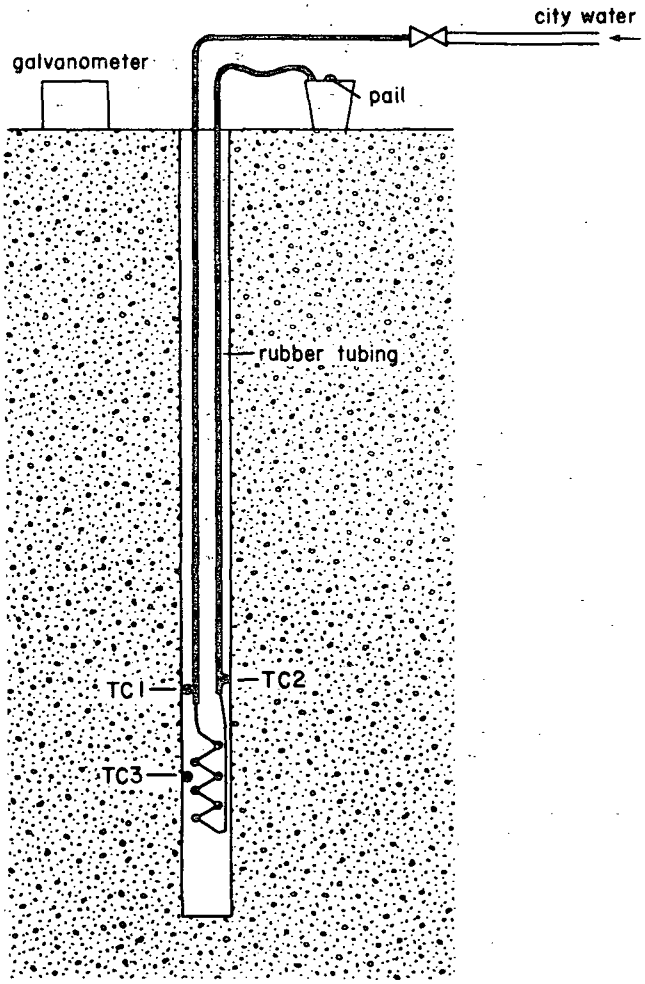


FIGURE 18. Scheme for geothermal well testing.

periodically recorded for all three thermocouples. From this data and equations such as (1), (3), (4), and (5), heat transfer coefficients can be calculated and compared to heat transfer coefficients for different fluid conditions.

Stability of TC3 indicates the heat flow capability. If readings on TC3 drop only slightly before stabilizing, the well has a high heat-flow capability. If TC3 steadily falls, the well probably has poor heat-flow capability. Energy balance calculations will determine what is happening with a depressed TC3.

System Evaluation

Calculations were made to evaluate the effects of several variable parameters on efficiency of heat extraction from geothermal wells. The analysis was limited to home heating; extraction of hot water for domestic uses was not considered.

Initially, heat flow from a hypothetical residence was estimated for the coldest night of the year, and length of baseboard heaters required to warm this house were estimated. Parameters in the baseboard estimate were: 1) input temperature to the heaters, 2) number of parallel branches, and 3) flow (in gpm) per branch. The temperature of outlet water from the baseboard heaters was also estimated.

Using inlet and outlet temperatures of the baseboard heaters as end conditions for the trombone, the parameters of $q = U \cdot A \cdot \Delta T$ (equation 1) were calculated using equations (4) and (5) to estimate $\underline{U}$. Values of $\underline{A}$ were used to calculate lengths of 2-inch copper tubing needed for trombone heaters. The same procedure was used to calculate required lengths of a helix made from 5/8-inch copper tubing. Manufacturers data on baseboard heaters obtained from a local plumbing supply house were extrapolated using generalized heat-transfer equations to a lower temperature range (given range: 240 to 170°F; extrapolated to 100°F). A hypothetical home heating system was then established. The system decided upon was one in which the residence would be heated by $\underline{n}$ parallel branches. Each branch would consist of two 15-foot segments of baseboard heater.

This study was based on an assumed cost of $200 per year for heating of a house. The heat load was established by dividing $200 per year by $1.86/million Btu (local natural gas cost), and then reducing this to Btu per hour. A similar analysis could be performed using unit costs for fuel oil or electricity. Maximum heat load was determined by multiplying this average figure by the ratio: temperature differential on coldest night to winter average temperature differential. This yielded q = 72,500 Btu/hr.

The value of $\underline{n}$ was then calculated for different values of trombone outlet temperature (T_O) and different values of flow per branch. Multiplying $\underline{n}$ times 30 then gave the total feet of baseboard heaters required. Figure 19 shows results.

The most significant observation is that the effect of gpm/branch is to reduce the length of heaters required. This reduction is less pronounced at high temperatures:

gpm/branch	Required length (ft)		Total gpm	
	100°F	220°F	100°F	220°F
1/2	712	121	12	2
2	587	94	39	6

Heater lengths are longer at lower flows because average water temperatures in the heaters are lower. A low average temperature is desirable for heat transfer from the thermal reservoir.

The next observation is that total flows are notably higher when branch flows are high. This is disadvantageous because it results in large well diameters. An additional 125 feet (712 minus 587) of baseboard heater at the low flow rate can be paid for by the reduced cost of a smaller diameter well. The advantage of low gpm/branch is more pronounced at higher trombone outlet temperatures.

The minimum trombone outlet temperature is established by examining figure 19a. A reasonable length for baseboard heaters that can be accommodated in the residence depends on size of rooms (assuming three baseboards of the average room can be heated):

Room Size	Feet of Baseboard per 100 ft^2
15x15	20
20x20	15
25x25	12

For a 3000-square-foot home, a maximum of 400 feet seems reasonable. Therefore, the probable limit to trombone outlet temperature for a house heated solely by baseboard heaters is in the vicinity of 125°F.

It is important to note that by making design changes in baseboard heaters, or by combining baseboard heaters with forced air heating, this limit might be pushed as low as 100°F, and that with only minor modifications, the limit could be between 100–125°F. For this study, a limit of 115°F is adopted for minimum trombone outlet temperature.

Reservoir Temperature

It is quite obvious that a high-temperature well is to be preferred over a low temperature one. The question is how low a temperature can be tolerated? The answer, to some extent, depends on the minimum baseboard temperature described in the previous section. It also depends on the design of the heat exchanger immersed in the well, and on the heat-flow characteristics of the well.

Figure 20 shows two schemes by which heat can be extracted from a hot water reservoir. Figure 20a describes a more compact, less costly installation than the simpler trombone seen in 20b.

Four basic elements make design (a) superior to design (b):

1. The judicious use of insulation keeps heat flowing into the tubing at all points instead of permitting heat to be lost in the cold zones.
2. T_i and T_o are lower for design (a). This requires more baseboard heating for the residence, but allows a shorter hot-zone length (L_h) which means less drilling.
3. Flow in (a) is lower than the flow in (b), therefore the diameter of tubing for (a) is smaller. The tubing can be coiled and more heat-transfer area can be packed into a given space. This too reduces required drilling.
4. Fluid velocity (V_w) is considerably higher in (a). This raises heat-transfer coefficient and reduces the required tubing diameter (and drilling costs) even more.

Figure 21 illustrates the hot-zone lengths required for the two systems at various T_o/T_r ratios. Obviously the ratio can never reach unity, but it approaches unity at much shorter hot-zone lengths using a 5/8-inch coil rather than the basic trombone. It is clear that the lowest exploitable temperature depends strongly on heat-exchanger design.

Figure 21 illustrates another important factor. Using a correctly designed heat exchanger, ratios of T_o/T_r greater than 0.95 can be achieved in reasonable lengths of hot zone (L_h). Therefore, since T_o(min.) is 115°F, it appears that T_r(min.) of a well with excellent heat-flow capability is 120°F. If the hot zone is quite long (say 100 feet), and if special baseboard heaters and forced air heaters are used, it is conceivable that a T_r of 105°F might be exploitable. This amounts to quite a string of "ifs." A minimum reservoir temperature of 120°F is more prudent.

High reservoir temperatures greatly simplify the matter of residential heating, as shown by figure 22. The ordinate corresponds to lengths of 2-inch trombone needed to exchange 72,500 Btu/hr. The four curves correspond to reservoir temperatures of 250, 205, 160, and 130°F. All curves are caught in a dual squeeze, but this is most apparent with the 130°F curve. The lower limit of the curve is the

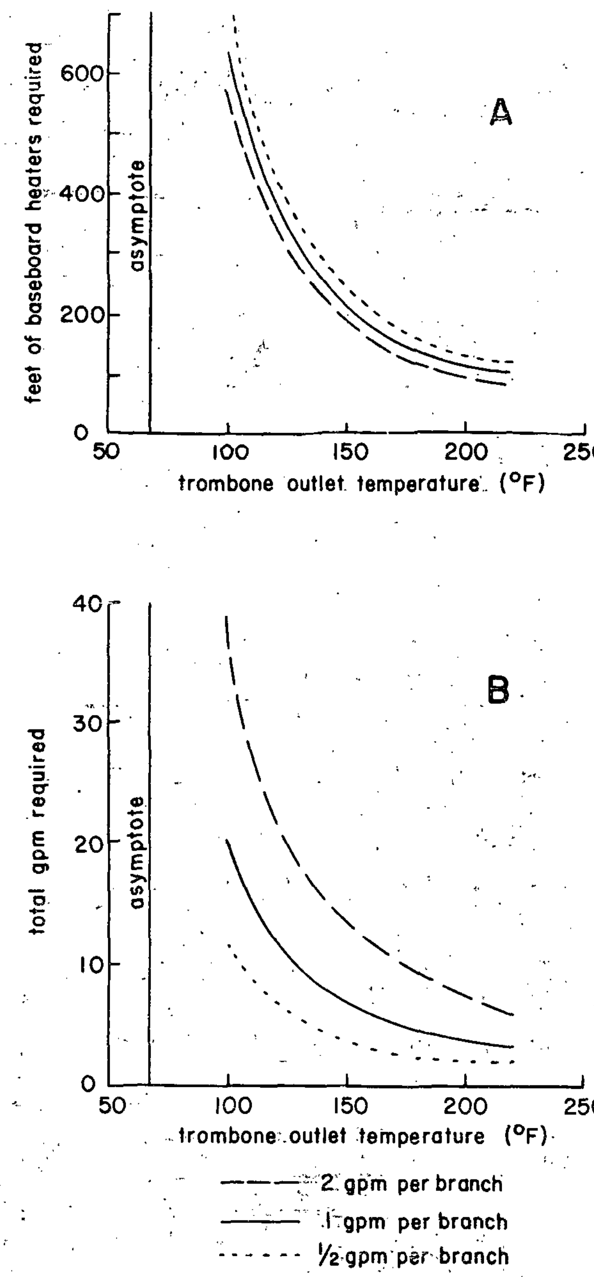


FIGURE 19. Effects of trombone outlet temperature and system flow rates.

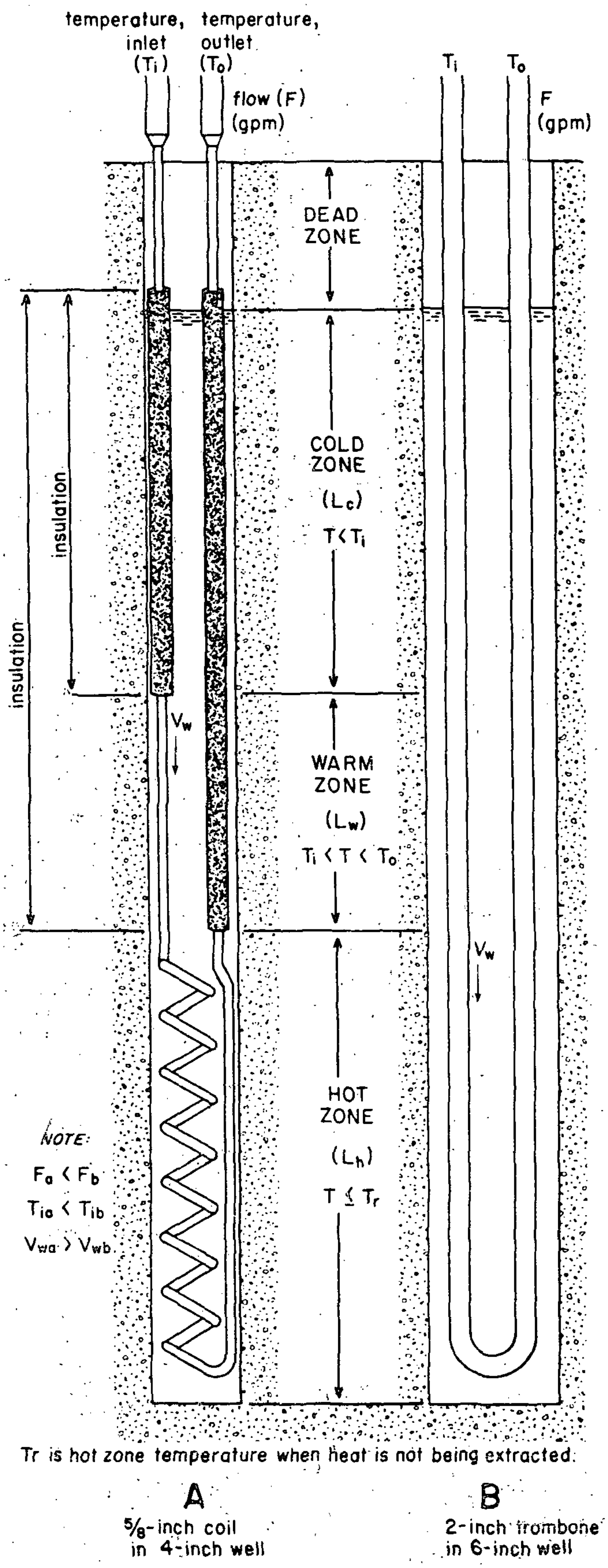


FIGURE 20. Heat-exchanger configurations.

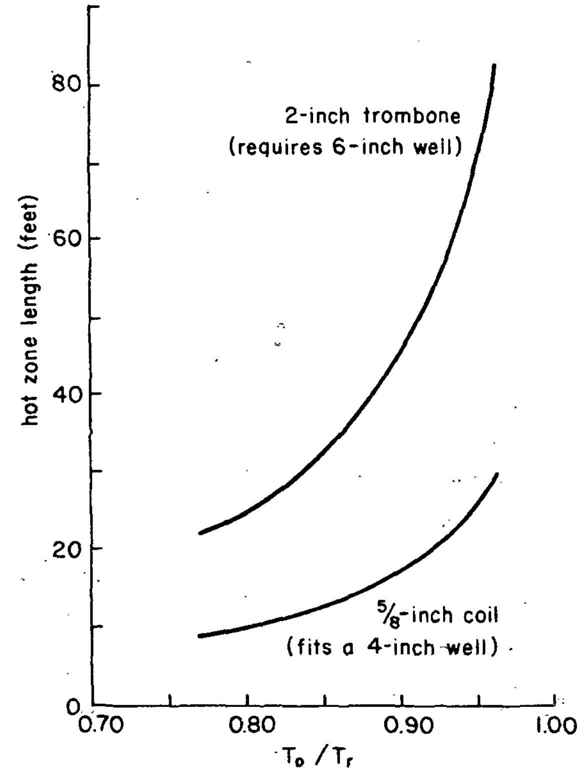


FIGURE 21. Hot zone lengths required at 130°F.

115°F temperature required by the baseboard heaters, a (T_o/T_r)min. of 0.885. The upper limit is the rapid increase of length required for the trombone. The situation with the 250°F curve is considerably less demanding, (T_o/T_r)min. = 0.46. Trombone length at T_o/T_r = 0.95 is quite reasonable.

Economics

Two kinds of costs are involved in any home heating system, the permanent investment (piping, furnace, pump, controls, plumbers fee, etc.), and operating expenses (electricity, maintenance, gas bills, etc.). Permanent investment can be regarded as a lump sum paid when permanent fixtures are installed. Operating expenses can be regarded as a steady cash flow that occurs over the life of the permanent fixtures.

As an example for geothermal heating systems, well drilling costs (permanent investment) are measured against the assumed $200 per year (operating expense) utility bill. This direct comparison is made by assuming costs of trombone heater, pump, and *extra* baseboard heaters are approximately equal to the cost of a conventionally fired furnace. It is assumed the individual desiring to install a well would want to earn 5 percent on his investment (drilling cost) and recover his investment over a period of 20 years. His permissible expenditure would then be:

$$P = 200 \frac{(1+i)^n - 1}{i(1+i)^n} = \frac{(1.05)^{20} - 1}{0.05(1.05)^{20}} \times 200 = \$2500$$

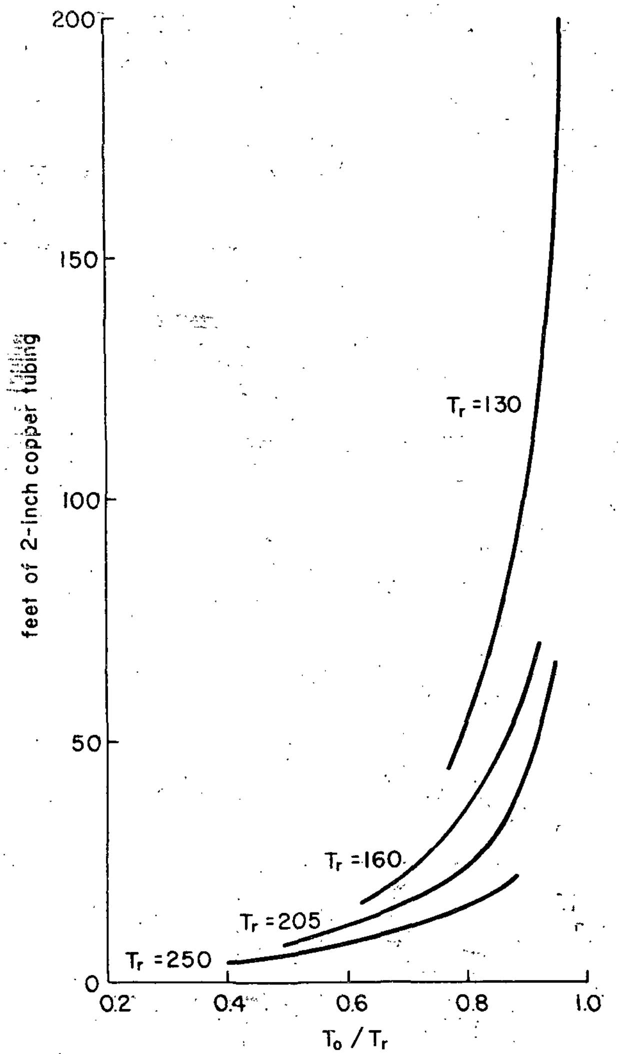


FIGURE 22. Trombone length requirement as a function of reservoir temperature (all curves for one gpm per branch).

In terms of permissible well depth, this works out to:

8 inch well . . . . . . 185 feet (@ \$13.50 per foot)
6 inch well . . . . . . 227 feet (@ \$11.00 per foot)

Clearly, this person assumes a smaller financial risk by going to the smaller diameter well. In effect, a well is an expensive conduit. It should be as small in size as possible, and flow of water should be sent through the heat exchanger at the highest practical velocity.

All economic arguments point to small-diameter wells for heat-exchanger systems in private homes. The lower limit of well diameter is established by the amount of heat transfer area that must be put into a well. The minimum bending radius of a 3/4-inch copper tube would allow a helix of such tubing to fit into a 4-inch well. The same copper tube would be large enough to accommodate substantial volumes of flow. An inherent assumption in suggesting smaller well diameters is that the heat-flow characteristics are equivalent to 8-inch wells. There is no reason to believe that they would not be.

REFERENCES CITED

Anderson, R. (1909) Geology and oil prospects of the Reno region, Nevada: U.S. Geol. Survey Bull. 381, p. 475–493.

Bird, R. B. (1960) Transport phenomena: John Wiley, New York, N.Y.

Bodvarsson, G. (1964) Utilization of geothermal energy for heating purposes and combined schemes involving power generation, heating, and/or by-products: United Nations Conf. New Sources Energy, Rome, 1961, Proc., v. 3 (Geothermal Energy 2), p. 429–445.

Bingler, E. C. (1975) Guidebook to the Quaternary geology along the western flank of the Truckee Meadows, Washoe County, Nevada: Nevada Bur. Mines and Geol. Rept. 22, 14 p.

Bonham, H. F., and K. G. Papke (1969) Geology and Mineral Deposits of Washoe and Storey Counties, Nevada: Nevada Bur. Mines, Bull. 170, 140 p.

Bonham, H. F., and Bingler, E. C. (1973) Geologic map Reno quadrangle: Nevada Bur. Mines and Geol. Environmental Ser., Reno Folio.

Brannock, W. W., Fix, P. F., Gianella, V. P., and White, D. E. (1948) Preliminary geochemical results at Steamboat Springs, Nevada: Am. Geophys. Union Trans., v. 29, no. 2, p. 211–226.

Cohen, P. (1961) An evaluation of uranium as a tool for studying the hydrogeochemistry of the Truckee Meadows area, Nevada: Jour. Geophys. Res., v. 66, no. 12, p. 4199–4206.

———— (1962) Source of sulphate in ground water of the Truckee Meadows area, Nevada: U.S. Geol. Survey Prof. Paper 450-C, p. 131–132.

Cohen, P., and Loeltz, O. J. (1964) Evaluation of hydrogeology and hydrogeochemistry of Truckee Meadows area, Washoe County, Nevada: U.S. Geol. Survey Water Supply Paper 1779-S, 63 p.

Cooley, R. L., Fordham, J. W., and Westphal, J. A. (1971) Hydrology of Truckee Meadows, Nevada: Center for Water Resources Research, Desert Research Inst., Univ. of Nevada System, Proj. Rept. no. 15, 49 p.

———— (1973) Some applications of statistical methods to ground-water flow system analysis: Center for Water Resources Research, Desert Research Inst., Univ. of Nevada System, Tech. Rept. Ser. H-W, Hydrology and Water Resources Pub. no. 14, 53 p.

Einarsson, S. S. (1970) Utilization of low enthalpy water for space heating, industrial, agricultural and other uses: United Nations Symp. Development Utilization Geothermal Resources, Pisa, 1970, Rapporteur's Rep., Section 10, in Geothermics, sp. issue 2.

Koenig, J. B. (1970) Geothermal exploration in the western United States: United Nations Symp. Development Utilization Geothermal Resources, Pisa, 1970, v. 2, pt. 1, in Geothermics, sp. issue 2, 13 p.

McAdams, W. H. (1954) Heat transmission, 3rd Ed.: McGraw-Hill, New York, N.Y.

McKee, J. E., and Wolf, H. W., Editors (1963) Water quality criteria: Resources Agency California, State Water Resources Control Board, Pub. no. 3-A, 548 p.

Nichols, C. R., Brockway, C. E., and Warnick, C. C. (1972) Geothermal water and power resource exploration and development for Idaho: Water Resources Research Inst., University of Idaho, Research Tech. Completion Rept., NSF-47-514, 38 p.

O'Leary, Mont, Lippert, R. H., and Spitz, O. T. (1966) Fortran IV and map program for computation and plotting of trend surfaces for degrees 1 through 6: Lawrence, Univ. of Kansas, State Geol. Survey, Computer Contrib. 3, 47 p.

Peterson, N. V., and Groh, E. A. (1967) Geothermal potential of the Klamath Falls area, Oregon—A preliminary study: Oregon Dept. Geol. Mineral Ind., The Ore Bin, v. 29, p. 209–231.

Stephens, R. (1971) Hydrochemistry of Truckee Meadows: unpublished manuscript.

Thompson, G. A. (1956) Geology of the Virginia City quadrangle, Nevada: U.S. Geol. Survey Bull. 1042-C, p. 45–77.

Thompson, G. A., and White, D. E. (1964) Regional geology of the Steamboat Springs area, Washoe County, Nevada: U.S. Geol. Survey Prof. Paper 458-A, 52 p.

U.S. Public Health Service (1962) Drinking water standards: Public Health Bull. 956, 61 p.
U.S. Department of Commerce-Weather Bureau (1960) Climates of the States-Nevada: Climatography of the United States, no. 60-26, Washington, D.C., 16 p.
Wells, M. W. (1971) Heat from the Earth's surface; early development of western geothermal resources: Journal of the West, v. 10, p. 53–71.
White, D. E. (1957) Thermal waters of volcanic origin: Geol. Soc. America Bull., v. 68, no. 12, pt. 1, p. 1637–1658.
_______ (1967) Some principals of geyser activity, mainly from Steamboat Springs, Nevada: Am. Jour. Sci., v. 265, no. 8, p. 641–684.
_______ (1968) Hydrology, activity, and heat flow of the Steamboat Springs thermal system, Washoe County, Nevada: U.S. Geol. Survey Prof. Paper 458-C, 109 p.
_______ (1974) Diverse origins of hydrothermal ore fluids: Econ. Geol., v. 69, p. 954–973.
White, D. E., and Brannock, W. W. (1950) The sources of heat and water supply of thermal springs, with particular reference to Steamboat Springs, Nevada: Am. Geophys. Union Trans., v. 31, no. 4, p. 566–574.
White, D. E., Thompson, G. A., and Sandburg, C. H. (1964) Rocks, structure, and geologic history of Steamboat Springs thermal area, Washoe County, Nevada: U.S. Geol. Survey Prof. Paper 458-B, 63 p.
White, D. E., and McNitt, J. R. (1966) Geothermal energy, in mineral resources of California: Calif. Div. Mines Geol., Bull. 191.
White, D. E., Craig, Harmon, and Begemann, F. (1967) Summary of the geology and isotope geochemistry of the Steamboat Springs area, Nevada: Proc. Spoleto Conf.

APPENDIXES

Sample Number	Location	Source	Depth (feet)	Date of Collection	Analyst	Temp. (°C)	Bicarbonate mg/l	Bicarbonate epm	Carbonate mg/l	Carbonate epm	Chloride mg/l	Chloride epm	Sulfate mg/l	Sulfate epm	Sodium mg/l	Sodium epm
30-4	18N 20E 9BD	Well	122	05-08-56	USBR	30	227	3.721	—	—	313	8.827	50	1.041	262	11.397
30-5	18N 20E 17DC	Spring	—	01-14-58	USGS	34.5	224	3.671	—	—	94	2.651	17	.354	130	5.655
30-6	18N 20E 17DC	Well	99	10-22-48	NSHD	45.5	461	7.556	—	—	82	2.312	10	.208	115	5.002
30-23	18N 20E 23BC	Well	—	—	DRI	41	306	5.015	—	—	337	9.503	147	3.061	318	13.833
30-63	18N 20E 27B	Well	115	11-02-72	NSHD	48.9	388	6.359	12	.400	950	26.790	75	1.561	762	33.147
30-64	18N 20E 27DDD	Well	—	08-25-59	NSHD	40	158	2.590	—	—	7	.197	504	10.493	112	4.872
30-11	18N 20E 28BA	Well	151	06-03-58	USGS	121	172	2.819	65	2.166	836	23.575	130	2.707	660	28.710
30-60	18N 20E 28BDC	Well	—	08-02-60	NSHD	75	256	4.196	—	—	805	22.701	130	2.707	630	27.405
30-19	18N 20E 28CB	Well	200	01-05-50	USGS	145	337	5.523	—	—	836	23.575	94	1.957	640	27.840
30-20	18N 20E 29BC	Well	82	06-49	USGS	34	78	1.278	—	—	2.6	.073	11	.229	12	.522
30-61	18N 20E 33AB	Well	—	09-28-68	DRI	52	300	4.917	46	1.533	999	28.172	121	2.159	770	33.495
30-27	18N 20E 33AB	Spring	—	08-49	USGS	89	305	4.999	—	—	865	24.393	100	2.082	653	28.405
30-26	18N 20E 33BA	Spring	—	07-45	USGS	95	292	4.786	20	.667	949	26.762	129	2.686	707	30.754
30-46	18N 20E 33BD	Spring	—	02-05-57	USGS	58	328	5.376	—	—	790	22.278	142	2.956	644	28.014
30-25	18N 20E 33CA	Spring	—	07-45	USGS	57	419	6.867	—	—	752	21.206	106	2.207	602	26.187
30-62	18N 20E 33DBA	Spring	—	08-27-68	DRI	54	336	5.507	—	—	767	21.269	141	2.936	635	27.622
30-28	18N 20E 33DB	Well	—	—	USGS	92	191	3.130	104	3.466	747	21.065	105	2.186	605	26.317
30-24	18N 20E 33DC	Well	258	—	—	75	146	2.393	19	.633	8.4	.237	2.3	.048	69	3.001
30-66	18N 20E 34C	Well	—	02-22-63	NSHD	70	242	3.966	—	—	6	.169	72	1.499	18	.783
30-67	18N 20E 34CAA	Well	—	01-07-63	NSHD	66	158	2.590	—	—	5	.141	72	1.499	5.8	.252
30-65	18N 20E 34DA	Well	—	—	NSHD	50	95	1.557	—	—	6	.169	480	9.994	101	4.393
30-68	19N 18E 13AC	Spring	—	02-11-58	USGS	49	12	.197	20	.667	57	1.607	144	2.998	117	5.089
30-50	19N 19E 22CD	Well	270	08-08-46	NSHD	30	378	6.195	—	—	26	.733	1959	40.786	500	21.750
30-51	19N 19E 23DA	Well	103	05-20-58	USGS	37	211	3.548	—	—	32	.902	325	6.766	199	8.656
30-47	19N 19E 13BC	Well	785	—	—	30	193	3.163	—	—	30	.846	258	5.372	148	6.438
30-121	19N 19E 24BBA	Well	900	—	DRI	42	131	2.147	—	—	31	.874	258.3	5.378	175	7.612
30-120	19N 19E 24CABA	Well	—	—	DRI	47.2	135.9	2.227	—	—	20.2	.570	170.6	3.552	139	6.046
30-133	19N 19E 24BCDB	Well	1006	—	DRI	59	143.6	2.356	—	—	26	.282	226.7	4.720	154.7	6.731
30-82	19N 19E 24DDC	Well	—	01-18-58	NSHD	48	119	1.950	—	—	31	.874	294	6.121	181.6	7.90
30-54	19N 19E 25BA	Well	67	—	—	36	165	2.704	—	—	16	.451	153	3.185	130	5.655
30-52	19N 19E 25BA	Well	700	02-11-58	USGS	45.5	134	2.196	—	—	24	.677	221	4.601	150	6.525
30-56	19N 19E 25BD	Well	77	04-74	DRI	33.5	159	2.606	—	—	17.3	.488	155.9	3.245	127.49	5.546
30-59	19N 19E 25BD	Well	95	07-09-47	NSHD	44.5	139	2.278	17	.567	32	.902	225	4.684	128	5.568
30-129	19N 19E 25CBBB	Well	225	—	DRI	63.1	131.5	2.156	—	—	33.5	.945	304.6	6.343	189.35	8.237
30-134	19N 19E 26ADAA	Well	247	—	DRI	84.2	107.68	1.765	—	—	54	1.523	462.8	9.635	266.2	11.581
30-135	19N 19E 26ADAB	Well	245	—	DRI	85	97.55	1.599	—	—	54	1.523	448.8	9.345	243.2	10.579
30-124	19N 19E 26ADA	Well	464	—	DRI	85	99	1.629	—	—	53	1.495	478.2	9.957	258.74	11.255
30-136	19N 19E 26ADCC	Well	230	—	DRI	90	146	2.472	—	—	42	1.184	348.3	7.252	203	8.832
30-119	19N 19E 26ADDA	Well	310	—	DRI	78	100.6	1.649	—	—	53	1.495	465.5	9.692	293	12.746
30-131	19N 19E 26ADDD	Well	150	—	DRI	89.9	86.2	1.413	—	—	50	1.410	457	9.514	243.19	10.579
30-128	19N 19E 26DACB	Well	150	—	DRI	85	85.8	1.407	—	—	48.3	1.362	454.6	9.465	235.64	10.250
30-122	19N 19E 26DABA	Well	198	02-18-74	DRI	80	95	1.557	—	—	53	1.495	419	8.724	248	10.788
30-79	19N 19E 26DC	Well	750	10-25-39	NSHD	82	88	1.442	—	—	52	1.466	478	9.952	241	10.483
30-86	20N 19E 23C	Well	—	02-05-58	NSHD	60	237	3.884	—	—	28	.790	271	5.642	—	—
30-87	20N 19E 23C	Well	—	02-05-58	NSHD	60	160	2.622	—	—	7.50	.212	126	2.623	—	—
30-88	20N 20E 27C	Well	—	08-28-60	NSHD	45	205	3.360	—	—	27	.761	110	2.290	77.03	3.351
20-39	17N 20E 7D	Well	107	—	NSHD	24	151	2.475	—	—	5	.141	3	.062	19	.826
20-44	18N 20E 6AB	Well	504	08-20-68	CLHT	21.7	154	2.524	—	—	2	.056	18	.375	45	1.958
20-5	18N 20E 9CA	Well	45	05-08-56	USBR	22.2	151	2.475	9	.300	128	3.610	30	.625	147	6.394
20-6	18N 20E 9CC	Well	84	05-19-58	USGS	26.7	224	3.671	—	—	160	4.512	17	.354	160	6.960
20-40	18N 20E 14B	Well	103	07-24-73	NSHD	22.2	268	4.393	—	—	490	13.818	143	2.977	330	14.355
20-7	18N 20E 14BB	Well	—	05-14-58	USGS	23.9	264	4.327	—	—	511	14.410	151	3.144	313	13.615
20-9	18N 20E 14BC	Well	48	05-14-58	USGS	21.7	258	4.229	—	—	360	10.152	125	2.602	202	8.787
20-10	18N 20E 17AD	Well	73	05-08-56	USBR	22.2	176	2.885	9.6	.320	6.0	.169	6.2	.129	79	3.436
20-11	18N 20E 17AD	Well	100	05-08-56	USBR	29.4	228	3.737	6.6	.220	12	.338	7.6	.158	94	4.089
20-14	18N 20E 20DD	Well	66	02-11-46	NSHD	23.5	102	1.672	—	—	14	.395	21	.437	4	.174
20-16	18N 20E 21CA	Well	44	05-19-58	USGS	21	126	2.065	—	—	6.0	.169	5.8	.121	22	.957
20-20	18N 20E 27DC	Well	195	03-29-59	USGS	29.4	148	2.426	—	—	6.2	.175	508	10.577	100	4.350
20-22	18N 20E 28AB	Well	80	05-14-58	USGS	22.2	241	3.950	—	—	73	2.059	22	.458	83	3.610
20-42	18N 20E 29B	Well	160	07-30-71	NSHD	23.3	212	3.475	—	—	6	.169	13	.271	18	.783
20-25	18N 20E 30CD	Well	300	02-11-58	USGS	20	162	2.655	—	—	2.9	.082	2.4	.050	22	.957
20-43	18N 20E 34	Well	120	04-17-72	NSHD	29.4	361	5.917	—	—	750	21.150	234	4.872	679	29.537
20-41	18N 20E 34BB	Well	225	06-11-73	NSHD	27.8	200	3.278	—	—	43	1.213	543	11.305	230	10.005
20-49	19N 19E 4DCC	Well	582	08-09-60	—	22	110	1.803	12	.400	8	.226	84	1.749	55	2.392
20-29	19N 19E 22AC	Well	184	02-13-58	USGS	23.3	156	2.557	—	—	22	.620	48	.999	23	1.000
20-51	19N 19E 36BAA	Well	—	06-04-62	NSHD	28	185	3.032	—	—	11	.310	28.8	.60	57.75	2.512
20-47	19N 20E 6DCD	Well	550	10-12-68	—	22	128	2.098	—	—	4	.113	98	2.040	35	1.522
20-30	19N 20E 8AD	Well	451	01-14-58	USGS	20	106	1.737	—	—	3.1	.087	59	1.228	48	2.088
20-31	19N 20E 8BDD	Well	752	08-24-59	—	23.3	116	1.901	—	—	7	.197	57	1.187	43	1.870
20-48	19N 20E 8DDB	Well	621	11-21-66	—	22	165	2.704	—	—	8	.226	149	3.102	126	5.481
20-32	19N 20E 17ADDB	Well	1025	08-04-59	CLHT	24	200	3.278	—	—	21	.592	204	4.247	157	6.829
20-45	19N 20E 18BBA	Well	660	05-22-59	CLHT	21.2	104	1.705	—	—	5	.141	70	1.457	69	3.001
20-46	19N 20E 18DB	Well	685	08-27-60	CLHT	21.2	122	2.000	—	—	5	.141	78	1.624	79.8	3.471
20-34	19N 20E 27AC	Well	650	01-13-58	USGS	22	241	3.950	—	—	264	7.445	225	4.685	160	6.960
20-35	19N 20E 30BC	Well	600	01-13-58	USGS	24	116	1.901	—	—	30	.846	280	5.380	170	7.395
20-50	19N 20E 30DA	Well	826	03-01-62	CLHT	20	168	2.754	—	—	14	.395	121	2.519	107	4.654

CLHT = Curtis Laboratories, Houston, Texas
DRI = Desert Research Institute–CWRR
NSHD = Nevada State Health Division
USBR = U.S. Bureau of Reclamation
USGS = U.S. Geological Survey

Ground Waters in the Truckee Meadows

Potassium mg/l	Potassium epm	Calcium mg/l	Calcium epm	Magnesium mg/l	Magnesium epm	Silica mg/l	Arsenic mg/l	Boron mg/l	Fluoride mg/l	Lithium mg/l	Total Dissolved Solids (sum of mg/l)	Specific Conductance (μmhos/cm @ 25°C)	pH
7.4	.189	19	.948	12	.987	115	—	12.3	.3	—	1032	1508	7.9
15	.384	9.3	.464	2.1	.173	134	—	—	.5	.4	632	729	7.6
*		72	3.593	18	1.480	23	—	5	—	—	786	623	7.57
27	.691	44	2.196	12.4	1.020	152	.28	22.1	—	—	1367	1837	7.1
*		30	1.497	3	.247	—	.64	—	—	—	2230	—	8.27
*		98	4.890	43	3.536	—	—	—	—	—	927	—	7.3
68	1.739	1.4	.070	.0	.000	121	—	17	2.5	10	2086	3360	8.7
*		27	1.347	11	.905	—	—	—	1.55	—	1862	—	7.05
64	27.840	11	.549	1.0	.082	299	—	46	2.1	7.6	2338	3150	7.6
5	.128	15	.748	2.8	.230	36	—	—	—	—	162	194	7.65
60	1.535	2.3	.115	.4	.033	235	—	—	2.6	—	2536	3661	8.7
71	1.816	5	.249	.8	.066	293	2.7	49	1.8	7.6	2354	—	7.9
75	1.918	12	.599	.5	.041	317	1.3	30	2.2	7	2542	—	8.2
59	1.509	14	.699	1.9	.156	205	—	2.2	2.2	—	2138	3240	6.7
54	1.381	23	1.148	2.0	.164	205	4	25	1.6	6	2196	—	7.7
65	1.663	25	1.247	.6	.049	245	—	58	2.2	—	2275	2933	7.05
56	1.432	3.9	.195	.5	.041	222	.4	24	1.8	6	2066	—	8.6
6.8	.174	2.0	.100	.4	.033	4.7	—	.1	—	—	182	348	9.0
*		67	3.343	18	1.480	—	—	—	—	—	423	—	7.22
*		66	3.293	8.8	.724	—	—	—	—	—	316	—	7.81
*		78	3.892	40	3.290	—	—	—	.5	—	806	—	7.75
5.4	.138	6.2	.309	.1	.008	46	—	1.3	2.5	.5	412	625	9.0
—	—	336	16.766	112	9.211	41	—	—	.4	—	3352	—	—
3.7	.095	21	1.048	4.1	.337	79	—	.74	1.5	.8	879	1210	7.9
*		39	1.946	12	.987	55	—	—	—	—	735	—	—
5.96	.152	15.8	.788	1.49	.123	57.8	.13	.75	.75	.12	679	942	7.95
7.38	.189	5.20	.259	.30	.025	85.4	.10	.76	.81	.17	567	724	8.06
6.55	.168	5.68	.283	.40	.033	85.8	.01	.6	.5	.18	650	886	7.76
*		19.2	.958	.97	.080	—	—	—	—	—	646	—	7.39
2.6	.067	16	.798	.7	.058	97	—	—	4.5	.8	586	697	8.0
8.2	.210	15	.748	.1	.008	86	—	—	2.1	.7	641	792	7.9
5.50	.141	12.14	.606	1.04	.085	50	.04	.882	2.9	.07	532	725	8.13
*		38	1.896	10	.822	27	—	—	—	—	616	—	—
5.50	.141	16.5	.824	.405	.033	92.6	.11	1.36	4.18	.14	780	1035	8.05
7.57	.194	13.08	.653	.255	.021	114	.06	2.08	5.1	.19	1033	1454	8.28
7.71	.197	14.23	.710	.19	.016	111	.01	1.87	5.1	.19	984	1423	8.35
7.17	.183	22.1	1.103	.79	.065	92.3	.11	2.08	4.8	.18	1012	1430	7.78
7.37	.188	28.98	1.446	.786	.065	134.7	.04	1.80	4.8	.16	918	1185	7.65
8.1	.207	25	1.247	.26	.021	103.2	.20	1.77	6.3	—	1057	1320	8.2
7.36	.188	23.4	1.166	.205	.017	102	.10	1.99	4.83	.19	975	1367	8.29
7.98	.204	23	1.148	.085	.007	106	.11	1.94	5.15	.19	969	1345	7.95
7.1	.182	20.5	1.028	.32	.026	103.7	.09	1.74	4.95	.22	959	1070	7.50
*		33	1.647	9.0	.740	95	—	—	—	—	996	1327	7.9
—	—	89.7	4.476	58.2	4.786	—	—	—	—	—	NA	—	—
—	—	49.60	2.475	25.30	2.081	—	—	—	—	—	NA	—	—
*		54.46	2.718	12.65	1.040	—	—	—	—	—	486	—	7.72
*		24	1.198	9	.740	—	—	—	—	—	211	—	7.97
*		14	.699	4	.329	62	—	—	.2	—	299	213	7.88
13	.333	3	.150	2.2	.181	111	—	8.2	.4	—	603	752	8.5
14	.358	10	.499	4.6	.378	102	—	.61	.3	3.1	696	969	7.5
28	.716	73	3.643	23	1.892	—	—	—	.21	—	1359	—	7.13
31	.793	63	3.144	46	3.783	113	—	.44	.3	4.4	1497	2320	7.5
24	.614	68	3.393	43	3.536	79	—	.66	.2	3.1	1163	1810	7.2
5.9	.151	3.8	.190	.4	.033	96	—	.88	1.0	—	385	369	8.4
9.4	.240	3.0	.150	2.7	.222	109	—	2.1	.7	—	490	457	8.3
*		27	1.347	8	.658	25	—	—	—	—	201	—	—
5.7	.146	19	.948	4.6	.378	79	—	.05	.1	.6	278	255	7.1
5.8	.148	114	5.689	36	2.961	38	—	.06	.1	—	957	1200	7.6
6.6	.169	34	1.697	9.2	.757	61	—	.03	.2	1.1	536	671	7.6
*		51	2.545	10	.822	—	—	—	—	—	310	—	8.04
2.5	.064	26	1.297	4.9	.403	29	—	.05	—	.3	256	267	7.4
*		32	1.597	8	.658	—	.005	—	1.24	—	2056	—	7.69
19	.486	64	3.194	16	1.316	—	.03	—	—	—	1117	—	7.23
*		26	1.297	6.2	.510	32	—	—	.2	—	333	—	8.6
2.6	.067	51	2.545	7.1	.584	41	—	—	.4	.4	351	436	8.1
*		20.82	1.039	5.85	.481	—	—	—	—	—	309	—	7.30
*		38	1.896	12	.987	56	—	—	.6	—	379	410	7.94
9.4	.240	11	.549	2.9	.238	73	—	—	.2	.3	314	331	7.8
*		22	1.098	3.9	.321	39	—	—	—	—	288	—	8.0
*		8	.399	2	.164	41	—	—	.8	—	500	616	7.64
*		15	.748	6.3	.518	—	—	—	—	—	604	796	8.1
*		4.8	.240	.7	.058	10	—	—	.3	—	264	321	8.25
*		4.2	.210	1.2	.099	18	—	—	.3	—	309	375	8.12
21	.537	107	5.339	41	3.372	88	—	—	.2	.2	1148	1600	7.4
9.5	.243	18	.898	.3	.025	94	—	49	2.5	.4	770	917	7.8
*		12.1	.604	4.6	.378	43	—	—	.3	—	470	58	7.8

*Difference between anions and cations, in epm, assumed to be sodium and potassium and calculated as sodium.

Sample Number	Location	Source	Depth (feet)	Date of Collection	Analyst	Temp. (°C)	Bicarbonate mg/l	Bicarbonate epm	Carbonate mg/l	Carbonate epm	Chloride mg/l	Chloride epm	Sulfate mg/l	Sulfate epm	Sodium mg/l	Sodium epm
10-41	17N 20E 8	Well	102	10-02-72	NSHD	13.9	156	2.557	—	—	4.0	.113	7.0	.146	21	.914
10-55	17N 20E 9	Well	115	03-26-73	NSHD	9.4	181	2.967	—	—	4.0	.113	13.0	.271	32	1.392
10-42	18N 19E 1	Well	170	07-03-73	NSHD	11.1	193	3.163	—	—	11	.310	19	.396	29	1.261
10-43	18N 19E 7	Well	120	10-06-71	NSHD	14.4	124	2.032	—	—	3	.085	3	.062	9	.392
10-1	18N 19E 10AA	Spring	—	01-14-58	USGS	15.6	138	2.262	—	—	3	.085	6.4	.133	19	.826
10-2	18N 19E 12AD	Well	135	06-03-58	USGS	15	164	2.688	—	—	7.1	.200	8.8	.183	14	.609
10-3	18N 19E 12CB	Well	240	01-14-58	USGS	15	222	3.639	—	—	4.0	.113	8.4	.175	19	.826
10-4	18N 20E 3BC	Well	107	05-11-56	USBR	12.8	255	4.179	—	—	282	7.952	66	1.374	163	7.090
10-5	18N 20E 6DB	Well	—	05-08-56	USBR	17.2	139	2.278	8.1	.270	3.6	.102	3.4	.071	14	.609
10-6	18N 20E 8AC	Well	200	05-11-56	USBR	17.8	115	1.885	12	.400	2.4	.068	2.9	.060	12	.522
10-7	18N 20E 8BB	Well	20	05-13-58	USGS	17.2	183	2.999	—	—	1.5	.042	4.1	.085	14	.609
10-45-A	18N 20E 17	Well	46	08-10-72	NSHD	12.8	68	1.115	—	—	5.0	.141	7.0	.146	6	.261
10-44	18N 20E 18	Well	14	02-12-73	NSHD	15	144	2.360	—	—	1.0	.028	4	.083	9	.392
10-9	18N 20E 20BB	Well	107	06-03-58	USGS	13.9	164	2.688	—	—	3.5	.099	4.4	.092	16	.696
10-45-B	18N 20E 29	Well	78	01-10-73	NSHD	14.4	232	3.802	—	—	5.0	.141	14	.291	28	1.218
10-54	18N 20E 30CD	Well	300	02-11-58	USGS	19.4	162	2.655	—	—	2.90	.082	2.40	.050	24.5	1.066
10-47	18N 20E 34	Well	213	08-21-72	NSHD	18.9	122	2.000	—	—	8.0	.226	990	20.612	100	4.350
10-49	18N 20E 34	Well	110	03-08-71	NSHD	18.9	198	3.245	—	—	11	.310	340	7.079	37	1.610
10-53	18N 20E 34	Well	160	01-14-71	NSHD	11.7	242	3.966	—	—	7	.197	62	1.291	31	1.349
10-48	18N 20E 34A	Well	—	04-06-72	NSHD	15.6	181	2.967	—	—	6.0	.169	125	2.602	87	3.785
10-10	18N 20E 34AC	Well	138	01-27-58	USGS	15.6	162	2.655	—	—	7	.197	375	7.807	37	1.609
10-11	18N 20E 34DB	Well	136	01-27-58	USGS	18.9	198	3.245	—	—	7	.197	154	3.206	29	1.261
10-50	19N 18E 14	Well	391	12-13-72	NSHD	13.3	122	2.000	—	—	19	.536	49	1.020	35	1.523
10-12	19N 19E 1BA	Well	23	05-20-58	USGS	13.9	435	7.130	—	—	96	2.707	1680	34.978	400	17.400
10-8	19N 19E 4CC	Well	295	05-19-58	USGS	16.1	133	2.180	—	—	5.8	.164	173	3.602	25	1.087
10-51	19N 19E 10	Well	250	02-28-73	NSHD	15.6	115	1.885	—	—	6.0	.169	103	2.144	12	.522
10-13	19N 19E 10CC	Well	90	02-11-58	USGS	12.8	233	3.819	—	—	3.4	.096	8.2	.171	19	.826
10-14	19N 19E 11DA	Well	352	1958	NSHD	13.9	154	2.524	—	—	10	.282	41	.854	13	.565
10-15	19N 19E 11DB	Well	190	02-27-46	NSHD	12.8	162	2.655	—	—	14	.395	46	.958	28	1.218
10-16	19N 19E 12AA	Well	583	06-02-58	USGS	13.9	240	3.934	—	—	14	.395	69	1.437	23	1.000
10-40	19N 19E 12BCD	Well	322	06-03-61	—	17.2	156.2	2.566	—	—	12	.338	69	1.437	29.10	1.266
10-17	19N 19E 13BC	Well	213	05-21-58	USGS	18.3	176	2.885	—	—	6.7	.189	38	.791	16	.696
10-18	19N 19E 17AD	Well	70	08-07-47	NSHD	14.4	427	6.999	—	—	25	.705	98	2.040	68	2.958
10-19	19N 20E 2AD	Well	210	05-13-58	USGS	16.7	128	2.089	—	—	24	.677	59	1.228	59	2.566
10-20	19N 20E 3CA	Well	213	02-13-58	USGS	14.4	76	1.246	16	.533	6.5	.183	66	1.374	25	1.087
10-21	19N 20E 4DC	Well	407	07-18-58	BCSF	14.4	112	1.836	—	—	5.0	.141	49	1.020	30	1.305
10-22	19N 20E 6BB	Well	147	05-20-58	USGS	14.4	246	4.032	—	—	21	.592	144	2.998	52	2.262
10-23	19N 20E 8AC	Well	41	01-14-58	USGS	11.7	155	2.540	—	—	7.4	.209	11	.229	12	.522
10-24	19N 20E 8AD	Well	18	02-13-58	USGS	12.2	135	2.213	—	—	170	4.794	14	.291	94	4.089
10-58	19N 20E 8BDD	Well	305	10-18-66	—	17	107	1.754	—	—	4	.113	36	.750	23	1.001
10-25	19N 20E 16AC	Well	300	05-11-56	USBR	13.9	104	1.705	3.6	.120	12	.338	111	2.311	75	3.262
10-26	19N 20E 16CD	Well	210	05-11-56	USBR	11.7	97	1.590	8.4	.280	13	.367	120	2.498	91	3.958
10-27	19N 20E 19AB	Well	197	01-14-58	USGS	15.6	139	2.278	—	—	7.8	.220	39	.812	25	1.087
10-28	19N 20E 19CB	Well	24	01-13-58	USGS	19.4	222	3.639	—	—	20	.564	174	3.623	120	5.220
10-52	19N 20E 20ADD	Well	204	11-09-60	—	15.5	170.8	2.799	—	—	5.0	.141	16.0	.333	43.9	1.910
10-29	19N 20E 20DA	Well	61	01-13-58	USGS	10.6	181	2.967	—	—	5.1	.130	51	.130	48	2.088
10-56	19N 20E 21BCB	Well	562	11-12-59	—	18.8	174.5	2.860	—	—	18	.508	143.2	2.981	130.1	5.659
10-30	19N 20E 22DA	Well	75	08-13-59	USGS	17.8	83	1.360	—	—	315	8.883	175	3.643	140	6.090
10-31	19N 20E 30DA	Well	83	01-13-58	USGS	12.2	256	4.196	—	—	4.5	.127	26	.541	31	1.348
10-46	19N 20E 31	Well	40	06-19-73	NSHD	10.0	256	4.196	—	—	6.0	.169	28	.583	29	1.261
10-59	19N 20E 31AAAB	Well	—	03-23-63	NSHD	13.3	405	6.638	—	—	9	.254	24	.500	35.74	1.555
10-32	19N 20E 31DA	Well	139	05-08-56	USBR	15.6	121	1.983	6.3	.210	1.4	.039	3.4	.071	12	.522
10-33	19N 20E 32AA	Spring	—	05-11-56	USBR	15.6	149	2.442	18	.600	2.8	.079	6.2	.129	18	.783
10-34	19N 20E 33BC	Spring	—	05-11-56	USBR	18.3	145	2.377	20	.667	7.1	.200	7.2	.150	34	1.479
10-35	19N 20E 33BD	Well	70	05-13-58	USGS	14.4	260	4.261	—	—	62	1.748	18	.375	75	3.262
10-36	19N 20E 33BD	Spring	—	05-13-58	USGS	16.7	207	3.393	—	—	29	.818	15	.312	60	2.610
10-37	20N 20E 31DD	Well	66	05-20-58	USGS	13.3	289	4.737	—	—	20	.564	239	4.976	56	2.436
10-38	20N 20E 33CB	Well	85	05-13-58	USGS	13.3	397	6.507	—	—	7	.197	82	1.707	92	4.002
10-39	20N 20E 34BC	Well	39	02-13-58	USGS	10.0	185	3.032	—	—	18	.508	271	5.642	43	1.870

BCSF = Brown and Caldwell Co., San Francisco, CA
NSHD = Nevada State Health Division
USBR = U.S. Bureau of Reclamation
USGS = U.S. Geological Survey

Waters in the Truckee Meadows (Continued)

Potassium mg/l	Potassium epm	Calcium mg/l	Calcium epm	Magnesium mg/l	Magnesium epm	Silica mg/l	Arsenic mg/l	Boron mg/l	Fluoride mg/l	Lithium mg/l	Total Dissolved Solids (sum of mg/l)	Specific Conductance (µmhos/cm @ 25°C)	pH
*		19	.948	13	1.069	—	.005	—	.9	—	226	—	7.49
*		27	1.347	9	.740	—	.005	—	.12	—	274	—	7.32
2	.051	32	1.597	15	1.234	—	.005	—	.3	—	308	—	7.99
*		19	.948	12	.987	—	—	—	.02	—	178	—	7.46
4.1	.105	18	.898	6.6	.543	76	—	—	.1	.4	272	237	7.6
2.9	.074	26	1.297	14	1.151	67	—	.02	.1	.4	308	309	7.0
3.3	.084	42	2.096	14	1.151	69	—	—	.4	.2	354	394	7.6
39	.998	71	3.543	27	2.220	49	—	127	.1	—	965	1428	8.1
5.1	.130	20	.998	13	1.069	81	—	.2	—	—	288	258	8.3
5.9	.151	17	.848	12	.987	75	—	—	—	—	254	236	8.6
5.9	.151	25	1.247	14	1.151	66	—	—	.1	.5	318	303	7.5
*		21	1.048	3	.247	—	.005	—	—	—	117	—	7.36
*		21	1.048	14	1.151	—	—	—	.15	—	199	—	7.46
6	.153	26	1.297	11	.905	57	—	.09	.2	.4	289	293	7.3
*		45	2.245	11	.905	—	.015	—	.01	—	343	—	7.97
*		26	1.297	4.90	.403	29	—	.05	—	—	256	—	7.4
*		237	11.826	80	6.579	—	—	—	.65	—	1542	—	7.04
*		123	6.138	36	2.961	—	—	—	.27	—	752	—	7.38
*		64	3.194	11	.905	—	—	—	.17	—	417	—	7.64
*		27	1.347	8	.658	—	—	—	—	—	436	—	7.9
2.1	.054	120	5.988	36	2.961	41	—	.02	.2	—	784	930	7.1
4.2	.107	71	3.543	20	1.645	22	—	.04	.2	—	508	609	7.2
*		21	1.048	9	.740	—	—	—	.21	—	263	—	7.18
4	.102	354	17.665	137	11.267	59	—	.34	.2	1.2	3278	3780	7.6
1.0	.026	62	3.094	20	1.645	29	—	—	.1	.4	450	593	7.9
*		45	2.245	18	1.480	—	—	—	—	—	304	—	7.66
2.5	.064	42	2.096	14	1.151	34	—	.03	—	.3	358	389	7.6
*		41	2.046	14	1.151	—	—	—	—	—	289	—	—
*		36	1.796	10	.822	18	—	—	—	—	314	—	—
2.2	.056	71	3.543	17	1.398	45	—	.03	.1	.4	490	571	7.9
*		38.8	1.936	13.9	1.143	21.9	—	—	.2	—	343	392	7.4
3.2	.082	38	1.896	16	1.316	33	—	.01	.1	.4	331	388	8.0
*		96	4.790	24	1.974	38	—	—	—	—	776	—	—
3.2	.082	21	1.048	34	.280	19	—	.01	.1	.4	319	433	8.2
6.1	.156	28	1.397	7.4	.609	48	—	—	.6	.7	281	323	8.8
*		21	1.048	8.1	.666	49	—	.10	.15	—	275	270	7.8
4.1	.105	69	3.443	26	2.138	52	—	—	.1	.4	628	746	7.9
2.6	.067	32	1.597	11	.905	37	—	—	.2	.3	274	316	7.6
4.6	.118	42	2.096	13	1.069	39	—	—	.6	.5	517	875	8.1
*		19	.948	8	.658	46	—	—	.5	—	244	255	7.85
7	.179	11	.549	6.5	.535	52	—	.34	—	—	383	459	8.2
6.3	.161	7.4	.369	3.8	.313	54	—	.40	.7	—	402	490	8.5
5.1	.130	28	1.397	7.7	.633	48	—	.24	.1	.2	304	341	8.0
9.5	.243	40	1.996	5.0	.411	101	—	—	1.2	.4	700	795	7.5
*		18.8	.938	5.2	.428	26.2	—	—	.3	—	287	295	7.6
5.1	.130	26	1.297	7.6	.625	75	—	.15	.6	—	403	432	7.5
*		7.9	.394	3.8	.313	31	—	—	.3	—	510	611	8.1
8.8	.225	85	4.241	39	3.207	15	—	6.1	.1	.0	869	1460	7.8
5.6	.143	33	1.647	21	1.727	71	—	—	.1	.5	453	510	7.0
5.0	.128	43	2.146	24	1.974	—	—	—	.09	—	391	—	7.59
*		59.26	2.957	35.06	2.883	—	—	—	—	—	568	—	7.72
5.1	.130	16	.798	13	1.069	77	—	.00	.0	—	256	240	8.5
5.1	.130	24	1.198	14	1.151	90	—	.00	.0	Tr	328	301	8.7
5.9	.151	20	.998	12	.987	93	—	.18	.0	.0	345	322	8.8
8.0	.205	36	1.796	13	1.069	68	—	.85	.2	1.4	548	656	7.8
4.9	.125	21	1.048	8.7	.715	67	—	.87	.2	.9	416	444	7.8
2.6	.067	122	6.088	24	1.974	54	—	.24	.2	.5	819	979	7.4
3.8	.097	62	3.094	15	1.234	53	—	1.1	.3	.4	723	794	7.9
3.6	.092	92	4.591	34	2.796	53	—	—	.3	.4	705	918	7.5

*Difference between anions and cations, in epm, assumed to be sodium and potassium and calculated as sodium.

Tr = Trace

APPENDIX B. Temperature Conversion Table

To Convert			To Convert			To Convert		
To °C	←°F or °C→	To °F	To °C	←°F or °C→	To °F	To °C	←°F or °C→	To °F
-23.33	-10	14	10	50	122	43.33	110	230
-22.78	-9	15.8	10.56	51	123.8	43.89	111	231.8
-22.22	-8	17.6	11.11	52	125.6	44.44	112	233.6
-21.67	-7	19.4	11.67	53	127.4	45	113	235.4
-21.11	-6	21.2	12.22	54	129.2	45.56	114	237.2
-20.56	-5	23	12.78	55	131	46.11	115	239
-20	-4	24.8	13.33	56	132.8	46.67	116	240.8
-19.44	-3	26.6	13.89	57	134.6	47.22	117	242.6
-18.89	-2	28.4	14.44	58	136.4	47.78	118	244.4
-18.33	-1	30.2	15	59	138.2	48.33	119	246.2
-17.78	0	32	15.56	60	140	48.89	120	248
-17.22	1	33.8	16.11	61	141.8	49.44	121	249.8
-16.67	2	35.6	16.67	62	143.6	50	122	251.6
-16.11	3	37.4	17.22	63	145.4	50.56	123	253.4
-15.56	4	39.2	17.78	64	147.2	51.11	124	255.2
-15	5	41	18.33	65	149	51.67	125	257
-14.44	6	42.8	18.89	66	150.8	52.22	126	258.8
-13.89	7	44.6	19.44	67	152.6	52.78	127	260.6
-13.33	8	46.4	20	68	154.4	53.33	128	262.4
-12.78	9	48.2	20.56	69	156.2	53.89	129	264.2
-12.22	10	50	21.11	70	158	54.44	130	266
-11.67	11	51.8	21.67	71	159.8	55	131	267.8
-11.11	12	53.6	22.22	72	161.6	55.56	132	269.6
-10.56	13	55.4	22.78	73	163.4	56.11	133	271.4
-10	14	57.2	23.33	74	165.2	56.67	134	273.2
-9.44	15	59	23.89	75	167	57.22	135	275
-8.89	16	60.8	24.44	76	168.8	57.78	136	276.8
-8.33	17	62.6	25	77	170.6	58.33	137	278.6
-7.78	18	64.4	25.56	78	172.4	58.89	138	280.4
-7.22	19	66.2	26.11	79	174.2	59.44	139	282.2
-6.67	20	68	26.67	80	176	60	140	284
-6.11	21	69.8	27.22	81	177.8	60.56	141	285.8
-5.56	22	71.6	27.78	82	179.6	61.11	142	287.6
-5	23	73.4	28.33	83	181.4	61.67	143	289.4
-4.44	24	75.2	28.89	84	183.2	62.22	144	291.2
-3.89	25	77	29.44	85	185	62.78	145	293
-3.33	26	78.8	30	86	186.8	63.33	146	294.8
-2.78	27	80.6	30.56	87	188.6	63.89	147	296.6
-2.22	28	82.4	31.11	88	190.4	64.44	148	298.4
-1.67	29	84.2	31.67	89	192.2	65	149	300.2
-1.11	30	86	32.22	90	194	65.56	150	302
-0.56	31	87.8	32.78	91	195.8	66.11	151	303.8
0	32	89.6	33.33	92	197.6	66.67	152	305.6
.56	33	91.4	33.89	93	199.4	67.22	153	307.4
1.11	34	93.2	34.44	94	201.2	67.78	154	309.2
1.67	35	95	35	95	203	68.33	155	311
2.22	36	96.8	35.56	96	204.8	68.89	156	312.8
2.78	37	98.6	36.11	97	206.6	69.44	157	314.6
3.33	38	100.4	36.67	98	208.4	70	158	316.4
3.89	39	102.2	37.22	99	210.2	70.56	159	318.2
4.44	40	104	37.78	100	212	71.11	160	320
5	41	105.8	38.33	101	213.8	71.67	161	321.8
5.56	42	107.6	38.89	102	215.6	72.22	162	323.6
6.11	43	109.4	39.44	103	217.4	72.78	163	325.4
6.67	44	111.2	40	104	219.2	73.33	164	327.2
7.22	45	113	40.56	105	221	73.89	165	329
7.78	46	114.8	41.11	106	222.8	74.44	166	330.8
8.33	47	116.6	41.67	107	224.6	75	167	332.6
8.89	48	118.4	42.22	108	226.4	75.56	168	334.4
9.44	49	120.2	42.78	109	228.2	76.11	169	336.2