Evaluation of Hydrogeology and Hydrogeochemistry of Truckee Meadows Area Washoe County, Nevada

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1779-S

Prepared in cooperation with the Nevada Department of Conservation and Natural Resources

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By PHILIP COHEN *and* OMAR J. LOELTZ

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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EVALUATION OF HYDROGEOLOGY AND HYDROGEOCHEMISTRY OF TRUCKEE MEADOWS AREA, WASHOE COUNTY, NEVADA

By Philip Cohen and Omar J. Loeltz

ABSTRACT

Practically all the ground water of economic importance in the Truckee Meadows area, an alluviated intermontane basin in western Nevada, is in the valley fill, which consists of unconsolidated and partially consolidated sedimentary deposits. The Mesozoic and Cenozoic consolidated rocks of the mountains bordering the valley contain some water in fractures and other openings, but they have virtually no interstitial permeability. The permeability of the valley fill is extremely variable. The Truckee Formation, which is the oldest deposit of the valley fill, yields very little water to wells. Permeable lenses of sand and gravel in the valley fill that are younger than the Truckee Formation yield moderate to large amounts of water to wells.

The estimated average annual recharge to and discharge from the ground-water reservoir is 35,000 acre-feet. About 25,000 acre-feet of the recharge is from the infiltration of irrigation water diverted from the Truckee River. Most of the discharge is by evapotranspiration and by seepage to ditches and streams.

Some water in the area is unsuitable for many uses because of its poor chemical quality. Water in the Steamboat Springs area is hot and has high concentrations of chloride and dissolved solids. Both water draining areas of bleached rock and ground water downgradient from areas of bleached rock have high concentrations of sulfate and dissolved solids. Surface water of low dissolved-solids content mixes with and dilutes some highly mineralized ground water.

Increased pumping in discharge areas will help to alleviate waterlogged conditions and will decrease ground-water losses by evapotranspiration. Increased pumping near the Truckee River may induce recharge from the river to the ground-water system.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

In the Truckee Meadows area, the second largest population center in Nevada, practically all water for irrigation and most water for municipal supply is diverted from the Truckee River. During periods of drought, as in 1959–61, deficient precipitation and runoff cause serious water shortages. The rapid increase of the area's population during the past two decades has caused an increased demand for water in the valley. Hence, water shortages during future periods of drought may be more serious.

On the average, surface water diverted into the valley for irrigation exceeds in amount the water beneficially used by crops. As a result, some of the land formerly used for agriculture in the northeastern part of the valley is waterlogged; that land is not suitable for urban development.

In some parts of the valley, ground water is unsuitable for many uses because of its poor chemical quality. Domestic wells and some large-capacity wells developed for municipal use have been abandoned because of excessive amounts of certain dissolved constituents in the water from these wells. Also, attempts to develop thermal water for generating power and for heating homes and greenhouses generally have been unsuccessful owing to the poor chemical quality of some of the water.

To obtain some of the data needed to utilize the water resources of the valley effectively, the U.S. Geological Survey in cooperation with the Office of the Nevada State Engineer (now a division of the Nevada Department of Conservation and Natural Resources) began in 1950 a study of several aspects of the ground-water hydrology of the area. The study was intended to stress those aspects of the ground-water system that bear directly on the hydrologic problems as described in the preceding text. To this end, the geology of the area was mapped with particular emphasis on the occurrence and water-bearing properties of the unconsolidated deposits of the valley fill. Seepage measurements were made along streams and irrigation ditches to determine areas of ground-water recharge and discharge and to obtain a rough approximation of the average annual recharge and discharge.

An intensive water-quality study was undertaken. Water samples were obtained from selected wells, streams, and ditches. Water-quality data also were obtained from several government agencies.

The content of this report is limited mainly to the aforementioned studies. During the investigation it became apparent that other detailed studies would be necessary to completely define the hydrology of the valley. For example, because the ground-water system is closely related to the surface-water system, comprehensive and coordinated ground-water and surface-water studies are needed. A detailed analysis of the flow of the Truckee River and tributary streams would help define more accurately the ground-water recharge and discharge and the possible uses of water in the valley. In 1961, gaging stations were constructed along Galena, Whites, Steamboat, and Hunter Creeks. Data obtained at these stations and at stations along the Truckee River should be useful in future more comprehensive studies.

LOCATION AND GENERAL FEATURES OF THE AREA

The Truckee Meadows area is one of a series of north-trending basins in northwestern Nevada that are bordered on the west by spurs of the Sierra Nevada and on the east by the Virginia Range and its southward extension, the Pine Nut Range. In this report, the term "Truckee Meadows area" defines the topographic basin bordered on the west by the Carson Range, which is a spur of the Sierra Nevada, on the east by the Virginia Range, on the north by units of these two ranges, and on the south by Pleasant Valley. Pleasant Valley is drained by Steamboat Creek, which flows northward into Steamboat Valley. Steamboat Valley is considered part of the Truckee Meadows area in this report. Spanish Springs Valley drains into the Truckee Meadows area from the north.

Reno and the adjoining city of Sparks are the major communities in the Truckee Meadows area. The total population in the area in 1960 was about 80,000.

The Truckee River, the principal stream in the area, heads in the Sierra Nevada south of Lake Tahoe and about 40 miles southwest of Reno, and it discharges into that lake near its southern shore. The river discharges from the northwestern margin of the lake and flows northward and northeastward through a steep-walled canyon to the city of Verdi, Nev., about 7 miles west of Reno. From there, the river flows eastward out of the highlands of the Sierra Nevada, follows a meandering course eastward through the Truckee Meadows area, and discharges from the valley through a narrow, steep-walled canyon in the Virginia Range. It next flows eastward to the city of Wadsworth, about 25 miles east of Reno, thence northward for about 15 miles and discharges into Pyramid Lake.

Steamboat Creek is the Truckee River's principal tributary in the study area. It enters the Truckee Meadows area through a bedrock constriction at the southern end of Steamboat Valley, receives ephemeral flow from Whites, Thomas, and Dry Creeks, and flows northward, discharging into the Truckee River near the gap in the Virginia Range. Most other streams in the area are ephemeral, but they are used locally as sources of irrigation water. The larger ephemeral streams drain the Carson Range and are,

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from north to south, Hunter, Alum, Evans, Dry, Thomas, Whites, Jones, and Galena Creeks.

A network of ditches supplies irrigation water to farms and ranches in the area. The larger ditches that carry water from the Truckee River include Steamboat, Last Chance, Lake, Cochran, Scott Ranch, and Pioneer ditches along the western margin of the valley, and the Highland and Orr ditches along the northern margin of the valley. The Orr ditch brings water to Spanish Springs Valley and returns excess water to the Truckee River by way of the North Truckee drain. Some of the water diverted from ditches along the western margin of the valley returns to the Truckee River by way of Boynton Slough and Steamboat Creek.

The Sierra Nevada is a major factor influencing the climate of the area. Moisture-laden air moving eastward is forced aloft by the mountains. The air cools and condenses, resulting in heavy precipitation in the mountains, locally more than 40 inches per year. Normally, the abundant precipitation in the mountains supplies plentiful surface water to the study area. The Truckee Meadows area is in the rain shadow of the Sierra Nevada; consequently, precipitation on the valley floor is small, and the climate is arid to semiarid. As a result, it is necessary to irrigate nearly all crops raised in the area.

The average annual precipitation in Reno during the period 1871–1959 was 7.14 inches. The maximum annual precipitation, 13.73 inches, occurred in 1890, and the minimum annual precipitation, 1.55 inches, occurred in 1947. More than half of the annual precipitation usually occurs from December through March (table 1).

TABLE 1.—*Average monthly precipitation at Reno, Nev., 1871–1959*

[From U.S. Weather Bureau records]

Month	Normal (inches)	Normal (percent of annual)	Month	Normal (inches)	Normal (percent of annual)
January	1. 39	19. 5	August	0. 20	2. 8
February	1. 07	15	September	. 24	3. 4
March	. 75	10. 5	October	. 38	5. 3
April	. 49	6. 9	November	. 58	8. 1
May	. 53	7. 4	December	. 98	13. 7
June	. 31	4. 3			
July	. 22	3. 1	Total annual	7. 14	100. 00

PREVIOUS INVESTIGATIONS

King (1878) briefly described a number of the geologic aspects of the area. The geology of the Comstock Lode mining district and of adjacent areas about 20 miles southeast of Reno was described by Becker (1882), Gianella (1936), Calkins (1944), and Calkins and Thayer (1945). Thompson (1952) described the character of the basin-and-range structure south of Reno and prepared a geologic map of the Virginia City quadrangle (1956). Some aspects of the hydrology of the Truckee Meadows area were discussed in a feasibility report prepared by the U.S. Bureau of Reclamation (1954). The results of a gravity survey in the area were given by Thompson and Sandburg (1958). Several aspects of the hydrogeochemistry of the area were discussed by Brannock, Fix, Gianella and White (1948), White (1957a,b), and Cohen (1961).

ACKNOWLEDGMENTS

The writers are grateful to the many local, State, and Federal agencies, private companies, and individual citizens of the Truckee Meadows area whose cooperation significantly aided the present study.

The Reno City Engineer's Office provided well data, maps, and observation-well measurements. The Nevada State Department of Health supplied records of hundreds of chemical analyses of water samples from the valley. The Nevada Bureau of Mines supplied preliminary unpublished geologic maps. The U.S. Bureau of Reclamation provided well records, chemical analyses, maps, and unpublished reports pertaining to the Truckee Meadows area. The Sierra Pacific Power Co. made the results of ground-water studies and reports by consulting firms available for this study. The U.S. District Court Water Master for the Truckee River provided data on surface-water diversions for irrigation.

D. E. White of the U.S. Geological Survey discussed many aspects of the hydrogeochemistry of the area with the writers and provided unpublished geologic maps and sections, charts, graphs, and chemical analyses pertaining to the Steamboat Springs subarea. G. A. Thompson discussed the geology of the area with the writers and supplied unpublished geologic data on the Mount Rose quadrangle. R. C. Scott encouraged the use of radiochemical analyses of the waters of Truckee Meadows and arranged for 47 of the chemical analyses given in this report.

NUMBERING SYSTEM OF WELLS, SPRINGS, AND CHEMICAL ANALYSES

The number assigned to a well, spring, or water-quality sampling site is both an identification and location number referred to the Mount Diablo base and meridian as prescribed by the General Land Office. The number consists of three units. The first unit is the number of the township north of the Mount Diablo base line. The second unit, separated from the first by a slanted line, is the number of the range east of the Mount Diablo Meridian. The third unit, separated from the second by a dash, is the section number followed by two lowercase letters designating the quarter and quarter-quarter section and, finally, a number designating the order in which the well, spring, or sampling site was recorded in the subdivision. The letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast quarters. For example, well number 19/19–13bc3 is the third well recorded in the SW¼NW¼ sec. 13, T. 19 N., R. 19 E. The number assigned to a water sample is the same as the number assigned to the sampling site. However, for the sake of clarity, in the text the numbers of samples collected from springs are preceded by the letters Sp, and the numbers of samples collected from streams, ditches, and lakes are preceded by the letters St. If no letters precede a sample number, the sample is from a well.

Because of space limitation, only the last two lowercase letters indicating the subdivision of the section and the number indicating the recording order of the well, spring, or sampling site are shown on maps (pls. 1, 2, 3) accompanying this report. Township and range numbers are shown along the edges of these maps, and section numbers are shown at or near the centers of the sections.

GEOLOGY

GEOMORPHOLOGY

The Truckee Meadows area is along the western margin of the Great Basin section of the Basin and Range physiographic province. In most aspects, the geomorphology of the area is typical of the Great Basin. The valley is a structural depression that is partly filled with unconsolidated and partially consolidated subaerial and lacustrine deposits.

MOUNTAINS

The ranges bordering the Truckee Meadows area are deeply dissected, complex, fault-block mountains composed of igneous, metamorphic, and sedimentary rocks, and they have been broken into troughs and ridges by normal faults. The Sierra Nevada and the subordinate Carson Range consist largely of granodiorite and other granitic rocks that have been emplaced into a complex sequence of metamorphic rocks and are covered by a thick sequence of lavas and lacustrine deposits. The Carson Range, a structural high, is separated from the main mass of the Sierra Nevada by a structural low. The Virginia Range also is a structural high that has been broken by normal faults, but it differs from the Carson Range in that it is composed of a higher percentage of extrusive rocks.

Complex internal folding and thrust faulting probably have had little control on the present overall height and form of the mountains. The topographic relief of the mountains has resulted principally from uplift and gentle warping associated with movement along normal faults. In detail, however, internal structure, volcanism, sedimentation, and erosion also have been major factors in the formation of the present land forms.

UPLAND EROSIONAL SURFACES

As viewed from the valley floor, the crest of the Carson Range appears to be a dissected, roughly planar surface that dips northward. Accordant summits are the rule although some peaks protrude above the plane defined by the accordant summits.

Remnants of planar erosional surfaces occur at successively lower altitudes along the mountain fronts. Some of these surfaces have much lateral continuity, but most are above an altitude of about 5,000 feet and can be traced only for short distances. The lateral continuity of these surfaces has been disrupted and obscured by faulting and erosion.

The surface having the greatest lateral continuity is called in this report the 5,000-foot terrace. In the Carson Range, the terrace has been formed on unconsolidated and partially consolidated deposits ranging in age from Pliocene to Pleistocene; however, in the canyon of the Truckee River west of Reno and in the foothills of the Carson Range, the terrace has been formed on tilted lacustrine and fluviatile deposits. The uppermost edge of the terrace, marked by a pronounced topographic break near the foot of Peavine Peak, is about 5,000 feet above sea level or about 600 feet above the valley floor. About 1½ miles south of Peavine Peak, the flat upper surface of Chalk Bluff in secs. 17 and 18, T. 19 N., R. 19 E., is part of the 5,000-foot terrace and is at an altitude of about 4,960 feet. Therefore, the terrace slopes southward gently from the break toward the Truckee River.

From the longitude of Chalk Bluff, the 5,000-foot terrace extends westward about 3 miles upstream and there merges with the present flood plain of the Truckee River. The terrace extends downstream along the northern margin of the valley for about 10 miles and then northward along the western margin of Spanish Springs Valley. The 5,000-foot terrace does not occur along the western slope of the Virginia Range.

ALLUVIAL FANS

Alluvial fans have only moderate to poor physiographic expression in the Truckee Meadows area. Distinct fans do not occur along the base of the Carson Range. Rather, the alluvial apron bordering this range is the previously described 5,000-foot terrace.

Small but distinct fans have been formed at the mouths of some of the streams draining the Virginia Range. These fans are mapped as fanglomerate on plate 1.

STREAMS

For the most part, the course of the river in the Sierra Nevada is structurally controlled. From Lake Tahoe to the vicinity of Reno, the Truckee River is characterized by rapids and waterfalls. On the valley floor of the Truckee Meadows area, the river is characterized by cutoff meanders, oxbow lakes, natural levees, and a wide flood plain. The river discharges from the valley through a bedrock gorge in the Virginia Range; there its gradient steepens and rapids are common. In the reach through the Virginia Range, the river cuts across the northward structural trend.

Steamboat Creek is a sluggish meandering stream. It flows northward across the valley and cuts obliquely across the structural trend of the Huffaker Hills. Most other tributary streams that drain the Carson and Virginia Ranges are characterized by rapids and waterfalls in the mountains and foothills and by sluggishness and meanders on the valley floor.

HYDROGEOLOGIC CHARACTER OF THE ROCKS

Most of the consolidated rocks of the ranges bordering the Truckee Meadows area have practically no interstitial permeability and do not store or transmit appreciable amounts of water. However, they are of hydrologic significance because most of the water-bearing sedimentary deposits of the valley fill, which is younger than the consolidated rocks, are composed of detritus derived from these rocks. Moreover, the chemical quality of the water of the area is affected by the mineralogy of the consolidated rocks. Therefore, some of the characteristics of the consolidated rocks are discussed in the following text.

CONSOLIDATED ROCKS

PRE-TERTIARY ROCKS

The oldest rocks in the Truckee Meadows area are metamorphosed sedimentary and metamorphosed igneous rocks that were assigned to the Triassic(?) System by Gianella (1936, p. 37–38). Most of the metamorphosed sedimentary rocks are considered older than the metamorphosed igneous rocks (Thompson, 1956, p. 48). The metamorphosed sedimentary rocks consist of argillite, slate, conglomerate, sandstone, and marble. The metamorphosed igneous rocks are mostly altered andesitic lavas.

Probably during the Cretaceous Period, granitic rocks were emplaced into the older rocks and metamorphosed them. Medium-grained light-colored granodiorite is the most common variety, but quartz monzonite also is moderately abundant. Pegmatitic, aplitic, and porphyritic varieties occur locally.

TERTIARY ROCKS

The following table summarizes the hydrogeologic character of the consolidated Tertiary rocks.

TABLE 2.—*Hydrogeology and distribution of Tertiary consolidated rocks in the Truckee Meadows area, Nevada*

[Adapted from Gianella (1936), Calkins (1944), and Thompson (1956)]

Age	Rock unit	Lithology	Distribution	Water-bearing character
Pliocene	Washington Hill Rhyolite.	Devitrified rhyolitic glass and perlite.	Virginia Range	Not water bearing.
Miocene or Pliocene	Kate Peak Formation.	Lava flows, agglomerate, tuff, tuff-breccia, vitrophyre; mostly andesitic.	Virginia Range, Steamboat Hills, Carson Range, Peavine Peak.	Virtually no interstitial permeability. Springs issue from fractured zones. Yields moderate amounts of water to wells.
Miocene(?)	Davidson Granodiorite.	Largely medium-grained granodiorite.	Virginia Range	Not water bearing.
	American Ravine Andesite Porphyry.	Dominantly dense fine-andesite; locally porphyritic.	Virginia Range	Not water bearing.
Oligocene(?)	Alta Formation	Tuff, tuff-breccia, flow-breccia, and lava flows generally of andesitic composition. Sutro Member composed of gray-green shale containing some andesitic and rhyolitic detritus.	Virginia Range, Carson Range, and Steamboat Hills.	Virtually no interstitial permeability; some local interflow permeability. Fractured zones may yield small quantities of water.
	Hartford Hill Rhyolite Tuff.	Crystal tuff, tuff-breccia, welded tuff, and rhyolite flows.	Virginia Range	Impermeable except for fractured zones.

TERTIARY AND QUATERNARY ROCKS

The following table summarizes the hydrogeologic character of the consolidated Tertiary and Quaternary rocks.

TABLE 3.—*Hydrogeology and distribution of Tertiary and Quaternary consolidated rocks in the Truckee Meadows area, Nevada*

[Adapted from Gianella (1936), Calkins (1944), and Thompson (1956)]

Age		Rock unit	Lithology	Distribution	Water-bearing character
Quaternary(?)	Pleistocene(?)	McClellan Peak Olivine Basalt.	Olivine basalt; lava flow and cinder cones.	Virginia Range	Not water bearing.
Quaternary(?)	Pleistocene(?)	Mustang Andesite.	Hornblende andesite	Virginia Range	Not water bearing.
Tertiary or Quaternary	Pliocene or Pleistocene	Steamboat Hills Rhyolite.	Pumiceous rhyolite	Steamboat Hills and 1½ miles northwest of Steamboat Hills.	Not water bearing.
		Lousetown Formation.	Lava flows ranging from andesite to olivine basalt.	Virginia Range, Carson Range, Steamboat Hills, Truckee River canyon west of Reno.	Springs issue from fractures and interflow zones.
		Knickerbocker Andesite.	Partly olivine-bearing pyroxene andesite.	Virginia Range	Not water bearing.

BLEACHED ROCKS

Many of the consolidated rocks of pre-Pliocene age have been modified to some degree by hydrothermal alteration. For example, andesitic rocks of the Kate Peak and Alta Formations commonly contain the secondary alteration minerals albite, clinozoisite, chlorite, epidote, calcite, and zeolites. Pyrite (FeS_2) was formed in the rocks at about the same time that these minerals were formed.

Oxidation of the pyrite resulted in the formation of sulfurous and sulfuric acids, which then bleached the hydrothermally altered rocks. The end products of the bleaching are dominantly clay and include some quartz and opal. That the bleaching is a near-surface phenomenon is shown in many of the mines in the area; at such mines, bleached rocks at the surface grade downward into weathered hydrothermally altered andesite.

Most of the rocks in the Steamboat Hills area, including the sedimentary deposits of Quaternary age, probably have been bleached by sulfurous and sulfuric acids formed by the oxidation of hydrogen sulfide gas being discharged from hot springs. However, sulfate compounds are not abundant in the rocks and water of the area.

Subareas of bleached rock, excluding the bleached rock in the Steamboat Hills, are shown on plates 1 and 3.

UNCONSOLIDATED AND PARTIALLY CONSOLIDATED ROCKS

The unconsolidated deposits of the valley fill are divided into three units—the Truckee Formation, the older alluvium, and the younger alluvium. The Truckee Formation is one of three lithologic units that constitute the water-bearing deposits of the valley fill. It is of early Pliocene age and consists mostly of fine-grained unconsolidated and partially consolidated lacustrine deposits. Moderately pure diatomite is interbedded with diatomaceous clay, silt, sand, gravel, and pumiceous material. The formation contains stream-channel and alluvial-fan deposits in minor amounts. The alluvial-fan deposits appear to be restricted to the lowest, or oldest, part of the formation. Boulders commonly are weathered and decomposed. In addition, the matrix of the fanglomerate commonly is moderately cemented with calcium carbonate.

The Truckee Formation is exposed in the Chalk Hills of the Virginia Range, along the eastern and northern slopes of the Carson Range, and north of the canyon of the Truckee River west of Reno (pl. 2). Thompson (1956, p. 55) suggested that the formation north of the canyon of the Truckee River may be as much as 3,000 feet thick; however, this thickness is uncertain because many small normal faults cut the formation and probably have increased its apparent thickness.

The Truckee Formation consists of porous deposits, and, owing to its great saturated thickness, it contains a large amount of ground water in storage. However, because most of the formation is composed of fine-grained material, wells penetrating it commonly yield only a few gallons per minute.

The distinction between the older and younger alluviums is made as follows: (1) The younger alluvium is structurally undeformed whereas the older alluvium is structurally deformed, (2) the younger alluvium is not appreciably eroded and is largely restricted to the valley lowlands and stream channels, whereas the older alluvium forms a well-dissected rolling topography in the foothills bordering the valley floor, and (3) the younger alluvium is characterized by a weakly to moderately developed soil profile, whereas the older alluvium is characterized by a well-developed soil profile.

Lithologically, the younger and older alluviums are very similar. Both are heterogeneous and contain rock particles ranging in size from clay to boulders. Beds of evaporites such as gypsum or halite are not common, though locally small crystals of these salts are mixed with the clastic particles. Calcium carbonate is abundant, occurring as beds of caliche or as coatings around individual fragments in weakly to moderately cemented deposits.

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The older alluvium consists mostly of erosional debris derived from the surrounding mountains. It is extremely heterogeneous, consisting of fine-grained lacustrine clay, silt, and sand; moderately to poorly sorted stream-channel deposits and fanglomerate; and angular poorly sorted colluvium. These deposits are exposed along the western and northern margins of the basin; there they underlie the 5,000-foot terrace and commonly are in fault contact with the Truckee Formation. Small isolated exposures also occur in the valley lowlands (pl. 2).

The younger alluvium, which unconformably overlies the older alluvium, is composed of lacustrine deposits of clay, silt, and sand; coarse-grained fluviatile deposits; and fanglomerate. The lacustrine deposits mainly are restricted to the eastern part of the valley north of the Huffaker Hills and consist mostly of organic-rich layers of clay and silt containing stringers of sand and gravel. The clay and silt were deposited in lakes that intermittently covered the area during Pleistocene time. The stringers of sand and gravel were deposited in the shifting channel of the Truckee River. The fluviatile deposits of the younger alluvium cover the valley floor west of the lacustrine deposits and south of the Huffaker Hills. These deposits commonly consist of moderately to well-sorted permeable sand and gravel. The deposits of fanglomerate in the younger alluvium occur along the base of the Virginia Range and consist mostly of poorly sorted mixtures of gravel, sand, silt, and clay.

It is difficult and in places impossible to distinguish between the younger and the older alluviums in the subsurface because structural deformation and the degree of development of soil profiles cannot be recognized readily from drill cuttings. Therefore, defining the thickness of the younger alluvium is difficult. Likewise, it is difficult to determine the thickness of the older alluvium because of the similarity between some units of the Truckee Formation and some units of both the older and the younger alluviums. The Truckee Formation can be recognized with certainty only if diatomite is penetrated; organic-rich lake beds at shallow depths in the eastern part of the valley are younger alluvium; coarse alluvium may be indicative of any of the three units though it is not abundant in the Truckee Formation.

On the basis of gravity surveys, Thompson and Sandburg (1958, p. 1275) calculated the maximum depth of the valley fill to be about 2,800 feet. However, as noted on p. S11, in places the Truckee Formation may be as much as 3,000 feet thick. Wells drilled in the valley fill have penetrated more than 1,000 feet of alluvium apparently without penetrating the Truckee Formation. Thus, the total thickness of the valley fill may be more than 4,000 feet.

In this report the Truckee Meadows area is considered to be divided into northern and southern areas. The northern area is north of the Huffaker Hills and includes the flood plain of the Truckee River, and the southern area is south of the Huffaker Hills and is drained by Steamboat Creek. An almost-continuous sheet of gravel, herein termed the "upper gravel," ranges in thickness from about 60 to about 200 feet and covers the lowlands of the western part of the northern area. The gravel is moderately to well sorted and consists of subrounded to angular rock fragments that range in size from clay to boulders. The porosity and permeability of this unit vary considerably, depending on the shape and degree of sorting of the rock fragments and on the degree of cementation. In general, however, the unit is moderately to highly porous and permeable, and wells tapping it have moderate to high yields.

The upper gravel has the greatest lateral continuity of any stratigraphic unit in the valley fill and can be recognized with a fair degree of certainty in most of the well logs in the northern area. It is thickest near the western margin of the area and thins eastward until it interfingers with lacustrine deposits. The character and distribution of the deposits underlying the gravel are extremely complex, and these deposits cannot readily be correlated from well to well.

The lithologic logs of wells 19/19–13bc2 and 19/20–4dc2 show the gross character of the upper gravel and of some underlying deposits. Well 19/19–13bc2 penetrated the upper gravel from land surface to a depth of about 180 feet. From 180 to 480 feet, strata of silt and clay and some thin stringers of sand and gravel were penetrated. From 480 to 660 feet, the percentage of gravel increased markedly. The deposits penetrated between 660 and 785 feet were predominantly fine grained and consisted mainly of fine sand, silt, and clay.

In the eastern part of the northern area, the upper gravel appears to be separated into two tongues by a lense of lacustrine deposits. In well 19/20–4dc2, the upper gravel was penetrated at depths of 2–69 feet and 78–89 feet below land surface. The intervening 9 feet was organic-rich sand, silt, and clay. The deposits below 89 feet mostly were fine sand, silt(?), and clay, but lenses of sand and gravel having an aggregate thickness of about 60 feet were penetrated from 150 to 264 feet below land surface. The driller reported much blue clay below a depth of 89 feet. In addition, there was a strong marsh-gas odor at the well. The blue clay and marsh-gas odor probably indicate a shallow lacustrine environment of deposition.

The deposits at land surface in the lowlands south of Huffaker Hills are mostly of fluviatile origin, but generally they are not as coarse as the fluviatile deposits in the lowlands north of Huffaker Hills. There does not appear to be a continuous sheet of gravel in the southern area equivalent to the upper gravel of the northern area. The absence of the upper gravel is the greatest difference between the deposits of the lowlands of the southern area and the deposits of the lowlands of the northern area. The mode and environment of sedimentation in the northern area has been controlled mainly by the Truckee River. Apparently, the Huffaker Hills are the southern limit of the meander belt of the Truckee River, and thus the hills mark the southern limit of the upper gravel.

As previously indicated, the eastern slope of the Carson Range is bordered by the dissected 5,000-foot terrace. South of the Huffaker Hills, most of the surface is underlain by faulted and moderately eroded older alluvium. Here, the older alluvium consists of alluvial-fan material, colluvium, and lacustrine deposits. Wells penetrating the older alluvium in this area generally tap deposits that are sufficiently permeable to yield adequate supplies of water for domestic use.

Because of rapidly changing depositional environments and because of structural deformation, the lithology and water-bearing character of the deposits of the valley fill vary markedly, both laterally and vertically, within short distances—commonly within a few feet. Future development of moderate- to high-capacity wells should be feasible in the northern area, especially if wells are developed in the upper gravel unit. Sand and gravel strata beneath the upper gravel also should be moderately productive.

To help define subareas in which moderate- to high-capacity wells might be developed, pumping tests were made to determine the coefficient of transmissibility of the deposits tapped by selected wells in the area. The field coefficient of transmissibility is defined as the rate of flow, in gallons per day, through a vertical strip of aquifer 1 foot wide extending the full height of the aquifer under a hydraulic gradient of 100 percent at the prevailing temperature.

Table 4 gives representative pumping-test data. Some of the wells that tap aquifers having the highest coefficients of transmissibility penetrate great thicknesses of permeable deposits, such as the upper gravel, above the uppermost perforations or sections of screen. Thus, it is possible that the values for the coefficients of transmissibility obtained from these wells do not represent maximum or near-maximum values. The data verify that the most permeable aquifers are in the area north of the Huffaker Hills.

TABLE 4.—*Selected pumping-test data for wells in the Truckee Meadows area, Nevada*

Well	Depth (feet)	Casing perforations or screened section (feet below land surface)	Yield (gpm)	Date of test	Length of test (hours)	Type of test [1]	Coefficient of transmissibility (gpd per ft)	Subarea [2]
18/20-9bd3	30	[3]	6	3-14-56	2	R	6,000	Southern area
9cc1	84	[3]	16	3-14-56	2	R	2,300	
16ba1	64	[3]	7	3-15-56	2	R	1,400	
17ad1	100	[3]	12	3-15-56	2	R	5,300	
19/19-11cb1	--------	[3]	500	1-24-59	1	R	55,000	Northern area
12aa2	583	203-469	860	6-2-58	1	R	42,000	
19/20-4dc1	402	135-258	750	7-9-58	1	R	26,000	
8bd1	665	453-645	3,000	9-8-59	48	R	29,000	
17ac1	563	214-548	2,600	11-1-59	48	R	30,000	
18ba1	660	326-640	3,000	7-12-59	6	D	48,000	
Do	660	326-640	3,000	7-12-59	48	D	36,000	
Do	660	326-660	3,000	7-14-59	24	R	48,000	
19cd1	60	[3]	4	3-19-56	1	R	6,600	
20ad1	338	174-335	1,000	11-9-60	24	R	34,000	

[1] D, drawdown; R, recovery.
[2] See text, p. S13.
[3] Unknown.

STRUCTURE

The Truckee Meadows basin is a structural depression. The basin has been depressed and the ranges have been raised with respect to each other. Displacement and warping have been caused by movement along normal faults that trend roughly northward and dip at moderate to high angles to either the east or the west.

The oldest rocks in the area, the metamorphosed rocks of Mesozoic(?) age, are intensely folded and thrusted. In addition, the rocks of Mesozoic(?) age and most of the overlying rocks of Cenozoic age are broken by many normal faults. The normal faults are mainly dip-slip faults that have throws ranging from less than a few tens of feet to perhaps as much as several thousand feet.

Thompson (1956, p. 64) believed that the western flank of the Virginia Range is the eastern limb of a broad syncline whose axis is in the Truckee Meadows valley. The western limb of the syncline is formed by the eastward-dipping rocks along the east side of the Carson Range. The formation of the syncline and the normal faulting are postulated to have occurred simultaneously during a period of broad gentle uplift.

In the foothills, the older alluvium is cut by normal faults that have brought rocks of different ages and lithologic character into juxtaposition. For example, the fairly impermeable deposits of the Truckee Formation are in fault contact with the older alluvium. The deposits buried beneath the younger alluvium in the valley lowlands probably also are broken by normal faults; however, the structure of these deposits is obscured by the mantle of undeformed younger alluvium.

GEOLOGIC HISTORY

The first major geologic event recorded in the rocks of the area probably occurred during the early part of the Mesozoic Era. This event was the deposition of sediments, partly in a marine environment. The deposition of these sediments was followed by a period of volcanism during which an unknown thickness of lava flows and pyroclastic rocks were extruded. In Late Jurassic or Early Cretaceous time these rocks were intensely folded, thrust faulted, and metamorphosed. Large plutons of granodiorite and other granitic rocks were emplaced into the metamorphosed sedimentary and igneous rocks at about the same time that the older rocks were deformed. Subsequently, the area was raised above sea level, and rugged alpine-type mountain ranges were formed by erosion.

The region again was deformed early in the Tertiary Period, probably in the Eocene or Oligocene Epochs. This deformation, which has continued sporadically, resulted in broad gentle uplift of the region associated with gentle warping and normal faulting. Extrusion of lava and pyroclastic rocks and intrusion of igneous rocks, mainly of intermediate to basic chemical composition, occurred at about the same time as the normal faulting.

Volcanism and normal faulting continued during late Oligocene, Miocene, and Pliocene times. Thousands of feet of andesitic lava and pyroclastic rocks were extruded over much of the area. Older lava flows of early Tertiary age were broken by normal faults and covered by younger lava flows which in turn also were broken by normal faults and covered by still younger lava flows. Movement commonly occurred along older normal faults, but new normal faults continued to be formed. The Kate Peak and Alta Formations, the two thickest sequences of andesitic lava, were deposited during this interval. Sometime after the extrusion of the Alta Formation, probably about the same time as the extrusion of the Kate Peak Formation, a stock of granodiorite, the Davidson Granodiorite, was emplaced in the vicinity of Virginia City about 20 miles southeast of Reno. Hydrothermal solutions related to this intrusion permeated the surrounding country rock and deposited the heavy metals associated with the Comstock Lode mining district in the vicinity of Virginia City.

Displacement along the normal faults formed elongate lofty mountain ranges and intervening valleys. The displacement disrupted the regional drainage system, and lakes were formed in the resulting structural basins. Thick deposits accumulated around the margins and within the lakes. Diatoms, which are microscopic algae, lived in the lakes; and their siliceous skeletal remains, interbedded with clay and silt, formed thick accumulations on the bottoms of the lakes. The bulk of the Truckee Formation was deposited in this manner. During the accumulation of the Truckee Formation, volcanic activity continued as indicated by interbedded diatomaceous deposits and tuff.

Normal faulting continued during and following the deposition of the Truckee Formation. The difference in the altitude of the Truckee Formation exposed in the Virginia Range and on the valley floor, about 1,500–2,000 feet, suggests the possible magnitude of the displacement resulting from movement along normal faults since the deposition of the formation. Intensified movement along normal faults during middle Pliocene time resulted in the disruption of the existing topography and the drainage of the existing lakes. The Truckee River drainage system was initiated, and the present topography was outlined.

The older alluvium was deposited in the valley lowlands following the deformation at the close of middle Pliocene time. Coarse-grained alluvial fans were deposited along the bases of the newly uplifted fault-block mountains. Continued relative uplift of the Virginia Range periodically blocked the course of the Truckee River, and lacustrine sediments deposited in the resulting lakes interfingered westward with subaerial and fluviatile sediments.

Overflow from the lakes eroded a water gap through the Virginia Range. Continued uplift of the range, however, again blocked the course of the river, and new lakes were formed. The cycle, consisting of uplift of the Virginia Range, formation of lakes, overflow of the lakes, erosion of the water gap, and draining of the lakes, probably was repeated many times.

The erosional surfaces—including the 5,000-foot terrace—in the ranges bordering the valley were formed as a consequence of the uplift of the Virginia Range. The lakes were the base level of the Truckee River and its tributaries, and the surfaces were cut in response to the levels of the lakes. Intermittent uplift of the ranges raised the surfaces with respect to the valley floor.

Faulting along the east side of the Carson Range influenced greatly the history of late Pliocene and early Pleistocene sedimentation in the valley. Alluvial fans that formed along the east side of the Carson Range were periodically broken by faults, and consequently they were deeply eroded and in many places were completely removed. The rejuvenated streams reworked the alluvial-fan material and deposited the sediments in the valley lowlands. The upper gravel was deposited in this manner.

In late Pleistocene time a large lake, Lake Lahontan, covered much of northwestern and north-central Nevada. However, the altitude of the Truckee Meadows area was above the highest altitude of Lake Lahontan; so the lake did not occupy the valley. A lake at an altitude somewhat higher than that of Lake Lahontan probably did occupy the valley intermittently. Shoreline features are not apparent in the area, but the lake is postulated on the basis of the lacustrine deposits of the younger alluvium in the lowlands of the northern area.

GROUND WATER

OCCURRENCE

Most of the economically recoverable ground water in the Truckee Meadows area occurs under artesian and water-table conditions in the unconsolidated and partially consolidated younger and older alluvium of the valley fill. Artesian conditions occur where the saturated deposits are overlain by impermeable strata and where the water at the top of the aquifer is under greater than atmospheric pressure. Water-table conditions exist where the saturated deposits are not confined by impermeable strata and where the water at the top of the zone of saturation, the water table, is under atmospheric pressure. Artesian heads in the study area commonly are less than 20 feet; the highest known artesian head is 21 feet above land surface.

Water in a confined aquifer is released from storage as a result of the compression of the aquifer and the expansion of the water, which are caused by a lowering of artesian head. Water in an unconfined aquifer is released from storage principally as a result of gravity drainage. The amount of water released from an unconfined aquifer per unit decline of head ordinarily is hundreds of times greater than the amount of water released from a confined aquifer. At a given distance from a pumped well, lowering of hydrostatic head ordinarily will occur much sooner in a confined aquifer than in an unconfined aquifer. Therefore, interference effects between wells tapping confined aquifers ordinarily occur sooner and are more pronounced than interference effects between wells tapping unconfined aquifers.

The area underlain by confined aquifers decreases and the area underlain by unconfined aquifers increases as a result of withdrawals from the ground-water system. Because artesian heads commonly are less than 20 feet in the study area, periods of prolonged pumping probably cause a change from artesian to water-table conditions over moderately large areas in fairly short periods of time.

There are hundreds of flowing wells in the study area. Most of these are in the northeastern part of the valley north of the Huffaker Hills; there the upper gravel is confined by the overlying lake beds of the younger alluvium. (See pl. 2.) The discharge from flowing wells in the Truckee Meadows area commonly is only a few gallons per minute, but some wells flow as much as 30–50 gpm (gallons per minute).

MOVEMENT

The contours of plate 2 show the altitude of water levels in wells and in U.S. Bureau of Reclamation test borings in the study area.

Because the horizontal component of ground-water movement is roughly perpendicular to the contours shown on the map, the map gives an approximate indication of the direction of ground-water movement. Most of the water-level altitudes shown on the map are based on single measurements made over a period of several years. Furthermore, data were insufficient for adequate control in some subareas and therefore the map is highly generalized and gives only a very rough approximation of the direction of ground-water movement in the study area.

In the area south of the Huffaker Hills, ground water moves toward the axis of the valley and thence northward toward the Huffaker Hills. The gradient decreases from more than 100 feet per mile near the western and southern margins of the area to less than 20 feet per mile in the meadowlands just south of the Huffaker Hills. The decrease in gradient may be caused partly by a northward and eastward increase in the permeability of the aquifers, but it probably results mostly from a decrease in the amount of ground water flowing northward, due to evapotranspiration and seepage into Steamboat Creek.

The Huffaker Hills are not complete barriers to the movement of ground water. The rocks of the hills are fractured; and as suggested by the contours of plate 2, some water probably moves through the hills northward toward the Truckee River.

In the area north of the Huffaker Hills, ground-water moves eastward from the Carson Range and southward and southeastward from the northern margin of the basin toward the gap in the Virginia Range. West of Reno, ground water apparently moves toward the Truckee River; however, this direction of movement is not certain because the available data are not sufficiently precise to permit determination of the hydraulic gradient and because seepage measurements along the Truckee River were not feasible. Ground-water movement beneath the city of Reno is approximately parallel to the course of the Truckee River. East of Reno, ground water moves from the river toward a natural discharge area near the Reno airport and toward a discharge area in secs. 10, 11, and 15, T. 19 N., R. 20 E.

The water-level contours shown on plate 2 indicate highly generalized average ground-water conditions. During above-average stages of the Truckee River, ground-water movement away from the river increases; and during below-average stages of the river, ground-water movement away from the river decreases. Probably, during periods of very high or very low river stages, gradient reversal occurs, causing the river to lose water in reaches where it ordinarily gains water or to gain water in reaches where it ordinarily loses water.

RECHARGE

Most of the recharge to the ground-water reservoir results from the infiltration of water diverted for irrigation, from the infiltration of streamflow and precipitation, and from underflow from tributary valleys.

INFILTRATION OF WATER DIVERTED FOR IRRIGATION

In the past decade or so, an average of about 27,000 acres per year was irrigated with surface water in the Truckee Meadows area. About 22,000 acres was irrigated with water diverted from the Truckee River; about 3,000 acres with water diverted from Steamboat Creek; about 500 acres with waste and drain water; and the remainder, about 1,500 acres, with water diverted from Whites, Thomas, and Evans Creeks. The estimated average application of irrigation water was about 4 acre-feet per acre per year. Thus, approximately 110,000 acre-feet of water was applied to the land each year. The consumption of the irrigation water by crops in the area was less than 2 acre-feet per acre per year (Houston, 1950, p. 11). Accordingly, the average application of about 4 acre-feet per acre per year caused a large amount of the diverted water to discharge into streams and ditches as surface flow or ground-water seepage, to infiltrate into the ground-water reservoir, to be transpired, or to evaporate. The portion of the unconsumed irrigation water that recharged the ground-water reservoir could not be determined directly. It is assumed, however, that about 1 acre-foot per acre percolated downward to the water table and that the resulting average annual recharge was about 25,000 acre-feet.

The U.S. District Court (1944) estimated that transit losses in ditches used to divert irrigation water from the Truckee River range from zero to about 30 percent for Steamboat ditch. The court estimated that transit losses from irrigation ditches total 25,000 acre-feet per year. Much of this water evaporates or is transpired by phreatophytes along the ditches. About one-fourth, or about 6,000 acre-feet per year, is assumed to recharge the ground-water reservoir.

INFILTRATION OF STREAMFLOW

Most of the water that infiltrates into the ground-water reservoir from the Truckee River is discharged in the Reno airport area and in the vicinity of sec. 10, 11, and 15, T. 19 N., R. 20 E. The total estimated average rate of ground-water discharge in these areas is 24 cfs (cubic feet per second) (p. S26). It was not possible to determine accurately how much of this water is derived from the Truckee River, but it is estimated to be about 6 cfs or about 4,000 acre-feet per year.

It is difficult to estimate the average annual recharge that infiltrates from streams draining the mountains bordering the study area because little is known about the flows of these streams. However, a few seepage measurements were made on July 15, 1957, during the present study, to determine the magnitude of the infiltration from Whites and Thomas Creeks. The flow of Whites Creek in the NW¼ sec. 34, T. 18 N., R. 19 E., was about 8 cfs. Approximately 3 miles downstream, in the NW¼ sec. 30, T. 18 N., R. 20 E., the flow was about 7.4 cfs. Since there were no visible diversion from or contributions to the stream, presumably evaporation, transpiration, and infiltration losses amounted to about 0.6 cfs. Because of the time of the year and because some reaches of the stream were bordered by willows and other plants that were transpiring water, it is probable that the evaporation and transpiration losses exceeded the amount of water infiltrating below the root zone. Thus, probably less than 0.3 cfs infiltrated below the root zone at the time of the July measurements. At other times of the year when transpiration losses are less and streamflow is greater, the net infiltration, or recharge to the ground-water system, may be more.

The flow of Thomas Creek in the SW¼ sec. 27, T. 18 N., R. 19 E., was also measured on July 15, 1957, and was found to be about 2.9 cfs. About 4 miles downstream, at a point 100 feet south of the intersection of the Steamboat ditch flume and Thomas Creek, the flow was about 2.5 cfs. The loss, about 0.4 cfs, resulted from evaporation, transpiration, and deep infiltration. Because evaporation and transpiration losses were high at this time of year, the amount of deep infiltration probably was negligible.

These seepage measurements suggest that the amount of recharge to the ground-water reservoir resulting from the infiltration of streamflow along the western margin of the valley is small. Along much of their courses, the streams draining the Carson Range flow across fairly impermeable deposits underlying the 5,000-foot terrace. As a result, the streams do not lose much water to the ground-water reservoir. Similarly, recharge resulting from the infiltration from streams draining the northern margin of the basin is small. Although the deposits along the front of the Virginia Range are more permeable than the deposits of the 5,000-foot terrace, the streams draining the Virginia Range carry considerably less water than the streams draining the Carson Range. Thus, recharge resulting from the infiltration from the streams along the eastern side of the Truckee Meadows area is small. The estimated total recharge resulting from the infiltration of streamflow, other than from the Truckee River, is less than 1,000 acre-feet per year.

INFILTRATION OF PRECIPITATION

Ground-water recharge resulting from the infiltration of precipitation within the study area varies considerably from one part of the area to another and depends on such factors as the magnitude and frequency of precipitation, the permeability of the rocks, and the vegetative cover. Some of the precipitation evaporates or is transpired by vegetation soon after it occurs. Some is stored in the zone of soil moisture and subsequently evaporates or is transpired. An unknown quantity percolates downward beneath the zone of soil moisture and recharges the ground-water reservoir.

UNDERFLOW FROM TRIBUTARY VALLEYS

Underflow from tributary valleys recharges the ground-water reservoir of the Truckee Meadows area; the principal contributing valleys are the Truckee River valley west of the study area, Pleasant Valley, and Spanish Springs Valley.

Because of limited data, only a rough estimate can be made of underflow through the deposits of the Truckee River valley west of Reno. Most of the underflow probably is through the younger and older alluviums rather than through the Truckee Formation. The average width of these deposits is about half a mile. If it is assumed that the average coefficient of transmissibility is 55,000 gpd per ft (gallons per day per foot), which is about the highest coefficient of transmissibility that was determined for these deposits in the Reno area, and that the hydraulic gradient is about the same as the gradient of the Truckee River, about 30 feet per mile, then the computed underflow is about 500 acre-feet per year.

Underflow from Spanish Springs Valley is small. At the mouth of the valley, the width of the deposits through which most of the underflow probably passes is about half a mile or less; the average coefficient of transmissibility probably is less than 30,000 gpd per ft; and the estimated hydraulic gradient is about 15 feet per mile. These parameters indicate that the underflow from Spanish Springs Valley is about 150 acre-feet per year. The actual underflow may be considerably less than this figure and probably does not exceed several hundred acre-feet a year.

Underflow from Pleasant Valley probably is small. The deposits through which most of the underflow passes are less than one-quarter mile wide and probably are fairly thin. If it is assumed that the average coefficient of transmissibility of the deposits through which the water is moving is 50,000 gpd per ft (which is probably a liberal estimate) and that the hydraulic gradient is 100 feet per mile, which is about the same as the gradient of Steamboat Creek near the mouth of Pleasant Valley, then the underflow through the section is about 700 acre-feet per year. The actual underflow probably is less than 700 acre-feet per year.

The foregoing underflow estimates suggest that the total recharge to the ground-water reservoir of the Truckee Meadows area resulting from underflow from tributary valleys probably does not exceed 1,000 acre-feet per year.

SUMMARY OF GROUND-WATER RECHARGE

The following is a summary of the estimated average annual ground-water recharge:

Source of recharge	*Acre-feet per year*
Infiltration of water diverted for irrigation:	
Water applied for irrigation	25,000
Ditch losses	6,000
Infiltration of streamflow:	
Truckee River	4,000
Small streams	<1,000
Infiltration of precipitation	Unknown
Underflow from tributary valleys	1,000
Total, rounded	35,000

The foregoing recharge estimates are based on rough assumptions and meager data. They are, however, probably in the correct order of magnitude and indicate the relative degree to which the various means recharge the ground-water reservoir in the study area. Thus, they may be of value in planning the future development of the ground-water resources of the area.

DISCHARGE

Most of the ground-water discharge in the Truckee Meadows area results from evapotranspiration and from seepage to streams and ditches. Smaller amounts of ground water are discharged by springs and by pumping from wells. Evapotranspiration in the waterlogged northeastern part of the basin is supported by surface and ground water. Also, little is known about the quantity of water consumed by the plants in the area. Therefore, it is not feasible to quantitatively estimate ground-water discharge by evapotranspiration.

In the following text, quantitative estimates of the total average annual ground-water discharge in the valley are made mainly on the basis of seepage measurements and partly on the basis of underflow estimates. In addition, discharge by springs, seeps, and pumping are evaluated separately to indicate the magnitude of these parameters.

AREA SOUTH OF THE HUFFAKER HILLS

Seepage measurements were made along Steamboat Creek on November 1, 1957, at which time antecedent effects of precipitation and irrigation were negligible. At a section where the creek crosses the south boundary of sec. 16, T. 18 N., R. 20 E., the flow was about 2.5 cfs. About 1¼ miles downstream, where the stream crosses the south boundary of sec. 10, T. 18 N., R. 20 E., the flow was about 3.9 cfs. The increase of streamflow of about 1.5 cfs in about 1¼ miles is equivalent to about 1.1 cfs per mile. This rate of seepage probably is slightly less than the maximum rate of seepage to the stream because the measurements were made when some ground water was being transpired by a 30-foot-wide belt of salt grass growing adjacent to the stream. In the summer, ground-water discharge along this reach probably is roughly comparable to the discharge observed during the November measurements. Seepage to the creek probably is less in the summer than in November, but transpiration losses probably are greater.

More detailed seepage measurements were made in December 1957 in the area south of the Huffaker Hills. Antecedent conditions were unusually good because precipitation and irrigation were negligible during the preceding several months. The flow of Steamboat Creek in the SW¼ sec. 34, T. 19 N., R. 20 E., was 21.4 cfs. Except for outflow from Alexander Lake and diversions from Thomas Creek, each of which was estimated to be about 1.5 cfs, this measurement included all the surface-water outflow from the area south of the Huffaker Hills.

The surface-water flow into the area was as follows: (1) The flow of Whites Creek in the NW¼ sec. 34, T. 18 N., R. 19 E., about 4 cfs; (2) the flow of Thomas Creek in the SW¼ sec. 27, T. 18 N., R. 19 E., about 2.5 cfs, of which about 1.5 cfs was diverted north of the Huffaker Hills, and about 1 cfs discharged into Steamboat Creek; (3) the flow of Streamboat Creek at the mouth of Pleasant Valley, about 3.5 cfs; and (4) the discharge from Steamboat Springs, about 0.7 cfs.

Surface-water outflow and inflow for the area south of the Huffaker Hills in December 1957 are summarized as follows:

Outflow	*Cfs*
Steamboat Creek	21.4
Ditch from Alexander Lake	1.5
Diversions from Thomas Creek	1.5
Total outflow	24.4
Inflow	
Whites Creek	4.0
Thomas Creek	2.5
Steamboat Creek	3.5
Steamboat Springs	.7
Total inflow	10.7

The difference between surface-water outflow and inflow, about 14 cfs, was due to seepage from the ground-water reservoir into Steamboat Creek and also to inflow from drains and ditches that are tributary to the creek. Evapotranspiration losses were virtually zero at the time, and pumpage from wells was small. Thus, the foregoing calculations probably are fairly indicative of the rate of ground-water discharge in December 1957. The hydraulic gradients toward Steamboat Creek in December do not differ substantially from the average hydraulic gradients toward the creek. Therefore, ground-water underflow toward the creek remains fairly constant. On this basis, the estimated average rate of ground-water discharge, excluding pumpage, in the area south of the Huffaker Hills is 14 cfs, or about 10,000 acre-feet per year.

AREA NORTH OF THE HUFFAKER HILLS

In December 1959, the total seepage to drains and sloughs at and east of the airport was about 9 cfs. An estimated additional 3 cfs ground water was discharged to drains in the subarea immediately north of the airport. Thus, the total ground-water discharge to drains and sloughs was about 12 cfs in the airport area.

The flows in the ditches and sloughs in secs. 10, 11, and 15, T. 19 N., R. 20 E., were large and consisted mostly of return flows of surface water diverted from the Truckee River. Therefore, it was impractical to estimate ground-water discharge in this area by seepage measurements. The hydrogeologic character and size of the area are similar to the hydrogeologic character and size of the discharge area near the Reno airport. On this basis, the estimated total ground-water discharge in secs. 10, 11, and 15, T. 19 N., R. 20 E., in December 1959 was 12 cfs.

The estimated total discharge, excluding pumpage, in the area north of the Huffaker Hills in December 1959 was 24 cfs. In this area the rate of ground-water discharge in the winter probably also is roughly equal to the average annual rate of discharge. Thus, the estimated average annual discharge, excluding pumpage, in the area north of the Huffaker Hills is about 24 cfs, or about 20,000 acre-feet.

PUMPAGE

Most of the water used for public supply in the Truckee Meadows area is diverted from the Truckee River. Additional water supplies in the valley are pumped from about 1,000 domestic, commercial, and stock wells, of which less than a dozen yield 1,000 gpm or more. The estimated average annual pumpage for the period 1947–59 is 3,000 acre-feet.

UNDERFLOW

Ground-water underflow out of the study area passes through the deposits bordering and underlying the Truckee River in the canyon east of Vista. The sides of the canyon are dense, consolidated rock having virtually no interstitial permeability, and bedrock is exposed in the streambed just east of Vista. Accordingly, ground-water discharge resulting from underflow out of the valley probably is less than 500 acre-feet per year.

SUMMARY OF GROUND-WATER DISCHARGE

The following is a summary of the estimated average annual ground-water discharge:

	Acre-feet
Area south of the Huffaker Hills (excluding pumpage)	10 000
Area north of the Huffaker Hills (excluding pumpage)	20 000
Pumpage	3 000
Underflow	<500
Total, rounded	35 000

GROUND-WATER BUDGET

Under natural conditions, the average annual ground-water recharge in the Truckee Meadows area was equal to the average annual ground-water discharge, and the average amount of ground water in storage remained virtually constant. In other words, the ground-water system was in dynamic equilibrium. In the late 1800's when diversions from the Truckee River and other streams began, the equilibrium was changed and recharge to the ground-water reservoir of the Truckee Meadows area was increased substantially. Ground-water levels rose, and the amount of ground water in storage increased, thereby increasing the discharge from the ground-water reservoir by additional evaporation, transpiration, and seepage to streams and drains. Eventually a new equilibrium was established, probably several decades ago. The preceding estimates of ground-water recharge and discharge are for the equilibrium conditions that have existed in the past several decades. Under these conditions, the average annual ground-water recharge and discharge are equal. Because data available are scanty, it is coincidental that the estimated average annual recharge and discharge, 35,000 acre-feet, as computed in the preceding text, are equal. Either figure may be as much as 10,000 acre-feet in error, and, if so, the other figure is equally in error.

FLUCTUATIONS OF GROUND-WATER LEVELS

Fluctuations of ground-water levels in the area are caused mostly by changes in the quantity of ground water in storage which are related to changes in rates of recharge to and discharge from the ground-water system. If recharge exceeds discharge, water levels rise. The opposite is true if discharge exceeds recharge. The largest changes in recharge and discharge rates and, consequently, the largest water-level fluctuations result from seasonal differences in the irrigation regimen.

Water levels and artesian pressures were measured periodically in about 40 wells in the Truckee Meadows area. Measurements were started in some wells in 1950 and in others in 1956. Representative hydrographs are shown in figures 1 and 2.

The hydrograph of well 18/20–7dc1 shows fluctuations resulting from surface-water diversions for irrigation. The well, which is about 800 feet northwest of the Last Chance ditch, is 203 feet deep, is unused, and reportedly is bottomed in andesite. There is a lag of about a month between the time water is diverted for irrigation and the time the water level in the well begins to rise. The lowest water level occurs in April or May, a month or two after water is first diverted into the canals and ditches along the western side of the valley. The water level rises rapidly, as much as 6 feet in some years, during and for a month or so after the beginning of the irrigation season. In November or December, after surface-water diversions are discontinued, the water level declines rapidly and continues to decline until the following spring.

The hydrograph of well 19/19–11bd1 is similar to that of well 18/20–7dc1, but it has a more uniform pattern. The well is about 60 feet deep, is unused, and is in the residential section of Reno. The hydrograph shows water-level fluctuations that are related to the watering of lawns in the city and to the flow of water in irrigation ditches along the northwestern margin of the valley. The

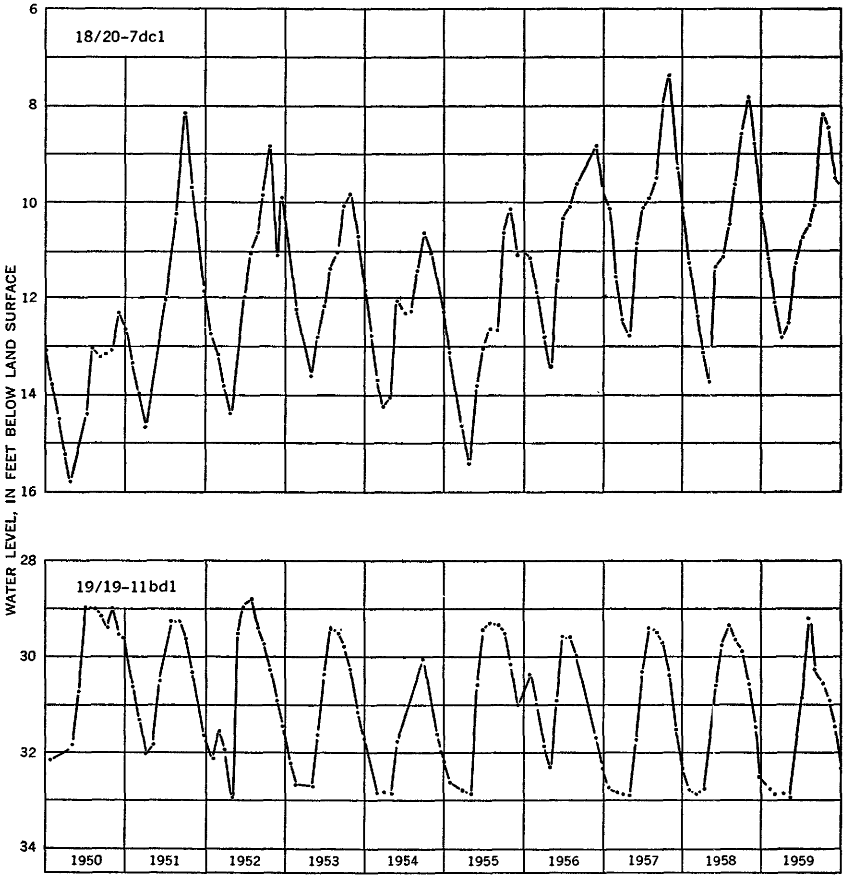

FIGURE 1.—Hydrographs of wells 18/20–7dc1 and 19/19–11bd1 in the Truckee Meadows area, Washoe County, Nev.

amplitude of the annual fluctuations in the vicinity of the well averages slightly more than 3 feet.

The hydrograph of well 19/19–10cc1 shows that larger annual fluctuations of water levels occur in some parts of the valley. The well is 90 feet deep, and the principal aquifer is sand and gravel (the upper gravel) about 50–90 feet below the land surface. The amplitude of the annual fluctuations averages about 15 feet. The water level in the well rises abruptly when irrigation water is diverted into the Orr ditch, which is about 200 feet north of the well. Shortly after the end of the irrigation season, the water level declines rapidly. The decline continues until irrigation water again is diverted into the Orr ditch the following spring.

The hydrograph of well 19/19–25cc1 is similar to that of well 19/19–10cc1. The well reportedly is 170 feet deep and is used for domestic supply. Water levels rise soon after water is diverted into the Last Chance ditch, about 500 feet west of the well, and fall soon after diversions to the ditch are discontinued.

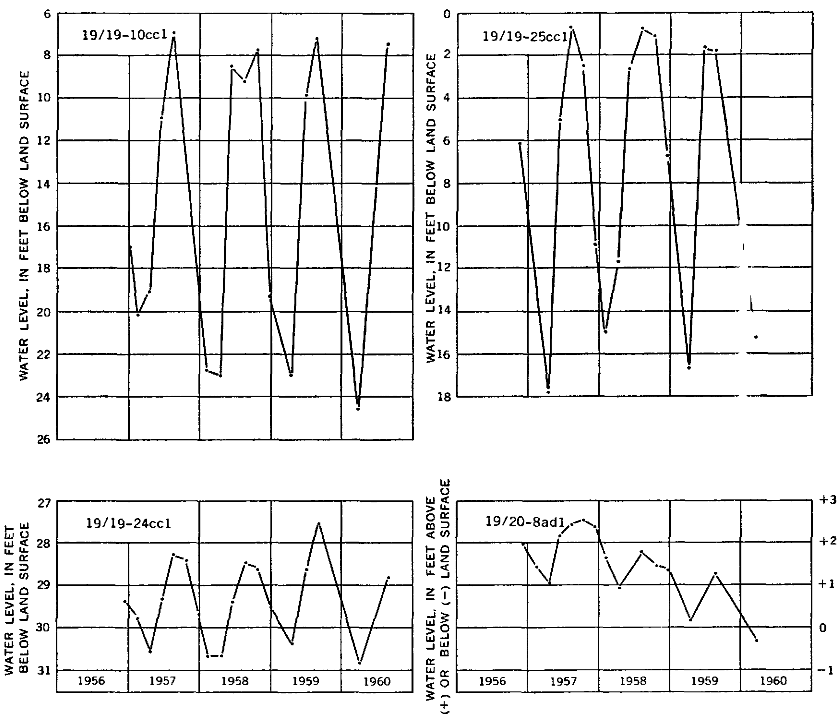

FIGURE 2.—Hydrographs of wells 19/19–10cc1, 19/19–24cc1, 19/19–25cc1, and 19/20–8ad1 in the Truckee Meadows area, Washoe County, Nev.

The hydrograph of well 19/19–24cc1 probably best represents the average fluctuations of water level in the western half of the Truckee Meadows area. Fluctuations of the water level in this well also result from diversions for irrigation; water levels rise soon after the beginning of the irrigation season and fall shortly after the end of the season. The amplitude of the annual fluctuations for the period of record averages about 2.5 feet.

The hydrograph of well 19/20–8ad1 shows the type of fluctuations that occur in deep artesian aquifers in the east-central and northeastern parts of the Truckee Meadows area. Reportedly, the well is 451 feet deep. On March 20, 1956, the well flowed 46 gpm from a 4-inch valve 7.5 feet below land surface. The shut-in head at the point of discharge was about 9.5 feet. The temperature of the water, 78°F, suggests that the flow probably came either from the bottom of the well or from strata near the bottom. The record is not complete, but it shows that the artesian head responds to diversions for irrigation. The decline of artesian head from 1957 to 1960 probably has resulted from increased pumping in the vicinity of the well.

HYDROGEOCHEMISTRY

The chemical and physical properties of some of the waters of the Truckee Meadows area impose serious limitations on their use. Described in this section of the report are the chemical and physical properties of the waters and the relations between these properties and the hydrogeologic environment. In addition, sufficient basic data and interpretations are given to help define areas and lithologic units from which ground water of suitable chemical quality for domestic, agricultural, or industrial use may be obtained.

SOURCE AND RELIABILITY OF DATA

Several hundred chemical analyses of water samples were obtained from various sources during the present study; 113 analyses are given in table 5, and most of these analyses are shown diagrammatically on plate 3.

Forty-seven samples were analyzed in the laboratories of the U.S. Geological Survey as part of the Survey's nationwide radioelement program. Additional hydrogeochemical data were obtained from other Federal agencies, the Nevada State Department of Health, and several private companies. Sources of the analyses are shown in table 5.

During the present study, most of the water samples were obtained from wells for which drillers' logs or well-construction data were available; it was desirable to know the depth at which the casing was perforated or at which the screen was set. Many of the wells in the area have perforations at different depths, and water from these wells may be a mixture of water from several aquifers. Therefore, analyses obtained from wells for which drillers' logs or well-construction data were not available have somewhat limited worth. However, samples from some wells for which logs were not available were collected because of geographic and other considerations.

UNITS USED IN REPORTING DATA

DISSOLVED SOLIDS

"Dissolved solids" and "dissolved-solids content," terms commonly used to describe the mineral content of water, lack standardization. The Geological Survey uses the terms to refer either to the residue of a known quantity of a sample dried at 180°C or to the sum of the determined constituents. Some of the agencies whose analyses are given in this report determine dissolved-solids content by evaporating a standard volume of water to a residue at 105°C. Most results obtained by this method do not differ substantially from the results obtained by the Survey. However, some results may differ considerably, and therefore the method of determining dissolved-solids content is given in table 5.

The unit that is most commonly used to express dissolved-solids content and that is the basis of most quantitative expressions in this report is parts per million (ppm). This unit expresses the number of milligrams of solute in 1 liter of solution. Ordinarily, in assuming that 1 liter of a naturally occurring water weighs 1 kilogram, the error is small and is disregarded.

Dissolved-solids content also may be described in milligram equivalents per million, commonly contracted to equivalents per million (epm). Equivalents per million are computed by dividing the concentration of an ion, in parts per million, by the combining weight (atomic or molecular weight divided by the valence) of the same ion. Equivalents per million take into account the concept of chemical equivalence and are useful in the analysis of water mixtures and in other chemical interpretations and evaluations. Because the number of equivalents per million of cations should equal the number of equivalents per million of anions, a comparison of these data may indicate the accuracy or completeness of an analysis. In addition, the specific conductance (p. S42) divided by 100 is roughly equal to the total equivalents per million of anions or cations. If this relation does not exist in a particular analysis, the analysis may be inaccurate, or no analysis may have been made for an abundant ionized constituent.

TABLE 5.—*Chemical analyses of the waters of the Truckee Meadows area, Washoe County, Nev.*

[All dissolved constituents are in parts per million except uranium, which is in parts per billion; Tr, trace. USBR, U.S. Bureau of Reclamation; USGS, U.S. Geological Survey; NSDH, Nevada State Department of Health; CLHT, Curtis Laboratories, Houston, Tex.; BCSF, Brown and Caldwell Co., San Francisco, Calif.]

Sample number and location	Source	Depth (feet)	Date of collection	Analyst	Temperature (°F)	Silica (SiO_2)	Aluminum (Al)	Iron (Fe)[1]	Iron (Fe)[2]	Manganese (Mn)[1]	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Sodium and Potassium (Na and K)[3]	Lithium (Li)
St17/20- 2ac1	Stream, south branch of Bailey Canyon.		1-27-58	USGS	46	35	0.09	0.02		0.00	101	26	31	2.6		0.0
2ad1	Stream, north branch of Bailey Canyon.		4-17-59	do	54	105	[5] 160	[6] 21		5.0	290	116	90	3.2		
3ad1	Stream, east side of Steamboat Valley.		1-27-58	do		60	.10	.03		.00	59	16	33	7.2		.0
5dc1	Steamboat Creek		1-27-58	do	38	50	.12	.03		.00	20	9.2	17	4.4		.0
Sp18/19-10aa1	Lone Tree Spring		1-14-58	do	60	76	.10	.01	0.01	.00	18	6.6	19	4.1		.4
12ad2	Well	135	6- 3-58	do	59	67	.00	.00	.01	.01	26	14	14	2.9		.4
St18/19-12bb1	Last Chance Ditch		5-25-56	USBR		24		.00			10	3.4	4.8	1.2		.0
12cb4	Well	240	1-14-58	USGS	59	69	.10	.00	.90	.00	42	14	19	3.3		.4
12da2	do	50	8-30-38	NSDH	57	63	Tr		Tr		60	13			16	
13da1	Thomas Creek		5-25-56	USBR		39		.00			6.6	3.4	4.1	2.3		.0
St18/20- 3bc1	Well	107	5-11-56	do	55	49		.05			71	27	163	39		
4aa1	Alexander Lake		11-8-47	NSDH		45	Tr		Tr		60	17			66	
6db1	Well		5- 8-56	USBR	63	81		.00			20	13	14	5.1		
8ac2	do	200	5-11-56	do	64	75		.00			17	12	12	5.9		
8bb1	do	20	5-13-58	USGS	63	66	.10	.00	.03	.00	25	14	14	5.9		.5
9bd3	do	122	5- 8-56	USBR	86	115		.02			19	12	262	7.4		
9ca1	do	45	5- 8-56	do	72	111		.03			3.0	2.2	147	13		
9cc1	do	84	5-19-58	USGS	80	102	.00	.00	.04	.01	10	4.6	160	14		3.1
14bb2	do		5-14-58	do	75	113	.10	.00	.04	.00	63	46	313	31		4.4
14bc3	do	48	5-14-58	do	71	79	.10	.06	.36	.02	68	43	202	24		3.1
17ad2	do	73	5- 8 56	USBR	72	96		.00			3.8	.4	79	5.9		

TABLE 5.—*Chemical analyses of the waters of the Truckee Meadows area, Washoe County, Nev.*—Continued

[All dissolved constituents are in parts per million except uranium, which is in parts per billion; Tr, trace. USBR, U.S. Bureau of Reclamation; USGS, U.S. Geological Survey; NSDH, Nevada State Department of Health; CLHT, Curtis Laboratories, Houston, Tex.; BCSF, Brown and Caldwell Co., San Francisco, Calif.]

Sample number and location	Source	Uranium (U)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Residue on evaporation at 180°C	Dissolved solids: Residue on evaporation at 105°C	Dissolved solids: Sum of determined constituents	Hardness as $CaCO_3$: Total	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Diagram field[4]	Suitability for irrigation
St17/20- 2ac1	Stream, south branch of Bailey Canyon.	...	286	0.0	191	6.4	0.0	0.3	0.03	543	...	535	360	125	764	8.0	2	C_3-S_1
2ad1	Stream, north branch of Bailey Canyon.	0.4	0	.0	2,570	10	.1	1.0	.04	4,020	...	3,300	1,200	1,200	3,430	3.1	2	C_4-S_1
3ad1	Stream, east side of Steamboat Valley.	...	257	.0	74	6.3	.3	.3	.06	382	...	382	212	1	534	8.0	2	C_2-S_1
5dc1	Steamboat Creek	...	154	.0	5.8	2.3	.3	.8	.02	...	...	186	88	0	242	8.0	3	C_1-S_1
Sp18/19-10aa1	Lone Tree Spring	.3	138	.0	6.4	3.0	.1	.8	...	203	...	176	72	0	237	7.6	3	C_1-S_1
12ad2	Well	.7	164	.0	8.8	7.1	.1	3.2	.02	225	...	225	122	0	309	7.0	3	C_2-S_1
St18/19-12bb1	Last Chance Ditch	...	48	.0	9.1	.0	.0	.5	...	...	79	...	39	...	96	7.7	3	C_1-S_1
12cb4	Well	1.9	222	.0	8.4	4.0	.2	8.8	...	279	...	264	162	0	394	7.6	3	C_2-S_1
12da2	do	...	273	.0	Tr	10	...	...	...	...	...	...	203	...	...	...	3	...
13da1	Thomas Creek	...	43	.0	.0	.0	.0	1.0	.00	...	85	...	30	...	80	8.2	3	C_1-S_1
St18/20- 3bc1	Well	...	224	[7] 31	66	282	.1	.2	12.7	...	876	...	287	...	1,428	8.1	1	C_3-S_1
4aa1	Alexander Lake	...	329	.0	12	58	...	...	...	...	448	...	220	...	...	...	1	...
6db1	Well	...	139	8.1	3.4	3.6	.0	1.1	.2	...	194	...	104	...	258	8.3	3	C_2-S_1
8ac2	do	...	115	12	2.9	2.4	.0	2.0	.00	...	181	...	91	...	236	8.6	3	C_1-S_1
8bb1	do	2.9	183	.0	4.1	1.5	.1	3.6	.00	236	...	225	120	0	303	7.5	3	C_2-S_1
9bd3	do	...	227	[7] 14	50	313	.3	.6	12.3	...	935	...	95	...	1,508	7.9	1	C_3-S_3
9ca1	do	...	151	9.0	30	128	.4	.2	8.2	...	524	...	17	...	752	8.5	1	C_3-S_3
9cc1	do	1.7	224	.0	17	160	.3	2.0	.61	709	...	584	44	0	969	7.5	1	C_3-S_2
14bb2	do	2.0	264	.0	151	511	.3	.8	.44	1,540	...	1,360	346	130	2,320	7.5	1	C_4-S_2
14bc3	do	3.3	258	.0	125	360	.2	1.0	.66	1,230	...	1,030	346	135	1,810	7.2	1	C_3-S_2
17ad2	do	...	176	9.6	6.2	6.0	1.0	15	.88	...	306	...	11	...	369	8.4	3	C_2-S_2

TABLE 5.—*Chemical analyses of the waters of the Truckee Meadows area, Washoe County, Nev.*—Continued

[All dissolved constituents are in parts per million except uranium, which is in parts per billion; Tr, trace. USBR, U.S. Bureau of Reclamation; USGS, U.S. Geological Survey; NSDH, Nevada State Department of Health; CLHT, Curtis Laboratories, Houston, Tex.; BCSF, Brown and Caldwell Co., San Francisco, Calif.]

Sample number and location	Source	Depth (feet)	Date of collection	Analyst	Temperature (°F)	Silica (SiO_2)	Aluminum (Al)	Iron (Fe) [1]	Iron (Fe) [2]	Manganese (Mn) [1]	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Sodium and Potassium (Na and K) [3]	Lithium (Li)
St18/20-17ad4	do	100	5-8-56	do	85	109		0.01			3.0	2.7	94	9.4		
17bd1	do	104	1-20-47	NSDH		58	Tr		Tr		31	11			30	
Sp18/20-17dc1	Spring		1-14-58	USGS	94	134	.10	.01	.53	.00	9.3	2.1	130	15		0.4
17dc2	Well	99	10-22-48	NSDH	114	23	Tr		Tr		72	18			115	
20bb4	do	107	6-3-58	USGS	57	57	.00	.00	.07	.00	26	11	16	6.0		.4
20dd1	do	66	2-11-46	NSDH	[8] 74	25	Tr		Tr		27	8.0			4.0	
21ca3	do	44	5-19-58	USGS	73	79	.00	.00	.05	.00	19	4.6	22	5.7		.6
27dc1	do	195	3-29-59	do	85	38	.60	.00	.74	.00	114	36	100	5.8		
28ab3	do	80	5-14-58	do	72	61	.00	.00	.08	.00	34	9.2	83	6.6		1.1
28ba2	do	151	6-3-58	do	[9] 271	121	.00	.00	.01	.00	1.4	.0	660	68		10
28cb1	do	200	1-5-50	do	[10] 293	299					11	1.0	640	64		7.6
29bc1	do	82	6-49	do	93	36					15	2.8	12	5.0		
St18/20-30aa1	Whites Creek		5-25-56	USBR		22		.00			6.6	1.7	3.2	1.6		.0
30cd1	Well	300	2-11-58	USGS	67	29	.00	.26	4.2	.03	26	4.9	22	2.5		.3
Sp18/20-33ac1	Spring (Steamboat Springs).		5-25-56	USBR	(hot)	125		.00			7.8	1.2	665	69		8.3
33bd2	Spring (Steamboat Springs).		2-5-57	USGS	136	205	.00		.08	.05	14	1.9	644	59		
34ac1	Well	138	1-27-58	do	[11] 60	41	.15	.00		.02	120	36	37	2.1		.0
34db1	do	136	1-27-58	do	[12] 66	22	.12	.00		.01	71	20	29	4.2		.0
Sp19/18-13ac1	Lawton Hot Springs		2-11-58	do	120	46	.10	.00	.00	.00	6.2	.1	117	5.4		.5
13ac2	Truckee River [13]		4-17-59	do	53	21	.80	1.2		.00	7.6	3.4	7.6	1.6		
Sp19/19-1ba1	Well	23	5-20-58	do	57	59	.30	.00	92.	.00	354	137	400	4.0		1.2

TABLE 5.—*Chemical analyses of the waters of the Truckee Meadows area, Washoe County, Nev.*—Continued

[All dissolved constituents are in parts per million except uranium, which is in parts per billion; Tr, trace. USBR, U.S. Bureau of Reclamation; USGS, U.S. Geological Survey; NSDH, Nevada State Department of Health; CLHT, Curtis Laboratories, Houston, Tex.; BCSF, Brown and Caldwell Co., San Francisco, Calif.]

Sample number and location	Source	Uranium (U)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Residue on evaporation at 180°C	Dissolved solids: Residue on evaporation at 105°C	Dissolved solids: Sum of determined constituents	Hardness as $CaCO_3$: Total	Hardness as $CaCO_3$: Noncarbonate	Specific Conductance (micromhos at 25°C)	pH	Diagram field[4]	Suitability for irrigation
Sp19/19-17ad4	do		228	6.6	7.6	12	0.7	15	2.1		382		19		457	8.3	3	C_2–S_2
17bd1	do		207		0	12							254				3	
Sp18/20-17dc1	Spring	2.0	224	.0	17	94	.5	3.0		514		562	32	0	729	7.6	1	C_2–S_2
17dc2	Well		461	Tr	10	82			5.02		505		378				1	
20bb4	do	4.0	164	.0	4.4	3.5	.2	7.0	.09	213		187	110	0	293	7.3	3	C_2–S_1
20dd1	do		102	.0	21	14					153		126				2	
21ca3	do	>.1	126	.0	5.8	6.0	.1	9.5	.05	221		217	66	0	255	7.1	3	C_2–S_1
27dc1	do	.2	148	.0	508	6.2	.1	.0	.06	929		881	432	311	1,200	7.6	2	C_3–S_1
28ab3	do	1.6	241	.0	22	73	.2	5.1	.03	439		416	123	0	671	7.6	1	C_2–S_1
28ba2	do	.7	172	65	130	836	2.5	2.0	17	2,230		1,980	4	0	3,360	8.7	1	C_4–S_1
28cb1	do		337		94	836	2.1		46			2,226			3,150	7.6	1	C_4–S_4
29bc1	do		78	.0	11	2.6						163				7.7	3	
St18/20-30aa1	Whites Creek		27	.0	6.2	.0	.0	1.9	.00		63		24		68	7.0	2	C_1–S_1
30cd1	Well	.3	162	.0	2.4	2.9	.0	.0	.05	172		168	85	0	267	7.4	3	C_2–S_2
Sp18/20-33ac1	Spring (Steamboat Springs).		212	62	118	889	2.0	1.0	36.9		2,360		25		3,555	8.3	1	C_4–S_4
33db2	Spring (Steamboat Springs).	<.1	328	.0	142	790	2.2	.4	2.2	2,130		2,020	43	0	3,240	6.7	1	C_4–S_4
34ac1	Well		162	.0	375	7.0	.2	3.9	.02	742		703	443	315	930	7.1	2	C_3–S_2
34db1	do		193	.0	154	7.0	.2	2.6	.04	436		408	260	97	609	7.2	2	C_2–S_1
Sp19/18-13ac1	Lawton Hot Springs	.1	12	20	144	57	2.5	.0	1.3	361		354	16	0	625	9.0	2	C_2–S_2
13ac2	Truckee River[13]	.2	47	.0	8.7	2.0	.1	.6	.04	76		75	33	0	103	7.1	2	C_1–S_1
Sp19/19-1ba1	Well	3	435	.0	1,680	96	.2	110	.34	3,420		3,060	1,450	1,090	3,780	7.6	2	C_4–S_2

TABLE 5.—*Chemical analyses of the waters of the Truckee Meadows area, Washoe County, Nev.*—Continued

[All dissolved constituents are in parts per million except uranium, which is in parts per billion; Tr, trace. USBR, U.S. Bureau of Reclamation; USGS, U.S. Geological Survey; NSDH, Nevada State Department of Health; CLHT, Curtis Laboratories, Houston, Tex.; BCSF, Brown and Caldwell Co., San Francisco, Calif.]

Sample number and location	Source	Depth (feet)	Date of collection	Analyst	Temperature (°F)	Silica (SiO_2)	Aluminum (Al)	Iron (Fe)[1]	Iron (Fe)[2]	Manganese (Mn)[1]	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Sodium and Potassium (Na and K)[3]	Lithium (Li)
Sp19/19- 1cc1	do	300	8-27-35	(14)							62	22	26			
4cc1	do	295	5-19-58	USGS	61	29	0.10	0.10	0.11	0.13	62	20	25	1.0		0.4
10cc1	do	90	2-11-58	do	55	34	.00	.00	.03	.00	42	14	19	2.5		.3
11bd1	do	60	1-11-28	NSDH		31	Tr		Tr		50	14			5.0	
11da1	do	352	1958	do	57				16		41	14			13	
11da2	do		1-13-46	do		10	Tr		Tr		38	13			6.0	
11db5	do	190	2-27-46	do	55	18	Tr		Tr		36	10			28	
11db11	do	98	10-15-37	do		28	Tr		Tr		54	12			7.0	
12aa2	do	583	6- 2-58	USGS	57	45	.00	.00	.18	.00	71	17	23	2.2		.4
12ba1	do	265	6-14-45	NSDH		39	Tr		Tr		44	18			15	
13bc2	do	785	6-26-31	do	86	55	Tr		Tr		39	12			148	
13bc3	do	213	5-21-58	USGS	65	33	.10	.00	.00	.00	38	16	16	3.2		.4
15dc1	do	227	10-13-41	NSDH		14	Tr		Tr		60	15			10	
17ac1	do	52	5-26-47	do		75			Tr		88	29			299	
17ad2	do	70	8- 7-47	do	58	38			Tr		96	24			68	
18cd1	do	85	12-30-58	do		68			Tr		112	37			59	
St19/19-18cd2	Truckee River		5-23-56	USBR		18		.00			6.0	2.1	2.5	.4		.0
19ab1	Hunter Creek		5-23-56	do		27		.00			9.0	3.3	3.9	.8		.0
22ac1	Well	184	2-13-58	USGS	74	41	.00	.00	.04	.00	51	7.1	23	2.6		.4
22cd1	do	270	8- 8-46	NSDH	87	41	Tr		Tr		336	112			500	
22dc1	do	150	1- 2-56	do		87					186	7.0			224	
23da2	do	103	5-20-58	USGS	99	79	.00	.04	.77	.00	21	4.1	199	3.7		.8
24da3	do	[15] 513	6- 3-59	CLHT		102			.70		22	2.4			184	
25ba2	do	700	2-11-58	USGS	114	86	.10	.00	.02	.00	15	.1	150	8.2		.7

TABLE 5.—*Chemical analyses of the waters of the Truckee Meadows area, Washoe County, Nev.*—Continued

[All dissolved constituents are in parts per million except uranium, which is in parts per billion; Tr, trace. USBR, U.S. Bureau of Reclamation; USGS, U.S. Geological Survey; NSDH, Nevada State Department of Health; CLHT, Curtis Laboratories, Houston, Tex.; BCSF, Brown and Caldwell Co., San Francisco, Calif.]

Sample number and location	Source	Uranium (U)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Residue on evaporation at 180°C	Dissolved solids: Residue on evaporation at 105°C	Dissolved solids: Sum of determined constituents	Hardness as $CaCO_3$: Total	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Diagram field[4]	Suitability for irrigation
St19/19–1cc1	do		190		101	29									614		2	C_2–S_1
4cc1	do	0.3	133	0.0	173	5.8	0.1	0.5	0.00	429		382	236	128	593	7.9	2	C_2–S_2
10cc1	do	3.6	233	.0	8.2	3.4	.0	1.6	.03	249		240	162	0	389	7.6	3	C_2–S_1
11bd1	do		169		34	10		7.0	.11		232		182				2	
11da1	do		154		41	10		10			234		162				2	
11da2	do		142	2.0	20	14					177		148				2	
11db5	do		162	.0	46	14					208						2	
11db11	do		142	.0	55	18					250		184				2	
12aa2	do	6.8	240	.0	69	14	.1	8.0	.03	368		367	347	51	571	7.9	2	C_2–S_1
12ba1	do		176	.0	50	13					268		184				2	
13bc2	do		193	.0	258	30					648		147				2	C_2–S_1
13bc3	do	3.8	176	.0	38	6.7	.1	3.8	.01	251		243	161	16	388	8.0	2	
15dc1	do		224	.0	32	15					295		211				2	
17ac1	do		205	22	576	24					1,151		339				2	
17ad2	do		427	.0	98	25					590		338				2	
18cd1	do		281	.0	292	18					735		432				2	
18cd2	Truckee River		30	.0	1.4	.0	.0	.5	.00		56		24		61	7.5	3	C_1–S_1
19ab1	Hunter Creek		29	.0	16	.0	.0	.5	.00		83		36		89	7.5	2	C_1–S_1
22ac1	Well	2.9	156	.0	48	22	.4	8.5		307		273	268	40	433	3.1	2	C_2–S_1
22cd1	do		378	.0	1,959	26					3,306		1,299				2	
22dc1	do		68	.0	886	24					1,621		518			7.2	2	
23da2	do	3.5	211	.0	325	32	1.5	2.0	.74	856		806	70	0	1,210	7.9	2	C_3–S_2
24da3	do		128	6.0	288	35					782		66		941	8.5	2	C_3–S_2
25ba2	do	.2	134	.0	221	24	2.1	.0		581		571	38	0	792	7.9	2	C_3–S_3

TABLE 5.—*Chemical analyses of the waters of the Truckee Meadows area, Washoe County, Nev.*—Continued

[All dissolved constituents are in parts per million except uranium, which is in parts per billion; Tr, trace. USBR, U.S. Bureau of Reclamation; USGS, U.S. Geological Survey; NSDH, Nevada State Department of Health; CLHT, Curtis Laboratories, Houston, Tex.; BCSF, Brown and Caldwell Co., San Francisco, Calif.]

Sample number and location	Source	Depth (feet)	Date of collection	Analyst	Temperature (°F)	Silica (SiO_2)	Aluminum (Al)	Iron (Fe)[1]	Iron (Fe)[2]	Manganese (Mn)[1]	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Sodium and Potassium (Na and K)[3]	Lithium (Li)
St19/19-25ba4	do	67	2-11-58	do	96	97	0.00	0.02	0.03	0.01	16	0.7	130	2.6		0.8
25bd4	do	95	7-9-47	NSDH	112	27	Tr		Tr		38	10			128	
25dc1	do	500	5-2-34	do		76	Tr		Tr		Tr	.0			159	
26ab1	do		9-18-46	do		60			Tr		34	11			47	
26ba1	do	240	7-10-45	do		94	Tr		Tr		116	40			405	
26dc1	do	750	10-25-39	do	180	95	Tr		Tr		33	9.0			241	
29ac1	Alum Creek		5-25-56	USBR		40		.00			24	15	13	2.7		.0
35ad1	Evans Creek		5-25-56	do		45		.00			19	6.0	10	2.7		.0
St19/20-2ad1	Well	210	5-13-58	USGS	62	19	.00	.01	.06	.00	21	3.4	59	3.2		.4
3ca1	do	213	2-13-58	do	58	48	.00	.17	.27	.10	28	7.4	25	6.1		.6
4dc1	do	402	7-18-58	BCSF	58	49		1.2		.22	21	8.1			30	
6bb1	do	147	5-20-58	USGS	58	52	.10	.01	.01	.00	69	26	52	4.1		.4
7ac1	do	201	1-15-58	NSDH		16					29.6	9.7			5.8	
7db1	do	48	7-29-38	do		23	Tr		Tr		24	Tr			16	
8ac1	do	41	1-14-58	USGS	53	37	.00	.00	.02	.00	32	11	12	2.6		.3
8ad1	do	451	1-14-58	do	68	73	.10	.13	.16	.03	11	2.9	48	9.4		.3
8ad2	do	18	2-13-58	do	54	39	.00	.01	.10	.00	42	13	94	4.3		.5
8bd2	do	752	7-24-59	CLHT	74	39	Tr		Tr		22	3.9			43	
9cd1	do	320	3-5-58	NSDH					.09		14	7.8			76	
11bc1	do	340	2-13-58	USGS		47	.00	.00	.06	.04	51	27	43	7.6		.7
11b1d1	do	65		NSDH		71	Tr		Tr		111	35			380	
2cd1	Truckee River[16]		4-17-59	USGS	56	28	.60	.71		.00	19	6.3	22	4.8		
16ac1	Well	300	5-11-56	USBR	57	52		.28			11	6.5	75	7.0		
16cd1	do	210	5-11-56	do	53	54		.13			7.4	3.8	91	6.3		

TABLE 5.—*Chemical analyses of the waters of the Truckee Meadows area, Washoe County, Nev.*—Continued

[All dissolved constituents are in parts per million except uranium, which is in parts per billion; Tr., trace. USBR, U.S. Bureau of Reclamation; USGS, U.S. Geological Survey; NSDH, Nevada State Department of Health; CLHT, Curtis Laboratories, Houston, Tex.; BCSF, Brown and Caldwell Co., San Francisco, Calif.]

Sample number and location	Source	Uranium (U)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Residue on evaporation at 180°C	Dissolved solids: Residue on evaporation at 105°C	Dissolved solids: Sum of determined constituents	Hardness as $CaCO_3$: Total	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Diagram field[4]	Suitability for irrigation
St19/20-25ba4	do	0.6	165	0.0	153	16	4.5	0.5		532		502	42	0	697	8.0	2	C_2-S_2
25bd4	do		139	17	225	32					528						2	
25dc1	do		188	.0	191	30					530		Tr				2	
26ab1	do		229		26	12					298		130				3	
26ba1	do		1.5	9.6	1,062	64					1,925						2	
26dc1	do		88	Tr	478	52					980		119		1,327	7.9	2	C_3-S_2
St19/19-29ac1	Alum Creek		.0	.0	119	1.8	.0	.4	.00		236		122		287	4.9	2	C_2-S_1
35ad1	Evans Creek		85	3.6	13	1.4	.0	.5	.09		150		71		179	8.2	3	C_1-S_1
St19/20- 2ad1	Well	1.0	128	.0	59	24	.1	1.8	.01	259		254	66	0	433	8.2	2	C_2-S_1
3ca1	do	.1	76	16	66	6.5	.7	.0		256		230	121	32	323	8.8	2	C_2-S_1
4dc1	do		112	.0	49	5.0	.15	1.0	.10		218		87		270	7.8	2	C_2-S_1
6bb1	do	6.6	246	.0	144	21	.1	13	.00	523		503	279	78	746	7.9	2	C_2-S_1
7ac1	do		122	.0	19	5.0					184		114	14			2	
7db1	do		90	Tr	15	4.0					143		60				2	
8ac1	do	1.0	155	.0	11	7.4	.2	6.0		196		187	125	0	316	7.6	3	C_2-S_1
8ad1	do	.1	106	.0	59	3.1	.2	1.0		261		250	39	0	331	7.8	2	C_2-S_1
8ad2	do	.6	135	.0	14	170	.6	3.8		511		455	158	47	875	8.1	1	C_3-S_1
8bd2	do		116	.0	57	7.0					313		71	0	325	8.0	2	C_2-S_1
9cd1	do		114	.0	118	12					336		68	0		8.2	2	
11bc1	do	3.2	190	.0	153	33	.5	.5		467		459	238	83	673	7.3	2	C_2-S_1
11bd1	do		359	.0	785	93					1,591		421				2	
12cd1	Truckee River[16]	.7	100	.0	21	13	.3	3.0	.41	172		166	73	0	255	6.9	2	C_2-S_1
16ac1	Well		104	3.6	111	12		.5	.34		320		55		459	8.2	2	C_2-S_1
16cd1	do		97	8.4	120	13	.7	.5	.40		339		34		490	8.5	2	C_2-S_1

TABLE 5.—*Chemical analyses of the waters of the Truckee Meadows area, Washoe County, Nev.*—Continued

[All dissolved constituents are in parts per million except uranium, which is in parts per billion; Tr, trace. USBR, U.S. Bureau of Reclamation; USGS, U.S. Geological Survey; NSDH, Nevada State Department of Health; CLHT, Curtis Laboratories, Houston, Tex.; BCSF, Brown and Caldwell Co., San Francisco, Calif.]

Sample number and location	Source	Depth (feet)	Date of collection	Analyst	Temperature (°F)	Silica (SiO_2)	Aluminum (Al)	Iron (Fe)[1]	Iron (Fe)[2]	Manganese (Mn)[1]	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Sodium and Potassium (Na and K)[3]	Lithium (Li)
St19/20-16db1	do	18	5-19-58	USGS		37	0.00	0.00	0.08	0.01	35	12	17	3.9		0.4
17bb2	do	[17]1,025	8-4-59	CLHT	75				.30		15	6.3			157	
18bb3	do	[18]660	5-22-59	do	70	10			.20		4.8	.7			69	
19ab1	do	197	1-14-58	USGS	60	48	.00	.00	.34	.00	28	7.7	25	5.1		.2
19cb1	do	24	1-13-58	USGS	67	101	.10	.00	.02	.00	40	5.0	120	9.5		.4
19db1	do	26	5-25-56	USBR		89		.00			7.8	.6	110	5.5		
20da3	do	61	1-13-58	USGS	51	75	.00	.00	.00	.00	26	7.6	48	5.1		
22da1	do	75	8-13-59	do	64	15					85	39	140	8.8		.0
27ac2	do	550	7-25-56	NSDH		50			Tr		103	34			203	
27ac3	do	650	1-13-58	USGS	72	88	.10	.01	.11	.00	107	41	160	21		.2
30da1	do	83	1-13-58	do	54	71	.10	.00	.01	.00	33	21	31	5.6		.5
30bc3	do	600	1-13-58	do	76	94	.10	.33	.35	.03	18	.3	170	9.5		.4
31cb3	do	112	7-14-45	NSDH		60	Tr		Tr		41	15			35	
31cb6	do	333	10-25-38	do		57	Tr		Tr		33	8			28	
31da1	do	139	5-8-56	USBR	60	77		.00			16	13	12	5.1		
Sp19/20-32aa1	Spring		5-11-56	do	60	90		.00			24	14	18	5.1		Tr
32bb1	Well	60	10-9-46	NSDH		80	Tr		Tr		36	Tr			61	
33bc1	Spring		5-11-56	USBR	65	93		.00			20	12	34	5.9		.0
33bd1	Well	70	5-13-58	USGS	58	68	.00	.00	.01	.02	36	13	75	8.0		1.4
33bd2	Spring		5-13-58	do	62	67	.00	.00	.00	.00	21	8.7	60	4.9		.9
Sp20/20-31dd1	Well	66	5-20-58	do	56	54	.00	.00	.03	.00	122	24	56	2.6		.5
33cb2	do	85	5-13-58	do	56	53	.00	.00	.00	.02	62	15	92	3.8		.4
34bc1	do	39	2-13-58	do	50	53	.00	.00	.00	.00	92	34	43	3.6		.4

[1] In solution at time of analysis.
[2] Total.
[3] Difference between anions and cations, in equivalents per million, assumed to be sodium and potassium, and calculated as sodium.
[4] See figure 3.
[5] Assumed to be ionized and reported as 17.79 epm.
[6] Assumed to be ionized and reported as 1.13 epm.
[7] Presence of carbonate cannot be reconciled with reported pH.
[8] Bottom-hole temperature, March 6, 1950.
[9] Bottom-hole temperature, January 1950.
[10] Bottom-hole temperature, August 1959.
[11] Bottom-hole temperature, August 1949.

TABLE 5.—*Chemical analyses of the waters of the Truckee Meadows area, Washoe County, Nev.*—Continued

[All dissolved constituents are in parts per million except uranium, which is in parts per billion; Tr., trace. USBR, U.S. Bureau of Reclamation; USGS, U.S. Geological Survey; NSDH, Nevada State Department of Health; CLHT, Curtis Laboratories, Houston, Tex.; BCSF, Brown and Caldwell Co., San Francisco, Calif.]

Sample number and location	Source	Uranium (U)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Residue on evaporation at 180°C	Dissolved solids: Residue on evaporation at 105°C	Dissolved solids: Sum of determined constituents	Hardness as $CaCO_3$: Total	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Diagram field[4]	Suitability for irrigation
Sp20/20-16db1	do	5.1	167	0.0	25	7.2	0.2	4.5	0.06	224		216	137	0	333	7.8	2	C_2–S_2
17bb2	do		200	.0	204	21					551		65		796	8.1	2	C_3–S_1
81bb3	do		104	.0	70	5.0					85		15		321	8.3	2	C_2–S_1
19ab1	do	1.9	139	.0	39	7.8	.1	3.8	.24	233		223	101	0	341	8.0	2	C_2–S_1
19cb1	do	.3	222	.0	174	20	1.2	6.5		584		567	120	0	795	7.5	2	C_3–S_1
19bd1	do		123	12	117	16	2.0	2.2	.47		402		22		554	8.6	2	C_2–S_2
20da3	do	3.1	181	.0	51	5.1	.6	3.5	.15	302		311	90	0	432	7.5	2	C_2–S_1
22da1	do		83	.0	175	315	.1	1.8	6.1	913			373	305	1,460	7.8	1	C_3–S_1
27ac2	do		293	.0	181	290					1,068		306			7.8	2	
27ac3	do	3.3	241	.0	225	264	.2	1.7		1,061		1,030	435	235	1,600	7.4	1	C_3–S_1
30da1	do	3.4	256	.0	26	4.5	.1	4.0		323		305	169	0	510	7.0	3	C_2–S_1
30bc3	do	.2	116	.0	280	30	2.5	.5	49	658		665	46	0	917	7.8	2	C_3–S_2
31cb3	do		246	.0	20	13					304		164				3	
31cb6	do		203	.0	Tr	8				226			115				3	
31da1	do		121	6.3	3.4	1.4	.0	1.2	.00		180		93		240	8.5	3	C_1–S_1
Sp19/20-32aa1	Spring		149	18	6.2	2.8	.0	1.4	.00		240		119		301	8.7	3	C_2–S_1
bb1	Well		244		Tr	10					338						3	
33bc1	Spring		145	20	7.2	7.1	.0	.8	.18		256		97		322	8.8	3	C_2–S_1
33bd1	Well	2.0	260	.0	18	62	.2	5.4	.85	418		418	148	0	656	7.8	1	C_2–S_1
33bd2	Spring	1.4	207	.0	15	29	.2	1.0	.87	306		305	88	0	444	7.8	1	C_2–S_1
Sp20/20-31dd1	Well	9.5	289	.0	239	20	.2	11	.24	696		672	402	166	979	7.4	2	C_3–S_1
33cb2	do	8.4	397	.0	82	7	.3	9.8	1.1	521		503	216	0	794	7.9	2	C_3–S_1
34bc1	do	4.1	185	.0	271	18	.3	4.3		729		610	368	216	918	7.5	2	C_3–S_1

[12] Bottom-hole temperature 71° F, March 1950.
[13] Estimated discharge, 200 cfs.
[14] Analysis reported in University of Nevada Bull. 187, p. 28, 1953.
[15] Sample collected with screen set at 235–245 feet below land surface; packer at 220 feet below land surface.
[16] Estimated discharge, 300 cfs.
[17] Sample collected with screen set at 753–763 feet below land surface; packer at 745 feet below land surface.
[18] Sample collected with screen set at 628–638 feet below land surface; packer at 620 feet below land surface.

SPECIFIC CONDUCTANCE

Specific conductance—electrical conductance or more simply conductivity—expressed in micromhos per centimeter at 25°C, is a measure of the ease with which an electric current will pass through a solution. Specific conductance increases with an increasing number of dissociated ions in solution and with increasing temperature. Therefore, if specific conductance is referred to a constant temperature, commonly 25°C, it is an approximate measure of the number of dissociated ions in solution, or a rough measure of the dissolved-solids content. In the Truckee Meadows area, dissolved-solids content can be estimated by multiplying specific conductance by about 0.7.

HYDROGEN ION CONCENTRATION (pH)

The pH of a solution is the negative logarithm of the hydrogen ion concentration. Generally, water having a pH of 7.0 is regarded as neutral. Water having a pH of less than 7.0 is considered acidic, and water having a pH of more than 7.0 is considered alkaline.

HARDNESS

Hardness is expressed in parts per million of calcium carbonate. This is done as a matter of convenience and does not necessarily imply that calcium carbonate is present in the solution. For example, since hardness is expressed in parts per million of calcium carbonate, if it is assumed that all the hardness in a particular sample is due to calcium, the parts per million of calcium can be computed as follows:

$$\text{ppm Ca} = \text{hardness (in ppm } CaCO_3) \times \frac{\text{at. wt Ca}}{\text{mol. wt } CaCO_3}$$

MAJOR CHEMICAL CONSTITUENTS

Generally, the cations sodium, potassium, calcium, and magnesium and the anions chloride, sulfate, and bicarbonate and carbonate are the most abundant and significant constituents in the waters of the Truckee Meadows area. In this report, these ions are referred to as major constituents. On plate 3, diagrams, which are modified from a diagram first used by Stiff (1951), indicate the major constituents, in equivalents per million, and thus indicate the general chemical character of the waters of the Truckee Meadows area.

SODIUM

Sodium is an abundant element in the waters of the study area. It is derived mainly from the chemical weathering of some of the plagioclase feldspars in the granitic rocks of the area, and also it is derived partly from some of the ferromagnesium minerals in these rocks. Sodium carbonate is one of the chief end products of the weathering of sodium-rich plagioclase feldspars, and it is readily dissolved by water, especially water containing carbon dioxide. The other principal source of sodium in the waters of the Truckee Meadows area is the Steamboat Springs system in and adjacent to the Steamboat Hills.

Calcium or magnesium ions in water in contact with minerals containing sodium may be exchanged for sodium. This mechanism, commonly termed "ion exchange" or "base exchange," is at least partly responsible for increasing the concentration of sodium in some of the waters of the area.

POTASSIUM

Potassium is less abundant than sodium both in the rocks of the area and in the waters that drain from the mountains of the area. Most of the ground waters in the valley contain less than 10 ppm potassium; however, some of the waters in the Steamboat Springs subarea contain about 70 ppm potassium.

CALCIUM AND MAGNESIUM

Calcium and magnesium occur in varying amounts in most of the volcanic rocks in the mountains and in the detritus derived from these rocks. Calcium occurs in most of the plagioclase feldspars in the andesite and basalt of the area. Also, calcium and magnesium occur in the pyroxene and amphibole mineral groups that are abundant in the rocks. Weathering of these minerals produces many calcium and magnesium compounds that are moderately to highly soluble in water.

The concentrations of calcium and magnesium in most of the surface waters of the area are low. The amount of calcium and magnesium in the ground-water system, however, varies greatly from one part of the valley to another. As calcium-and-magnesium-rich ground water moves downgradient, it generally is diluted by infiltration of irrigation water having a low dissolved-solids content, and the concentration of calcium and magnesium decreases. The percentage of calcium and magnesium commonly also decreases because of ion exchange.

Calcium and magnesium carbonate are readily soluble in water in the presence of carbon dioxide. Therefore, depending partly on the availability of carbon dioxide, which varies with changing physical and chemical environments, calcium carbonate and magnesium carbonate may be precipitated or dissolved from the alluvium. Accumulations of calcium and magnesium salts in the alluvium, especially calcium and magnesium carbonate, locally control the chemical character of the waters of the study area.

CARBONATE AND BICARBONATE

As mentioned above (p. S43), carbonate and bicarbonate are end products of the chemical weathering of feldspars. Carbon dioxide, which is most commonly obtained from the atmosphere and the soil, and water are the principal agents which attack and break down the feldspars. In general, the igneous rocks of the area and the detritus derived from them include 50–60 percent feldspars. Many other abundant minerals in the rocks of the area are decomposed by water containing carbon dioxide and thereby also yield carbonate or bicarbonate compounds. Owing to the abundance of minerals that react with carbon dioxide and water to yield carbonate or bicarbonate compounds, it is readily apparent why carbonate and bicarbonate ions are a major constituent in the waters of the area.

The analyses given in table 5 show that carbonate is rare in the waters of the area. The maximum carbonate content, given in table 5 as 65 ppm, was noted in Sp18/20–28ba2. Bicarbonate is present in most of the samples; the maximum bicarbonate content is 461 ppm. Commonly, carbonate cannot be detected in water having a pH of less than about 8.2, and bicarbonate cannot be detected in water having a pH of less than 4.5. The pH values of most of the waters of the area fall within this range. Thus, bicarbonate is abundant and carbonate is comparatively rare.

SULFATE

The highest concentrations of sulfate are found in some of the samples obtained near the margins of the valley. Sulfate commonly occurs in many of the waters of alluvial basins in Nevada as a result of the leaching of evaporites such as gypsum and anhydrite. If leaching were responsible for sulfate in the waters of the Truckee Meadows area, there would be a general increasing trend in sulfate concentration as the ground waters move downgradient. Mostly, the opposite occurs in the Truckee Meadows area; and although the alluvium may contain some local accumulations of gypsum and anhydrite which add sulfate to the ground waters of the area, the major source of sulfate in the waters of the area is the rocks of the mountains and foothills bordering the valley.

Most of the sulfate in the waters of the Truckee Meadows area is derived from bleached rock. (See p. S10.) Alum Creek drains an area of bleached rock, and the dominant anion in the creek is sulfate. (See analysis of sample St19/19–29ac1.) Sample 19/19–1ba1, obtained from a shallow well dug in bleached rock, contained 1,680 ppm sulfate. Sample 19/19–22cd1, obtained from a fairly deep well downgradient from an area of bleached rock, contained 1,959 ppm sulfate. The ephemeral streams in the southern and northern branches of the Bailey Canyon and wells north of the mouth of the canyon also show the relation between bleached rocks and sulfate. The south branch of Bailey Canyon drains an area underlain predominantly by unbleached rock, whereas the stream in the north branch of the canyon drains a large area of bleached rock. Sample St17/20–2ac1 from the southern branch of Bailey Canyon contained 191 ppm sulfate, and sample St17/20–2ad1 from the northern branch of Bailey Canyon contained 2,570 ppm sulfate.

On plate 3, the relation between bleached rock and sulfate in the waters is apparent. For example, note the shape of the diagrams depicting the major ions in the water of the creek in the north branch of Bailey Canyon. Also, note the shape of the diagrams for the waters in the wells downgradient from the mouth of Bailey Canyon. It is probable that the water in most of the wells near the mouth of Bailey Canyon consists at least partly of water infiltrating from Bailey Canyon.

CHLORIDE

Minerals containing soluble chloride compounds are rare in the rocks of the area, and probably most of the small amount of chloride in the streams draining the mountains is derived from precipitation.

Large amounts of chloride are added to the ground-water system in the Steamboat Springs subarea. (See analyses of samples Sp18/20–33ac1 and Sp18/20–33db2.) White (1957a, p. 1646) concluded that the chloride in the waters of the Steamboat Springs subarea is derived from a magmatic source and is transported from depth in a dense vapor solution. As the waters, rich in chloride, move downgradient from the springs, they mix with and are diluted by waters that contain very little chloride. Therefore, the amount of chloride in the waters of the area generally decreases with increasing distance from the Steamboat Springs subarea.

Chloride compounds are not common in the alluvium downgradient from the springs. For the most part, chloride probably is not precipitated in the alluvium but is carried in solution, is discharged into the Truckee River, and thence is removed from the basin. Samples St19/18–13ac2 and St19/20–12cd1 indicate that about 10 ppm chloride was added to the Truckee River in the study area on April 17, 1959.

MINOR CHEMICAL CONSTITUENTS

IRON AND MANGANESE

Iron and manganese in the waters of the Truckee Meadows area are similar in their chemistry and occurrence. In table 5, of the two data columns on the occurrence of iron—one represents iron in solution at the time of analysis, and the other represents total iron. The data column for manganese represents manganese in solution at the time of analysis.

Iron is a very abundant element and manganese is a somewhat less abundant element in the rocks of the area. The presence of either element in water, however, depends on a number of complex interrelated factors such as pH, availability of oxygen, the presence of other chemical constituents, and, in some water, the prescence of bacteria. A sample containing abundant dissolved iron at the time of collection may contain little or no dissolved iron at the time of analysis. Commonly, the dissolved iron is precipitated in the sample container in the form of ferric hydroxide soon after the sample is obtained. In addition, many samples may be high in iron content as a result of being in contact with the steel well casing or pump column. Therefore, the data in table 5 pertaining to iron have only limited use for geochemical interpretation, but they are useful for evaluating the suitability of the waters for various uses (p. S52).

LITHIUM

Lithium is an alkali metal similar in many characteristics to sodium and potassium. Data on lithium in the waters are meager; however, the data suggest that, similar to boron (p. S47), most of the lithium is derived from the Steamboat Springs system. The highest concentrations of lithium, 10 and 8.3 ppm, were noted in samples 18/20–28ba2 and Sp18/20–33ac1, respectively.

URANIUM

As part of the Survey's nationwide radioelement sampling program, 47 water samples from the study area were analyzed for uranium and radium in addition to the usual elements and compounds. The presence of uranium in the waters of the Truckee Meadows area is discussed in a previous report (Cohen, 1961, p. 4199–4206). The following is a brief summary of the information given in that report.

Uranium content tends to increase with increasing bicarbonate and carbonate concentrations. It appears to be related also to chloride and sulfate concentrations. Waters containing high concentrations of chloride tend to be low in uranium, whereas some of the waters containing high concentrations of sulfate are comparatively rich in uranium.

FLUORIDE

Fluoride is a rare element in the rocks of the Truckee Meadows area; mostly, it occurs in concentrations of less than 1 ppm in the waters of the area. The highest concentration of fluoride, 4.5 ppm, was noted in sample 19/19–25ba4.

NITRATE

Most of the nitrate in the waters of the area probably is of organic origin. Some plants in the area add nitrogen compounds to the soil; in addition, the leaching of fertilizers and of animal excreta and sewage effluent add nitrate to the waters of the area.

The waters of the streams draining the mountains and the waters of most of the wells commonly contain less than 1 ppm nitrate. However, concentrations of nitrate in the waters in some of the wells in the valley are as high as 15 ppm. Sample 19/19–1ba1, from a shallow dug well, contained 110 ppm nitrate.

BORON

Boron is rare in the rocks of the area; mostly, it occurs in concentrations of less than 1 ppm in the waters of the area. However, unusually high concentrations of boron, as much as 46 ppm, occur in both the waters in and the waters downgradient from the Steamboat Springs subarea.

Boron is a significant constituent in the waters of many hot springs throughout the world. Most writers agree that high concentrations of boron in thermal waters indicate a probable magmatic origin for at least part of the thermal waters.

TEMPERATURE

Ground-water temperatures in the Truckee Meadows area cover a wide range. The minimum temperature is about 52°F, and the maximum temperature at land surface is at the boiling point. Water temperatures in shallow wells that are not influenced by the water from thermal areas are about 53°F, which is about 3° warmer than the average annual air temperature.

A principal source of thermal water is the Steamboat Springs system. At shallow depths, the temperature of much of the water is above the boiling point. Structural deformation and stratification of the water-transmitting deposits downgradient from the Steamboat Springs subarea locally cause marked changes in water temperature in wells only short distances apart.

The Moana Springs subarea in secs. 13, 14, 20, 23, 24, 26, 27, and 28, T. 19 N., R. 19 E., is the other major thermal ground-water system in the study area. At land surface, the water temperature of this system generally is somewhat lower than the water temperature of the Steamboat Springs system. The hottest temperature of water at the land surface is 188°F at well 19/19–26db1, which is reported to be 86 feet deep.

For the most part, other areas whose ground-water temperature is higher than normal are smaller and less defined than the Steamboat Springs and Moana Springs subareas. One such area is in sec. 12, T. 18 N., R. 19 E. On May 13, 1949, the temperature of the water flowing from well 18/19–12db1 was 68°F. The well is 301 feet deep, and it reportedly penetrated andesite at 232 feet below land surface. The well later was perforated at shallow depths and was pumped. When pumped at the rate of about 1,000 gpm, the water temperature was 62°F. The lower temperature probably resulted from the mixing of water from deep aquifers with cooler water from shallower aquifers. On the basis of the temperature in other shallow wells nearby, the temperature of the water in the shallow aquifers is estimated to be about 54°F.

Ground-water temperatures normally increase with depth. The rate of temperature increase with depth in the study area depends considerably on local conditions, but on the average, as exemplified below, the rate is about 1°F for each 30–50 feet of depth. In the interval from 634 to 644 feet below land surface in well 19/20–8bd1, the water temperature is 74°F; and in the interval from 753 to 763 feet below land surface in well 19/20–17ac1, the water temperature is 75°F. These temperatures are about 20°F higher than that of the water in shallow wells in the same areas.

VARIATIONS IN CHEMICAL QUALITY

As indicated on page S43, the percentage of the major cations, sodium, potassium, calcium, and magnesium, depends to some degree on the process of ion exchange. This phenomenon, coupled with the extreme variation in the abundance of these elements in the rocks of the area, makes it difficult to classify the waters of the area on the basis of the major cations. A classification based on the major anions, carbonate, bicarbonate, sulfate, and chloride, is possible, and it is useful for evaluating the hydrogeochemistry of the area.

Based on figure 3, which is a trilinear plot of the percentage of equivalents per million of carbonate plus bicarbonate, sulfate, and chloride, the waters are divided into three groups:

1. Waters in which the percentage of equivalents per million of chloride is greater than the percentage of equivalents per million of sulfate and in which the percentage of equivalents per million of carbonate plus bicarbonate is less than 80 percent of the total equivalents per million of the four anions. These waters, plotted in field I of figure 3, are classified as chloride waters.
2. Waters in which the percentage of equivalents per million of sulfate is greater than the percentage of equivalents per million of chloride and in which the percentage of equivalents per million of carbonate plus bicarbonate is less than 80 percent of the total equivalents per million of the four anions. These waters, plotted in field II of figure 3, are classified as sulfate waters.

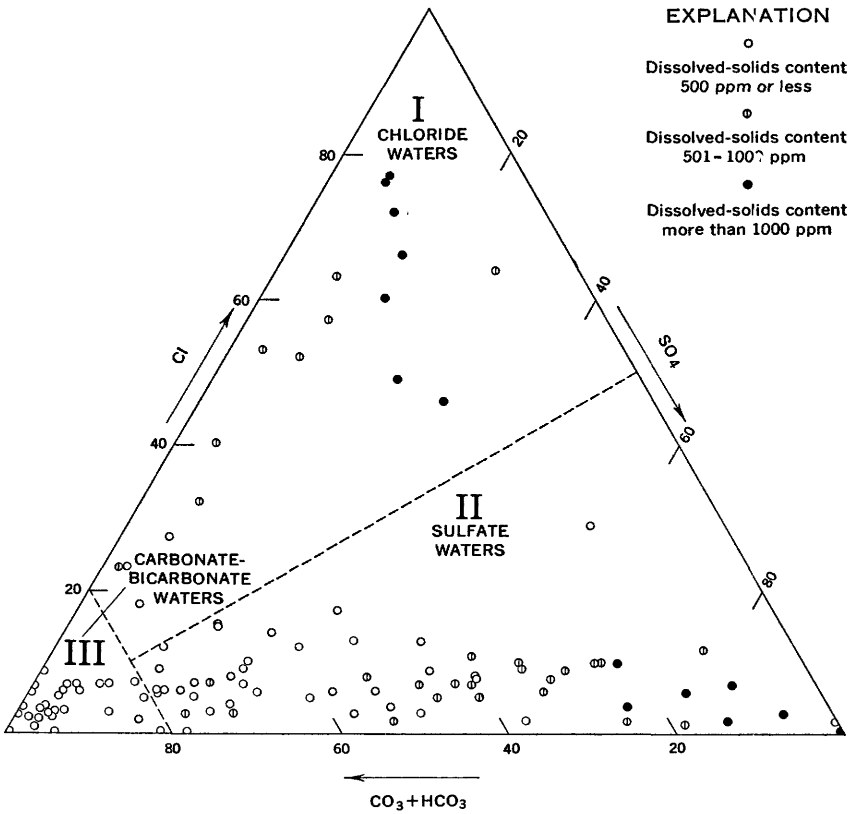

FIGURE 3.—Classification of the waters of the Truckee Meadows area, Washoe County, Nev. Scale is in percentage of total equivalents per million of carbonate plus bicarbonate, sulfate, and chloride.

3. Waters in which the percentage of equivalents per million of carbonate plus bicarbonate is greater than 80 percent of the four anions. These waters, plotted in field III of figure 3, are classified as carbonate-bicarbonate waters.

Of the 113 analyses given in table 5, 29 are classified as carbonate-bicarbonate waters. The plots of these waters fall in a fairly continuous band along the base of the triangle opposite the 100-percent-chloride vertex and represent mixtures of carbonate-bicarbonate and sulfate waters in varying proportions. Therefore, the use of the 80-percent carbonate-bicarbonate value to separate the carbonate-bicarbonate waters from the chloride and sulfate waters is somewhat arbitrary. There is no apparent break in the band of points that indicates where the line separating field III from fields I and II should be drawn. However, the 80-percent break is useful because most of the waters that drain areas of unbleached rock and most of the waters diverted for irrigation contain about 80-percent or more carbonate plus bicarbonate.

Sixty-five samples, plotted in field II of figure 3, are classified as sulfate waters. Nineteen samples, plotted in field I of figure 3, are classified as chloride waters. All but one of the chloride waters, sample 19/20–8ad2, were collected from the Steamboat Springs subarea or downgradient from the springs. Plots of samples Sp18/20–33ac1, Sp18/20–33db2, and 18/20–28ba2 are closest to the 100-percent-chloride vertex. Sample 18/20–28ba2 was obtained from a steaming well having a bottom-of-hole temperature of 271°F, and the other two samples were obtained from hot springs.

Partly on the basis of an evaluation of the thermal conductivity of the rocks and an evaluation of the enthalpy—heat content above 0°C—of the waters of the Steamboat Springs subarea, White (1957a, p. 1642–1643) concluded that the chief source of the heat in the Steamboat Springs system must be a magma. He further hypothesized that the chloride in the waters of the Steamboat Springs subarea is associated with magmatic activity.

As noted above, all the waters whose plots lie in field I of figure 3 except sample 19/20–8ad2 are in or downgradient from the Steamboat Springs subarea. The chloride content in sample 19/20–8ad2 is anomalously high. The sample was collected from a shallow dug well in an area in which sodium chloride formerly was used to ice railroad cars. The high chloride content in the sample is interpreted as resulting from leaching of the sodium chloride on the ground.

MOVEMENT AND BLENDING OF THE WATERS

The distribution of the points in figure 3 illustrates a number of significant aspects of the hydrogeochemistry of the area. There is a marked tendency for the points to fall into two bands, one of which is parallel to the leg of the triangle opposite the 100-percent-chloride vertex and the other of which is parallel to the leg of the triangle opposite the 100-percent-sulfate vertex. There is no concentration of points parallel to the leg of the triangle opposite the 100-percent-carbonate-bicarbonate vertex.

The points in the band opposite the 100-percent-chloride vertex represent carbonate-bicarbonate waters, sulfate waters, and mixtures of the two. Waters associated with and downgradient from the area of bleached rock in the Carson Range southwest of Reno illustrate the movement and the mixing of carbonate-bicarbonate waters and sulfate waters. Alum Creek drains an area of bleached rock (pl. 3), and sulfate constituted 98 percent of the total equivalents per million of the major anions of the water from the creek. The remaining 2 percent was chloride. Analyses of samples 19/20–22cd1 and 19/20–22dc1 show the chemical quality of waters in wells immediately downgradient from the area of bleached rock. Sulfate constituted about 85 percent and about 91 percent of the total equivalents per million of the major anions of samples 19/20–22cd1 and 19/20–22dc1, respectively. Although the percentage contents of sulfate in these two samples are comparable with the percentage content of sulfate in the sample from Alum Creek, the waters from the wells contained about 7–16 times more sulfate than did the water from the creek. This quantity difference probably was related to the time of sampling of Alum Creek. The sample was collected during a period of peak discharge. Therefore, it is presumed that the sample was greatly diluted by snowmelt. During most of the year the chemical quality of the water in the creek probably is similar to the chemical quality of the two well samples.

Sample 19/19–22ac1, which is from a well in the same general area as Alum Creek, contained only about 1 epm sulfate, whereas samples 19/20–22cd1 and 19/20–22dc1 contained about 41 and 18 epm sulfate, respectively. The three wells are of comparable depth and probably of comparable construction. Well 19/19–22ac1 was drilled in moderately permeable older alluvium near the edge of a deep canyon that carries snowmelt runoff during part of the year. Samples 19/20–22cd1 and 19/20–22dc1 also were obtained from wells near canyons that periodically carry snowmelt runoff. However, these wells penetrated fairly impermeable diatomite, diatomaceous clay, and silt of the Truckee Formation. Because of the moderately permeable nature of the older alluvium in this area, a large part of the ephemeral streamflow in the canyon adjacent to well 19/19–22ac1 probably recharges the ground-water reservoir. In effect, well 19/19–22ac1 probably is tapping a fresh-water lense overlying waters rich in sulfate. If withdrawals from the fresh-water lense are increased significantly, the water quality probably will deteriorate.

Samples of ground water downgradient from areas of bleached rock generally show the following trends: (1) The percentage of equivalents per million of sulfate decreases and the percentage of equivalents per million of carbonate-bicarbonate increases; (2) the dissolved-solids content, particularly the sulfate content, decreases; and (3) the percentage of equivalents per million of calcium and magnesium decreases and the percentage of sodium increases. The first two trends result almost entirely from the dilution of sulfate-rich waters with carbonate-bicarbonate waters that infiltrate from irrigation waters diverted from the Truckee River and from streams draining areas of unbleached rock. The third trend results mostly from ion exchange.

Sulfate derived from areas of bleached rock also occurs in thermal wells and springs in the Moana Springs subarea. Except for their above-normal temperatures, these waters are similar to the cold sulfate waters in other parts of the valley. The higher temperatures probably are caused by deep circulation of the waters of the subarea.

The band of points parallel to the leg of the triangle opposite the 100-percent-sulfate vertex in figure 3 are chloride waters, carbonate-bicarbonate waters, and mixtures of the two. The shape of the water-level contours of plate 2 suggests that the chloride-rich ground waters originating in the Steamboat Springs subarea move in a northward direction toward the Huffaker Hills. The carbonate-bicarbonate waters that mix with and dilute the chloride waters are derived principally from Whites Creek (sample St18/20–30aa1), Thomas Creek (sample St18/19–13da1), Evans Creek (sample St19/19–35ad1), Steamboat Creek (sample St17/20–5dc1), Steamboat ditch, and Last Chance ditch (St18/19–12bb1).

SUITABILITY FOR USE

The chemical data given in this report help define some of the chemical and physical characteristics of the waters of the area. These characteristics are significant, but they are not the only factors that should be evaluated in order to determine whether a certain water is suitable for a particular use. Bacteria content and, for surface water, sediment content are two significant factors that were not evaluated during the present study. Thus, the remarks pertaining to suitability, given below, are restricted to an evaluation of the data given in table 5 and do not indicate the sanitary conditions and sediment content of the waters.

DOMESTIC

According to the U.S. Public Health Service (1962), waters containing more than 1.7 ppm fluoride may not be supplied by interstate common carriers to passengers. Trace amounts of fluoride, about 1.0 ppm or less, are believed by many to be beneficial in preventing tooth decay in children. A report by the California State Water Pollution Control Board (1952, p. 238) implies that concentrations of more than 4 ppm fluoride may affect bone structure adversely. Only one of the samples of waters in the Truckee Meadows area, sample 19/19–25ba4, contained more than 4 ppm fluoride. Upper limits for other chemical constituents as established by the U.S. Public Health Service are:

Constituent	*Parts per million*
Iron and manganese (sum)	0.3
Magnesium	125
Chloride	250
Sulfate	250
Total dissolved solids:	
Good-quality water	500
Where no better water available	1,000

Iron and manganese are objectionable in water used for laundering. Excessive amounts of these elements and their compounds commonly leave stains on clothing and plumbing fixtures.

Chloride concentrations of more than 250 ppm, especially in the presence of an equivalent amount of sodium, may impart a noticeable taste to the water. Chloride concentrations of more than 250 ppm are common in the ground waters in and downgradient from the Steamboat Springs subarea.

Sulfate concentrations of more than 250 ppm may have a laxative effect when combined with other ions, notably sodium or magnesium. Waters containing more than 250 ppm sulfate occur near the margins of the valley downgradient from areas of bleached rock.

Hardness principally is caused by the alkaline-earth elements, of which calcium and magnesium are the most abundant. Hard water is objectionable for most domestic uses. However, it is difficult to set limits on the hardness of water that is tolerable. Generally, water having a hardness of more than 100 ppm, expressed as calcium carbonate, is considered hard. If water has a hardness of 200 ppm, it is considered very hard, and commonly it is softened by artificial means. Many of the waters of the area have a hardness in excess of 200 ppm.

The temperature of the waters in and near the Steamboat Springs and the Moana Springs subareas commonly is high. Except in special situations (p. S56–57), the high temperatures of the waters in these subareas detract from their suitability for domestic use.

IRRIGATION

The suitability of water for irrigation depends mainly on the chemical quality of the water, but it also depends on the nature of the soil, the type of crop, irrigation practices, and many economic considerations. A number of general criteria, however, can be used to evaluate the suitability of water for irrigation.

One of the most critical elements in irrigation waters is boron. Boron is essential for proper plant nutrition in small amounts, but it is toxic to many plants in concentrations only slightly above the needed amounts. Even those crops that are most tolerant to boron commonly cannot survive waters having a concentration of about 4 or more parts per million of boron. Plants that are very sensitive to boron cannot survive if the waters contain as much as 1 ppm boron. Many of the waters in and downgradient from the Steamboat Springs subarea contain much more than 4 ppm boron; therefore, future development of ground water for irrigation in this subarea probably will be limited.

No classification adequately relates water quality to all the variables that commonly are considered when evaluating the suitability of water for irrigation. However, a classification proposed by the U.S. Salinity Laboratory Staff (1954) has proven to be a useful guide for classifying waters for irrigation. The classification is based on the electrical conductivity and the sodium-adsorption-ratio (SAR). The latter is defined by the equation

$$SAR=\frac{Na^{+1}}{\sqrt{\frac{Ca^{+2}+Mg^{+2}}{2}}}$$

and is related to the experimentally determined adsorption of sodium by soil. Excess sodium commonly causes clay particles in soil to disperse and thereby reduces the permeability of the soil.

A modified form of the diagram proposed by the U.S. Salinity Laboratory Staff (1954, p. 80) is shown in figure 4. SAR is plotted

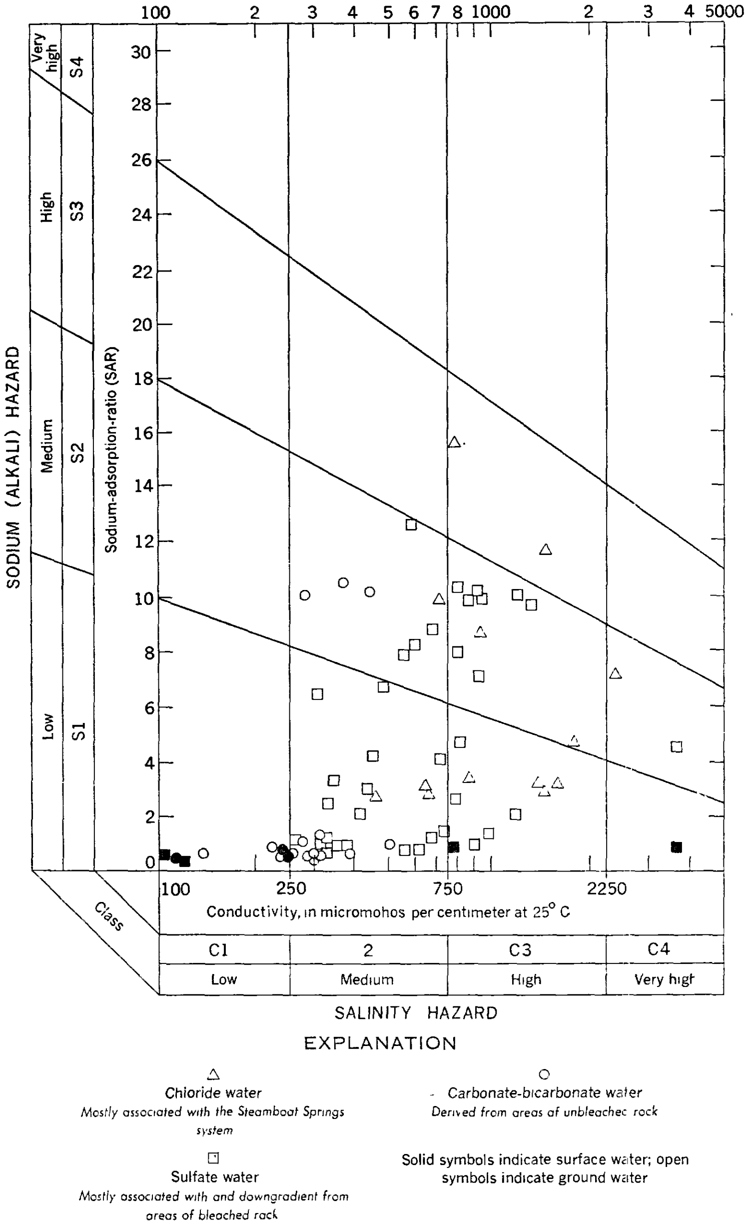

FIGURE 4.—Diagram for classifying irrigation water on the basis of conductivity and sodium-adsorption-ratio.

as the ordinate, and salinity hazard or conductivity as the abscissa. The following classification of irrigation water with respect to salinity hazard and SAR is given by Wilcox (1955, p. 7):

[1] Low-salinity water (C1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

[2] Medium-salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

[3] High-salinity water (C3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

[4] Very high salinity water (C4) is not suitable for irrigation under ordinary conditions but may be used occasionally under very special circumstances.

[5] Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stonefruit trees and avocados may accumulate injurious concentrations of sodium.

[6] Medium-sodium water (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

[7] High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management—good drainage, high leaching, and organic matter additions.

[8] Very high sodium water (S4) is generally unsatisfactory for irrigation purposes except under special circumstances.

The classification of the suitability of the waters of the Truckee Meadows area for irrigation, based on the classification by Wilcox, is given in table 3.

INDUSTRIAL

Because of the wide variation in quality standards for industrial water, this report does not include a detailed discussion of the suitability of waters of the area for industry. Most industrial supplies of ground water have been developed near the Truckee River. Ground waters in this subarea generally have a low dissolved-solids content, although they are somewhat hard in the western part of Reno and west of Reno. Increased development of ground water near the Truckee River may improve the quality of the ground water as a result of induced recharge from the river to the ground-water reservoir.

HEAT AND POWER

Thermal waters from the Steamboat Springs, Moana Springs, and Lawton Hot Springs (SW¼NE¼ sec. 13, T. 19 N., R. 18 E.) subareas are used for resort purposes. Because waters from the Steamboat Springs subarea tend to corrode pipes and deposit scale, attempts to use these waters for heating greenhouses and private homes generally have failed. However, some of the waters from the Moana Springs subarea are being used successfully to heat private homes and a motel. Future attempts to develop thermal waters in the Moana Springs subarea for heating therefore may be successful.

Exploratory wells have been drilled in the Steamboat Springs region in an attempt to develop a source of steam for generating electric power. The exploratory work is in a preliminary stage, and it is too early to determine whether steam can be recovered economically. Probably, sufficient heat is associated with the Steamboat Springs subarea to develop large amounts of steam, but it is not known whether there is sufficient recharge to the springs system to support steam wells large enough for the economic generation of electrical power.

FUTURE DEVELOPMENT

In the past decade, there has been increased urban and industrial development in the Truckee Meadows area. Industrial development has been concentrated mostly near the Truckee River, and urban development has occurred in the cities of Reno and Sparks and in the areas bordering the cities. Many areas formerly under cultivation are now homesites, and if the trend continues, the irrigated acreage will decline as urbanization expands. As a result, it is possible that ground-water recharge will decrease substantially; consequently, the problems associated with the high ground-water levels in the northeastern part of the Truckee Meadows area may be alleviated.

Increased pumping near the Truckee River, to supply more water for municipal and industrial use, probably will induce increased recharge from the river to the ground-water reservoir. Losses from the river, however, may be less than the amount of pumpage to the extent that increased pumping in discharge areas may help salvage ground water currently being evaporated or transpired.

At present, ground-water levels reach their maximum altitudes in the summer as a result of infiltration from surface water diverted for irrigation. Thus, during the summer, when the flow of the Truckee River is low, and, as a result, the amount of surface water available for municipal and other uses may be in short supply, ground-water levels are at or near their yearly peaks and evapotranspiration losses are greatest. Increased ground-water pumping, especially in the waterlogged northeastern part of the basin, could increase the amount of water available for municipal and industrial use and, at the same time, could both relieve the waterlogging problems and decrease water losses by evaporation and transpiration.

More detailed information will be needed to help define the relation between surface and ground water in the area. When this information becomes available, it is possible that methods can be developed to cause some of the floodwaters of the Truckee River to recharge the ground-water reservoir and, subsequently, to be diverted to wells.

The aforementioned methods of modifying the hydrologic regimen of the Truckee Meadows area are possible. However, any or all of these modifications probably can best be made as part of an integrated plan for the development of the surface-water and ground-water resources of the area.

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