Preliminary Results of Hydrogeologic Investigations in the Valley of the Humboldt River Near Winnemucca, Nevada

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1754

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

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By PHILIP COHEN

ABSTRACT

Most of the ground water of economic importance and nearly all the ground water closely associated with the flow of the Humboldt River in the 40-mile reach near Winnemucca, Nev., are in unconsolidated sedimentary deposits. These deposits range in age from Pliocene to Recent and range in character from coarse poorly sorted fanglomerate to lacustrine strata of clay, silt, sand, and gravel. The most permeable deposit consists of sand and gravel of Lake Lahontan age—the so-called medial gravel unit—which is underlain and overlain by fairly impermeable silt and clay also of Lake Lahontan age.

The ultimate source of nearly all the water in the study area is precipitation within the drainage basin of the Humboldt River. Much of this water reaches the study area as flow or underflow of the Humboldt River and as underflow from other valleys tributary to the study area. Little if any flow from the tributary streams in the study area usually reaches the Humboldt River. Most of the tributary streamflow within the study area evaporates or is transpired by vegetation, but a part percolates downward through unconsolidated deposits of the alluvial fans flanking the mountains and moves downgradient as ground-water underflow toward the Humboldt River.

Areas that contribute significant amounts of ground-water underflow to the valley of the Humboldt River within the study area are (1) the valley of the Humboldt River upstream from the study area, (2) the Pole Creek–Rock Creek area, (3) Paradise Valley, and (4) Grass Valley and the northwestern slope of the Sonoma Range. The total average underflow from these areas in the period 1949–61 was about 14,000–19,000 acre-feet per year. Much of this underflow discharged into the Humboldt River within the study area and constituted a large part of the base flow of the river.

Streamflow in the Humboldt River increases substantially in the early spring, principally because of runoff to the river in the reaches upstream from the study area. The resulting increase of the stage of the river causes the river to lose large amounts of water by infiltration to the ground-water reservoir in the study area. In addition, there is much recharge to the ground-water reservoir in the spring and early summer as a result of seepage losses from irrigation ditches and the downward percolation of some of the excess water applied for irrigation. The average net increase of ground water in storage in the deposits beneath and adjacent to the flood plain of the Humboldt River during the spring and early summer is about 10,000 acre-feet.

INTRODUCTION

LOCATION AND GENERAL FEATURES OF THE AREA

The present study is being made in a segment of the valley of the Humboldt River between U.S. Geological Survey stream-gaging stations at Comus (SE¼NE¼SE¼ sec. 14, T. 36 N., R. 41 E.) and near Rose Creek (NW¼SE¼NW¼ sec. 36, T. 35 N., R. 35 E.), Nev. These stations are about 22 miles east and 15 miles southwest of the city of Winnemucca, respectively. Winnemucca is the county seat of Humboldt County. The area described in this report is in north central Nevada. (See pl. 1.)

The Humboldt River flows approximately perpendicular to the regional northward trend of the mountain ranges in the study area. From east to west these mountain ranges include the Osgood Mountains, which border the east side of Paradise Valley; Edna Mountain, the southern extension of the Osgood Mountains; the Sonoma Range, which borders the east side of Grass Valley; Winnemucca Mountain, a southward extension of the Santa Rosa Range which borders the west side of Paradise Valley; and the East Range, which borders the west side of Grass Valley. The Osgood Mountains rise to an altitude of 8,678 feet at Adam Peak, about 11 miles north of the stream-gaging station at Comus; the Sonoma Range rises to an altitude of 9,395 feet at Sonoma Peak, about 10 miles southeast of Winnemucca; Winnemucca Mountain rises to an altitude of 6,203 feet; and the East Range rises to an altitude of 7,441 feet at Dun Glen Peak, about 7 miles southeast of the stream-gaging station near Rose Creek. The altitude of the Humboldt River is about 4,360 feet at the stream-gaging station at Comus, about 4,260 feet at Winnemucca, and about 4,200 feet at the stream-gaging station near Rose Creek. The maximum relief of the area, therefore, is about 5,000 feet.

The climate of the area is characterized by hot summers and cold winters. Temperatures commonly rise above 100°F in July and August and at times fall below 0°F in December and January. Extremes of more than 105°F and less than −30°F have been recorded at the Winnemucca weather station. Diurnal temperature fluctuations as great as 50° F are common. Precipitation is meager; it averages about 8 inches per year on the valley floor and probably reaches a maximum of about 24 inches per year on and near the highest peaks. Because precipitation on the valley floor is scanty, irrigation is usually necessary to sustain the growth of wild hay and alfalfa, the principal crops of the area.

Irrigated land is restricted almost entirely to the flood plain of the river. Although about 10–15 wells in this segment of the river are at times used to supply supplemental water for irrigation, more than 90 percent of the water for irrigation is diverted directly from the Humboldt River. The extent of irrigation changes markedly from year to year, as it is dependent on the availability of surface water.

Winnemucca was formerly the center of a large and prosperous mining industry. The principal ores recovered were those of gold, silver, tungsten, and mercury. As mining operations have now almost ceased, the present economy is largely dependent upon cattle raising and the tourist industry.

SCOPE OF THE INVESTIGATION AND PURPOSE AND SCOPE OF THE REPORT

The Humboldt River basin is one of the chief agricultural areas in Nevada. To plan for optimum development of the water resources of the basin, the Nevada Department of Conservation and Natural Resources initiated the Humboldt River Research Project. One of the major objectives of the research project is to evaluate the various components of the hydrologic cycle that are operative within the Humboldt River basin. Initial studies are being made in the segment of the basin described in this report. The U.S. Geological Survey and other Federal Agencies are cooperating with the Nevada Department of Conservation and Natural Resources to complete the project.

Investigations being made by the Ground Water Branch of the Geological Survey include studies of (1) seasonal and long-term changes of ground water in storage, (2) the relation between the Humboldt River and the ground-water reservoir, (3) ground-water underflow into and out of the study area, and (4) the chemical quality of the waters of the area.

Fieldwork, which includes sample and data collection and laboratory studies, is not yet completed. The water-quality phase of the program is in the earliest stages and will be discussed in a subsequent report.

This report on the preliminary results of the investigation (to June 1961) is prepared as an aid to other agencies cooperating in the project and those concerned with the hydrology of the study area. As one of the major objectives of the report is to evaluate the hydrogeologic environment of the study area, some of the geomorphic features of the area that are pertinent to an understanding of the origin of the water-bearing deposits are discussed. Because the

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Humboldt River is one of the principal features of the hydrologic environment, geomorphic features of the river are emphasized. The report includes a review of the lithology and water-bearing properties of the rocks of the area with emphasis on the water-bearing sedimentary deposits, especially the Lake Lahontan deposits. The distribution and physical properties of the Lake Lahontan deposits, especially the medial gravel (p. 20–23), are described in detail because a thorough understanding of the hydrogeology of these deposits is necessary to achieve the major objectives of the investigation.

A preliminary qualitative and quantitative appraisal of the hydrologic objectives of the investigation, other than the water-quality phase, also is given in the report.

PREVIOUS WORK

The geology of selected areas in Nevada, including part of the Humboldt River basin, was described by King (1878). I. C. Russell (1885) described some of the characteristics of the Lake Lahontan lacustrine deposits in the study area. The geology of the Winnemucca and Golconda quadrangles was mapped by Ferguson, Muller, and Roberts (1951) and Ferguson, Roberts, and Muller (1952), respectively, who concentrated their efforts on the geology of the consolidated rocks of the mountain ranges. C. R. Willden (1961) prepared a reconnaissance geologic map of Humboldt County, and Hotz and Willden (1961) prepared a preliminary geologic map of part of the Osgood Mountains. Loeltz, Phoenix, and Robinson studied the ground-water resources of Paradise Valley (1949).

ACKNOWLEDGMENTS

The writer is grateful for the cooperation of various local, State, and Federal agencies, private companies, and residents of the study area. Personnel of the Nevada Department of Conservation and Natural Resources were valuable coworkers. Their preliminary unpublished data on various aspects of the geology of the area helped in the preparation of this report. Some of the maps and aerial photographs used in the study were supplied by the Soil Conservation Service through the Nevada Department of Conservation and Natural Resources. The Southern Pacific and Western Pacific railroad companies permitted access to their properties and the Southern Pacific Co. provided topographic maps of their lands. Local property owners were most cooperative in permitting test borings and the installation of observation wells on their properties.

NUMBERING SYSTEM OF WELLS AND TEST BORINGS

A number assigned to a well or test boring in this report is an identification and location number. The number is based on the Mount Diablo base line and meridian of the General Land Office and 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 first two units by a dash, comprises the section number; three letters that designate the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section, respectively; and a number to show the order in which the well or test boring was recorded within the subdivision. The letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast quarters of each unit. For example, well number 35/36–15dba1 designates the first well or test boring recorded in the NE¼NW¼SE¼ sec. 15, T. 35 N., R. 36 E., Mount Diablo base line and meridian. Because of space limitation and because the number designating the order in which the well or test boring was recorded is 1 for each well or test boring shown on these maps, only that part of the number designating the subdivision of the section is shown on plates 2, 3, and 4. The section, township, and range numbers also are shown on these plates.

For clarity and because of space limitations on plates 2, 3, and 4, letter symbols are used to designate streamflow measuring stations. These letter symbols are identified in table 5.

METHODS OF INVESTIGATION

FIELD PROGRAM

Test holes were augered in the unconsolidated sedimentary deposits of the study area to evaluate the geology of the water-bearing deposits and to establish a network of observation wells.

Fieldwork began in September 1959. Shortly afterward, a power auger equipped to drill 4-inch-diameter holes about 100 feet deep was assigned to the project for about 7 weeks. A power auger again was assigned to the project for an additional 7 weeks in July 1960. At that time it was equipped to drill 8-inch-diameter holes in addition to 4-inch-diameter holes. The power-takeoff unit of the drilling rig rotates continuous-spiral-auger flights so that material from deposits penetrated by the auger is brought to the surface as the hole is deepened. Samples generally were collected at 2½-foot intervals for about the first 20 feet and at increasingly larger intervals at greater depths. Sample recovery ranged from excellent to poor, the quality depending mainly upon the texture and moisture content of the deposits and the depth of penetration. Sediments collected from a depth of about 50 feet or more were usually mixed and were not exactly representative of the materials penetrated by the drill. Where coarse sand or gravel was penetrated, samples recovered from depths below 10 feet were often poor.

Test holes were drilled at 175 sites during the drilling program in 1959–60, and the data relative to the program are summarized in table 1. The procedure generally followed at each drilling site was as follows. A pilot hole was drilled to a depth of about 5–10 feet below the water table (some test holes, however, were drilled to depths as much as 75 feet below the water table at sites of special geologic interest) and the recovered sediments were examined and described in detail at the time of collection. Calcium carbonate content, size distribution, roundness, sphericity, color, and other physical properties of the sediments were noted. The pilot hole was completed as an observation well, in most instances, by installing 1¼-inch-diameter plastic casing, the bottom 5 feet of which was perforated. A second hole then was drilled with the power auger to a depth of about 1 foot above the sediments to be sampled. A hand auger was used to complete the drilling to the desired sampling depth. Undisturbed samples then were collected by means of a Pomona core barrel. This equipment consists of a 2-inch-diameter by 4-inch-long core barrel containing two brass liners. The barrel was driven into the sediments by using a 25-pound slip hammer and extension rods. Upon recovery, the core in the upper brass liner was discarded to avoid the possibility of contamination due to material falling into the hole prior to and while inserting the core barrel. The lower brass liner then was capped and sealed with wax. This procedure was repeated until all the desired samples were collected at each drilling site. Generally, an attempt was made to sample all representative lithologic units within the zone of anticipated ground-water-level fluctuations. Where it was impractical or impossible to collect undisturbed core samples, disturbed samples were collected and repacked in the laboratory in an attempt to recreate their original texture. The packing machine used by the Hydrologic Laboratory supposedly repacks the material (especially if it is sand or gravel) to about its natural porosity and permeability.

The sample-collection program was modified somewhat in the summer of 1960. Geologists of the Nevada Department of Conservation and Natural Resources mapped the geology of the flood plain and collected 75 samples, mainly from the banks of the river.

Forty additional samples, as previously described, were collected by the Geological Survey.

In 1960, nine 8-inch-diameter test holes were drilled and equipped with 6-inch-diameter factory-perforated casings. Five of these wells were equipped with water-stage recorders. To help evaluate changes of ground water in storage, bimonthly water-level measurements at about 150 observation wells and bimonthly streamflow measurements are being made concurrently. (See pls. 2, 3, and 4 for location of observation wells and streamflow measuring stations.)

TABLE 1.—*Summary of test drilling in the valley of the Humboldt River near Winnemucca, Nev., 1959–60*

	1959	1960	Total
Number of test-boring sites	97	78	175
Observation wells completed	93	69	162
Number of feet drilled using power auger	2,870	3,620	6,490
Number of feet drilled using hand auger ... estimate	200	200	400
Length of casing installed ... feet	2,265	2,131	4,396
1¼-inch-diameter plastic ... do	2,265	1,660	3,925
1¼-inch-diameter steel ... do	0	127	127
2-inch-diameter steel ... do	0	167	167
6-inch-diameter steel ... do	0	177	177
Number of sediment samples collected for laboratory determination of specific yield and particle-size distribution	219	115	334

LABORATORY STUDIES

Laboratory studies consisted of determining the particle-size distribution and specific yield of the samples. The particle-size classification used by the Ground Water Branch of the Geological Survey is used in this report and is as follows:

Description	*Diameter* (mm)
Gravel	>2.0
Very coarse sand	1.0 –2.0
Coarse sand	.5 –1.0
Medium sand	.25 –0.5
Fine sand	.125 –0.25
Very fine sand	.0625–0.125
Silt	.004 –0.0625
Clay	<0.004

The specific yield of a rock or sediment sample was defined by Meinzer (1923, p. 28) as "* * * the ratio of (1) the volume of water which, after being saturated, it will yield by gravity to (2) its own volume." Another definition of specific yield and one that is more applicable to the laboratory procedure is: specific yield is the porosity (the percentage of the total volume of the rock or sediment sample occupied by interstices) minus the specific retention. Meinzer (1923, p. 28) defined the specific retention of a rock or sediment sample as "* * * the ratio of (1) the volume of water which, after being saturated, it will retain against the pull of gravity to (2) its own volume."

Specific yield was determined in the laboratory by the centrifuge-moisture-equivalent method. First, porosity was determined in the laboratory. Then, the centrifuge moisture equivalent was determined. The ratio of the volume of water retained by the sample to the total volume of the sample, multiplied by 100, is the centrifuge moisture equivalent expressed in percent. Centrifuge moisture equivalent then was converted to specific retention based upon data given by Piper and others (1939, p. 19). Finally, specific yield was calculated by subtracting specific retention from porosity. A summary of the specific-yield data are given in table 9. These data are discussed briefly in a previous report (Cohen, 1961).

GEOLOGY

GEOMORPHIC FEATURES

The valley of the Humboldt River is within the Great Basin section of the Basin and Range physiographic province. The Great Basin is a broad high plateau characterized by roughly north-trending mountain ranges and intervening valleys. The crests of some of the ranges attain altitudes higher than 10,000 feet, but most are not more than 9,000 feet high. The altitudes of the valleys commonly range from somewhat less than 4,000 feet to more than 6,000 feet. This section of the province is called the Great Basin because it is a closed hydrologic unit in which all the water originates as precipitation and is either stored within the basin or is discharged by evapotranspiration. Practically none of the water within the Great Basin discharges into the ocean.

MOUNTAINS

The mountains bordering the valley of the Humboldt River are deeply dissected complex, fault-block mountains composed of igneous, metamorphic, and sedimentary rocks. Complex internal folding and thrust faulting probably had little control on the present height and form of the mountains. Rather, the present topographic relief of the mountains is due principally to uplift and gentle warping associated with normal faults. However, internal structure and lithology, volcanism, and sedimentation were significant factors in the formation of the present land forms.

The shapes of the western and eastern slopes of the ranges are generally similar, but the western slopes commonly are somewhat steeper. The steeper western slopes commonly are eroded fault planes, and the gentle-back slopes are a modification of the topography before faulting.

UPLAND EROSIONAL SURFACES AND ALLUVIAL FANS

Alluvial fans and pediments cut on unconsolidated and partly consolidated sedimentary deposits border the ranges of the study area. In addition, remnants of older alluvial fans and remnants of pediments formed on indurated rock occur within the ranges. The character and extent of the four alluvial-fan units shown on plate 2 are based partly upon unpublished notes and maps prepared by W. E. Wilson and J. W. Hawley of the Nevada Department of Conservation and Natural Resources and partly upon the work of Ferguson, Muller, and Roberts (1951), and Ferguson, Roberts, and Muller (1952).

Three main planar erosional surfaces have been cut in the mountain areas according to Ferguson, Muller, and Roberts (1951). The highest erosional surface, cut on chert and slate, is of comparatively low relief and occurs as isolated remnants in the Sonoma Range at altitudes ranging from about 8,000 to 8,500 feet. Low rounded ridges of quartzite protrude above this surface. Remnants of a lower erosional surface are at an altitude of about 6,500–7,000 feet on the western slope of the Sonoma Range between Thomas and Sonoma Canyons. A moderately extensive gravel-covered bench whose upper edge is at an altitude of about 5,400 feet and whose lower edge is at an altitude of about 4,600 feet flanks the northwestern slope of the Sonoma Range. Remnants of the surface at 6,500–7,000 feet also occur in the East Range near Dun Glen Peak, and remnants of the gravel bench (4,600–5,400 ft) are near the northwestern slope of the East Range.

Similar surfaces also occur in adjacent areas, and Ferguson, Roberts, and Muller (1952) infer that these geomorphic features indicate broad regional uplift of extensive subdued surfaces. The surfaces at successively higher altitudes presumably represent stages in the uplift of the mountain ranges.

PHYSIOGRAPHIC FEATURES FORMED BY LAKE LAHONTAN

Lake Lahontan, a large deep lake of late Pleistocene age, inundate many valleys in western and central Nevada. Russell (1885) chose a major period of inundation to define the beginning of Lake Lahontan and a major period of desiccation to define its termination. In addition, he chose an altitude of about 4,400 feet as the highest level of the lake. Other lakes exsting at the time, whose maximum altitudes were above about 4,400 feet, were excluded from Lake Lahontan by Russell.

Lake Lahontan covered much of the lowlands of the present study area. The history of the lake is recorded in the sediments deposited within and near the shore of the lake and in physiographic shoreline features. The character of the sediments associated with Lake Lahontan—referred to as Lake Lahontan deposits, or more simply, Lahontan deposits—is discussed in the section, "Lake Lahontan deposits."

Lake Lahontan can be described by its erosional and depositional features. The erosional features were formed by wave action and include wave-cut nicks or scarps and wave-cut benches. These features commonly can be identified in the field, but they are more readily visible as distinct lineaments as viewed from the air or on aerial photographs. Wave-cut benches commonly have been obscured by erosion and sedimentation; thus these features are not shown on plate 2. However, the more prominent wave-cut scarps, are shown. Two scarps, each about 1 mile long and at an altitude of about 4,400 feet, have been cut in the unconsolidated alluvial deposits along the northwestern slope of the Sonoma Range. This is the only place within the study area where, to date, scarps probably associated with Lake Lahontan have been observed at this altitude. The rest of the prominent wave-cut scarps also are cut in unconsolidated alluvial deposits but are at altitudes of about 4,360 feet. The most prominent scarps at this altitude are about 7 miles northwest of the Krum Hills, along the northwestern and northeastern slopes of the East Range, along the eastern slope of Winnemucca Mountain, and along the northwestern and northern slopes of the Sonoma Range.

Depositional physiographic features formed by Lake Lahontan include beaches and bars. The beaches are not well preserved, but isolated remnants still exist as thin deposits of sand or sand and gravel atop some of the wave-cut benches. The largest exposed gravel bar, which is about 3 miles long and as much as a quarter of a mile wide, is along the west bank of the Little Humboldt River. Other gravel bars are exposed chiefly as a result of excavating. Most of the bars shown on plate 2 are composed of gravel in a sandy matrix.

Another prominent depositional physiographic feature associated with Lake Lahontan is the upper terrace which extends eastward from the west edge of the study area to within about 1 mile of the town of Golconda. This flat terrace surface, except as it has been modified by wind and stream action, represents the floor of Lake Lahontan. The upper terrace has a gradient of about 4 feet per mile to the northwest near the mouth of Grass Valley but is almost horizontal near the mouth of Paradise Valley.

STREAMS AND ASSOCIATED GEOMORPHIC FORMS

HUMBOLDT RIVER

The principal stream in the area is the Humboldt River. The following is a discussion of geographic and physiographic features of the river and its valley. Its hydrologic character is discussed later in the text.

The Humboldt River is one of the longest rivers in North America that does not discharge into the ocean. It heads near the east border of Nevada and flows westward for about 200 miles before entering the study area. (See pl. 1.) It then flows westward for about another 40 miles before discharging into Rye Patch Reservoir. Before the construction of the reservoir, it flowed southwestward from the reservoir site for another 17 miles to the Humboldt Sink, from which the water evaporated. During periods of unusually high runoff, water sometimes overflowed the Humboldt Sink southwestward into the Carson Sink, from which the water eventually evaporated. Since construction of the Rye Patch Reservoir, the Humboldt River rarely discharges into the Humboldt Sink. Almost all the water that flows to the sink is excess irrigation water applied to farm lands below the reservoir.

The course of the Humboldt River in the present study area is transverse to the northward-trending regional structure. The river is assumedly an antecedent stream in the study area (Ferguson, Muller, and Roberts, 1951). Lobeck (1939, p. 173) defined an antecedent stream as "* * * one which has maintained its course across an uplift which it antedates." Thus, an antecedent stream is a stream that erodes its channel about as rapidly as the mountain range is uplifted. Such a history possibly explains how the Humboldt River cut the bedrock gorge at Emigrant Canyon.

At least four flat surfaces or terraces border the channel of the Humboldt River at successively higher altitudes. The highest terrace surface, known as the upper terrace, is discussed on page 10. In descending order, the others are: The middle terrace, a river-cut bench; the lower terrace, also a river-cut bench; and the meander-scroll plain, which is the present flood plain of the river. The four terraces are illustrated on the geologic map (pl. 2), and three of the terraces are shown on the geologic section. Because the principal objective of the geologic map is to show the areal distribution of the unconsolidated sedimentary deposits of the area, each terrace is designated by symbols that refer to the deposits underlying it.

A nearly flat surface is adjacent to, and topographically higher than, the meander-scroll plain in secs. 4 and 25, T. 35 N., R. 35 E., and secs. 15–20, T. 35 N., R. 36 E. This surface probably is a river-

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cut terrace, but its precise relationship to the meander-scroll plain and the lower and middle terraces is unknown because it is covered by dune sand.

Nearly vertical scarps form the boundaries between the upper and lower terraces. These scarps extend along both sides of the meander-scroll plain from the west edge of the study area eastward to about the vicinity of the town of Golconda. The middle terrace is best formed in the reach of the Humboldt River between Winnemucca and Golconda, and the lower terrace is best formed downstream from Winnemucca. Only two small remnants of the middle terrace occur downstream from Winnemucca, and each has an areal extent of less than 1 square mile. The remainder of the middle terrace downstream from Winnemucca has been removed by erosion.

Locally the lower terrace has been completely removed by erosion, as along the southeast edge of the meander-scroll plain near the west margin of the study area, where a nearly vertical scarp about 50 feet high separates the meander-scroll plain from the upper terrace. A remnant of the lower terrace still exists along the south margin of the meander-scroll plain about 2½ miles upstream from the west margin of the study area. Here, a scarp about 15–20 feet high separates the meander-scroll plain from the lower terrace, and another scarp about 30–35 feet high separates the lower and upper terraces.

Beds of partly consolidated sedimentary deposits of Tertiary age (probably of Miocene or Pliocene age) underlie an area of about 3–4 square miles at the north end of the Sonoma Range and are exposed beneath the northwest edge of the basalt flow northeast of the point of confluence of the Little Humboldt and Humboldt Rivers. They consist of conglomerate, sandstone, and siltstone and contain lesser amounts of limestone, marl, and tuff. They generally are dense and do not store or transmit appreciable amounts of water.

Although the gradients of the lower and middle terraces vary, they average about 3–4 feet per mile downstream, about the same as the gradient of the meander-scroll plain and the river itself. As the upper terrace commonly has a gentler gradient, the height of the scarps between the upper and lower terraces becomes progressively less upstream until, in the vicinity of Golconda, the scarps no longer exist. When only the relative altitudes and the almost identical gradients of the terrace surfaces are considered, remnants of the lower terrace should extend farther upstream than remnants of the middle terrace. However, the lower terrace extends upstream only to about the vicinity of Winnemucca, whereas the middle terrace is best preserved between Winnemucca and Golconda.

The meander-scroll plain, or the flood plain of the Humboldt River, is the surface that periodically is covered by floodwaters. In this report the meander-scroll plain is considered as a single geomorphic and lithologic unit. The Humboldt River is a meandering stream characterized by meander loops of the present river channel and meander scrolls of abandoned channels of the river. The width of the meander belt of the present channel ranges from about one-half the width of the meander scroll plain, as in sec. 15, T. 35 N., R. 36 E., to less than one-eighth the width of the meander scroll plain, as in sec. 12, T. 36 N., R. 39 E.

The meander-scroll plain also is characterized by nearly straight channels or depressions that carry water only during periods of flood. These features probably are drainage channels created and maintained by floodflows.

The depth of meander scrolls and floodflow channels varies according to the time of formation. Some are about as deep as the present channel of the river (6–15 ft), whereas others are very slight depressions visible only on aerial photographs. Eolian and overbank deposits partly fill some of these depressions.

LITTLE HUMBOLDT RIVER

The Little Humboldt River, on the basis of its drainage area of about 1,500 square miles, is the principal tributary of the Humboldt River in the present study area, although it rarely discharges into the Humboldt River. Its north fork heads in the Santa Rosa Range about 50 miles north of Winnemucca, and its south fork heads in an unnamed mountain range north of the Osgood Mountains about 70 miles northeast of Winnemucca. (See pl. 1.) The river drains Paradise Valley and is a tributary to a secondary channel of the Humboldt River in sec. 34, T. 37 N., R. 38 E. The channel of the Little Humboldt River is poorly defined at and near its junction with the Humboldt River.

In the mountain ranges the Little Humboldt River is a perennial stream, but on the floor of Paradise Valley it is an ephemeral stream. It displays many of the characteristics of a youthful stream at its headwaters where its gradient is steep and rapids are common. Farther downstream, on the floor of Paradise Valley, it is a sluggish meandering stream; and near its junction with the Humboldt River, its gradient is about 4 feet per mile. An east trending actively moving belt of sand dunes, in places more than 1 mile wide, periodically blocks the course of the Little Humboldt River in a reach about 5 miles north of its confluence with the Humboldt River.

An areally extensive shallow lake forms when the dunes block the river channel. The lake, locally referred to as Gumboot Lake, is ephemeral. The rate of flow of the Little Humboldt River and the extent to which the dunes block the channel mainly determine the existence and extent of the lake. Ranchers periodically clear the channel when it is blocked by dunes.

SMALL TRIBUTARY STREAMS

Many small streams within the study area are tributaries to the Humboldt River valley. Rose Creek is the principal stream that heads in the East Range, and Clear Creek is the principal stream that drains the floor of Grass Valley. Beyond where Rose and Clear Creeks merge in sec. 24, T. 35 N., R. 36 E., the combined channel trends northwestward onto the meander-scroll plain but rarely carries water below the point of confluence of the two streams. A pronounced channel through the upper terrace is evidence that the combined discharge of the two streams was probably much greater in the geologic past. The gradient of the channel flattens abruptly where the channel opens onto the meander-scroll plain, and, at this point, a small but distinct alluvial fan has been formed. (See pl. 2.)

The principal streams that drain the part of the Sonoma Range shown on plate 2 are, from south to north; the streams in Mullen and Dry Canyons, Thomas Creek, the streams in Water and Harmony Canyons, Pole Creek, and Rock Creek. Most of these streams are perennial in their upper reaches and ephemeral in their lower reaches, but their discharges rarely reach the Humboldt River, even during the spring runoff. The discharge of Water Canyon is used as part of the Winnemucca municipal supply, and the discharge of some of the other streams are diverted for irrigation.

Many other small streams, mostly unnamed, drain the mountains bordering the study area. Most are ephemeral in their upper reaches, and all are ephemeral in their lower reaches. They rarely, if ever, discharge directly into the Humboldt River.

Except for the Humboldt and Little Humboldt Rivers, Kelly Creek is the longest stream within the study area. It heads on an unnamed mountain range east of the Osgood Mountains and flows southwestward for about 25 miles before joining the Humboldt River at a point about 1 mile downstream from the gaging station at Comus. It is ephemeral in its lower reaches and rarely discharges directly into the Humboldt River.

The streams mentioned have a number of physiographic features in common. All head fairly high in the mountain ranges, where they have steep gradients. They are commonly consequent upon either the steep frontal slopes or the gentler dip slopes of the fault-block mountains. In detail, however, the channels of most of the streams have adjusted to local structural and lithologic control. The gradients of the streams are abruptly flatter below the contact between the indurated rocks of the mountain ranges and the unconsolidated deposits of the alluvial aprons bordering the ranges. Changes in climate, tectonic activity, or a combination of both factors have caused moderate rejuvenation of these streams as evidenced by fan-head trenches.

LITHOLOGY AND WATER-BEARING CHARACTER OF THE ROCKS

The rocks of the area range in age from Paleozoic to Cenozoic. The strata of Paleozoic and Mesozoic age comprise consolidated sedimentary, igneous, and metamorphic rocks. Some of the rocks of Cenozoic age also are of igneous origin, but most of them are unconsolidated sedimentary deposits.

CONSOLIDATED ROCKS

ROCKS OF PALEOZOIC AND MESOZOIC AGE

Locally, the Paleozoic and Mesozoic rocks might yield small amounts of water from fractures or solution channels. However, most of these rocks probably are barriers to the movement of water, and their principal significance in this area is that they are partly the source of the materials in the water-bearing sedimentary deposits of Cenozoic age. The rocks of Paleozoic and Mesozoic age are described briefly in table 2, and their areal distribution is shown on plate 2.

ROCKS OF CENOZOIC AGE

The most widespread rocks of the Tertiary System are rhyolitic lava and associated tuff, andesite, and lesser amounts of associated intrusive rocks. They are not distinguished separately on the geologic map (pl. 2), because their water-bearing properties are similar to the water-bearing properties of the older Paleozoic and Mesozoic rocks. They are most widely distributed in the Sonoma Range within the mapped area shown on plate 2. Here, the lava flows are at least 1,000 feet thick and fill topographic depressions that existed in the underlying Paleozoic rocks.

ROCKS OF LATE TERTIARY AND QUATERNARY AGE

Basalt flows of Pliocene or Pleistocene age, or both, occur in scattered localities throughout the study area. These flows are less deformed than the older rocks. In most areas they are broken by normal faults, commonly dip valleyward at angles ranging from about 10° to 20°, and form distinct topographic forms known as flatirons or louderbacks. The most prominent louderbacks are in the Krum Hills, near the point of confluence of the Little Humboldt and Humboldt Rivers, and south of the Humboldt River near the stream-gaging station at Comus.

TABLE 2.—*Lithology and distribution of the rocks of Paleozoic and Mesozoic age in and near the valley of the Humboldt River, near Winnemucca, Nev.*

[Modified after Ferguson, Muller, and Roberts (1951) and Ferguson, Roberts, and Muller (1952)]

	Age	Formation name	Lithology	Distribution	Remarks
Mesozoic	Jurassic(?)	Unnamed	Granite, granodiorite, quartz monzonite and diorite.	East Range, Sonoma Range, Santa Rosa Range, and Edna Mountain.	Thickness ranges from a few to several thousand ft.
	Late Triassic	Raspberry Formation	Slate, locally phyllitic; limestone and quartzite lenses locally abundant.	East Range and Krum Hills.	Thickness, approximately 3,000 ft.
		Winnemucca Formation	Shale and sandstone, some limestone and dolomite; locally slate and quartzite present in upper part.	East Range, Sonoma Range Winnemucca Mountain, and Krum Hills.	Maximum thickness, 3,000 ft.
		Dun Glen Formation	Massive dolomite with interbedded limestone and shale in lower 100 ft.	East Range and Sonoma.	Maximum thickness, about 1,200 ft.
		Grass Valley Formation	Slaty shale with interbedded quartzite; limestone lenses near top.	East Range and Sonoma Range.	Thickness may exceed 2,000 ft.
	Middle and Late Triassic	Natchez Pass Formation	Massive dolomite and limestone; contains interbedded basic lava flows, breccias, and pebble conglomerates.	East Range and Sonoma Range.	Maximum thickness, about 1,700 ft in East Range and about 1,000 ft in Sonoma Range.
Paleozoic	Permian and Early Triassic	Koipato Formation	Rhyolite and trachyte flows, breccias and tuffs, some andesite, small amounts of conglomerate, sandstone and tuffaceous slate.	East Range and Sonoma Range.	Maximum thickness, at least 4,500 ft.
	Permian	Tallman Fanglomerate	Large blocks of quartzite and chert, thin beds of chert pebbles.	Local deposit only present at mouth of Thomas Canyon, Sonoma Range.	Thickness uncertain; may be 2,000–5,000 ft.
		Edna Mountain Formation	Sandstone, quartzite and slate containing a few beds of limestone.	Sonoma Range and Edna Mountain.	Maximum thickness, about 250–300 ft. Contains brachiopods of Permian age.

TABLE 2.—*Lithology and distribution of the rocks of Paleozoic and Mesozoic age in and near the valley of the Humboldt River, near Winnemucca, Nev.*—Con.

Age			Formation name	Lithology	Distribution	Remarks
Paleozoic		Pennsylvanian and Permian	Havallah Formation	Mostly quartzite with some chert, limestone, slate, greenstone, graywacke, conglomerate and grit.	East Range and Sonoma Range.	
Paleozoic	Carboniferous	Late Pennsylvanian and Permian	Antler Peak Limestone	Massive to thin-bedded limestone. Local sandy and pebbly layers. Shaly beds in upper part.	Edna Mountain and Osgood Mountains.	Maximum thickness, about 200 ft. Fossils indicate rocks are Late Pennsylvanian to Early Permian in age.
Paleozoic	Carboniferous	Middle Pennsylvanian	Highway Limestone	Massive light-gray limestone. Cherty near base; pebbly and sandy layers common.	Edna Mountain	Maximum thickness, 200 ft. Thins westward. Contains fossils of Middle Pennsylvanian age.
Paleozoic	Carboniferous	Mississippian(?)	Inskip Formation	Mostly quartzite, slate and limestone; some graywacke and conglomerate.	East Range	Maximum thickness, about 9,000 ft.
Paleozoic		Early, Middle and Late Ordovician	Valmy Formation	Quartzite, chert, and siliceous slate; some argillite and greenstone.	Sonoma Range	Maximum thickness, about 2,000 ft. Contains *Climacograptus*.
Paleozoic		Ordovician(?)	Sonoma Range Formation	Chert, siliceous argillite, slate, limestone, and a little quartzite.	Sonoma Range	Maximum thickness, about 3,000 ft. Unfossiliferous.
Paleozoic		Early and Middle Ordovician	Comus Formation	Chert, siliceous slate, and minor amounts of limestone and quartzite.	Osgood Mountains and eastern slope of Edna Mountain.	Thickness uncertain; may be about 3,000 ft. Contains *Tetragraptus*.
Paleozoic		Late Cambrian	Harmony Formation	Sandstones and grits, feldspathic and micaceous; some argillite.	Sonoma Range	Maximum thickness, about 5,000 ft. Contains no fossils.

TABLE 2.—*Lithology and distribution of the rocks of Paleozoic and Mesozoic age in and near the valley of the Humboldt River, near Winnemucca, Nev.*—Con.

	Age	Formation name	Lithology	Distribution	Remarks
Paleozoic	Middle and Late Cambrian	Preble Formation	Slate, phyllite, and mica schist; limestone lenses in lower part with quartzite near base.	Osgood Mountains, eastern slope of Sonoma Range and north end of Edna Mountain (in Emigrant Canyon).	Maximum thickness, about 12,000 ft. Contains *Lingula*.
	Early Cambrian(?)	Osgood Mountain Quartzite	Massive, light brown quartzite, commonly fine-grained, locally crossbedded.	Osgood Mountains and eastern slope of the Sonoma Range.	Base not exposed; probably about 5,000 ft thick. Contains no fossils; age uncertain.

The water-bearing properties of the basalt flows are not well-known. Water-level contours (pl. 3) appear to indicate that the flows block the movement of ground-water; however, at least locally, the basalt flows may be permeable. An irrigation well and the well used to supply part of the Winnemucca municipal supply reportedly tap volcanic rocks, probably basalt. (These wells are not shown on pls. 2, 3, and 4 because these figures show only the location of test borings and observation wells established as a result of the test-drilling program and the location of one irrigation well in Grass Valley.)

UNCONSOLIDATED ROCKS

PRE-LAKE LAHONTAN DEPOSITS

The pre-Lake Lahontan deposits shown on plate 2 include the units designated "older fanglomerate," "medial fanglomerate," and "undifferentiated fanglomerate." The older fanglomerate is exposed along the northwestern slope of the Sonoma Range and is of Pliocene and (or) Pleistocene age. This deposit consists of coarse partially consolidated poorly sorted fanglomerate which contains boulders as large as 10 feet in diameter in a matrix of sand and silt; clay-size particles and clay minerals are not common in the matrix. Cementation is common and locally is pronounced. For example, a bed of caliche (lime-cemented fanglomerate), which probably is part of a soil profile, occurs at depths ranging from about 10 to 20 inches below land surface.

The medial fanglomerate consists of alluvial-fan deposits that also are of Pliocene or Pleistocene age but which are probably younger than those of the previously described alluvial unit. These deposits are coarse unconsolidated poorly sorted fanglomerate containing boulders 4–5 feet in diameter in a matrix of sand and silt.

The undifferentiated fanglomerate consists of alluvial-fan deposits that are younger than the medial fanglomerate and older than the deposits of Lake Lahontan age. Deposits of alluvial fans that are covered by sand dunes and alluvial fans that have not yet been studied in detail are included in this unit mainly because of topographic position and geomorphic expression.

Many of the alluvial-fan deposits contain about 15–25 inches of silt at and just below the surface. This silt overlies poorly sorted unconsolidated fanglomerate. As is characteristic of the older alluvial-fan deposits, the matrix of the fanglomerate consists of silt and sand and contains little or no clay. A fossil soil, probably indicative of a pluvial period perhaps during Lake Lahontan time, has been recognized on several of these alluvial fans at depths ranging from about 15–50 inches below land surface. Commonly, the upper 10–25 inches of these alluvial fans has been leached of carbonate.

The permeability all of the alluvial-fan deposits varies considerably, not only from fan to fan, but within the fans themselves. Part of the variability is due to different degrees of cementation, and part is due to differences in texture of the deposits. Generally, the younger alluvial fans tend to be less cemented than the older alluvial fans. Lenses or stringers of permeable sand, or sand and gravel, commonly enclosed within less permeable silt and silty sand, are the main cause of the wide range in permeability of individual fans.

LAKE LAHONTAN DEPOSITS

Lake Lahontan deposits comprise five major hydrogeologic units within the study area: the lower silt and clay unit, a unit termed "alluvium," the medial gravel unit, the upper silt and clay unit, and a unit termed "gravel-bar deposits." The lower silt and clay, the medial gravel, and the upper silt and clay correspond to the lower lacustral clays, medial gravels, and upper lacustral clays described by Russell (1885, p. 125), who stated, "* * * wherever any considerable section of Lahontan sediments is exposed these three divisions appear in unvarying sequence." The remaining two units are gravel-bar and alluvial deposits interbedded with the lacustrine deposits. The relations between these units are described in the following text and are shown on plate 2.

LOWER SILT AND CLAY UNIT

The oldest of the five lithologic units of Lake Lahontan age, the lower silt and clay unit, was penetrated in well 34/37–3ddc1 between about 95 and 110 feet below land surface and probably in test boring 35/37–28ada1 between about 80 and 105 feet below land surface. (See pl. 2.) None of the other test borings penetrated this unit with certainty; therefore, only a few details are known about its character and extent within the study area. Well 34/37–3ddc1 was drilled using a cable-tool drilling rig which enabled examination of fairly large pieces of the unit. Briefly, the lower silt and clay unit penetrated in the well consists of dense blocky clayey silt containing ostracodes. It is identical with the upper silt and clay unit. (See page 23.) Russell 1885, p. 127–128) recognized the similarity between these two units in other parts of Nevada and states,

A comparison of the upper and lower clays indicates that they are very similar in their nature and were probably accumulated under nearly identical conditions; they are both evenly laminated, fine-grained, drab-colored clays, that are unusually marly and saline, and frequently exhibit a well-marked jointed structure.

The areal extent of the lower silt and clay unit is unknown, but, based upon the work of Russell (1885), it assumedly underlies much of that part of the study area covered by the upper silt and clay unit.

As the lower silt and clay unit is nearly impermeable and probably has a low specific yield, it is insignificant as an economic source of ground water. Where it overlies permeable alluvial-fan deposits or other permeable deposits, it locally is a confining layer that holds water under artesian pressure in the underlying strata.

ALLUVIUM

The alluvial deposits of Lake Lahontan age interfinger with the lower silt and clay and with the medial gravel units. These alluvial deposits are not exposed at the surface but were penetrated during the test-drilling program. They are made up of moderately to poorly sorted materials ranging in size from clay to gravel that were deposited near the margins of Lake Lahontan and within the area formerly occupied by the lake during periods of desiccation.

MEDIAL GRAVEL UNIT

In this report, the term "medial gravel" is virtually synonymous with Russell's "medial gravels." It designates a thick mass of sand and gravel that generally overlies the lower silt and clay unit and is overlain by the upper silt and clay unit. The areal distribution and thickness of this deposit is not precisely known. Test borings, however, show that it underlies the flood plain of the Humboldt River from the southwest edge of the study area upstream to at least the vicinity of Golconda and perhaps to the east border of the study area. The top of the gravel commonly was found at depths ranging from about 10 to 15 feet below land surface in test borings in the meander-scroll plain, from less than 1 foot to about 10 feet below land surface on the lower and middle terraces, and from about 50 to 60 feet below land surface on the upper terrace. The deeper test borings on the meander-scroll plain and on the lower and middle terraces penetrated a maximum of about 100 feet of this unit. Although its total thickness beneath the present channel of the Humboldt River is unknown, the section on plate 2 suggests that it probably does attain its maximum thickness in this locale. The shape of the mass of sand and gravel as shown on plate 2, suggests that these strata were deposited in, and filled, a wide deep pre-Lake Lahontan valley of the Humboldt River. The gravel thins rapidly northward and southward from the filled valley. (See pl. 2.)

The medial gravel unit consists of well-sorted sand and gravel. Pebbles range in size from about 2 to 16 mm (very fine to medium gravel) but commonly are less than 10 mm in maximum diameter. Most are subangular to subrounded and tend to be tabular or bladed. Much of the unit is nearly free of sand. A sample of medial gravel collected from a depth of about 40 feet below land surface from test boring 35/36–15dac1, evidences the sand-free nature of some of the gravel (fig. 1). Although the sample was not washed before being photographed and some sand may have been washed away as the sample was rotated by the drill, the gravel shown in figure 1 completely lacks sand particles. This sample is typical of most of the medial gravel penetrated during the test drilling.

In figure 2, pebbles of the same sample are separated by roundness into two groups. The pebbles on the left side of the photograph probably represent a beach deposit because they are rounded to subrounded and tend to be tabular or bladed. If this conclusion is true, much of the medial gravel was deposited along lake beaches. On the right side of the photograph, the pebbles are angular to subangular and are also probably part of a beach deposit. Most of the angular pebbles are fragments of dense black chert, which is extremely resistant to abrasion. Thus, the difference in shape of the pebbles probably indicates differences in mineralogy rather than in mode of deposition or distance of transportation. The widespread occurrence of the gravel indicates that it was deposited along rapidly transgressing and regressing shorelines.

A different facies of the medial gravel is shown in figure 3. The sample in figure 3 was collected from a depth of about 20 feet below land surface from test boring 35/36–15ddb1. The particles shown in the photograph range in size from medium sand to medium gravel. This material commonly is interbedded with the very "clean" gravel described previously. The medial gravel also changes facies laterally in the study area as it grades from gravel or sand and

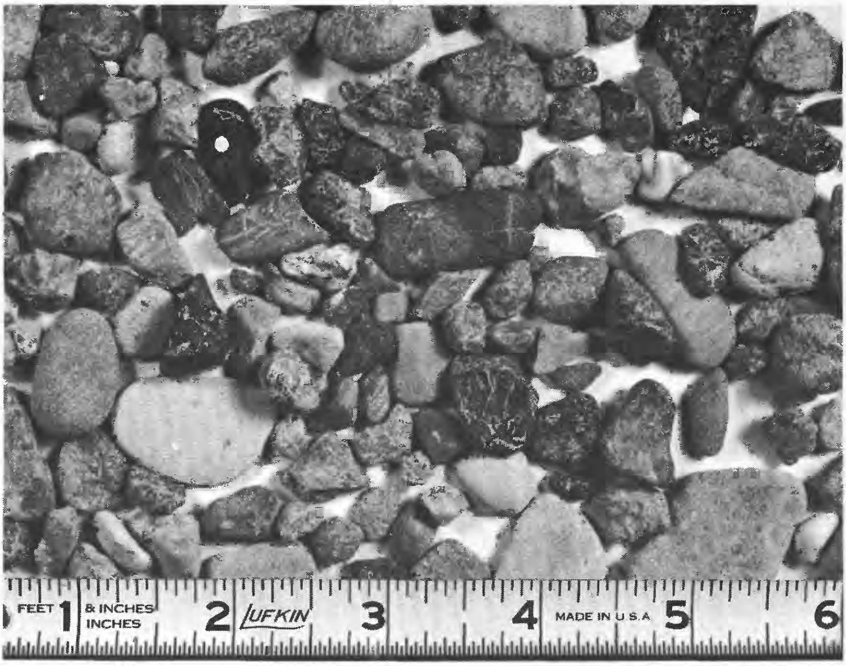

FIGURE 1.—Medial gravel collected from test boring 35/36–15dac1. Sample was collected from a depth of about 40 feet below land surface and was not washed before being photographed. Photograph by D. C. Clendenon.

gravel in the upstream reach to fine to medium sand near the gaging station close to Rose Creek.

The medial gravel probably is the most permeable unit penetrated during the test-drilling program. The coefficient of permeability of the gravel facies of the medial gravel, based partly upon short-term pumping tests, is estimated as about 2,000 gpd per ft ^{2} (gallons per day per square foot). (The coefficient of permeability is defined as the rate of water flow, in gallons per day, through a cross-sectional area of 1 square foot of aquifer under a hydraulic gradient of 1 foot per foot at a temperature of 60°F.) The coefficient of permeability multiplied by 100 (the minimum thickness, in feet, of the gravel along the axis of the valley of the Humboldt River) gives a conservative estimate of 200,000 gpd per ft (gallons per day per foot) for the average coefficient of transmissibility of the gravel. (See p. 44 for definition of coefficient of transmissibility.) This is probably a conservative estimate because, according to drillers' logs, the gravel may locally be about 150 feet thick, and the average coefficient of permeability may be as high as 5,000 gpd per ft ^{2}. Therefore, the coefficient of transmissibility locally could possibly be about 750,000 gpd per ft.

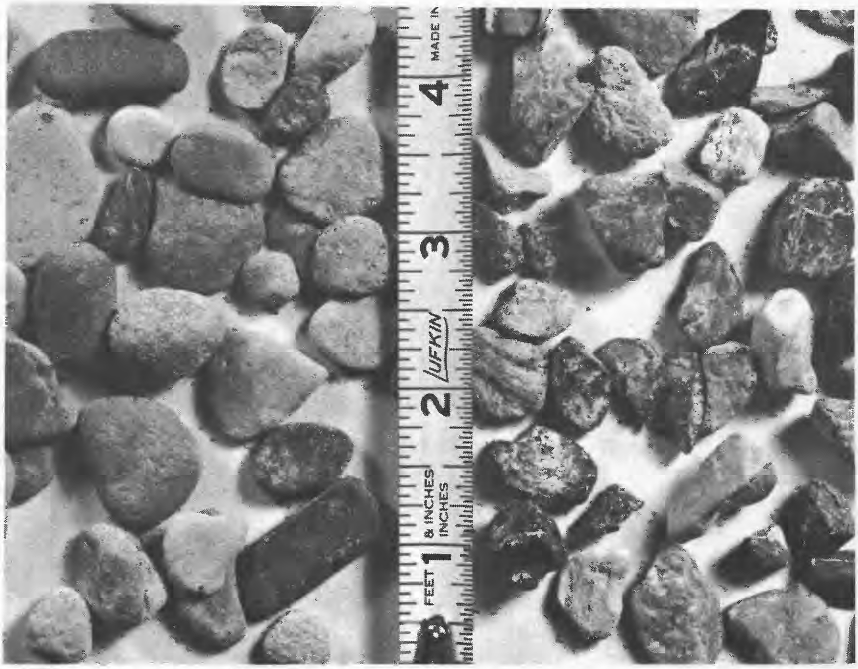

FIGURE 2.—Medial gravel collected from test boring 35/36–15dac1; sorted according to degree of roundness. Pebbles at left are rounded to subrounded. Pebbles at right are angular to subangular. Photograph by D. C. Clendenon.

UPPER SILT AND CLAY UNIT

The most widely exposed lithologic unit of Lake Lahontan age is the upper silt and clay unit. This unit underlies the upper terrace and is exposed in the river-cut scarps bordering the flood plain of the Humboldt River. Figure 4 is a diagram showing the character of the strata exposed along a river-cut scarp in the SE¼SE¼SW¼ sec. 7, T. 35 N., R. 37 E. Most of the beds illustrated in the diagram can be traced downstream to the southwest edge of the study area and upstream almost to the city of Winnemucca.

The upper silt and clay unit can be subdivided into two facies—a silty clay facies and a silt and fine-sand facies. Although this subdivision is not shown on plate 2, it is useful for describing the general character of the unit. The geologic section shown in figure 4 contains sandy beds but is generally typical of the silty clay facies of the unit. The clayey beds were deposited in the quiet deep waters of Lake Lahontan, and the silty and sandy beds were deposited closer to the shores of the lake. The abrupt vertical change in character of the deposit as illustrated in figure 4, represents rapid changes in the levels of the lake. The differences in depositional environment also

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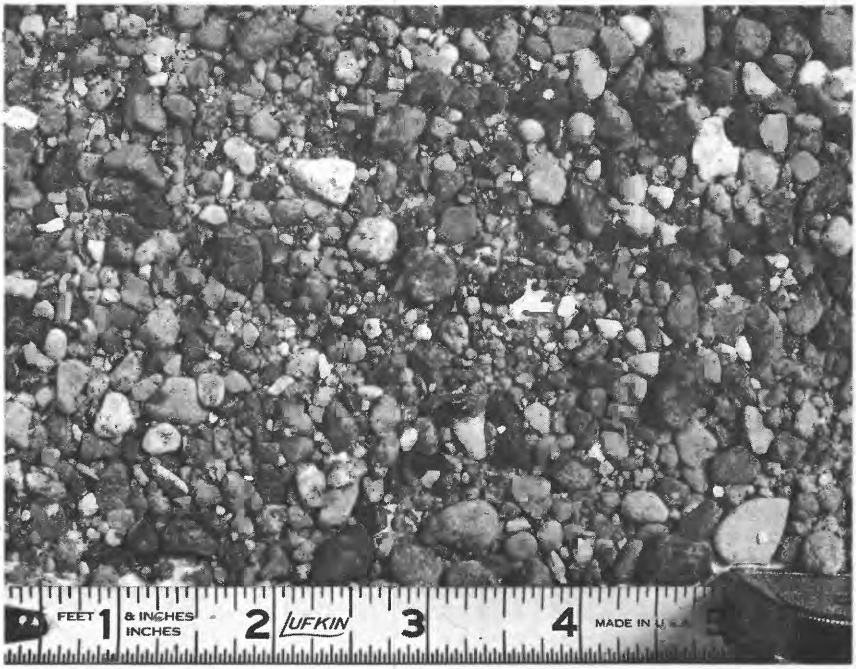

FIGURE 3.—Medial gravel collected from test boring 35/36–15ddb1. Sample was collected from a depth of about 20 feet below land surface and was not washed before being photographed. Photograph by D. C. Clendenon.

are indicated by the organic remains within the deposit. Ostracode shells are found in the more clayey beds, but clam and snail shells are found in the sandy beds. The ostracodes indicate a deepwater depositional environment, and the clams and snails indicate a shallow-water depositional environment.

Upstream from the city of Winnemucca and near the margins of Grass and Paradise Valleys, the upper silt and clay unit consists predominantly of silt and some fine sand. The silty and sandy facies of this unit roughly outlines the areal extent of the second deep stage of Lake Lahontan within the study area. The extent of the first deep stage, represented by the lower silt and clay, is unknown. The upper limit of silt and sand deposited during the second deep-lake stage is about 4,355 feet above mean sea level. This level correlates with the wave-cut scarps at an altitude of 4,360 feet. The wave-cut scarps at an altitude of about 4,400 feet possibly were formed during the first deep-lake stage, within which the lower silt and clay was deposited. Most of the Lake Lahontan deposits at altitudes between 4,360 and 4,400 feet were removed by erosion during a period of desiccation that separated the two deep-lake stages.

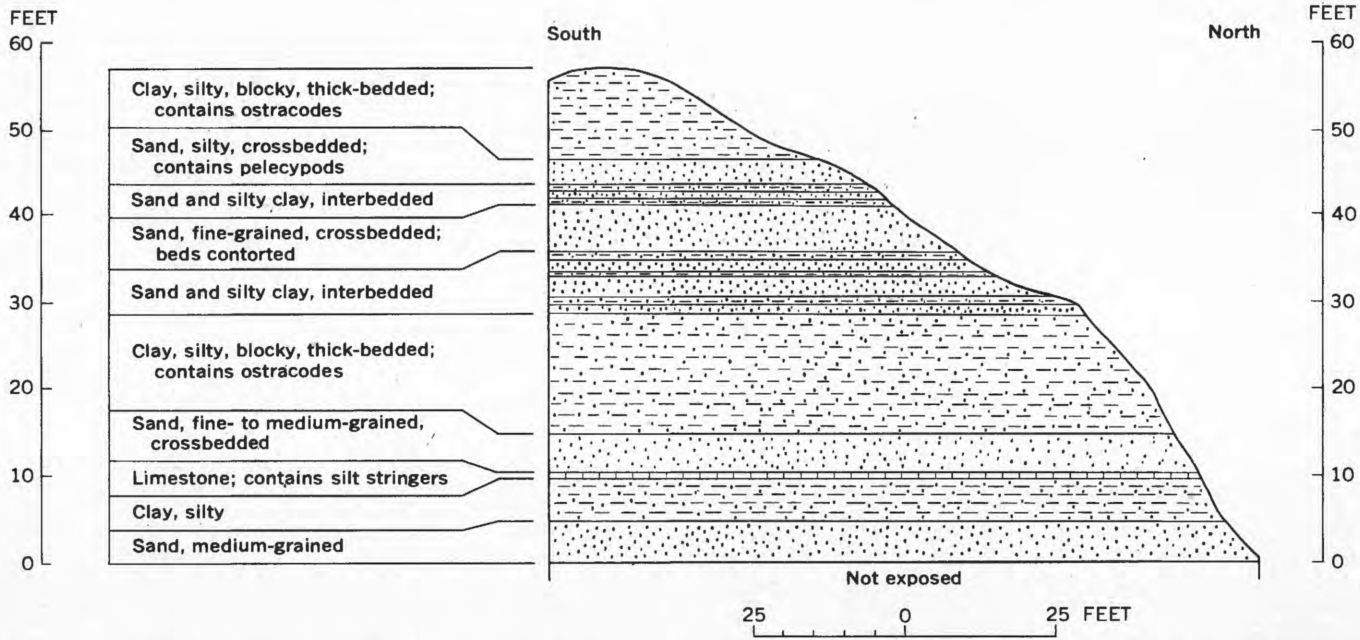

FIGURE 4.—Generalized geologic section of upper silt and clay unit exposed in the SE¼SE¼SW¼ sec. 7, T. 35 N., R. 37 E. (After Cartwright, Keros, 1961, A study of the Lake Lahontan sediments in the Winnemucca area, Nevada: Univ. of Nevada M.S. thesis, p. 29.)

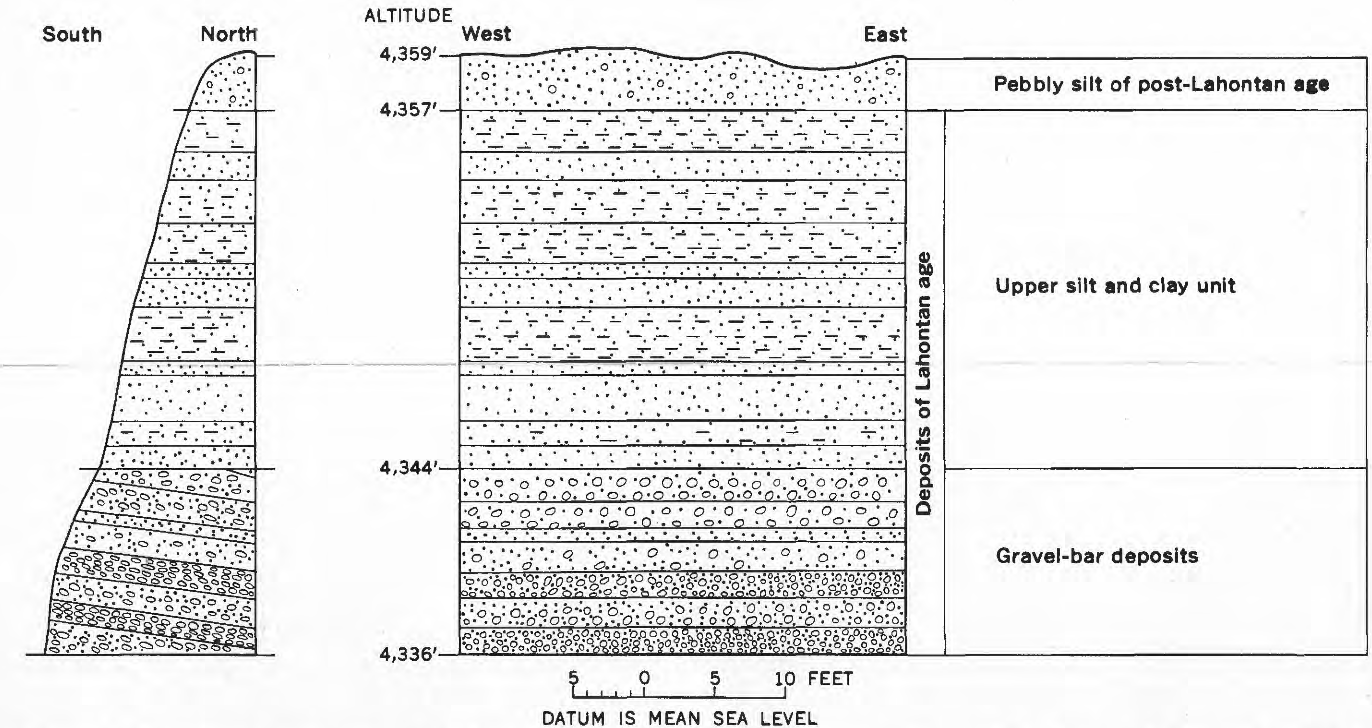

FIGURE 5.—Generalized geologic section of a Lahontan gravel bar exposed in the N¼SW¼NW¼ sec. 25, T. 36 N., R. 37 E. (After Cartwright, Keros, 1961. (A study of the Lake Lahontan sediments in the Winnemucca area, Nevada: Nevada Univ. M.S. thesis, p. 34.)

The upper silt and clay unit is fairly impermeable and commonly impedes the movement of gound water; however, the silt and sand facies of the unit is somewhat more permeable. Locally, the clayey strata of the upper silt and clay unit act as a confining layer which holds water in the underlying medial gravel under artesian pressure. Elsewhere, especially where water-level fluctuations are small, upward leakage from the medial gravel unit establishes and maintains a water table within the upper silt and clay unit.

GRAVEL-BAR DEPOSITS

Sand and gravel deposits of Lahontan age form gravel bars exposed along and near the former margins of Lake Lahontan. Figure 5 shows a section of part of a gravel bar exposed in a quarry in the NE¼SW¼NW¼ sec. 25, T. 36 N., R. 37 E. The deposit consists of pebbles that range in diameter from about 2 to 16 millimeters in a matrix of silt and very fine to very coarse sand. Imbricate structure indicative of wave or current action is common. About 8 feet of gravel is exposed at the base of the quarry. The gravel is overlain by about 13 feet of the upper silt and clay, which in turn is overlain by about 2 feet of alluvium. The northward-dipping gravel beds suggest that the deposit exposed in the quarry is part of the northern flank of a westward-trending gravel bar.

Some of the other gravel bars exposed in the study area may be the surface outcrop of the medial gravel; however, most bars probably are younger than the medial gravel and contemporaneous with the upper silt and clay unit.

The gravel-bar deposits, where saturated, probably form permeable aquifers. Where they are above the water table, they allow substantial amounts of water to percolate downward through them to recharge the ground-water reservoir.

POST-LAKE LAHONTAN DEPOSITS

The sedimentary deposits of post-Lake Lahontan age are subdivided into (1) terrace deposits, (2) fluviatile and subaerial deposits, (3) fluviatile and lacustrine deposits, (4) younger fanglomerate, and (5) windblown deposits.

TERRACE DEPOSITS

The Lake Lahontan deposits of the upper terrace were discussed on page 23. The upper silt and clay unit completely filled the channel of the Humboldt River. After the final dessication of Lake Lahontan within the study area, the valley floor had the nearly featureless form of the bottom of the lake; then, when the base level was lowered as a result of the continuing dessication of the lake downstream from the study area, the Humboldt River incised its channel into the underlying lake beds and cut the middle and lower terraces. The river cut through the upper silt and clay unit to the medial gravel.

The deposits underlying the middle and lower terraces consist of the medial gravel overlain by fluviatile deposits laid down by the river as it cut the terraces. These fluviatile deposits range in texture from clay to sandy gravel and attain a maximum thickness of about 6 feet. The fluviatile deposits, in turn, are overlain by a veneer of windblown silt and sand that ranges in thickness from several inches to more than 4 feet.

FLUVIATILE AND SUBAERIAL DEPOSITS OF THE MEANDER-SCROLL PLAIN

The deposits of the meander-scroll plain are fluviatile and subaerial deposits of varying thickness—commonly less than 15 feet thick—that overlie Lahontan medial gravel. They consist of lateral and vertical accretion deposits.

The lateral accretion deposits commonly are well-sorted crossbedded permeable sand and gravel that accumulated as bars within the channel of the Humboldt River or as point bars on the slip-off slopes of meanders. Lateral accretion deposits commonly are overlain by vertical accretion deposits consisting mostly of silt and clay of variable thickness. Most vertical accretion deposits accumulated in oxbow lakes, abandoned drainage channels, and other depressions on the hummocky meander-scroll plain during periods of flood. Vertical accretion deposits of the meander-scroll plain also include volcanic ash, windblown silt and sand, and slope wash.

Overbank deposits in depressions commonly consist of silt and clay rich in organic material. Gastropod shells and woody plant material are very abundant. Despite the fine-grained texture of these deposits, they are permeable because of a high secondary interconnected porosity related to burrowing organisms. Overbank deposits other than those deposited in depressions commonly consist of clay, silty clay, and silt of low permeability. Locally, the porosity and permeability of these deposits has also been increased by plant and animal action.

A layer (or layers?) of volcanic ash about 1 foot thick was penetrated in many of the test borings in the meander-scroll plain. It is a chalk-white fine-grained deposit that contains glass shards. Most of the particles are in the silt-size range.

FLUVIATILE AND LACUSTRINE DEPOSITS

Other stream-channel deposits of post-Lake Lahontan age occur in the channels of some of the smaller creeks in the area, such as Clear Creek, the Little Humboldt River, and the unnamed former channel of the Humboldt River near the mouth of Paradise Valley. In addition, lake sediments of Recent age were deposited in Gumboot Lake in Paradise Valley.

The deposits in the channel of Clear Creek in Grass Valley are thin and consist mostly of reworked Lahontan upper silt and clay. The deposits in the channel and on the flood plain of the Little Humboldt River within the study area are very similar to the deposits of the channel and flood plain of the Humboldt River. Little is known about the nature of the deposits in the abandoned channel of the Humboldt River near the mouth of Paradise Valley. One test boring was drilled within this abandoned channel (37/39–28ada1). The upper 20 feet of strata penetrated in the boring are poorly sorted pebbly sand and silt that overlie the gravel facies of the medial gravel. Deposits in Gumboot Lake consist mainly of silt and clay of low permeability.

YOUNGER FANGLOMERATE

The criteria used to distinguish the alluvial-fan deposits of post-Lake Lahontan age from the older alluvial-fan deposits are: (1) Soil development on the alluvial fans of post-Lake Lahontan age is almost negligible; (2) carbonate commonly has not been leached from the post-Lake Lahontan alluvial fans, and, where it has been leached, the leached zone commonly extends less than 10 inches below land surface; (3) some of the post-Lake Lahontan alluvial fans cover Lake Lahontan wave-cut scarps, benches, and deposits; and (4) the older alluvial fans commonly are cut by faults, but the post-Lake Lahontan alluvial fans usually are not.

The alluvial fans of post-Lake Lahontan age do not cover large areas and are relatively thin as compared to the older alluvial fans. Their composition and texture vary greatly. Although collectively mapped as younger fanglomerate, some of the fans are composed of coarse fanglomerate, whereas others, especially those on the meander-scroll plain, are composed mainly of clay and silt derived from the upper terrace.

The post-Lake Lahontan alluvial fans are largely above the zone of saturation and, therefore, yield practically no water to wells.

WINDBLOWN DEPOSITS

Much of the upper terrace is covered with windblown silt and sand. Locally, the silt and sand have formed dunes as much as 30 feet high. Somewhat smaller dunes are on the middle and lower terraces. Dunes also are conspicuous near the mouth of Paradise Valley (p. 13).

Much of the windblown silt and sand is derived locally from the upper silt and clay unit, but some is derived from these strata downstream from the study area. The material forming the dunes near the mouth of Paradise Valley has its source in the valleys west of of the Santa Rosa Mountains. The horns of the crescent-shaped dunes (barchans) in the lower Paradise Valley area point eastward, the direction in which the dunes are moving. In contrast to the actively moving dunes in the lower Paradise Valley area, most of the dunes in the valley of the Humboldt River have been stabilized by vegetation.

The windblown deposits covering the upper terrace are porous and entrap most of the precipitation that falls on the upper terrace. This action usually makes the runoff from precipitation on the terrace negligible.

STRUCTURAL GEOLOGY

The region has undergone two distinct types of structural deformation (Ferguson, Muller, and Roberts, 1951). The earlier intervals of deformation were characterized by folding and thrust faulting associated with orogenic compression. The later intervals were characterized by gentle warping and block faulting associated with epirogenic extension. Rocks of pre-Jurassic age are tightly folded and are cut by low-angle thrust faults. A major period of orogenic deformation before Middle Pennsylvanian time is well illustrated at Battle Mountain, about 40 miles southeast of Winnemucca. Here, rocks of Ordovician age have been thrust above Mississippian rocks and are overlain by conglomerate of Early Pennsylvanian age. No contemporaneous thrusting is known in the area immediately around Winnemucca, although Pennsylvanian or Permian rocks unconformably overlie rocks of Mississippian age.

Another period of orogenic deformation occurred during the early part of the Permian Period. In the Sonoma Range, rocks of the Carboniferous Systems are thrust over rocks of the Permian(?) System. The orogenic deformation culminated in post-Triassic time—probably in Jurassic or Early Cretaceous time—contemporaneous with or immediately before the emplacement of Jurassic(?) granitic plutons.

All the Cenozoic rocks except the sedimentary deposits of Lahontan and post-Lahontan age are cut by high-angle normal faults, and vertical displacements along these faults—probably amounting to 3,000 feet or more—outlined the present topography. Along the western fronts of the mountain ranges, frontal faults are not everywhere apparent; but along parts of the western slopes of the Sonoma and East Ranges and in many of the alluvial aprons bordering the ranges, normal frontal faults are readily apparent. These faults show that the western fronts of the ranges have been upthrown with respect to the valleys.

SURFACE WATER

Enough surface-water data are presented and interpreted in this report to show the relation between the surface water and ground water of the area.

HUMBOLDT RIVER

Records of streamflow in the Humboldt River within the present study area are being collected by the Geological Survey at three gaging stations equipped with automatic stage recorders—"Humboldt River at Comus, Nev.," "Humboldt River near Winnemucca, Nev.," and "Humboldt River near Rose Creek, Nev."

COMUS GAGING STATION

The Comus gaging station (Humboldt River at Comus) is about 9 miles northeast of Golconda in the SE¼NE¼SE¼ sec. 14, T. 36 N., R. 41 E. The drainage area of the Humboldt River and its tributaries above the gaging station is about 12,000 square miles. The station was established in 1894, and from that time until 1926, data were collected by daily and other periodic readings of a staff gage. No measurements were made between 1926 and 1945. A continuous water-stage recorder was installed during the water year 1946. (The 12-month period ending September 30 is called the water year, and is designated by the calendar year in which it ends.) Monthly and yearly streamflow records for the Humboldt River at the Comus gaging station for the periods October 1894–December 1909, September 1910–September 1926, and October 1945–September 1960 are given in the Geological Survey publications listed in the following table.

Water year	Water-supply paper	Water year	Water-supply paper
1895-1950 [1]	1314	1956	1444
1951	1214	1957	1514
1952	1244	1958	1564
1953	1284	1959	1634
1954	1344	1960	Unpublished
1955	1394		

[1] Incomplete records for 1910; no records for 1927–45.

The average rate of streamflow at the Comus gaging station for 46 water years of record (1895–1909, 1911–26, and 1946–60) was about 280 cfs (cubic feet per second), or about 200,000 acre-feet per year. The maximum rate of streamflow during the same period of record was 5,860 cfs on May 6, 1952. The river was dry in the late summer and early fall of a few years of record. The maximum range in stage of the river was about 10.5 feet. The maximum total streamflow in a water year was about 688,100 acre-feet or an average of 950 cfs in the water year 1907. The minimum total streamflow in a water year was about 26,700 acre-feet or an average of about 36.8 cfs in the water year 1920. Total streamflow in the water year 1907 thus was about 26 times greater than total streamflow in the water year 1920.

ROSE CREEK GAGING STATION

The Rose Creek gaging station (Humboldt River near Rose Creek) is about 15 miles southwest of Winnemucca in NW¼SE¼-NW¼ sec. 36, T. 35 N., R. 35 E. The drainage area of the Humboldt River and its tributaries above this gaging station is about 15,200 square miles. The station was established in 1948, and streamflow records have been collected by using a continuous water-stage recorder since that time. Streamflow records for this gaging station are available in Geological Survey water-supply papers and are summarized in table 4.

The average rate of streamflow for 12 years of record, 1949–60, was about 220 cfs or about 160,000 acre-feet per year. The maximum rate of streamflow for the period of record was 5,810 cfs on May 8, 1952, and the minimum was 3.7 cfs on December 27, 1959. This minimum streamflow was partly due to freezing temperatures which caused much of the water to go into temporary storage as ice. The maximum range in stage of the river at the Rose Creek gaging station was about 10 feet, which is comparable with the maximum range in stage noted at the Comus gaging station. The maximum streamflow in a water year was 535,800 acre-feet, or an average of 738 cfs, and occurred in water year 1952. The minimum streamflow was 21,840 acre-feet, or an average of 30 cfs, and occurred in water year 1955. Thus, the streamflow in the water year 1952 was about 25 times greater than the streamflow in the water year 1955.

WINNEMUCCA GAGING STATION

Some data collected at the Winnemucca gaging station (Humboldt River near Winnemucca) are given in table 6 and figure 6, but because few streamflow records have been published, a detailed discussion of the record is not included in this report.

RELATION BETWEEN STREAMFLOW AT THE COMUS AND ROSE CREEK GAGING STATIONS

Long-term streamflow characteristics can be approximated from streamflow data for the water years 1949–60, the period during which both the Comus and Rose Creek gaging stations were operating. Table 3 shows streamflow data for the Comus gaging station for the entire period of record since 1895 and for the 12-year period of record since 1949. The data shown for the 12-year period of record are roughly comparable with the data for the entire period of record.

TABLE 3.—*Streamflow, in acre-feet, of the Humboldt River at the Comus gaging station*

[Data from water-supply papers and unpublished records of the U.S. Geol. Survey]

Water-year streamflow	Period of record (water years)	
	1895–1909, 1911–26, 1946–60	1949–60
Maximum	688, 100	558, 500
Minimum	26, 700	27, 530
Average	200, 000	173, 100
Median	149, 500	156, 700

Table 4 shows monthly streamflow data for 1949–60, the common period of record for the Comus and Rose Creek gaging stations. Monthly streamflow varies widely from year to year, but the general character of the monthly streamflow pattern of the Humboldt River within the study area can be evaluated from the average streamflow for each month as shown in table 4. The lowest monthly streamflow at both gaging stations usually occurs in October. In November, streamflow begins to increase substantially, and this trend continues until it reaches a peak in May. From May until the end of the water year, streamflow continually decreases.

TABLE 4.—*Monthly and yearly streamflow, in acre-feet, of the Humboldt River at the Comus and Rose Creek gaging stations, 1949–60*

[Data from water-supply papers and unpublished records of the U.S. Geol. Survey]

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
Humboldt River at Comus													
1949	17	25	1,040	954	1,490	13,540	33,380	41,440	46,860	9,380	358	17	148,500
1950	8.1	247	1,550	1,810	8,060	20,240	32,690	29,580	43,680	24,200	2,840	36	164,900
1951	29	3,760	16,150	14,200	36,210	39,380	45,240	45,610	43,170	12,100	1,800	47	257,700
1952	11	1,500	2,730	3,830	10,470	16,860	135,200	246,100	97,150	36,030	7,440	1,170	558,500
1953	525	2,410	5,460	10,410	12,590	13,890	8,420	6,960	23,980	24,540	2,830	69	112,100
1954	2.8	779	3,350	3,790	7,060	12,380	10,500	4,220	1,480	14	5.2	6.0	43,590
1955	6.1	6.0	6.1	6.1	8.7	4,070	6,600	5,240	9,520	2,050	7.7	10	27,530
1956	7.5	6.0	848	15,240	13,130	29,040	45,970	48,310	64,180	21,590	1,890	38	240,200
1957	25	701	2,470	2,640	9,010	27,410	24,270	30,050	73,330	39,500	4,020	116	213,500
1958	362	3,240	5,430	6,070	14,100	30,360	43,850	49,220	58,390	15,840	1,850	53	223,800
1959	86	1,780	3,930	5,550	6,170	8,160	5,600	1,900	1,640	75	9.5	6.1	34,910
1960	13	12	9.1	6.5	1,960	8,530	13,490	8,640	12,780	1,340	9.9	8.5	46,800
Maximum	525	3,760	16,150	15,240	36,210	39,380	135,200	246,100	97,150	39,500	7,440	1,170	558,500
Mean	91	1,210	3,580	5,380	10,020	18,660	33,770	43,110	39,680	16,560	1,920	131	173,100
Minimum	2.8	6.0	6.1	6.1	8.7	4,070	5,600	1,900	1,480	14	5.2	6.1	27,530
Humboldt River near Rose Creek													
1949	1,300	1,510	1,600	1,610	2,080	9,910	20,180	27,430	34,390	13,750	3,450	1,290	118,500
1950	1,360	1,290	1,780	2,100	7,290	16,550	19,220	20,970	28,790	26,790	6,140	2,720	135,000
1951	2,020	3,050	14,600	13,790	25,520	38,480	35,930	39,220	35,390	17,070	4,920	2,670	232,700
1952	2,310	2,740	4,030	5,120	11,210	15,930	81,990	249,200	99,210	46,600	12,130	5,330	535,800
1953	3,560	4,000	6,090	10,240	12,270	21,690	13,780	5,330	11,250	23,240	6,230	2,410	120,100
1954	1,910	2,010	3,850	4,760	6,950	10,920	7,970	2,310	1,250	827	766	746	44,270
1955	778	998	1,130	1,110	1,160	2,130	3,190	2,490	4,940	2,660	714	541	21,840
1956	633	772	1,000	9,210	13,340	22,010	32,310	36,850	44,700	28,100	5,860	2,380	197,200
1957	1,990	2,100	3,170	3,660	5,970	23,240	17,930	20,530	46,240	44,270	8,140	3,550	180,800
1958	2,770	4,350	6,190	7,090	12,800	27,000	44,530	54,850	53,630	21,670	5,530	2,800	243,200
1959	2,390	3,110	5,110	6,520	7,220	8,390	3,390	2,740	1,130	1,080	803	764	42,650
1960	891	893	962	1,010	2,350	5,740	7,160	5,800	7,470	2,560	834	621	36,290
Maximum	3,560	4,350	14,600	13,790	25,520	38,480	81,990	249,200	99,210	46,600	12,130	5,330	535,800
Mean	1,830	2,240	4,130	5,520	9,010	16,830	23,970	33,980	30,700	19,050	4,630	2,150	159,000
Minimum	633	772	962	1,010	1,160	2,130	3,190	2,310	1,130	827	714	541	21,840

The increase of streamflow in November and December is partly due to a reduction of evaporation and of transpiration by vegetation. Thus as the amount of water transpired by vegetation decreases in the early fall and commonly becomes negligible in middle or late November, streamflow correspondingly increases.

The streamflow data for water year 1955 are the lowest recorded during the 12-year period and clearly show the effect of transpiration on streamflow. During the 5-month period October–February 1955, almost no tributary streamflow reached the Humboldt River within the study area. Surface-water inflow to the study area was limited to the flow of the Humboldt River and ranged from about 6 to 9 acre-feet per month at the Comus gaging station. Surface-water discharge from the study area as recorded at the Rose Creek gaging station was about 778 acre-feet in October, 998 acre-feet in November, 1,130 acre-feet in December, 1,110 acre-feet in January, and 1,160 acre-feet in February. Almost all the increase of streamflow between the Comus and Rose Creek gaging stations was due to ground-water discharge into the Humboldt River. (See p. 50.) The increased streamflow from October to November was due to decreased transpiration by phreatophytes. (See p. 51.) The further increase in December was due to the nearly complete cessation of transpiration by these plants. During January and February, months in which transpiration was negligible, the increase of streamflow between the two gaging stations was almost the same as the increase in December.

Table 4 shows that an average of more than 65 percent of the total streamflow in the Humboldt River occurred in April, May, and June. This streamflow originated mainly in the drainage basin upstream from the Comus gaging station. During the 3-month period an average of about 23,000 acre-feet more water passed the Comus gaging station than passed the Rose Creek gaging station. The loss in streamflow between these stations during this period undoubtedly was partly due to irrigation. Some of the water diverted for irrigation returned to the river, but most was transpired by vegetation, was evaporated from open bodies of water on flooded meadowlands, or was stored temporarily as soil moisture and in large part subsequently evaporated. The rest of the water lost between the two stations recharged the ground-water reservoir.

In contrast to the losses in streamflow of the Humboldt River in April, May, and June, the river tended to gain water in July, August, and September; the total increase in streamflow in the three months averaged about 7,200 acre-feet. Most of this gain was due to the return flow to the river of water temporarily stored in the ground-water reservoir during the spring and early summer.

The flow of the river between the two gaging stations also increased in November, December, and January, mainly because of the underflow of ground water from valleys tributary to the Humboldt River. (See p. 44–48.) Monthly streamflow increased substantially in February and March because of winter precipitation. During these 2 months, the Humboldt River commonly lost water between the Comus and Rose Creek gaging stations.

These generalizations tend to be valid only during an average water year. The data in table 4 show that monthly streamflows in individual years depart markedly from the monthly averages. During periods of low streamflow, the river tends to gain water no matter what the month of the year; conversely, during periods of high streamflow, the river tends to lose water, also irrespective of the time of the year. Periods of high streamflow commonly correspond with the irrigation season. An exception was the high streamflow in January 1956, at which time more than 6,000 acre-feet of water was lost between the Comus and Rose Creek gaging stations. The high streamflow resulted from an unusually large amount of precipitation during the month—more than 250 percent above normal.

SEEPAGE GAINS AND LOSSES ALONG THE HUMBOLDT RIVER

During the course of this investigation, 19 streamflow measuring stations were established along the Humboldt River between the Comus and Rose Creek gaging stations to study seepage gains and losses of the Humboldt River. Eighteen of the stations are equipped with staff gages; the 19th, Winnemucca station, is equipped with a continuous water-stage recorder. Bimonthly streamflow measurements and concurrent determinations of the altitude of the river are being made at the stations coincident with the measurement of water levels in observation wells. The location of the stations is shown on plates 2, 3, and 4, and in table 5. The results of the streamflow measurements at these stations are shown in figure 6 and in table 6.

The ground-water reservoir within and adjacent to the flood plain of the Humboldt River is connected to the river by permeable deposits. Seepage loss (ground-water recharge) from the river to the ground-water body occurs when and where the hydrostatic head in the river is higher than the hydrostatic head in the ground-water reservoir. Ground-water discharge to the river occurs when and where the hydrostatic head in the ground-water reservoir is higher than the river stage.

The data given in table 6 and the graphs of figure 6 help define the reaches of the river where seepage gains or losss occurred in the period 1959–61. In figure 6, each streamflow measurement is plotted

TABLE 5.—*Designation and location of streamflow measuring stations along the Humboldt River, near Winnemucca, Nev.*

Symbol [1]	Designation	Location	Remarks
	Humboldt River—		
A	at Comus, Nev	SE¼NE¼SE¼ sec. 14, T. 36 N., R. 41 E.	Continuous water-stage recorder.
B	below Comus, Nev	SW¼SE¼SW¼ sec. 11, T. 36 N., R. 41 E.	Staff gage.
C	above Preble, Nev	NE¼NE¼NE¼ sec. 21, T. 36 N., R. 41 E.	Do.
D	at Preble, Nev	SW¼SE¼SE¼ sec. 19, T. 36 N., R. 41 E.	Do.
E	above Stahl Dam, Nev	NW¼SW¼SE¼ sec. 25, T. 36 N., R. 40 E.	Do.
F	at Stahl Dam, Nev	SW¼NW¼NW¼ sec. 35, T. 36 N., R. 40 E.	Do.
G	at Golconda, Nev	SE¼NE¼NW¼ sec. 28, T. 36 N., R. 40 E.	Do.
H	at Eden Valley Road Bridge, Nev	NW¼NW¼SW¼ sec. 21, T. 36 N., R. 40 E.	Do.
I	at Diamond S Ranch, Nev	SE¼SE¼SW¼ sec. 17, T. 36 N., R. 40 E.	Do.
J	below Diamond S Ranch, Nev	NE¼NE¼NE¼ sec. 13, T. 36 N., R. 39 E.	Do.
K	at C S Ranch, Nev	SE¼NE¼NE¼ sec. 4, T. 36 N., R. 29 E.	Do.
L	at Kearns Ranch, Nev	SW¼NE¼NW¼ sec. 2, T. 36 N., R. 38 E.	Do.
M	near Winnemucca, Nev	NE¼SW¼NE¼ sec. 17, T. 36 N., R. 38 E.	Continuous water-stage recorder.
N	at Winnemucca, Nev	NW¼SW¼SW¼ sec. 20, T. 36 N., R. 38 E.	Staff gage.
O	at Harrer Ranch, Nev	NE¼SE¼SE¼ sec. 34, T. 36 N., R. 37 E.	Do.
P	at Upper Hillyer Ranch, Nev	NW¼NW¼NE¼ sec. 9, T. 35 N., R. 37 E.	Do.
Q	above Lower Hillyer Ranch, Nev	NW¼SW¼SE¼ sec. 12, T. 35 N., R. 36 E.	Do.
R	at Lower Hillyer Ranch, Nev	SW¼SW¼NW¼ sec. 14, T. 35 N., R. 36 E.	Do.
S	at Lower McNinch Ranch, Nev	NW¼NW¼NE¼ sec. 21, T. 35 N., R. 36 E.	Do.
T	below Lower McNinch Ranch, Nev	NW¼NW¼NW¼ sec. 21, T. 35 N., R. 36 E.	Do.
U	near Rose Creek, Nev	NW¼SE¼NW¼ sec. 36, T. 35 N., R. 35 E.	Continuous water-stage recorder.

[1] Symbol used to identify streamflow measuring station on plates 2, 3, and 4.

at the approximate river mile below the Comus gaging station. The slope of the graph between the plotted points of each series of measurements shows whether the stream was gaining or losing water. If the slope of the graph between two or more stations is downward, the river was losing water in that reach; conversely, if the slope of the graph is upward between two or more stations, the river was gaining water in that reach. These data are used in the preliminary evaluation and interpretation of streamflow gains and losses.

The streamflow measurements in September 1959 and in August, October, and December 1960 are used to help define reaches of the river in which seepage gains and losses occurred during periods of low streamflow. All four series of low-flow measurements at stations A through D were too small to be shown graphically in figure 7. However, the data in table 6 show that there were no substantial gains or losses between these stations. Between stations D and J there was a distinct gain in streamflow; between stations J and M, a small increase in streamflow. Streamflow decreased between

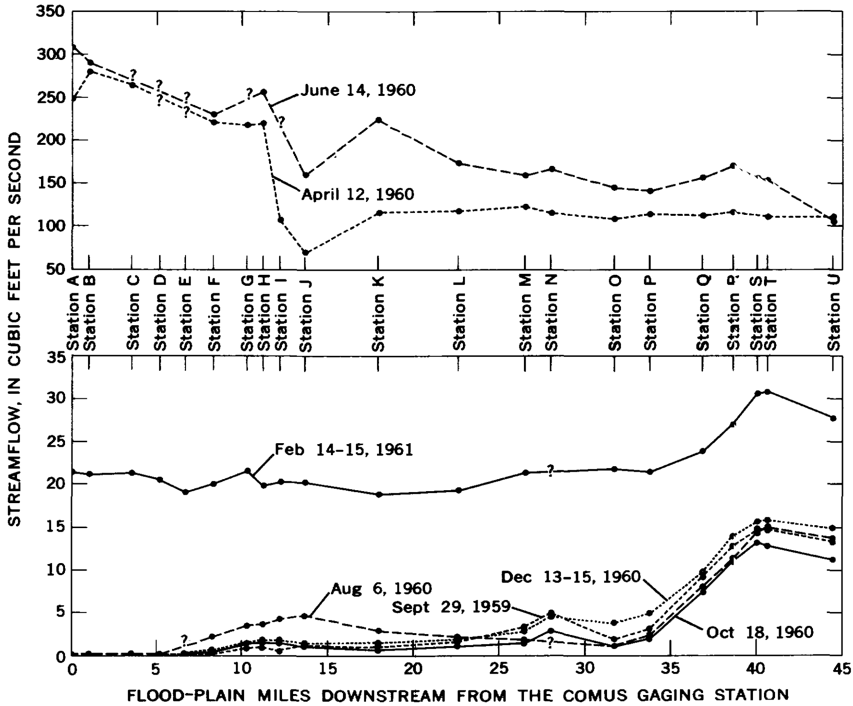

FIGURE 6.—Streamflow measurements along the Humboldt River between the Comus and Rose Creek gaging stations, 1959–61. See plate 3 for location of stream-gaging stations.

stations J and M on August 6, 1960, and increased between stations M and N on September 29, 1959, and on October 18 and Demember 13–15, 1960. (A streamflow measurement was not made at station N on August 6, 1960). Streamflow diminished between stations N and O and increased between stations O and S during the four series of low-flow measurements.

The net gains in streamflow between stations O and S are shown in table 6; during periods of low flow they ranged from a low of about 11.8 cfs on October 18, 1960, to a high of about 12.7 cfs on September 29, 1959. That the upward-sloping lines in figure 6 between stations O and S are roughly parallel indicates that the increase in streamflow between these stations was about the same during each of the four series of low-flow measurements. Furthermore, the lines are nearly straight between stations P and S, and this indicates that the rate of increase in streamflow between these stations was about constant. Streamflow decreased slightly between stations T and U; the average decrease for the four series of measurements was about 1.4 cfs.

TABLE 6.—*Streamflow measurements, in cubic feet per second, along the Humboldt River between the Comus and Rose Creek gaging stations, 1959–61*

Map symbol [1]	Flood-plain miles [2]	Station designation	Sept. 29, 1959		Apr. 12, 1960		June 14, 1960		Aug. 9, 1960		Oct. 18, 1960		Dec. 13–15, 1960		Feb. 14–15, 1961	
			Measured discharge	Difference	Measured discharge	Difference	Measured discharge	Difference	Measured discharge	Difference	Measured discharge	Difference	Measured discharge	Difference	Measured discharge	Difference
		Humboldt River—														
A	0	at Comus, Nev	0.06		251		310		0.09		0.05		0.07		21.5	
B	1.0	below Comus, Nev	.12	+0.06	283	+32	293	−17	.02	−.07	.19	+0.14	.20	+0.13	21.3	−0.2
C	3.5	above Preble, Nev	0	−.12	267	−16	([3])		.09	+.07	0	−.19	.16	−.04	21.4	+.1
D	5.2	at Preble, Nev	0	0	([3])		([3])		.1	+.01	0	0	.11	−.05	20.5	−.9
E	6.7	above Stahl Dam, Nev	.04	+.04	([3])		([3])		([3])		.20	+.20	.27	+.16	19.2	−1.3
F	8.3	at Stahl Dam, Nev	.19	+.15	224		232		2.24		.79	+.59	.60	+.33	20.2	+1.0
G	10.3	at Golconda, Nev	.87	+.68	220	−4			3.63	+1.39	1.38	+.59	1.42	+.82	21.7	+1.5
H	11.2	at Eden Valley Road Bridge, Nev.	1.03	+.16	222	+2	258		3.72	+.09	1.60	+.22	1.71	+.29	19.9	−1.8
I	12.2	at Diamond S Ranch, Nev	.57	−.46	[4] 110	[4] −112			4.33	+.61	1.64	+.04	1.78	+.07	20.3	+.4
J	13.7	below Diamond S Ranch, Nev.	1.22	+.65	70.6	−39.4	[4] 162		4.83	+.50	1.44	−.20	1.62	−.16	20.3	
K	17.9	at C S Ranch, Nev	1.08	−.14	[5] 118	[5] +47.4	[5] 227	[5] +65	3.12	−1.71	.78	−.66	1.66	+.04	19.0	−1.3
L	22.6	at Kearns Ranch, Nev	1.68	+.60	120	+2	[4] 176	[4] −51	2.29	−.83	1.31	+.53	2.26	+.60	19.6	+.6
M	26.5	near Winnemucca, Nev	3.50	+1.82	126	+6	163	−13	2.07	−.22	1.74	+.43	3.02	+.76	21.6	+2.0
N	28.0	at Winnemucca, Nev	5.01	+1.51	118	−8	169	+6			3.11	+1.37	4.75	+1.73		
O	31.7	at Harrer Ranch, Nev	2.13	−2.88	112	−6	148	−21	1.60		1.66	−1.45	4.04	−.71	22.0	
P	33.7	at Upper Hillyer Ranch, Nev.	3.26	+1.13	117	+5	144	−4	2.58	−.98	2.64	+.98	5.10	+1.06	21.6	−.4
Q	36.8	above Lower Hillyer Ranch, Nev.	9.35	+6.09	116	−1	159	+15	8.37	+5.79	7.63	+4.99	9.79	+4.69	24.1	+2.5
R	38.7	at Lower Hillyer Ranch, Nev.	12.9	+3.55	119	+3	163	+4	12.7	+4.33	11.6	+3.97	14.4	+4.61	27.4	+3.3
S	40.1	at Lower McNinch Ranch, Nev.	14.8	+1.9	116	−3	158	−5	14.7	+2.0	13.5	+1.9	15.9	+1.5	30.8	+3.4
T	40.7	below Lower McNinch Ranch, Nev.	14.8	0	114	−2	156	−2	15.2	+.5	13.0	−.5	16.2	+.3	31.0	+.2
U	44.5	near Rose Creek, Nev	13.4	−1.4	114	0	108	−48	13.8	−1.4	11.4	−1.6	15.0	−1.2	27.8	−3.2
Net difference in streamflow between gaging stations at site O and site 3			+12.7		+4		+10		+13.1		+11.8		+11.9		+8.8	

[1] See table 5 and plates 2, 3, and 4 for location.
[2] Approximate.
[3] Affected by backwater from Stahl Dam.
[4] Affected by diversion for irrigation.
[5] Affected by return flow of water diverted for irrigation.

OTHER STREAMS

In 1954 the Office of the Nevada State Engineer installed a continuous water-stage recorder on Pole Creek, and in 1960 the Geological Survey assumed responsibility for operation of the station during the present study. The station was moved farther upstream in 1960 and is now in the SW¼SE¼SE¼ sec. 12, T. 35 N., R. 39 E., and is designated by the symbol AA′ on plates 2, 3, and 4. The drainage area above the station is about 10 square miles, which is roughly comparable with the drainage area of many of the other major streams draining the mountains within the study area. The station at Pole Creek will be used as an index station for estimating streamflow in the other small tributary streams in the area.

The few data that are available on the streamflow in Pole Creek are given in table 7.

TABLE 7.—*Streamflow, in acre-feet, at the Pole Creek gaging station, 1956–60*

[Data from unpublished records of the Office of the Nevada State Engineer]

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual [1]
1956	27	48	258	59	49	587	637	1,630	1,100	95	26	24	4,540
1957	25	42	75	31	199	483	770	1,840	1,370	108	23	24	4,990
1958	40	39	40	41	181	299	747	1,820	721	165	71	42	4,210
1959	46	51	79	75	73	117	216	231	99	12	16	44	1,060
1960	133	128	144	181	271	537	430	585	230	3.6	3.8	3.7	2,650

[1] Rounded.

GROUND WATER

PRINCIPLES OF OCCURRENCE

According to Meinzer (1923, p. 23), water is in three major zones in the ground—the zone of rock flowage, the zone of saturation, and the zone of aeration. (See fig. 7.) Water in the zone of rock flowage is not considered in this report. Ground water is the water that occupies the interstices or pore spaces within the zone of saturation. The zone of saturation is the zone in which the pore spaces are filled with water under pressure equal to or greater than atmospheric. The top of the zone of saturation, where water is under pressure equal to one atmosphere, is known as the water table.

Vadose water is the interstitial water within the zone of aeration, the zone that commonly overlies the zone of saturation. The capillary fringe is the lowermost layer of the zone of aeration and is continuous with the ground water in the zone of saturation. However, water within the pore spaces within the capillary fringe is under less than atmospheric pressure. The height of the capillary fringe above the water table may extend from only a few inches to several tens

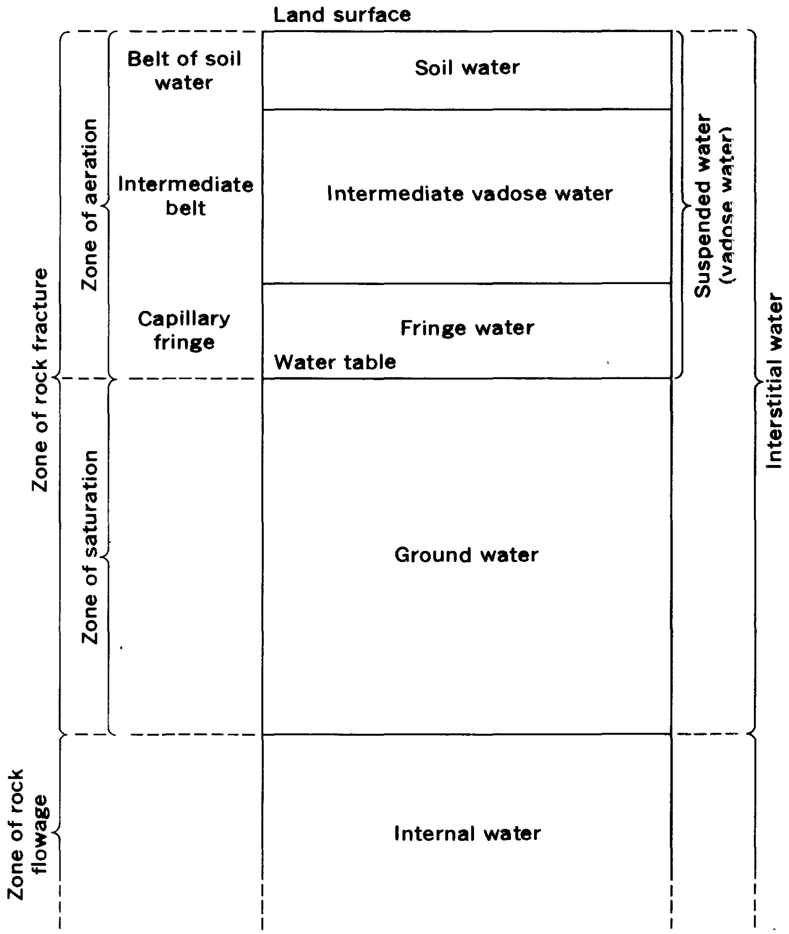

FIGURE 7.—Divisions of subsurface waters (after Meinzer (1923, p. 23).

of feet above the zone of saturation, the extension depending mainly on the size of the particles and the pore spaces. The height of the capillary fringe above the water table has no appreciable effect upon the altitude of the water level in a well. A well is a super-capillary opening; therefore, water in a well is at atmospheric or greater than atmospheric pressure. Because water in the capillary fringe is at less than atmospheric pressure, it will not enter a well.

A zone of intermediate vadose water commonly overlies the capillary fringe and commonly is overlain by a zone of soil water. The intermediate and upper parts of the zone of aeration, the zone of intermediate vadose water, and the zone of soil water are absent where the water table is at or very close to land surface; however, the intermediate zone may be tens or hundreds of feet thick where the water table is far below land surface.

Water commonly forms films around individual rock particles in the intermediate and upper parts of the zone of aeration. The thickness of the films of water adhering to the rock particles depends mainly upon the size of the particles. At field capacity the attractive forces holding the films of water to the rock particles are balanced by the force of gravity. Water in excess of the field capacity will drain downward to the capillary fringe and cause water from the capillary fringe to move downward to the water table. Transpiration by plants and evaporation can decrease the water content in the zones of soil water and intermediate vadose water to below field capacity.

If water within the zone of saturation is overlain by a bed of fairly impermeable material which holds the water in the aquifer under pressure, both the aquifer and the water are termed "artesian." The surface defined by the level at which artesian water from a specific aquifer will stand in a well tapping only the aquifer defines what is known as a piezometric (pressure) surface. The levels at which water stands in wells tapping an unconfined aquifer define the surface known as the water table.

Fluctuations of the water table indicate changes in storage in an unconfined aquifer. Fluctuations of a piezometric surface, however, indicate pressure changes within a confined aquifer rather than changes in storage of an aquifer. Thus, the change in storage per unit change in head in a confined aquifer is often many times less than the change in storage per unit change in head in an unconfined aquifer.

Most of the deposits in the zone of water-level fluctuation in the valley of the Humboldt River consist of lenses of sand and gravel in a matrix of clay and silt. These lenses are interconnected either by direct contact or by deposits of intermediate permeability. Even so, rapid changes in water level may result in temporary artesian conditions within the sand and gravel lenses and cause the water level in a well tapping these lenses to be temporarily higher than the water level in a nearby well tapping only clay or silt. However, these differences in water levels become negligible after short periods of time. After a rapid rise in water level, the aquifers behave as if they were artesian, but commonly after only a few days or weeks they have the hydraulic characteristics of unconfined aquifers.

OCCURRENCE AND MOVEMENT OF GROUND WATER

Nearly all ground water of economic importance in the valley of the Humboldt River is in aquifers consisting of unconsolidated deposits. The aquifers are unconfined, semiconfined, and confined. Ground water also occurs in fractures and other openings in the indurated rocks that border, form buried bedrock "highs" within, and underlie the deposits of the valley fill. Because of the low economic value of ground water in the indurated rocks and because significant short-term changes of ground water in storage associated with changes in the amount of streamflow in the Humboldt River occur only within the deposits of the valley fill, this report is concerned principally with ground water in the valley fill.

Ground water moves in the direction of least head—perpendicular to water-level contours—from areas of recharge toward areas of discharge. The water-level contour map (pl. 3) shows the altitude and shape of the water table in December 1960. The altitude of the surface in December 1960 probably was about 2 feet lower than average because of severe drought conditions in 1959 and 1960. The surface defined by these contours approximates the shape of the water table during most of the year, except in the spring and early summer when high streamflow causes rapidly rising ground-water levels.

The water-level surface on plate 3 is based mainly on the altitude of water levels in wells which penetrate only the upper few feet of the zone of saturation. Therefore, the water-level surface does not everywhere indicate precisely the direction of movement of ground water at any appreciable depth below the water table. However, the movement of ground water at depth probably is roughly similar to the movement of ground water in the shallower aquifers.

Locally, artesian pressure causes ground-water mounds as high as 100 feet above the regional water table. Inasmuch as these levels have little apparent effect upon the interrelation between ground water and the Humboldt River, they are not discussed further in this report and are not shown on plate 3.

GROUND-WATER RECHARGE

The unconsolidated deposits of the valley fill within the zone of saturation constitute the ground-water reservoir. Water within the ground-water reservoir is the ground-water body. The addition of water to the ground-water reservoir is referred to as recharge to the ground-water reservoir or, more simply, ground-water recharge.

The ultimate source of practically all ground water in the study area is precipitation within the drainage basin of the Humboldt River. Recharge to the ground-water reservoir occurs principally by underflow from tributary areas and seepage from streams and irrigation ditches. A smaller amount of ground-water recharge results from the direct infiltration and deep percolation of a small fraction of the precipitation in the study area and some of the excess water applied for irrigation.

PRELIMINARY ESTIMATES OF UNDERFLOW FROM TRIBUTARY AREAS

Underflow from tributary areas is a major source of recharge to the ground-water reservoir of the study area. The major tributary areas include Grass Valley and the northwestern slope of the Sonoma Range, Paradise Valley, the drainage basins of Pole Creek and Rock Creek—referred to here as the Pole Creek–Rock Creek area—and the valley of the Humboldt River upstream from the study area. Underflow into the valley of the Humboldt River from Winnemucca Mountain, the Krum Hills and the area north of the Krum Hills, and the East Range is disregarded in this report because it is estimated as only a few hundred acre-feet per year. This estimate is based on the slope of the water-level contours of plate 3 and consideration of the small watersheds of the areas.

Estimates of underflow from tributary areas are based on seepage gains and losses of the Humboldt River and on estimates of underflow within the valley of the Humboldt River in December 1960. Underflow from Grass Valley and the northwestern slope of the Sonoma Range in December 1960 probably did not differ substantially from the average rate of underflow in the period 1949–60 (p. 46). General geologic and hydrologic conditions in other tributary areas are similar to those in Grass Valley, and the underflow from these tributary areas in December 1960 probably did not differ substantially from the average rate of underflow in the period 1949–60.

Underflow within the valley of the Humboldt River—that is, underflow roughly parallel to the river—can be estimated by the equation

$$Q = TIW,$$

where Q is underflow, in gallons per day; T is the field coefficient of transmissibility, in gallons per day per foot, or the rate of underflow, in gallons per day, through a vertical strip of aquifer 1 foot wide that extends the full height of the saturated sediments under a hydraulic gradient of 100 percent at the prevailing water temperature; I is the hydraulic gradient, in feet per mile; and W is the width of section of the aquifer, in miles. Values for the hydraulic gradient and width for any section perpendicular to the Humboldt River can be determined from plate 3; however, few preliminary pumping-test data are available on which to base an estimate of the cofficients of transmissibility. The estimated coefficients at selected sections perpendicular to the Humboldt River given in table 8 are based on preliminary pumping-test data and geologic information obtained during the test-drilling program. The table also shows preliminary estimates of underflow and the data used to compute these estimates.

TABLE 8.—*Preliminary estimates of underflow through selected sections perpendicular to the Humboldt River*

(1) Location of sections perpendicular to the Humboldt River	(2) Estimated range within which the average coefficient of transmissibility probably falls (gallons per day per foot)	(3) Approximate water-table gradient (feet per mile)	(4) Approximate width of section (miles)	(5) Estimated underflow [1] (figures rounded)		
				Thousands of gallons per day	Cubic feet per second	Acre-feet per year
At station C	100,000-200,000	3	1	300-600	0.5-1	400-700
Near station K	100,000-200,000	4	3	1,200-2,400	2.0-4	1,500-3,000
At station O	200,000-500,000	4	2	1,600-4,000	2.5-6	2,000-4,500
At station S	200,000-500,000	7	2	2,800-7,000	4.0-11	3,000-8,000

[1] Column 5 is the product of columns 2, 3, and 4.

GRASS VALLEY AND THE NORTHWESTERN SLOPE OF THE SONOMA RANGE

Seepage from streams draining the Sonoma Range and the East Range is the principal source of recharge to the ground-water reservoir of Grass Valley. The average annual recharge to the ground-water body of Grass Valley in excess of the average annual discharge of ground water within the valley is approximately equal to the average annual underflow from Grass Valley to the valley of the Humboldt River.

Water-level contours near the mouth of Grass Valley (pl. 3) show that ground water is moving northward and northwestward from Grass Valley toward the valley of the Humboldt River. Near the Winnemucca Airport, the water-level contours are more closely spaced, thereby indicating a steeper hydraulic gradient, than they are in the area just north and northeast of the airport. Since practically the same amount of water moves through about the same cross-sectional area of saturated sediments in both areas, the hydraulic gradient must be steeper near the airport because the sediments within the zone of saturation there are less permeable than the sediments within the zone of saturation north of the airport.

The water-level contours of plate 3 suggest that some, but probably not all, of the underflow from Grass Valley and the northwestern slope of the Sonoma Range was discharged into the Humboldt River between stations O and S and that part of the underflow may have moved downgradient past station S. Practically no ground water was discharged by evapotranspiration, and pumping in this segment of the valley was not significant. In addition, ground water in storage did not change significantly, nor did the channel storage in the Humboldt River. Thus, except for the difference between underflow into the segment near station O and underflow out of the segment near station S, the increase of streamflow between station O and S in December 1960 was equal to the bulk of the underflow from Grass Valley and the northwestern slope of the Sonoma Range. The increase of streamflow between stations O and S on December 13–15, 1960, was about 12 cfs. Thus, the total underflow from Grass Valley and the northwestern slope of the Sonoma Range is estimated to have been about 12 cfs plus the difference in the amount of underflow parallel to the Humboldt River near station O and near station S. The difference between the amount of underflow parallel to the Humboldt River near each of these stations is estimated from table 8 to have been about 1.5–5 cfs, the underflow at station S being the larger of the two estimates. The underflow from Grass Valley to the valley of the Humboldt River in December 1960, therefore, is estimated to have been about 14–17 cfs.

Water-level measurements in observation wells in the area during the period 1949–61 indicate that the hydraulic gradient, and therefore the underflow from Grass Valley and the northwestern slope of the Sonoma Range, has not varied more than about 10 percent from season to season or from year to year. Therefore, the average rate of underflow from Grass Valley and the northwestern slope the Sonoma Range since 1949 probably has not varied much more than about plus or minus 10 percent of 14–17 cfs. Accordingly, the preliminary estimate of the long-term average annual underflow from Grass Valley and the northwestern slope of the Sonoma Range is about 10,000–12,000 acre-feet.

PARADISE VALLEY

Water-level contours of plate 3 indicate that there is ground-water underflow toward the valley of the Humboldt River from Paradise Valley. The observation wells shown on plate 3 served only as partial controls for drawing the water-level contours in the mouth of Paradise Valley. Water-level contours shown near the channel of the Little Humboldt River are inferred mainly from data presented by Loeltz, Phoenix, and Robinson (1949, table 7, p. 54).

Loeltz, Phoenix, and Robinson (p. 42) estimated that the average annual underflow from Paradise Valley to the valley of the Humboldt River was about 3,200 acre-feet. This estimate was obtained by evaluating the increase of flow of the Humboldt River opposite the mouth of Paradise Valley.

The increase of streamflow between stations K and O in December 1960 was about 2.4 cfs (table 6). The estimated underflow parallel to the Humboldt River near station O was about 0.5–2 cfs greater than the underflow near station K (table 8). Thus, the preliminary estimate of underflow from Paradise Valley is 3–4 cfs or about 2,000 to 3,000 acre-feet per year.

POLE CREEK-ROCK CREEK AREA

The water-level contours of plate 3 show that there is underflow from the Pole Creek–Rock Creek area to the valley of the Humboldt River. The contours show a pronounced ground-water mound along the channel of Rock Creek and a less distinct but moderately pronounced mound near the mouth of Pole Creek. These mounds indicate that part of the ephemeral streamflow of these creeks percolates downward into the permeable alluvial fans and recharges the ground-water body.

Virtually all the underflow from the Pole Creek–Rock Creek area discharged into the valley of the Humboldt River between stations C and K December 13–15, 1960. However, the increase of streamflow between these stations is not a measure of the total underflow from this area because the water-level contours show that, in addition to underflow toward the Humboldt River from the southeast, there was underflow away from the river toward the northwest. The contours indicate that ground water moves in a broad band parallel to the river downstream toward Winnemucca.

The increase of streamflow between stations C and K was about 1.5 cfs on December 13–15, 1960. The estimated underflow parallel to the Humboldt River is 1.5–3 cfs greater near station K than at station C (table 8). Thus, the preliminary estimate of underflow from the Pole Creek–Rock Creek area is 3–4 cfs or about 2,000–3,000 acre-feet per year.

VALLEY OF THE HUMBOLDT RIVER UPSTREAM FROM THE STUDY AREA

Virtually no ground-water was discharged between the upstream margin of the study area near station A and station C in December 1960. Also, the increase of streamflow between these stations in December 1960 was negligible (table 6). Therefore, underflow near station C probably is a measure of underflow into the study area at station A. The preliminary estimate of underflow near station C (table 8) is 0.5–1 cfs or about 400–700 acre-feet per year.

SUMMARY OF UNDERFLOW FROM TRIBUTARY AREAS

The preliminary estimates of the average annual underflow from major tributary areas to the valley of the Humboldt River are as follows:

Area	Underflow	
	Cubic-feet per second	Acre-feet per year
Grass Valley and the northwestern slope of the Sonoma Range	14–17	10, 000–12, 000
Paradise Valley	3–4	2, 000–3, 000
Pole Creek-Rock Creek area	3–4	2, 000–3, 000
Valley of the Humboldt River upstream from the study area	. 5–1	400–700

Thus, according to the available preliminary data, the total annual underflow in the period 1949–60 is estimated to range between about 14,000 and 19,000 acre-feet per year.

SEEPAGE LOSSES FROM THE HUMBOLDT RIVER

Seepage losses from the Humboldt River recharge the ground-water reservoir, especially beneath the meander-scroll plain and the lower and middle terraces. The most significant seepage losses occur in the spring and early summer when the stage of the river is highest. As shown earlier (p. 32), the stage of the river rises as much as 10 feet during periods of extremely high streamflow. This commonly results in a hydraulic gradient or head differential from the river to the ground-water body and consequent seepage from the river to the ground-water reservoir. To date, insufficient data are available to construct a map showing water-level contours during and immediately after the spring runoff. Such maps are planned for inclusion in a subsequent report.

Water from the Humboldt River seeps to the ground-water reservoir along some reaches of the river within the study area even during periods of low streamflow. The water-level contours of plate 3 help define reaches of the river in which seepage losses to the ground-water reservoir occurred in December 13–15, 1960. Seepage losses from the Humboldt River were not significant between stations A and G (table 6). In this reach, the lack of seepage losses is also suggested by the water-level contours which were roughly perpendicular to the river. The contours further show that, in the reach of the river between station G and a point about 1 mile downstream from station J, the underflow was northwestward across the general course of the river. Table 6 shows that streamflow increased about 0.2 cfs between stations G and J. Streamflow in this reach of the river apparently increased slightly because the rate of effluent seepage to the river from the south and southeast was slightly more than rate of influent seepage to the ground-water reservoir to the northwest.

The water-level contours of plate 3 suggest that the river lost water to the ground-water reservoir by seepage in the reach of the river between station N and a point about half a mile downstream from station O. Table 5 shows that the decrease in streamflow between stations N and O was about 0.7 cfs in December 1960. In addition, figure 6 shows a decline in streamflow between these stations during each of the four series of low streamflow measurements. The streamflow in this segment of the river decreased in spite of the underflow from the northwestern slope of the Sonoma Range toward the Humboldt River, probably because the width of the permeable deposits near station O is several times the width near station N. The increased width of the permeable section allows the same quantity of water to be transmitted at a lower gradient, which tends to lower the water level in the ground-water reservoir below the river level and induce seepage from the river to the ground-water reservoir.

Streamflow also diminished between stations T and U during each of the four series of low streamflow measurements. The decrease in streamflow was about 1.2 cfs in December 1960. The decline in streamflow in this segment of the river probably has an origin similar to the decline in streamflow between stations N and C—that is, a marked increase in the width and, therefore, in the water-transmitting capacity of the permeable deposits underlying the meander-scroll plain downstream from station T.

RECHARGE RESULTING FROM IRRIGATION

Water is removed from the Humboldt River during the irrigation season (commonly mid-April to late June or early July) by diversion into ditches and by overbank flooding owing to the installation of headgates and temporary dams. Some recharge to the ground-water reservoir results from seepage from the ditches, especially where they cross permeable sand and gravel. Recharge also results from overbank flooding, either natural or induced by man, because some of the water that stands in abandoned meander scrolls, oxbow lakes, and other abandoned drainageways percolates downward to the ground-water body and because water commonly is applied in excess of field capacity of the soil.

The amount of recharge to the ground-water body resulting from irrigation cannot be determined directly from the data available. However, recharge resulting from irrigation is included in the discussion of short-term changes of ground water in storage (p. 55).

DIRECT PRECIPITATION ON THE VALLEY FLOOR

A small, probably negligible, amount of recharge to the ground-water reservoir results from the downward percolation of precipitation on the valley floor. The moisture content of the zone of soil moisture commonly is considerably below field capacity in the late summer, fall, and winter, owing to evapotranspiration during the previous growing season. Thus, most of the precipitation on the valley floor, which occurs in the winter, is probably retained in the zone of soil moisture and does not recharge the ground-water body.

GROUND-WATER DISCHARGE

Most of the ground-water discharge from the study area is by (1) underflow from the study area near the Rose Creek gaging station, (2) seepage into the Humboldt River, and (3) evapotranspiration. Some ground water also is discharged from wells and springs; but as this discharge probably amounts to only a few thousand acre-feet per year, it is disregarded in this report.

UNDERFLOW NEAR THE ROSE CREEK GAGING STATION

Underflow out of the study area at station U—the Rose Creek gaging station—probably is somewhat more than underflow parallel to the Humboldt River at station S. The preliminary estimate of average annual underflow near station S is 4–11 cfs (table 8) or about 3,000–8,000 acre-feet per year. Because the river loses about 1 cfs to the ground-water reservoir between stations S and U during periods of low flow (fig. 6), the preliminary estimated underflow out of the study area near station U is about 5–12 cfs or about 4,000–9,000 acre-feet per year.

EFFLUENT SEEPAGE TO THE HUMBOLDT RIVER

The estimated ground-water underflow from tributary valleys that discharged into the Humboldt River within the study area in December 1960 was about 15 cfs (table 6). Variation in the rate of discharge into the river probably is small. On this basis the average annual ground-water discharge into the Humboldt River is estimated as about 11,000 acre-feet.

A large amount of the water that goes into temporary storage in the ground-water reservoir during the irrigaion season is discharged into the river during and soon after the irrigation season. The interrelationship between the Humboldt River and the ground-water body during the irrigation season is difficult to evaluate quantitatively. The amount of ground water discharged into the Humboldt River during the irrigation season will be studied and any estimates made will be given in a subsequent report when evapotranspiration and other data are available.

EVAPOTRANSPIRATION

Evapotranspiration is a major form of ground-water discharge in the study area. Various phases of the processes of evapotranspiration are being studied in detail during the present investigation by the following Federal agencies in cooperation with the Nevada Department of Conservation and Natural Resources: Agricultural Research Service, Bureau of Reclamation, Geological Survey, and Soil Conservation Service. To date, however, very few direct quantitative data are available.

The chief processes of evapotranspiration resulting in the discharge of ground water within the study area include (1) evaporation from open bodies of water, (2) evaporation from the capillary fringe, and (3) transpiration by plants (phreatophytes) that obtain water principally from the ground-water reservoir or the capillary fringe.

When ground-water levels reach their maximum altitude—usually in the spring and early summer—within the flood plain of the Humboldt River, the water table is close enough to land surface to intersect some abandoned stream channels. The water that is evaporated from such open bodies of water is ground-water discharge.

The dominant native phreatophytes include greasewood (*Sarcobatus vermiculatus*), rabbitbrush (*Chrysothamnus graveolens*), salt grass (*Distichlis stricta*), rye grass (*Elymus triticoides*), a number of as yet unidentified species of sedges, and willows (*Salix?*). Cultivated alfalfa also is a phreatophyte locally.

Greasewood probably covers more of the area than does any of the other bush-type phreatophytes. It is the dominant type of vegetation on the middle and lower terraces and commonly is associated with lesser amounts of the other phreatophytes and sagebrush, which ordinarily is not a phreatophyte. Depth to the water table is apparently one of the major factors controlling the distribution of greasewood as well as most of the other phreatophytes. Of the aforementioned phreatophytes, greasewood commonly grows in areas where the water table ranges from about 7 to 25 feet below land surface. Rabbitbrush commonly grows in areas where the water table ranges from about 6 to 12 feet below land surface, the grasses commonly grow in areas where the water table ranges from about 2 to 10 feet below land surface, and willows commonly are restricted to stream channels and sloughs where the water table ranges from less than 1 foot to about 5 feet below land surface.

CHANGES OF GROUND WATER IN STORAGE

Ground water in storage occupies the interstices or pore spaces between rock particles within the zone of saturation. The amount of water that will drain by gravity from a given volume of sediments is less than the amount of ground water in storage. Some water will be held within the sediments against the pull of gravity, principally by the attractive forces between thin films of water and the rock particles with which they are in contact.

Changes in the amount of ground water in storage are needed to help compute a water budget for the study area. The method used in this report to compute changes of ground water in storage involves the volume of sediments unwatered or resaturated and the short-term specific yield of the sediments. (See tables 10, 11.)

To interpret more radily the specific-yield data given in tables 9 and 10, a brief discussion of specific retention and porosity and their relation to the specific-yield data follows.

SPECIFIC RETENTION

Meinzer's definition of specific retention given on page 7 can be expressed by the equation

$$Sr=\frac{Vr}{Vs}\times 100=P-Sy,$$

where Sr is the specific retention, in percent; Vr is the volume of water retained in the sediments after complete gravity drainage; Vs is the volume of the saturated sediments; P is the porosity, in percent; and Sy is the specific yield.

Many factors affect the specific retention of sedimentary deposits. One of the chief factors is the size of the particles composing the deposits; all other factors being equal, a given volume of sediments consisting of small particles will have a higher specific retention than a like volume of sediments consisting of larger particles. The degree of assortment also is a major factor affecting specific retention; all other factors being equal, samples that are poorly sorted have a higher specific retention than samples that are well sorted. Other factors that affect specific retention include the shape, mineralogy, and degree of compaction and cementation of the particles.

Specific-retention values of 209 sediment samples collected in the fall of 1959 range from about 40 percent for samples of silt and clayey silt to about 7 percent for samples of medium sand to gravel.

POROSITY

Porosity was determined in the laboratory by the standard pycnometer method. It was computed by the equation.

$$P=\frac{Ys-Yd}{Ys}\times 100,$$

where P is the porosity of the sample, in percent, Ys is the absolute specific gravity of the particles; and Yd is the apparent specific gravity of the sample.

Some of the factors that affect the porosity of sedimentary deposits are the shape and degree of assortment of the particles, the degree of compaction and cementation, and primary and secondary structures, some of which are partly independent of the aforementioned factors. Deposits containing particles of similar size tend to have a higher porosity than deposits consisting of particles of dissimilar size.

The porosity values of the previously mentioned 209 samples seem to be related principally to the size of the particles composing the samples. In general, samples of clay and clayey silt have the highest porosity values, and the porosity values decrease as the samples become coarser. Porosity values are fairly high for the fine-grained samples, partly because of secondary structures and partly because of a lack of compaction of the sediments. Most of the fine-grained samples were collected from a depth of less than 10 feet below land surface. These deposits were never buried at a much greater depth than at present and, therefore, still retain at least part of the initial high porosity that usually is associated with recent deposits of clay and clayey silt.

SPECIFIC YIELD

Specific yield may be expressed by the equation

$$Sy=P-Sr$$

where Sy is specific yield, in percent; P is porosity, in percent; and Sr is specific retention, in percent. A summary of the specific-yield values for 209 samples collected in the fall of 1959 is presented in table 9. Figure 8 is a histogram showing the distribution of the specific-yield values of these samples. The sediments are divided into classes in table 9 on the basis of the median grain-size diameters of the samples. Table 9 and figure 8 show the extreme range and large dispersion of specific-yield values within each class.

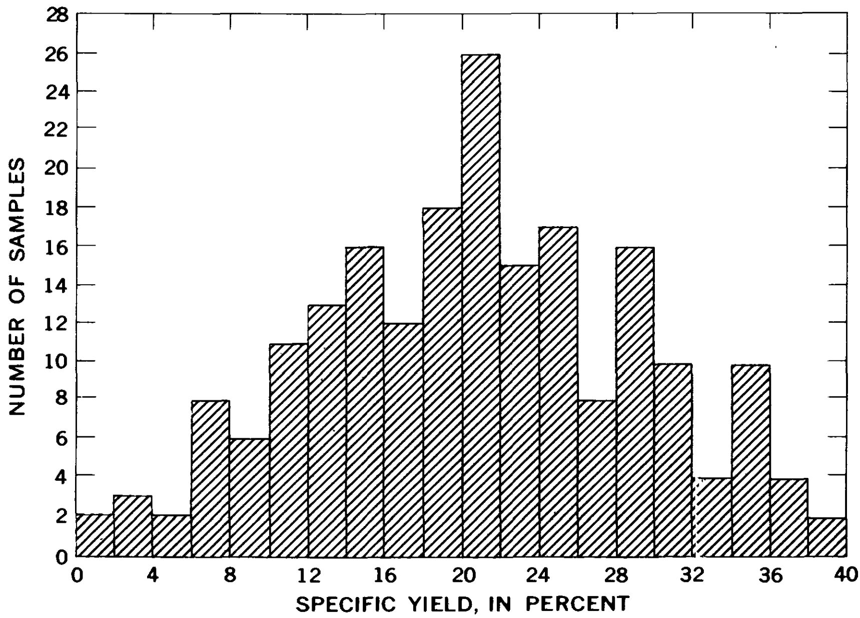

FIGURE 8.—Histogram showing the frequency distribution of specific-yield values for 209 sediment samples from the valley of the Humboldt River near Winnemucca, Nev.

Furthermore, the mean and median specific yield of samples whose median grain-size diameters are in the silt-size class are unusually high—about 19 percent.

TABLE 9.—*Laboratory specific-yield values of sediment samples from the valley of the Humboldt River near Winnemucca, Nev.*

	Particle-size diameter, in millimeters								All samples
	0.004–0.0625	0.0625–0.125	0.125–0.25	0.25–0.5	0.5–1	1–2	2–4	4–8	
Number of samples whose median-particle-size diameter values are within the size range indicated	121	15	17	23	6	19	7	1	209
Mean specific yield, in percent	19.1	21.4	25.9	25.9	22.2	20.8	17.4	17.4	20.7
Median specific yield, in percent	19.3	24.0	29.8	25.1	20.3	21.4	19.6	------	21.2
Range of specific yield, in percent	1.0–34.1	2.5–36.5	7.0–35.4	7.2–39.5	10.7–35.3	4.6–36.2	4.9–27.4	------	1.0–39.5

Specific yield determined by the centrifuge-moisture-equivalent method is a measure of the volume of water that will drain by gravity from a given volume of sediments during a long period of time. Short-term specific-yield values are needed to compute seasonal changes of ground water in storage in the valley of the

Humboldt River. Even if the laboratory data could be readily converted to short-term specific-yield values, several other factors detract from their usefulness. One is that the amount of water that will drain during 1 year from a given volume of sediments in the valley of the Humboldt River is considerably less than the amount of water that is needed to refill the sediments. This difference is due principally to evapotranspiration during the summer and early fall. As ground-water levels decline during these periods, the moisture content of the sediments that formerly were in the zone of saturation commonly decreases below field capacity, which is nearly identical to specific retention. Therefore, when ground-water levels recover during the following spring, the amount of water that is needed to resaturate these sediments is equal to the amount of water that drained downward due to gravity plus the amount that was lost by evapotranspiration.

CHANGES RELATED TO RISING GROUND-WATER LEVELS

The most rapid and probably the most significant short-term changes of ground water in storage occur in the spring and early summer when ground-water levels rise rapidly in response to increased streamflow in the Humboldt River and as a result of irrigation practices. Typically, ground-water levels begin to rise in early April, soon after the beginning of the spring runoff, and reach a peak in June. The following text gives a computation of the probable average net increase of ground water in storage during the months of April, May, and June.

The study area is divided into 29 storage units for computing changes of ground water in storage; these units are shown on plate 4. All significant seasonal changes of ground water in storage associated with the flow of the Humboldt River occur within these storage units. Several criteria are used to define each of the storage units: (1) character of the deposits in the zone of water-level fluctuations, (2) extent and magnitude of the water-level fluctuations, (3) irrigation practices, and (4) vegetative cover.

The character of the deposits in the zone of water-level fluctuations and the average short-term specific yield assigned to these sediments for each storage unit are summarized in table 10. The specific-yield values are only approximate and are based upon the laboratory data, modified according to the geologic and hydrologic character of the sediments. These values are very rough approximations that are used only for short-term changes of ground water in storage, associated with rapidly rising ground-water levels in the present study area. The values were selected by considering the average specific yield of the sediments within each storage unit and the general hydrologic character of each storage unit.

TABLE 10.—*Ground-water storage units and short-term specific-yield values for rising ground-water levels in the valley of the Humboldt River near Winnemucca, Nev.*

Storage unit	Material within zone of ground-water level fluctuations	Assigned specific yield (percent)
Toby Ranch	Gravel; sand and gravel (partly lacustrine and partly alluvial-fan deposits).	12
Lower McNinch Ranch	Sand and gravel; silt and silty clay (flood-plain deposits).	8
Lower Hillyer Ranch	Sand, medium- to coarse-grained (lacustrine deposits).	12
Clear Creek	Sand and gravel; gravel; silty sand and gravel (alluvial-fan deposits).	10
Krum	Sand and gravel; gravel; silty sand and gravel (alluvial-fan deposits).	10
Airport	Silty clay; silt (lacustrine deposits)	2
Harrer Ranch	Gravel; sand and gravel (lacustrine deposits).	20
Upper Hillyer Ranch	Clayey silt; very fine grained to medium-grained sand; sand and gravel; gravelly silt and sand (flood-plain deposits).	6
Western Pacific	Sand and gravel; gravel; sand (lacustrine deposits).	20
Harmony Creek	Sand and gravel; gravel; silty sand and gravel (alluvial-fan deposits).	10
Winnemucca	Clayey silt, high secondary porosity; silt (flood-plain deposits).	6
Weso	Sand and gravel; gravel; medium-grained to very coarse-grained sand (lacustrine deposits).	20
Kearns Ranch	Clayey silt, high secondary porosity; silt; silty gravel (flood-plain deposits).	6
Prospect West	Sand and gravel, silty (alluvial-fan deposits)	10
Little Humboldt River	Clayey silt; silt (flood-plain deposits)	4
Prospect East	Sand and gravel, silty and sandy (alluvial-fan deposits).	6
Bliss	Gravel; sand and gravel; silty sand and gravel (partly lacustrine and partly alluvial-fan deposits).	15
Paradise Valley	Sand and gravel, silty (alluvial deposits?)	10
Pole Creek	Sand and gravel, silty (alluvial-fan deposits).	10
Bull Head	Sand and gravel; medium- to coarse-grained sand (lacustrine deposits).	20
Diamond S Ranch	Clayey silt; very fine grained to medium-grained sand; sand and gravel; gravelly silt and sand (flood-plain deposits).	6
Eden Valley	Sand and gravel, silty (alluvial-fan deposits)	10
Rock Creek	Sand and gravel, silty (alluvial-fan deposits)	10
Golconda	Clayey silt; very fine grained to medium-grained sand; sand and gravel; gravelly silt and sand (flood-plain deposits).	6
Preble	Sand and gravel, silty (alluvial-fan and slope-wash deposits).	5
Stahl Dam	Clayey silt; silty sand and gravel (flood-plain deposits and interbedded alluvial-fan and slope-wash deposits).	4
Edna Mountain	Sand and gravel, silty (alluvial-fan and wash deposits).	5
Comus	Clayey silt; silty sand and gravel; fine- to medium-grained sand (flood-plain deposits).	6
Bains Ranch	Sand and gravel, silty (alluvial-fan deposits)	10

For example, the average short-term specific yield (for rapidly rising water levels) assigned to the airport storage unit is 2 percent. Based solely upon laboratory data, the average long-term specific yield of the sediments within the zone of water-level fluctuation (clayey silt) is about 20 percent. An average short-term specific-yield value of about 20 percent for these dense fine-grained sediments is considered far too large. Accordingly, the short-term specific yield for rapidly rising water levels of the deposits in the zone of water-level fluctuation in the airport storage unit is estimated as only 2 percent.

Table 11 shows the data used to compute the increase of ground water in storage during the period April, May, and June of an aver-

TABLE 11.—*Increase of ground water in storage resulting from rising ground-water levels during April, May, and June in the valley of the Humboldt River near Winnemucca, Nev.*

(1) Storage unit	(2) Area (acres)	(3) Average rise of ground-water levels [1] (feet)	(4) Assigned specific yield [2] (percent)	(5) Increase of ground-water in storage [3] (acre-feet)
Toby Ranch	4, 350	1	12	500
Lower McNinch Ranch	3, 400	3	8	800
Lower Hillyer Ranch	1, 400	1	12	200
Clear Creek	2, 550	. 5	10	100
Krum	7, 950	. 5	10	400
Airport	7, 800	1	2	200
Harrer Ranch	4, 300	1	20	900
Upper Hillyer Ranch	4, 400	3	6	800
Western Pacific	1, 550	1	20	300
Harmony Creek	4, 950	. 5	10	300
Winnemucca	1, 900	3	6	300
Weso	2, 600	1	20	500
Kearns Ranch	5, 500	3	6	1, 000
Prospect West	1, 250	. 5	10	60
Little Humboldt River	1, 500	4	4	300
Prospect East	1, 300	. 5	10	100
Bliss	3, 700	1	15	600
Paradise Valley	5, 800	. 5	10	300
Pole Creek	4, 500	. 5	10	200
Bull Head	1, 800	1	20	400
Diamond S Ranch	4, 350	3	6	800
Eden Valley	6, 750	. 5	10	300
Rock Creek	1, 250	1	10	100
Golconda	1, 000	3	6	200
Preble	580	. 5	5	10
Stahl Dam	380	5	4	80
Edna Mountain	560	. 5	5	10
Comus	2, 710	3	6	500
Bains Ranch	1, 930	. 5	10	100
Total (rounded)	92, 000			10, 000

[1] See text, page 58.
[2] See table 10.
[3] Columns 2×3×4, rounded.

age water year. Although enough data are not available to determine precisely the average rise of ground-water levels for this 3-month period in an average year, the average rise of ground-water levels assigned to each storage unit is roughly correct for this 3-month period during an average water year. Table 11 shows that for the indicated rise of ground-water levels in April, May, and June, the net increase of ground water in storage is about 10,000 acre-feet.

SUMMARY AND CONCLUSIONS

The preliminary estimate of ground-water underflow from tributary valleys to the study area in recent years is 14,000–19,000 acre-feet per year. Estimated underflow out of the study area near the Rose Creek gaging station is 4,000–9,000 acre-feet per year. During the last 12 years of record, water years 1949–60, streamflow at the Comus gaging station averaged about 14,000 acre-feet per water year more than streamflow at the Rose Creek gaging station. An estimated average of 11,000 acre-feet per year of ground water discharged into the Humboldt River in the study area. Thus, the average loss of streamflow during the 12-year period actually was about 25,000 acre-feet per year.

More than 65 percent of the total streamflow of the Humboldt River was during the irrigation season—April, May, and June. Also, streamflow of the Humboldt River during the 3-month period averaged about 23,000 acre-feet more at the upstream margin of the segment of the river than at the downstream margin of the segment. An average estimate of about 10,000 acre-feet of the 23,000 acre-feet of water apparently lost in this segment was temporarily stored in the ground-water reservoir bordering and underlying the Humboldt River and subsequently was partly transpired by phreatophytes and partly discharged into the Humboldt River. The rest of the 23,000 acre-feet of water apparently lost was stored in the zone of soil moisture, transpired by plants, or evaporated.

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