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AN EVALUATION OF THE WATER RESOURCES OF THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEVADA

By PHILIP COHEN

With sections on

Surface Water
By R. L. Hanson

Water-use Studies Utilizing Evapotranspiration Tanks
By T. W. Robinson

and

Water-content Changes in Shallow Flood-plain Deposits at Three Sites
By A. O. Waananen

Prepared in cooperation with the

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GEOLOGICAL SURVEY

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ILLUSTRATIONS

TABLES

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FOREWORD

This bulletin, entitled, "An Evaluation of the Water Resources of the Humboldt River Valley Near Winnemucca, Nevada," prepared by Mr. Philip Cohen of the U.S. Geological Survey, is No. 24 in the series of Water Resources Bulletins of the Department of Conservation and Natural Resources.

This bulletin summarizes much of the technical information on the geology and hydrology of the area which has been collected over the past several years in the operations of the Humboldt River Research Project. Information has been drawn from reports which have been made on studies conducted by the Desert Research Institute and the Mackay School of Mines of the University of Nevada, and the Department of Geology of the University of Illinois, as well as those carried out by the U.S. Geological Survey. Data on soils and vegetation in the area have been contributed from surveys conducted by the Soil Conservation Service. The Agriculture Research Service and the General Hydrology Branch of the U.S. Geological Survey have furnished data from their experiments on the consumptive use of water by meadow grasses and sedges and by woody phreatophytes. Detailed climatic data have been collected at the Winnemucca experimental plot from a class A weather station operated by the Department of Conservation and Natural Resources.

The quantitative estimates given in previously prepared interim reports are refined in this bulletin. It gives the final results of those phases of the study that have been completed and also gives the preliminary results of the phreatophytic and soil moisture studies. Qualitative interrelationships among the hydraulic systems are described in considerable detail. In addition, the quantitative interrelations are summarized by means of water budget analyses prepared for high, low, and normal water supply years.

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AN EVALUATION OF THE WATER RESOURCES OF THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEVADA

By Philip Cohen

ABSTRACT

This report, resulting from studies made by the U.S. Geological Survey as part of the interagency Humboldt River Research Project, describes the qualitative and quantitative relations among the components of the hydrologic system in the Winnemucca Reach of the Humboldt River valley. The study area includes the segment of the Humboldt River valley between the Comus and Rose Creek gaging stations. It is almost entirely in Humboldt County in north-central Nevada, and is about 200 miles downstream from the headwaters of the Humboldt River.

Agriculture is the major economic activity in the area. Inasmuch as the valley lowlands receive an average of about 8 inches of precipitation per year and because the rate of evaporation from free-water surfaces is about six times the average annual precipitation, all crops in the area (largely forage crops) are irrigated. About 85 percent of the cultivated land is irrigated with Humboldt River water; the remainder is irrigated from about 20 irrigation wells.

The consolidated rocks of the uplifted fault-block mountains are largely barriers to the movement of ground water and form ground-water and surface-water divides. Unconsolidated deposits of late Tertiary and Quaternary age underlie the valley lowlands to a maximum depth of about 5,000 feet. These deposits are in hydraulic continuity with the Humboldt River and store and transmit most of the economically recoverable ground water. Included in the valley fill is a highly permeable sand and gravel deposit having a maximum thickness of about 90 to 100 feet; it underlies the flood plain and bordering terraces throughout most of the project area. This deposit is almost completely saturated and contains about 500,000 acre-feet of ground water in storage.

The Humboldt River is the source of 90 to 95 percent of the surface-water inflow to the study area. In water years 1949–62 the average annual streamflow at the Comus gaging station at the upstream margin of the area was 172,100 acre-feet; outflow at the Rose Creek gaging station averaged about 155,400 acre-feet. Accordingly, the measured loss of Humboldt River streamflow averaged nearly 17,000 acre-feet per year. Most of this water was transpired by phreatophytes and crops, evaporated from free-water surfaces, and evaporated from bare soil.

Inasmuch as practically no tributary streamflow normally discharges into the river in the Winnemucca Reach and because pumpage is virtually negligible during the nonirrigation season, gains and losses of streamflow during most of the year reflect the close interrelation of the Humboldt River and the ground-water reservoir. An estimated average of about 14,000 acre-feet per year of ground-water underflow moves toward the Humboldt River from tributary areas. Much of this water discharges into the Humboldt River; however, some evaporates or is transpired before reaching the river.

More than 65 percent of the average annual flow of the river normally occurs in April, May, and June, owing to the spring runoff. The stage of the river usually rises rapidly during these months causing water to move from the river to the ground-water reservoir. Furthermore, the period of high streamflow normally coincides with the irrigation season, and much of the excess irrigation water diverted from the river percolates downward to the zone of saturation.

The net measured loss of streamflow in April–June, which averaged about 24,000 acre-feet in water years 1949–62, was about 7,000 acre-feet more than the average annual loss. The estimated net average annual increase of ground water in storage during these months in this period was on the order of 10,000 acre-feet. Following the spring runoff and the irrigation season, normally in July, some of the ground water stored in the flood-plain deposits during the spring runoff begins to discharge into the river. In addition, ground-water inflow from tributary areas again begins to discharge into the river.

Experiments utilizing a neutron-scattering soil-moisture meter suggest that considerable water is

stored in the zone of aeration in the shallow flood-plain deposits during the spring runoff. Most of this water eventually evaporates or is transpired by phreatophytes. Preliminary results of evapotranspiration experiments indicate that, of the plants studied, willow uses the most water, about 4 acre-feet per acre per year.

Sodium and bicarbonate commonly are the most abundant ions in the surface water and ground water of the area. The dissolved-solids content of most of the ground water is less than 600 ppm, although locally it is more than 5,000 ppm. Almost all the water is moderate to very hard; otherwise, it is suitable for most uses.

In December 1961, nearly all the water in the Humboldt River between the Comus and Rose Creek gaging stations was seepage from the ground-water reservoir. The chemical quality of the river largely reflected the chemical quality of ground-water underflow from tributary areas.

An estimated average of 95,000 to 120,000 acre-feet per year of the total inflow to the lowlands of the study area, including streamflow, ground-water inflow, and precipitation, was lost by evapotranspiration in water years 1949–62. Increased irrigation efficiency and the conjunctive use of ground water and surface water would conserve much of this water. However, intensive ground-water development, especially from the sand and gravel aquifer beneath the flood plain, will partly deplete the flow of the Humboldt River and may infringe upon downstream surface-water rights.

INTRODUCTION

THE HUMBOLDT RIVER RESEARCH PROJECT

The Humboldt River Research Project is a Federal-State cooperative interagency study largely concerned with developing data and techniques needed to evaluate the water resources of the Humboldt River basin. The project was authorized by the 1959 Nevada Legislature (Ch. 97, Stats. 1959), and the Nevada Department of Conservation and Natural Resources was designated the coordinating agency. Federal agencies participating in the study are the United States Geological Survey, Bureau of Reclamation, Bureau of Land Management, Soil Conservation Service, Agricultural Research Service, Forest Service, and the Weather Bureau. State agencies participating in the study are the Nevada Department of Conservation and Natural Resources, including the Division of Water Resources and the Division of Forestry; the University of Nevada, including the Department of Geology, the Max C. Fleischmann College of Agriculture, and the Desert Research Institute; the Nevada Bureau of Mines; and the Department of Geology of the University of Illinois. Each agency is studying one or more aspects of the hydrologic system or related physical and economic features of the basin.

The principal hydrologic objective of the project is to provide the information needed to achieve the most effective use of the water resources of the basin. Specifically, information was desired relative to (a) the amount, disposition, and chemical quality of water in the basin, (b) the interrelations among the components of the hydrologic system, and (c) the effects of possible modifications of the hydrologic regimen. Research aspects of the study include devising and testing methods for evaluating the components of the hydrologic system, and determining the feasibility of replacing phreatophytes with more beneficial vegetation.

Because of the large size of the basin and because of the complexity of the hydrologic system, most of the initial studies are being made in the so-called "Winnemucca Reach" of the Humboldt River valley (page 14). Less intensive preliminary studies are being made by some of the agencies in the upstream reaches of the basin.

SCOPE OF THE INVESTIGATION AND PURPOSE OF THE REPORT

In 1959 the U.S. Geological Survey entered into a cooperative agreement with the Nevada Department of Conservation and Natural Resources to participate in the interagency Humboldt River Research Project. It was agreed that the Geological Survey would study the following components of the hydrologic system in the Winnemucca Reach of the Humboldt River valley: (a) Ground-water recharge and surface-water inflow; (b) routing, disposition, and storage of ground and surface water within the area; (c) ground-water discharge and surface-water outflow; (d) use of water by selected phreatophytes, including greasewood, rabbitbrush, willow, and wildrose; and (e) the chemical quality of the water. In 1961 the participation by the Geological Survey was expanded to include an evaluation of the use of a neutron-scattering soil-moisture meter to determine changes in the total water content of the shallow flood-plain deposits. In 1962 the Geological Survey accepted the responsibility of preparing an interagency summary report when the work of all the participating agencies is completed.

Field work began in 1959 and most of it was completed by December 1962. The research aspects of the Geological Survey's studies, the phreatophyte and soil-moisture experiments, probably will be continued for several years. The work has been accomplished in large part with cooperative funds made available jointly by the Geological Survey and the State. The Bureau of Reclamation is supplying funds to help defray the cost of the phreatophyte experiments.

Three moderately detailed interim reports and several short papers and progress reports, describing field and laboratory procedures and giving the preliminary results of the studies, have been prepared. (See page 16.) The purpose of this report is to summarize the hydrogeologic information and refine the quantitative estimates given in those reports, to give the final results of the completed studies, and to describe the preliminary results of the phreatophyte and soil-moisture studies.

Some aspects of the climatology and geology of the area and their relation to the hydrologic system are described. The geology is considered briefly and only to the extent that it bears upon the hydrologic system. Quantitative and qualitative interrelations among the major components of the hydrologic system, especially those between the Humboldt River and the ground-water reservoir, are emphasized. To describe further the quantitative interrelations among the components of the hydrologic system, preliminary hydrologic-budget analyses are given for three selected time intervals. Finally, the results of the hydrologic studies are used to evaluate some of the more significant water-management problems.

The investigation was begun under the direct supervision of O. J. Loeltz, formerly district engineer of the Ground Water Branch of the Geological Survey in charge of ground-water studies in Nevada, and was completed under the supervision of G. F. Worts, Jr., district chief in charge of hydrologic investigations in the State. The ground-water and interpretive water-quality studies were made by Philip Cohen, assisted by R. A. Lyman, Jr. R. L. Hanson was in charge of the surface-water studies. T. W. Robinson supervised the phreatophyte experiments, and the soil-moisture studies were made by A. O. Waananen. Particle-size-distribution, specific-yield, and permeability determinations were made at the Geological Survey's Hydrologic Laboratory under the supervision of A. I. Johnson. In addition, a power auger operated by personnel of the Hydrologic Laboratory was used to drill several hundred test holes and complete about 160 observation wells (Plate 5). Chemical analyses of water samples were made at the Geological Survey laboratories in Sacramento, California, under the supervision of Eugene Brown.

LOCATION AND GENERAL GEOGRAPHIC FEATURES

The Humboldt River drainage basin, which has an area of about 18,000 square miles, includes about 16 percent of the total area of Nevada (Figure 1) and about one-third the irrigated land of the State. Agriculture is the major economic activity, and cattle raising and the production of forage crops, nearly all of which are irrigated, provide most of the agricultural income. About 80 percent of the irrigated land in the basin, approximately 230,000 acres, is irrigated with Humboldt River water.

The project area as described in this report includes the entire area shown on the plates accompanying the report. It is about 520 miles in area (Figure 1). It comprises the Winnemucca Reach of the Humboldt River valley between the Comus gaging station ("Humboldt River at Comus") in the SE¼NE¼SE¼ sec. 14, T. 36 N., R. 41 E., and the Rose Creek gaging station ("Humboldt River Near Rose Creek") in the NW¼SE¼NW¼ sec. 36, T. 35 N., R. 35 E. The gaging stations are about 22 miles east and 15 miles southwest of the city of Winnemucca, respectively.

In addition to the Humboldt River valley, the project area includes the downstream segments of Paradise and Grass Valleys and parts of the mountains and foothills bordering the Humboldt River valley.

The mountains trend roughly northward and their crests range in altitude from about 7,500 to 9,500 feet. The altitude of the Humboldt River is about 4,360 feet at the Comus gaging station, about 4,260 feet at Winnemucca, and about 4,200 feet at the Rose Creek gaging station. Accordingly, the maximum relief of the area is on the order of 5,000 feet.

Meadow grasses are the principal crops raised in the area. About 85 percent of the irrigated land is on the flood plain of the Humboldt River and practically all the irrigation water for this land is diverted from the Humboldt River. Meadows on the flood plain are irrigated partly by overbank flooding and partly by diversionary structures and a network of unlined ditches. All of the diversionary structures are privately owned, the largest being the Stahl Dam about 15 miles east of Winnemucca (Figure 6). The acreage of irrigated land is difficult to estimate because it changes markedly from year to year depending largely on the flow of the Humboldt River. During years of average or near average streamflow, about 50 percent of the flood plain, or about 12,000 acres, is irrigated; in years of low flow probably only about 20 percent of the flood plain, or about 5,000 acres, is irrigated.

Some of the smaller streams in the area, notably Kelly, Rock, Pole, Thomas, and Rose Creeks, also are used to irrigate meadow grasses and alfalfa. During the irrigation season, virtually all the water from Kelly Creek is diverted upstream from the project area. Water from Pole and Rock Creeks is used to irrigate the lower alluvial slopes and flood plain near the town of Golconda. Thomas Creek is diverted onto cultivated land in the mouth of Grass Valley, and Rose Creek is used to irrigate land near the toe of the alluvial fan.

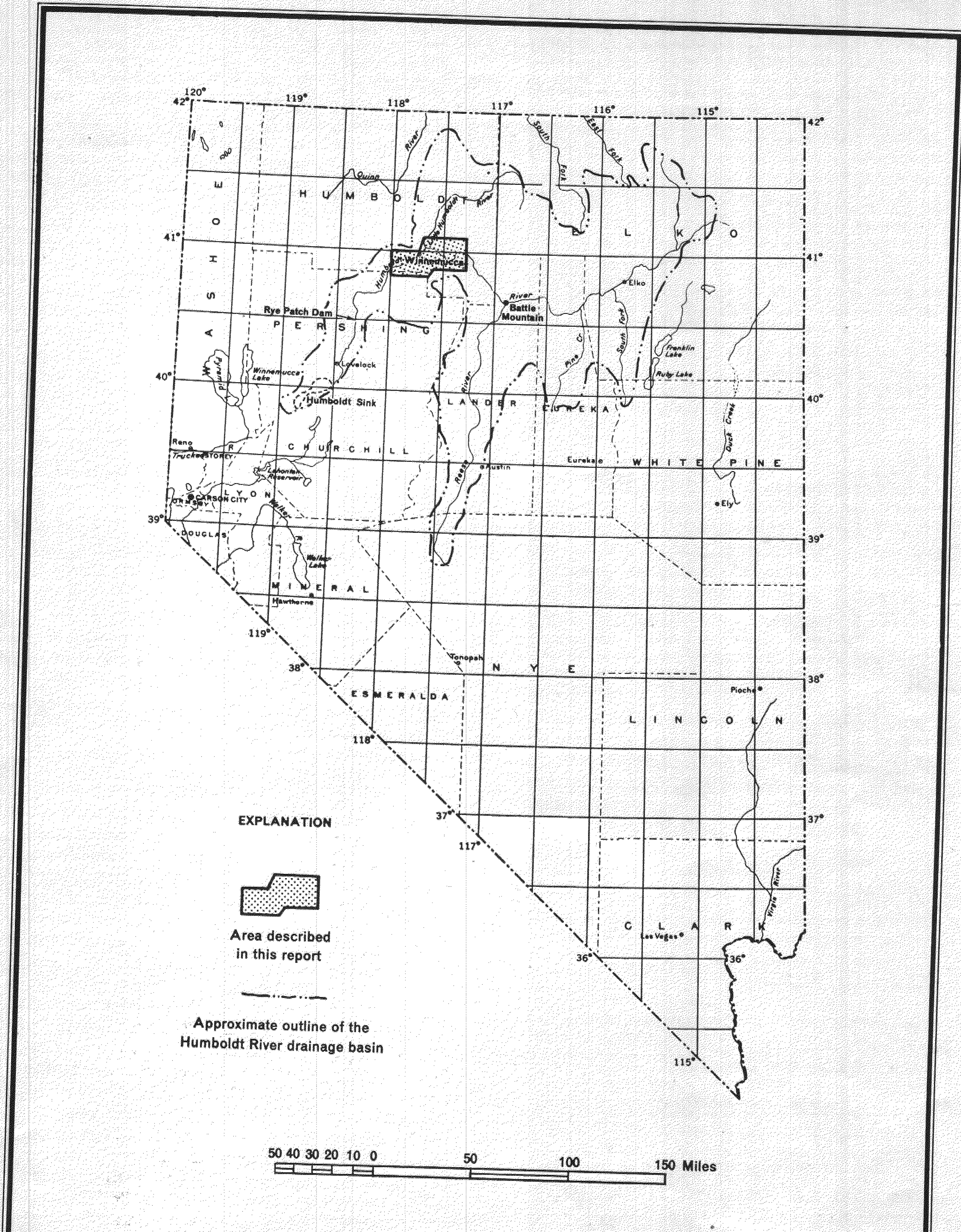

FIGURE 1.— Map of Nevada showing the location of the area described in this report

In 1962 about 20 wells were used for irrigation. Crops irrigated by ground water include native grasses, alfalfa, small grains, and potatoes. Most of the acreage irrigated with ground water is in the mouth of Grass Valley and on the terraces bordering the Humboldt River.

Winnemucca formerly was the center of a thriving mining industry. The principal products were gold, silver, mercury, and tungsten. At present little mining is done in the area, although recently one of the larger gold mines, about 30 miles east of the project area, was reactivated. The population of Winnemucca, the county seat of Humboldt County, was nearly 3,500 in 1960.

PREVIOUS WORK

Many published and unpublished reports on the hydrology, geology, and other physical features of the project area and vicinity have been prepared. Reports of historic interest, those used in the preparation of this report, and those prepared as part of the Humboldt River Research Project are described in the following paragraphs.

The first investigation of the geology of the project area was made during the survey of the 40th parallel under the direction of King (1878). The geology of the Lake Lahontan deposits in Nevada, including those exposed in the project area, was described by Russell (1883, 1885). Some of the informal stratigraphic terms introduced by Russell are maintained, with only slight modification, in the present report. Ferguson, Muller, and Roberts (1951) and Ferguson, Roberts, and Muller (1952) mapped the geology of the Winnemucca and Golconda quadrangles, respectively. They concentrated most of their efforts on the geology of the consolidated rocks. A reconnaissance geologic map of Humboldt County was prepared by Willden (1961), and the geology of the Osgood Mountains quadrangle near the eastern margin of the project area was mapped by Hotz and Willden (1961).

A report describing the occurrence of ground water in Paradise Valley was prepared by Loeltz, Phoenix, and Robinson (1949). Ground water in Grass Valley was described by Robinson, Loeltz and Phoenix (1949). Water and related land resources of Paradise Valley, and floods in the Humboldt River basin were described in joint publications by the Nevada Department of Conservation and Natural Resources and the U.S. Department of Agriculture (1962a, b). Thomas and Lamke (1962) discussed floods in the Humboldt River basin in 1962.

Published reports resulting from the Humboldt River Research Project include a general description of the project by Maxey and Shamberger (1961), a description of geophysical studies by Dudley and McGinnis (1962), and analyses of several aspects of the hydrogeology of the area by Cohen (1961a, b, and c; 1962a, b, c, and d; and 1963). Four interagency progress reports largely describing the purpose and scope of the project, field techniques, and preliminary results of some of the studies were published by the Nevada Department of Conservation and Natural Resources (1960, 1961, 1962, and 1963).

A moderately detailed report describing the hydrogeology of the area has been prepared (Cohen, in press). Five unpublished theses resulting from studies made as part of the Humboldt River Research Project have been completed. These describe the results of geophysical studies by G. M. Wilson (1960), an evaluation of the occurrence of carbonate compounds in the alluvial fans by Onuschak (1960), studies of Lake Lahontan stratigraphy by Cartwright (1961), an evaluation of the Pleistocene and Recent geology by Hawley (1962), and studies of the lithology and geomorphology of the piedmont slopes by W. E. Wilson (1962).

NUMBERING OF CONTROL POINTS AND SAMPLES

Numbering of all control points and samples, except streamflow measuring stations along the Humboldt River and water samples from the river, is based on the rectangular system for the subdivision of public lands (Figure 2). Accordingly, the numbers both identify and locate each control point and sample. The first unit of each number indicates the township north of the Mount Diablo base line. The second unit, separated from the first by a slant, indicates the range east of the Mount Diablo meridian. The third unit, separated from the first two units by a hyphen, lists the section number, followed in turn by three letters that designate the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section, respectively. The three letters are followed by a number that indicates the chronological order in which the control point was recorded within the 10-acre subdivision. The letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast quarters of each unit. For example, well number 36/37–25bdbl designates the first well recorded in the NW¼SE¼NW¼ sec. 25, T. 36 N., R. 37 E., Mount Diablo base line and meridian. Because of the limitation of space, only that part of the

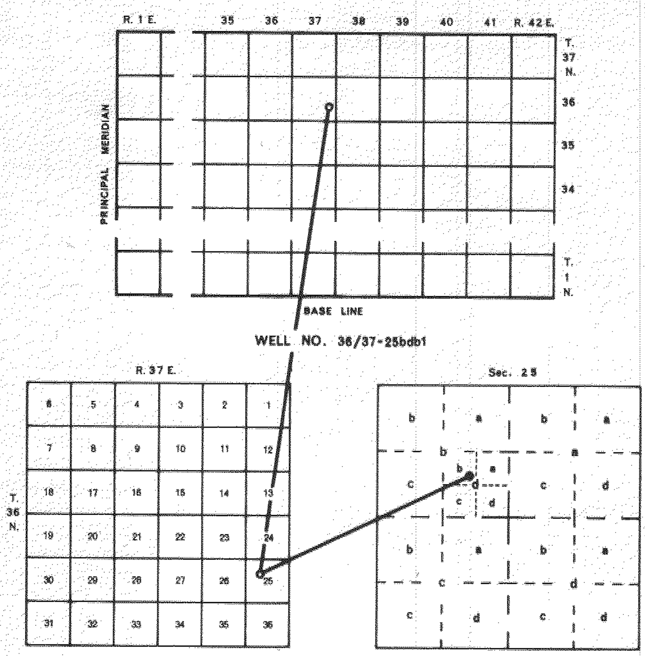

FIGURE 2.— Diagram showing numbering system for wells, springs, other control points, and samples

number designating the subdivision of the section and the order in which the control point was recorded is shown on the maps accompanying this report.

For clarity and in accordance with previous usage, streamflow measuring stations along the Humboldt River are identified by capital letters. The letters assigned to these stations and their location are listed in Table 12.

Samples are given numbers corresponding to the sites at which they were obtained. The order in which a sample was obtained at a given site is indicated by a number, preceded by a hyphen, following the control-point number or letter. For example, number 36/37–25bdbl–2 was assigned to the second water sample obtained from the previously described well; water sample M–3 is the third sample obtained from the Humboldt River at streamflow measuring station M.

ACKNOWLEDGMENTS

The cooperation and assistance of various local, state, and federal agencies, private companies, and residents of the study area are gratefully acknowledged. Personnel of the Nevada Department of Conservation and Natural Resources were of assistance during virtually every phase of the study. The Soil Conservation Service provided detailed topographic maps and low-altitude aerial photographs of the river flood plain. The Southern Pacific Co. provided topographic maps of parts of the project area. In addition, the Southern Pacific Co. and the Western Pacific Railroad Co. provided access to and permitted test drilling on their lands.

Local residents permitted test drilling and access to their property and their cooperation is appreciated. The cooperation and assistance of Mr. and Mrs. H. Harrer, on whose property the evapotranspiration experimental site was established, is especially appreciated.

Special acknowledgment is given J. W. Hawley, formerly of the Nevada Department of Conservation and Natural Resources. Dr. Hawley's studies of the geology of the area provided the basis for much of the geologic information given in this report.

CLIMATE

The most significant factors controlling the climate of the project area are the regional prevailing eastward flow of air and the Sierra Nevada range about 150 miles to the west. Warm moist air masses moving eastward from the Pacific Ocean are forced aloft by the Sierra Nevada and, as a result, the air cools and moisture condenses causing heavy precipitation in the mountains. Consequently, air masses moving eastward over the project area normally have a low moisture content causing the climate of the valley lowlands to be arid to semiarid. Orographic effects, similar to those caused by the Sierra Nevada but of a lesser magnitude, result in greater precipitation in the mountain ranges of the project area where the climate locally is subhumid.

Weather records have been obtained by the U.S. Weather Bureau at and near Winnemucca since 1870. Prior to 1948, the station was in Winnemucca. In 1948 the station was moved to the Winnemucca airport, about 6 miles southwest of the city. Table 1 and Figures 3, 4, and 5 summarize temperature and precipitation data. The mean daily temperature is 49°F. The highest temperature of record, 108°F., occurred on July 20, 1931; the lowest temperature of record, —36°F., occurred on January 21, 1937. Owing largely to the normally very low humidity and the relatively high altitude of the project area, diurnal temperature fluctuations of more than 50°F., are common. Freezing temperatures have occurred in every month of the year but are not common in June, July, and August.

The average annual precipitation for the period 1871–1962 is 8.40 inches. Most of the precipitation normally occurs in December and January; the least precipitation normally occurs in July and August (Figure 5). In the winter, precipitation normally occurs as snow and, in the summer, commonly as rain from isolated thunderstorms. During the period of record, precipitation of nearly an inch or more in a 24-hour period occurred in every month of the year but August. The maximum monthly recorded precipitation, 5.23 inches, occurred in March 1884. No precipitation occurred in many months.

In Figure 4, the slope of the graph showing cumulative departure from average precipitation indicates whether precipitation in a given year or in several successive years was above or below average. A positive or upward slope to the right indicates above-average precipitation; a negative slope indicates below-average precipitation. A cumulative deficiency of precipitation of about 11 inches occurred during the 10-year period 1871–80. The period 1880–85 was one of above-average precipitation. Although there were some years of above-average precipitation, the period 1885–1933 was characterized largely by below-average precipitation. Precipitation generally was

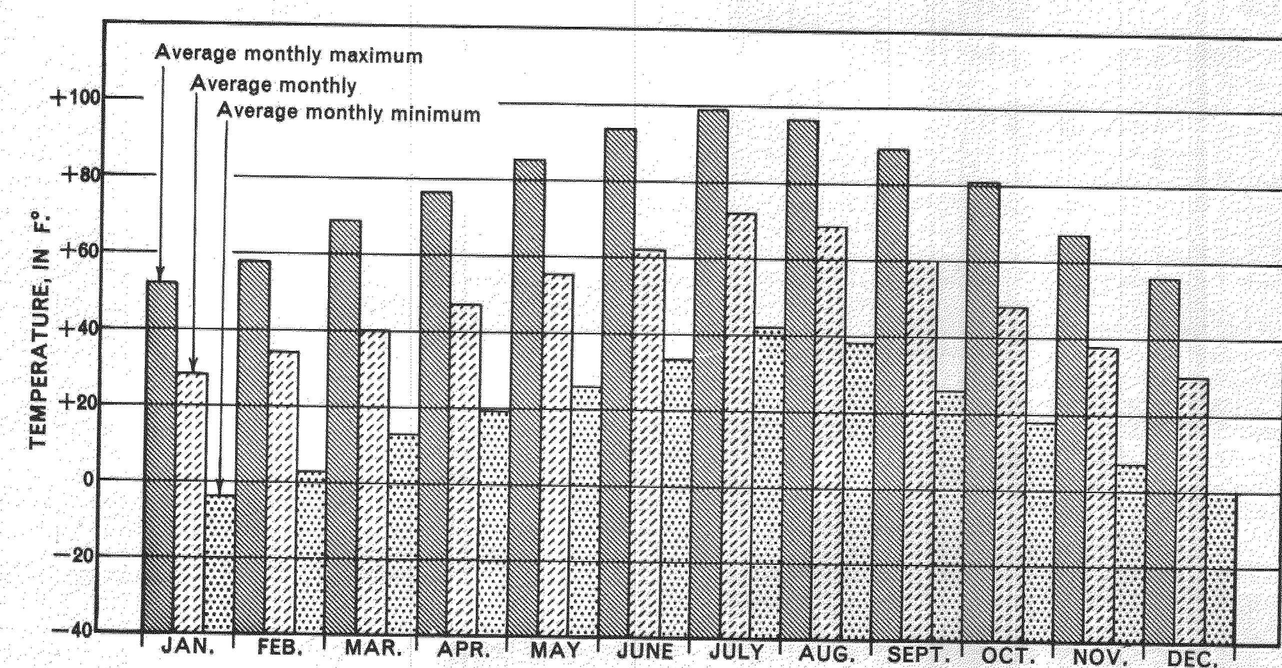

FIGURE 3.—Average monthly temperature data at and near Winnemucca, Nev., 1872-1962

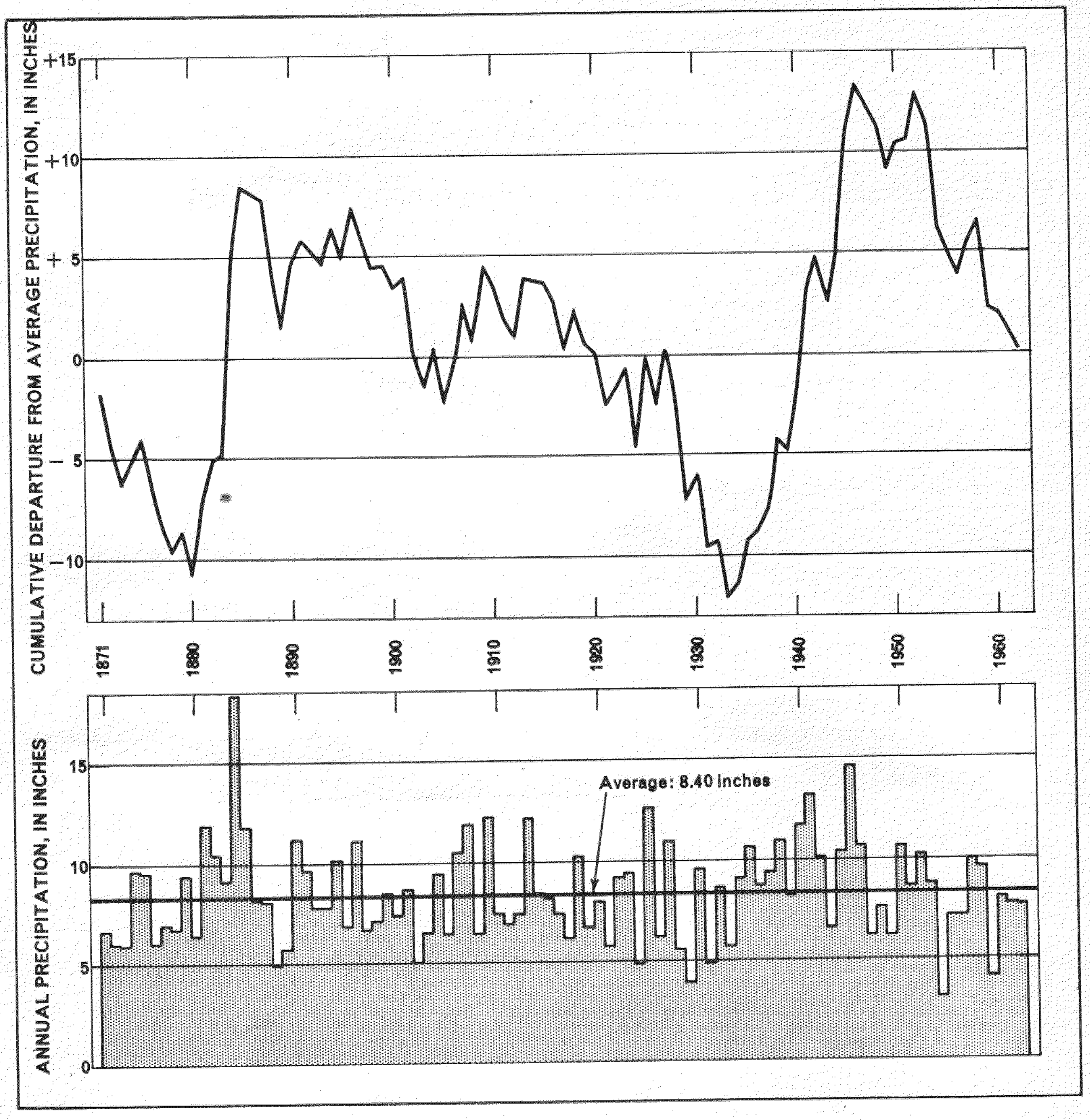

FIGURE 4.— Annual precipitation and cumulative departure from average precipitation at and near Winnemucca, Nev., 1871-1962

TABLE 1—SUMMARY OF CLIMATOLOGICAL DATA AT AND NEAR WINNEMUCCA, NEVADA

[Data from published records of the U.S. Weather Bureau]

	Period (years)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	The year
Average monthly maximum temperature, degrees Fahrenheit	83	52	58	69	77	86	94	99	97	90	81	67	56	78
Average monthly minimum temperature, degrees Fahrenheit	83	—4	3	13	19	26	33	42	38	26	18	7	0	18
Average monthly temperature, degrees Fahrenheit	83	28	34	40	47	55	62	72	69	60	48	38	30	49
Highest temperature of record, degrees Fahrenheit	83	61	69	82	88	98	104	108	106	103	90	75	70	108
Lowest temperature of record, degrees Fahrenheit	83	—36	—26	—3	9	12	23	29	26	12	9	—9	—27	—36
Average monthly precipitation, inches	91	1.05	.92	.90	.78	.88	.68	.22	.18	.36	.67	.77	.99	.70
Maximum monthly precipitation, inches	91	3.08	2.75	5.23	3.34	2.82	2.86	1.55	1.26	1.53	2.93	3.78	3.40	5.23
Minimum monthly precipitation, inches	91	0	*	0	.06	.02	0	0	0	0	0	0	*	0
Maximum 24-hour precipitation, inches	82	1.45	.99	.97	.92	1.44	1.56	1.85	.59	1.00	1.58	1.56	1.08	1.85

*Trace.

considerably above average in the period 1933–46 and below average in the period 1952–62.

Evaporation-pan data have been obtained in the Winnemucca area only since the beginning of the Humboldt River Research Project. The average annual rate of evaporation cannot be estimated from these meager data; however, data obtained at Rye Patch Reservoir (page 26) and data given by Kohler, Nordenson, and Baker (1959) suggest that the average rate of evaporation from free-water surfaces in the Winnemucca area is on the order of 4 feet per year. Accordingly, the estimated average annual rate of evaporation from free-water surfaces is nearly six times the average annual precipitation.

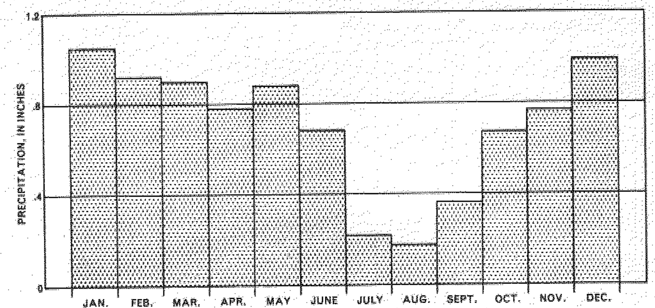

FIGURE 5.— Average monthly precipitation at and near Winnemucca, Nev., 1871-1962

GEOLOGY AND ITS RELATION TO THE HYDROLOGIC SYSTEM

Many aspects of the hydrology and geology of the area are closely related. It is apparent that streamflow characteristics are at least partly related to the geomorphology and geometry of the stream channels. Similarly, the rate of ground-water movement is a function of several interrelated geologic and hydrologic parameters. Largely because of orographic effects, even the occurrence and intensity of precipitation is controlled partly by the geology of the project area. Thus, an evaluation of pertinent aspects of the geology is an integral part of an analysis of the hydrology.

LAND FORMS AND DRAINAGE

The project area is in the Great Basin section of the Basin and Range physiographic province, and the geomorphology of the area is typical of the Great Basin. The gross topographic features, elongate north-trending mountains and intervening valleys of approximately equal width, were formed as a result of displacement along roughly north-trending, high-angle, normal faults. Although some of the faults cut younger, unconsolidated, relatively permeable sedimentary deposits, most of the displacement involves older consolidated and relatively impermeable rocks. The relatively impermeable rocks of the structural highs commonly impede the movement of water between adjacent valleys and normally do not yield large quantities of water to wells. Nearly all the ground water is stored in and transmitted through relatively permeable unconsolidated sedimentary deposits filling structural lows, or is stored in and transmitted through stream-channel deposits connecting adjoining valleys.

Mountains

The ranges are asymmetrical, fault-block mountains composed largely of dense, comparatively impermeable, consolidated rocks. Their crests are the surface-water drainage divides. Similarly, the ranges are largely barriers to the movement of ground water and form ground-water divides. Because most of the precipitation occurs in the mountains, the gross directions of surface-water and ground-water movement are from the mountains toward the valley lowlands.

Most of the normal faults within and bordering the ranges dip westward; therefore, the western slopes of the ranges commonly are steeper than the eastern slopes. Some of the western slopes are eroded fault planes but most are complex fault zones that have been modified by erosion. The eastern slopes largely are modifications of the topography prior to faulting.

In overall aspect the topography is independent of the lithology and internal structure of the ranges; however, locally the topography reflects these features. The topography of areas underlain by granitic rocks, as at Winnemucca Mountain, and partly consolidated sedimentary rocks, as in parts of the East Range, is characterized by low rounded ridges and smooth valley walls. Sharp rugged crests occur in areas underlain by limestone, quartzite, and extrusive volcanic rocks. Streamflow in the latter areas commonly is less flashy and the opportunity for ground-water recharge is greater.

Alluvial Apron

The alluvial apron is the area of intermediate slope between the mountains and the comparatively flat valley floor. It consists largely of coalescing alluvial fans which are depositional features, but locally includes pediments which are erosional features.

Alluvial fans and remnants of alluvial fans of at least four ages occur in the area; however, largely on the basis of their hydrologic significance, the alluvial-fan deposits are subdivided into three units in this report (Plate 1 and Table 3). The oldest alluvial-fan deposits, mapped as older fanglomerate, are structurally deformed, deeply eroded, and occur as remnant pediment surfaces along the northwestern slope of the Sonoma Range. Isolated exposures of moderately cemented and structurally deformed fanglomerate along the slopes of the Osgood Mountains probably are equivalent in age to the deposits along the northwestern slope of the Sonoma Range and are mapped as older fanglomerate.

Most of the alluvial apron is composed of structurally deformed and moderately eroded alluvial fans of late Tertiary or Quaternary age. These alluvial-fan deposits are mapped as younger fanglomerate. The youngest alluvial fans are of Recent age and are included in the unit mapped as younger alluvium. These deposits are post-Lake Lahontan in age (page 24), for the most part are structurally undeformed, and are not appreciably eroded.

Throughout most of the year, nearly all the streamflow originating in the mountains normally is dissipated on the alluvial apron. Some of the flow evaporates, some is transpired by vegetation along the streams, and some percolates downward to the ground-water reservoir. During the spring and early summer when the flows commonly are highest, some streamflow discharges from the alluvial apron onto the valley floor where it largely evaporates or is transpired.

As a result of unusually large amounts of precipitation in August 1961 (page 57), sheet wash and mud flows occurred in the Sonoma Range. Large amounts of alluvial debris were washed out of the mountains onto the alluvial apron. According to some of the oldest residents in the area, this was one of the few times this phenomenon occurred in the last 50 years. Even during this unusually large runoff, streams flowing across the alluvial apron along the western slope of the Sonoma Range did not reach the Humboldt River, but discharged onto the floor of Grass Valley where an ephemeral lake was formed. A small amount of the flow in Pole Creek probably discharged into the Humboldt River at the time.

Valley Floor

Considerable ground-water recharge occurs on parts of the valley floor largely as a result of seepage from the Humboldt River (pages 66–68), and most of the ground-water discharge occurs there by evapotranspiration. The Humboldt River, of course, is the most prominent stream.

Features Formed by Lake Lahontan

Lake Lahontan, a large and relatively deep lake covered the lowlands of the project area in late Pleistocene time and some of the physiographic features of the valley floor were formed at that time. The maximum altitude of the lake was roughly 4,400 feet. Shoreline features and deposits formed within and near the margins of the lake suggest that, in gross aspect, two deep stages and one intervening period of desiccation characterized the history of Lake Lahontan. (See Russell, 1885; Morrison, 1961; and Cohen, 1962c.) Beaches, bars, and wave-cut terraces and scarps occur at altitudes ranging from about 4,260 to 4,400 feet. The beaches largely have been obscured by erosion and sedimentation and, therefore, are not shown in Plate 1; the more prominent wave-cut terraces and scarps are shown. The floors of Paradise and Grass Valleys, except as they have been modified by post-Lake Lahontan wind and stream action, represent the floor of the second and most recent deep stage of the lake. This surface is nearly flat, has a gradient of about 3 to 4 feet per mile to the northwest near the mouth of Grass Valley, and is almost horizontal in the mouth of Paradise Valley.

Because of its relatively recent age and low gradient the drainage system on the former floor of Lake Lahontan is poorly developed. The floor of Paradise Valley is drained by the Little Humboldt River and the floor of Grass Valley is drained by Clear Creek. Both streams have very low gradients and their channel capacities are small. As a result, nearly all the streamflow from the bordering mountains that reaches the floors of Paradise and Grass Valleys ponds and quickly evaporates. Gumboot Lake, an ephemeral lake in the mouth of Paradise Valley, contains water only during years of unusually high runoff or when sand dunes block the course of the Little Humboldt River (page 40).

The deposits of the former bottom of Lake Lahontan are composed largely of strata of silt and clay that have a very low permeability and high field capacity (ability to retain moisture in the soil against the downward pull of gravity). Accordingly, virtually none of the precipitation and practically none of the streamflow on the former bottom of Lake Lahontan recharges the ground-water reservoir.

Flood Plain and Terraces of the Humboldt River

Four relatively flat surfaces or terraces border the channel of the Humboldt River at successively higher altitudes. The highest surface, the so-called "upper terrace," is the former floor of Lake Lahontan and is largely a depositional feature. The next two lower surfaces are river-cut terraces referred to as the "middle terrace" and "lower terrace." The lowest surface is the present flood plain of the Humboldt River; it is a complex surface characterized by both depositional and erosional features.

The lower and middle terraces discontinuously border the flood plain of the Humboldt River from the downstream margin of the project area upstream to about the vicinity of Golconda. Both are nearly flat surfaces that locally have been modified by wind action; sand dunes as high as 20 feet are common. In places, as near the southwestern margin of the study area, both terraces have been removed by erosion and nearly vertical scarps about 50 feet high separate the flood plain from the upper terrace. The lower terrace is preserved only downstream from Winnemucca, and the middle terrace is best exposed between Winnemucca and Golconda. Two small remnants of the middle terrace, each less than 1 square mile in area, occur downstream from Winnemucca (Plate 1).

The downstream gradients of the lower and middle terraces vary slightly and they are about the same as that of the flood plain, averaging about 3 to 4 feet per mile. Locally, as immediately upstream from Winnemucca, the middle terrace is almost horizontal. Because the gradient of the upper terrace is somewhat less than the average gradient of the river-cut terraces and the flood plain, the height of the scarps bordering the flood plain generally becomes progressively less upstream.

The flood plain of the Humboldt River is the surface bordering the river that periodically largely is covered by flood water; it includes local physiographic features such as sand dunes that rarely if ever are covered by water. In this report the flood plain is considered a single physiographic unit. Its most characteristic geomorphic features are meander loops of the Humboldt River, meander scrolls of abandoned channels, and floodflow channels which are relatively straight depressions that normally carry water only during periods of flood or as a result of irrigation practices. (See Figures 7, 9, and 21.) The width of the meander belt of the present channel ranges from about one-half the width of the flood plain, as in sec. 15, T. 35 N., R. 36 E., to less than one-eighth the width of the flood plain, as in sec. 12, T. 36 N., R. 39 E.

The width of the flood plain ranges from about 0.2 mile to 5 miles. At the upstream margin of the project area it is about 5 miles wide; in Emigrant Canyon it narrows to about 0.2 mile in width; at Button Point it is about 0.7 mile wide; and near Winnemucca at the so-called Winnemucca narrows it is about 0.3 mile wide. The flood plain is about 1 mile wide opposite the mouth of Grass Valley and narrows to about 0.3 mile at the Rose Creek constriction.

Emigrant Canyon, the Winnemucca narrows, and the Rose Creek constriction are areas where the width of the flood plain and the thickness of the deposits of the ground-water reservoir decrease markedly. Test drilling and geophysical studies (Dudley and McGinnis, 1962, p. 11–13) suggest that bedrock occurs at a depth of about 40 to 50 feet in Emigrant Canyon. (See Plate 2, Section A-A′; and Figure 6.)

At the Winnemucca narrows the flood plain is constricted by alluvial-fans deposited along the flanks of Winnemucca Mountain and the Sonoma Range. Consolidated rock, probably basalt, reportedly was penetrated by well 36/38–19dcal at a depth of 500 feet. Well 36/38–30dcal, about half a mile southwest of Winnemucca, reportedly penetrated lava at a depth of 495 feet. Well 36/38–2bcbl, about 4.5 miles northeast of Winnemucca, reportedly penetrated consolidated rock at a depth of about 300 feet below land surface. Diamond-core test hole 37/38–34adal, about 1 mile north of well 36/38–2bcbl, penetrated basalt at a depth of about 47 feet (Plate 2, Section C-C′). Basalt is exposed at land surface about 1½ miles north and northwest of the diamond-core test hole. These data plus geophysical data (Dudley and McGinnis, 1962, p. 12–17; and G. M. Wilson, 1960) suggest that consolidated rocks form a fairly shallow

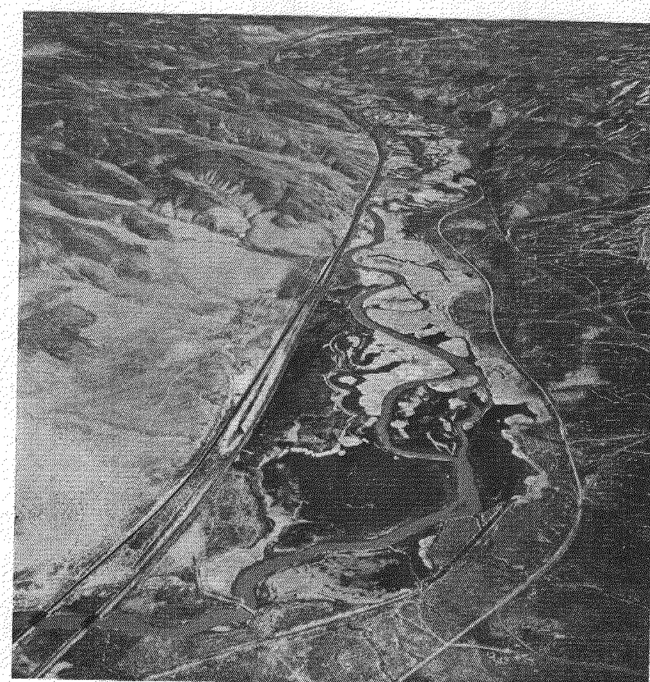

FIGURE 6.—Aerial view of Emigrant Canyon about 15 miles east of Winnemucca, Nev. View is toward the east. Virtually impermeable slate, phyllite, schist, and quartzite border the canyon. Stahl dam is in the foreground. *Photograph by L. L. Gourley.*

trough beneath the unconsolidated deposits of the ground-water reservoir in the Winnemucca narrows and in the area extending about 4 to 5 miles upstream. The buried bedrock surface appears to plunge southwestward toward the mouth of Grass Valley where the estimated depth to bedrock is on the order of 5,000 feet (G. M. Wilson, 1960).

At the Rose Creek constriction the flood plain is contained between the Krum Hills and the alluvial apron along the northern slope of the East Range. (See Plate 3, Section F-F′; and Figure 7.) A consolidated siliceous spring deposit is exposed in the NW¼ sec. 21, T. 35 N., R. 36 E.

Further, diamond-core test hole 35/36–21ccc3 penetrated consolidated rock at a depth of about 40 feet, and well 35/36–21bdb2 reportedly penetrated consolidated rock at a depth of about 15 feet and hydrothermally altered rock(?) from 15 to 430 feet. Lithologic logs of other wells in the area, test borings, water-quality data, and geophysical studies suggest that bedrock occurring at and close to land surface in the Rose Creek constriction is related to vertical displacement along the normal fault bordering the west side of the East Range and extending northeastward beneath the flood plain of the Humboldt River (Dudley and McGinnis, 1962; Cohen, 1962a; and G. M. Wilson, 1960).

FIGURE 7.—Aerial view of the Humboldt River valley at the Rose Creek constriction about 12 miles downstream from Winnemucca, Nev. View is toward the northeast. Impermeable slate and shale of Triassic age exposed in the hills in the upper left of the picture. *Photograph by L. L. Gourley.*

FIGURE 8.—Aerial view of Rye Patch Dam and Reservoir about 45 miles southwest of Winnemucca, Nev. Lake Lahontan deposits exposed along the banks of the reservoir. *Photograph by L. L. Gourley.*

STREAMS

Humboldt River

The Humboldt River, one of the largest streams in North America that does not discharge into the ocean, heads near the eastern border of Nevada and flows westward for about 200 miles before entering the study area (Figure 1). It then flows southwestward for about 70 miles to Rye Patch Reservoir, the largest reservoir on the river (Figure 8). The natural terminus of the river is the Humboldt Sink, about 17 miles southwest of the reservoir. Prior to construction of the reservoir, water sometimes overflowed southwestward from the Humboldt Sink into the Carson Sink where Humboldt River water mixed with water from the Carson River which drains the Sierra Nevada.

Most of the water released from Rye Patch Reservoir is used for irrigation in the Lovelock area several miles downstream from the reservoir. (See Robinson and Fredericks, 1946; and Eakin, 1962.) Most of the water currently discharging to the Humboldt Sink is excess irrigation water and tail waste from the Lovelock area.

The course of the Humboldt River in the project area is transverse to the north-trending regional structure. The river probably is an antecedent stream, having eroded its channel about as rapidly as the fault-block mountains were uplifted. Throughout most of the year the stream is sluggish and meandering, locally eroding and locally depositing material. During the spring runoff, it actively erodes its channel, cuts off meander loops, and scours deep floodflow channels. Thin layers of silt and clay normally are deposited on the flood plain during periods of overbank flooding.

The river-mile distance between the Comus and

Rose Creek gaging stations, that is, the distance measured along the meandering channel of the Humboldt River during periods of low streamflow is about 92 miles. The flood-plain distance, or the distance measured along straight segments parallel to the main thread of the river, is about 45 miles, or about one-half the river-mile distance. The average gradient of the river is about 1.7 feet per mile or about one-half the gradient of the flood plain. The depth of the channel ranges from about 6 to 15 feet and averages about 8 feet (Figure 21). Its width ranges from 40 to 150 feet and averages about 80 feet. Locally, abandoned channels and floodflow channels are nearly as deep and as wide as the present channel.

Smaller Streams

Based on its drainage area (Table 6), the Little Humboldt River is the second largest stream in the project area. Its south fork heads in an unnamed mountain range north of the Osgood Mountains about 70 miles northeast of Winnemucca, and its north fork heads in the Santa Rosa Range about 50 miles north of Winnemucca. Both forks join about 35 miles northeast of Winnemucca; the river then flows along the axis of Paradise Valley and joins a secondary channel of the Humboldt River in sec. 34, T. 37 N., R. 38 E. (Figure 9). Near its junction with the Humboldt River its gradient is about 4 feet per mile.

During the period of this study (1959–62), the Little Humboldt River discharged little water into the Humboldt River. Nearly the entire flow normally is diverted for irrigation in Paradise Valley and eventually evaporates, is transpired, or percolates downward to the water table. During the spring and early summer when the altitudes of water levels are usually highest, the channel commonly intersects the water table and contains water from sec. 21, T. 37 N., R. 38 E. southwestward to the Humboldt River.

Kelly Creek heads in an unnamed range east of the Osgood Mountains, flows southwestward for about 25 miles and joins the Humboldt River about 2 miles downstream from the Comus gaging station. It is ephemeral in its lower reaches and rarely discharges into the Humboldt River.

From southwest to northeast, the principal streams draining the Sonoma Range are those in Mullen and Dry Canyons, Thomas Creek, those in Water, Harmony, and Devils Canyon, Pole Creek, and Rock Creek. All are locally perennial in their upper reaches, ephemeral in their lower reaches, and rarely discharge into the Humboldt River.

Rose Creek, the principal stream draining that portion of the East Range in the project area, flows northward toward the Humboldt River. It joins Clear Creek, which drains the axis of Grass Valley, in sec. 24, T. 35 N., R. 36 E. The combined channel, which is deeply incised into the upper terrace, rarely carries water even during the spring runoff.

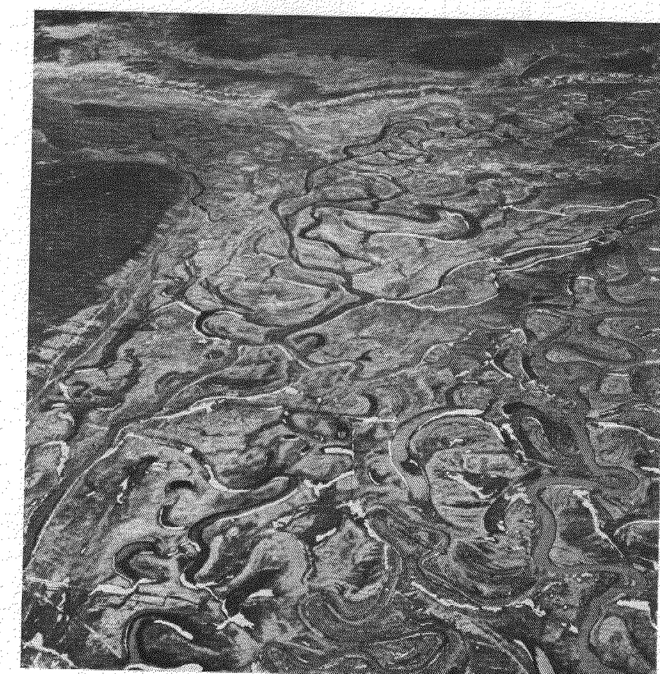

FIGURE 9.—Aerial view of the Humboldt River valley about 4 miles upstream from Winnemucca, Nev. View is toward the northeast. The Little Humboldt River flows between basalt flows and joins the Humboldt River near the upper left of the picture. Light colored beds exposed near the bases of the basalt flows are strata of the upper silt and clay unit of Lake Lahontan age. *Photograph by L. L. Gourley.*

HYDROGEOLOGIC CHARACTER OF THE ROCKS

Based largely on their hydrologic properties, the rocks of the area are divided into two groups: consolidated rocks, most of which have virtually no interstitial porosity and permeability, and unconsolidated and partly consolidated sedimentary deposits which store and transmit most of the ground water. Their hydrologic properties, lithology, occurrence, and other pertinent characteristics are summarized in Tables 2 and 3. More detailed information is given in a previous report (Cohen, in press). Inasmuch as only one of the

TABLE 2. SUMMARY OF THE HYDROGEOLOGIC CHARACTER OF THE CONSOLIDATED ROCKS NEAR WINNEMUCCA, NEVADA

[Partly adapted from Ferguson, Muller, and Roberts (1951), Ferguson, Roberts, and Muller (1952), Hotz and Willden (1961), and Willden (1962)]

Age		Unit	Lithology	Surface distribution	Hydrologic properties	Remarks
CENOZOIC	Quaternary	Spring sinter	Siliceous and calcareous spring deposits.	Hot springs along the East Range fault and near Golconda.	Virtually impermeable.	Probably not more than 20 feet thick.
CENOZOIC	Tertiary or Quaternary	Basalt	Basalt, commonly rich in olivine.	Edna Mountain (near the Comus gaging station), mouth of Paradise Valley near the Little Humboldt River, and Krum Hills. Also occurs as small isolated exposures in the valley fill.	Porous and permeable at and near contacts between lava flows; locally scoriaceous. Reportedly yields water to wells 36/38-2bcbl, 36/38-19dcal, and 36/38-3dcal. Well 36/38-19dcal, the only non-thermal flowing well in the area, reportedly flows at a rate of 300 gpm.	Subsurface distribution and thickness not precisely known; probably penetrated by test boring 35/36-22bcbl at a depth of 75 feet; penetrated in well 37/38-33 adal at a depth of 47 feet.
CENOZOIC	Teritary	Volcanic rocks	Rhyolitic lava and associated tuff, andesite and lesser amounts of intrusive rocks.	Sonoma Range and Osgood Mountains.	Commonly has little interstitial porosity and permeability; tuff locally has high porosity but very little permeability.	At least 1,000 feet thick in the Sonoma Range where it fills depressions in the underlying Paleozoic rocks.
MESOZOIC	Jurassic (?)	Intrusive rocks	Granite, granodiorite, quartz monzonite, and diorite.	East Range, Sonoma Range, Winnemucca Mountain, and Edna Mountain.	Virtually no interstitial porosity and permeability. Transmits small amounts of water through near-surface fractures and weathered zones.	Thickness ranges from a few to several thousand feet.
MESOZOIC	Late Triassic	Raspberry Formation	Slate and some phyllite; limestone and quartzite lenses locally abundant.	East Range and Krum Hills.	Slate, phyllite and quartzite store and transmit very little water. Solution openings in limestone locally may transmit water.	Maximum thickness, approximately 3,000 feet. Impermeable slate and phyllite underlies the flood plain of the Humboldt River at a depth of 40 feet at the Rose Creek constriction.
MESOZOIC	Late Triassic	Winnemucca Formation	Shale and sandtsone locally metamorphosed to slate and quartzite; contains lesser amounts of limestone and dolomite.	East Range, Sonoma Range, Winnemucca Mountain, and Krum Hills.	do	Maximum thickness, 3,000 feet.
MESOZOIC	Late Triassic	Dun Glen Formation	Dolomite with interbedded limestone and shale in lower 100 feet.	East Range (?) and Sonoma Range.	Dolomite is dense and massive and probably contains very little water. Limestone locally may transmit water through solution openings.	Maximum thickness, about 1,200 feet in the Sonoma Range.
MESOZOIC	Late Triassic	Grass Valley Formation	Mostly slaty shale with interbedded quartzite; limestone near the top.	East Range (?) and Sonoma Range.	Practically non-water bearing.	Thickness may exceed 2,000 feet.
MESOZOIC	Middle and Late Triassic	Natchez Pass Formation	Massive dolomite and limestone; contains interbedded basic lava flows, breccias, and pebble conglomerate.	East Range (?) and Sonoma Range.	Little or no interstitial porosity or permeability. Solution openings locally may store and transmit water.	Maximum thickness, about 1,700 feet in the East Range and about 1,000 feet in the Sonoma Range.
	Permian and Early Triassic	Koipato Formation	Rhyolite and trachyte lava flows, breccias and tuffs; some andesite and small amounts of conglomerate, sandstone, and tuffaceous slate.	East Range and Sonoma Range.	Stores and transmits practically no water.	Maximum thickness, at least 4,500 feet.
	Permian	Tallman Fanglomerate	Large blocks of quartzite and chert, and thin beds of cemented chert pebbles.	Occurs only at the mouth of Thomas Canyon in the Sonoma Range.	Dense and impermeable. Probably largely above the zone of saturation.	Maximum thickness uncertain; may be 2,000 to 5,000 feet.
	Permian	Edna Mountain Formation	Sandstone, quartzite, and slate; a few beds of limestone.	Sonoma Range and Edna Mountain.	Limestone may store and transmit water in solution openings. The remainder of the formation has practically no interstitial porosity and permeability.	Maximum thickness, about 250 to 300 feet. Contains Permian brachiopods.

Era	Period	Age	Formation	Lithology	Occurrence	Water-bearing properties	Remarks
PALEOZOIC	CARBONIFEROUS	Pennsylvanian and Permian	Havallah Formation	Largely slate and quartzite; some chert, limestone, greenstone, graywacke, conglomerate, and grit.	East Range and Sonoma Range.	do	Estimated maximum thickness, at least 10,000 feet.
PALEOZOIC	CARBONIFEROUS	Late Pennsylvanian and Early Permian	Antler Peak Limestone	Massive to thin-bedded limestone. Sandy and pebbly layers locally common. Shaly beds in upper part.	Edna Mountain and Osgood Mountains.	May transmit fairly large quantities of water through solution openings.	Maximum thickness, about 200 feet. Contains fossils of Late Pennsylvanian and Early Permian age.
PALEOZOIC	CARBONIFEROUS	Middle Pennsylvanian	Highway Limestone	Massive limestone. Cherty near base; pebbly and sandy layers common.	Edna Mountain.	do	Maximum thickness, 200 feet. Contains fossils of Middle Pennsylvanian age.
PALEOZOIC	CARBONIFEROUS	Mississippian (?)	Inskip Formation	Mostly quartzite, slate, and limestone; some graywacke and conglomerate.	East Range.	Largely barrier to the movement of water; limestone locally may contain water.	Maximum thickness, at least 9,000 feet.
PALEOZOIC		Early and Middle Ordovician	Valmy Formation	Quartzite, chert, and siliceous slate; some argillite and greenstone.	Sonoma Range.	Virtually no interstitial porosity or permeability.	Maximum thickness about 2,000 feet. Contains **Climacograptus.**
PALEOZOIC		Ordovician (?)	Sonoma Range Formation	Chert, siliceous argillite, slate, limestone, and a little quartzite.	Sonoma Range.	do	Maximum thickness, about 3,000 feet. Contains no fossils.
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.	do	Thickness uncertain, may be about 3,000 feet. Contains **Tetragraptus.**
PALEOZOIC		Late Cambrian	Harmony Formation	Sandstone and grit, feldspathic and micaceous; some argillite.	Sonoma Range.	Stores and transmits little or no water.	Maximum thickness, about 5,000 feet. Contains no fossils.
PALEOZOIC		Middle and Late Cambrian	Preble Formation	Slate, phyllite, and mica schist; limestone lenses in lower part; quartzite near base.	Osgood Mountains, eastern slope of the Sonoma Range, and north end of Edna Mountain.	do	Thickness about 12,000 feet. Contains **Lingula.** Underlies the medial gravel unit in Emigrant Canyon at a depth of about 40 feet below land surface.
PALEOZOIC		Early Cambrian (?)	Osgood Mountain Quartzite	Massive quartzite, commonly fine grained, locally crossbedded.	Osgood Mountains and eastern slope of the Sonoma Range.	do	Probably about 5,000 feet thick. Contains no fossils; age uncertain. May partly underlie medial gravel unit in Emigrant Canyon.

TABLE 3. SUMMARY OF THE HYDROGEOLOGIC CHARACTER OF THE UNCONSOLIDATED AND PARTLY CONSOLIDATED DEPOSITS OF THE GROUND-WATER RESERVOIR IN THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEVADA

Age		Informal designation of lithologic units	Lithology	Thickness (feet)	Occurrence	Hydrologic features	Remarks
Quaternary	Recent	Windblown deposits	Silt and sand; well-sorted; individual particles well-rounded and commonly frosted.	0–30	Forms stabilized dunes in the Humboldt River valley, and active eastward-moving crescent-shaped dunes in the southwestern part of Paradise Valley. Thin deposits occur locally throughout most of the valley lowlands.	Moderate to high porosity; relatively low permeability. Entraps most of the precipitation falling upon it, thereby reducing surface-water runoff. Favors the growth of sagebrush, a nonphreatophyte.	Dunes in Paradise Valley derived largely from the valleys to the west; windblown deposits in the Humboldt River valley derived from the upper silt and clay unit within and downstream from the project area. Not shown on Plate 1.
		Younger alluvium	Gravel, sand, silt, and clay; moderately to poorly sorted.	0–50 (?)	Forms comparatively small alluvial fans in scattered localities throughout the basin; includes channel deposits in some of the smaller streams of the area, and lacustrine deposits in Gumboot Lake in the mouth of Paradise Valley.	Largely above zone of saturation; yields practically no water to wells. Receives little ground-water recharge.	Almost negligible soil development; contains abundant carbonate at and near land surface; locally covers Lake Lahontan deposits and physiographic features; largely structurally undeformed. Partly of the same age and partly younger than the flood-plain deposits of the Humboldt and Little Humboldt Rivers.
		Flood-plain deposits	Gravel, sand, silt, and clay; well-sorted to poorly sorted. Contains layers of volcanic ash and windblown material.	0–20	Flood-plain deposits of the Humboldt and Little Humboldt Rivers; includes lateral-accretion deposits such as stream-channel bars and point bars, and vertical-accretion deposits formed in oxbow lakes, drainage channels, and other depressions in the Humboldt River flood plain; locally contains volcanic ash.	Ranges from highly permeable stringers of sand and gravel to dense, relatively impermeable clay; fine-grained deposits locally have a high secondary porosity. Recharged largely by seepage from streams and by overbank flooding; stores and transmits considerable water. Tapped by very few production wells. Ground water is discharged from the unit largely by evapotranspiration and by seepage to streams. Supports much of the phreatophyte growth in the project area.	Maximum thickness in the Humboldt River flood plain, about 20 feet; locally highly saline.
		Terrace deposits	Gravel, sandy and silty, sand, silt, and clay; moderately to poorly sorted.	0–20	Covers river-cut terraces adjacent to the Humboldt River flood plain; also occurs in an abandoned stream channel in the mouth of Paradise Valley.	Partly above the zone of saturation; yields practically no water to wells. Transmits small amount of recharge resulting from the infiltration of irrigation water to underlying deposits. Supports substantial growth of greasewood which discharges ground water from the underlying saturated deposits.	Largely disconformably overlies medial gravel unit; deposited largely by the streams that cut the terraces. Partly composed of reworked underlying medial gravel unit; includes some slope wash.
		Gravel-bar deposits	Sand and gravel; well sorted; imbricate structure common.	0–30 (?)	Exposed in gravel pits and in scattered localities near the former margin of Lake Lahontan.	Probably forms highly permeable aquifers, though of limited areal extent; not known to be tapped by any producing wells.	Deposited near the margins of Lake Lahontan as beaches, bay-mouth bars, and off-shore bars. Partly time correlative with youngest strata of the upper silt and clay unit.
		Upper silt and clay	Clay, silty clay, clayey silt, silt, and very fine to medium sand; contains clams, snails, and ostracodes.	0–60	Most widely exposed lithologic unit of Lake Lahontan age; covers the floors of Grass and Paradise Valleys, and the valley floor adjacent to the Humboldt River flood plain and river-cut terraces as far upstream as the vicinity of Golconda.	Relatively impermeable; locally, clayey layers confine water in the underlying deposits under artesian pressure; upward leakage from the underlying deposits commonly is sufficient to establish and maintain a water table in the unit throughout part of the area.	Deposited in the second deep stage of Lake Lahontan. Sandy facies occurs around the margins of the basin and upstream from Winnemucca; clayey facies occurs downstream from Winnemucca in the topographically lower parts of the valley. Clayey facies contains many salts including NaCL, $CaSO_4$, and $CaCO_3$.

	Pleistocene Lake Lahontan deposits	Medial gravel	Sand and gravel; moderately to well-sorted.	0–90 (?)	Exposed at land surface in only a few localities at or near the bases of river-cut scarps bordering the Humboldt River; underlies the Humboldt River flood-plain deposits, river-cut terraces, and the upper silt and clay unit throughout most of the area; probably extends to the eastern margin of the project area roughly underlying the channel of the Humboldt River.	Most permeable aquifer in the project area. Yields up to 700 gpm to wells; can yield considerably more to adequately constructed and equipped wells. Recharged largely by underflow from tributary areas and seepage from the Humboldt River. Ground water is discharged from the unit principally by transpiration and seepage to the Humboldt River.	Deposited along rapidly shifting shoreline of Lake Lahontan by the Humboldt River and tributary streams. Thins markedly near the margins of the valley. Chiefly coarse sand and gravel throughout most of the area; sandy facies occurs near the western margin of the area.
		Older alluvium	Gravel, sand, silt, and clay; moderately to poorly sorted.	0–35	Recognized in the subsurface in the mouth of Grass Valley.	Probably of moderate to low permeability; seemingly of little importance as a potential aquifer.	Interfingers with the upper silt and clay, medial gravel and lower silt and clay units. Younger than most of the lower silt and clay unit and older than most of the upper silt and clay unit.
		Lower silt and clay	Clay, silty clay, clayey silt, silt, and very fine to medium sand; contains ostracodes.	0–20 (?)	Recognized with certainty only in the subsurface in the mouth of Grass Valley.	Relatively impermeable; probably confines water in underlying deposits under artesian pressure.	Virtually identical to the upper silt and clay unit. Deposited in the first deep stage of Lake Lahontan. May locally have been removed by erosion prior to and during the deposition of the medial gravel unit.
Tertiary or Quaternary	Pliocene or Pleistocene	Younger fanglomerate (undifferentiated alluvium in the subsurface of the valley lowlands)	Gravel, sand, and silt; contains practically no clay at or near the surface; well-sorted to poorly sorted.	0–1,000+ (?)	Occurs as alluvial fans along the margins of the basin. Probably is correlative with much of the undifferentiated alluvial deposits underlying the Lake Lahontan deposits.	Ranges from highly permeable to relatively impermeable material. Receives ground-water recharge largely by underflow from the consolidated rocks in the mountains and by the infiltration of tributary streamflow. Ground water discharged from the unit largely by underflow toward the Humboldt River. Yields more than 1,000 gpm to wells.	In most places, the upper 10 to 25 inches leached of calcium carbonate; commonly contains a fossil pluvial soil, perhaps of Lake Lahontan age, from 15 to 50 inches below land surface. Structurally deformed; moderately eroded.
		Older fanglomerate	Gravel, sand, and silt; contains practically no clay at or near the surface; commonly poorly sorted, locally moderately cemented; contains boulders up to 10 feet in diameter.	?	Recognized on pediment surfaces along the northwestern slope of the Sonoma Range and in comparatively small exposures along the flanks of the Osgood Mountains; may be correlative with some of the undifferentiated alluvial deposits occurring at depth in the valley lowlands.	Relatively impermeable; receives only small amounts of ground-water recharge; probably would yield small amounts of water to wells.	Contains thick beds of caliche. Structurally deformed; deeply eroded.
Tertiary	Miocene or Pliocene	Older sedimentary deposits	Conglomerate, sandstone, and siltstone, with lesser amounts of limestone, marl, and tuff.	?	Underlies 3 to 4 square miles at the north end of the Sonoma Range; exposed beneath the northwestern edge of the basalt flow northeast of the confluence of the Little Humboldt and Humboldt Rivers; and exposed north of the Krum Hills. Probably occurs at depth in the valley fill, but the depth at which it occurs and its thickness are unknown throughout most of the project area.	Relatively impermeable; probably stores and transmits only small amounts of water.	Locally, highly metamorphosed and silicified. Structurally deformed and deeply eroded.

consolidated-rock units (basalt) yields water readily to wells and because the hydrologic properties of the consolidated rocks were not studied in detail in the field or in the laboratory, the hydrologic information listed in Table 2 necessarily is generalized.

Most of the unconsolidated deposits tapped by irrigation wells in the area are older than the Lake Lahontan deposits and younger than the older sedimentary deposits of Tertiary age. These deposits are largely of fluviatile origin and probably are largely the stratigraphic time correlatives of the younger fanglomerate. These subsurface deposits are shown as undifferentiated alluvium in Plates 1 and 2.

The hydrogeologic properties of the unconsolidated deposits forming the ground-water reservoir were studied in the field and in the laboratory. Representative data are shown in Table 4 and in Figures 10, 11, and 12. More detailed information on specific yield and related data are given in Table 22 and on pages 77–80.

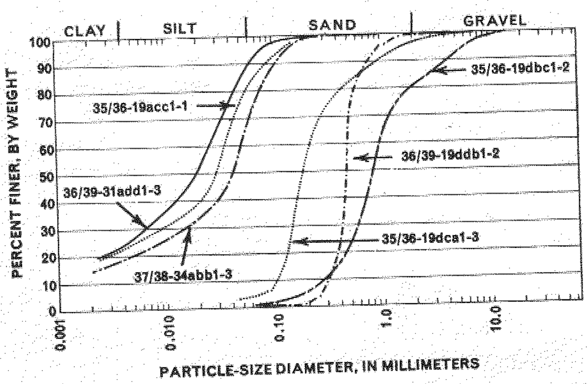

FIGURE 10.— Particle-size distribution of selected samples of fluviatile deposits in the flood plain of the Humboldt River near Winnemucca, Nev.

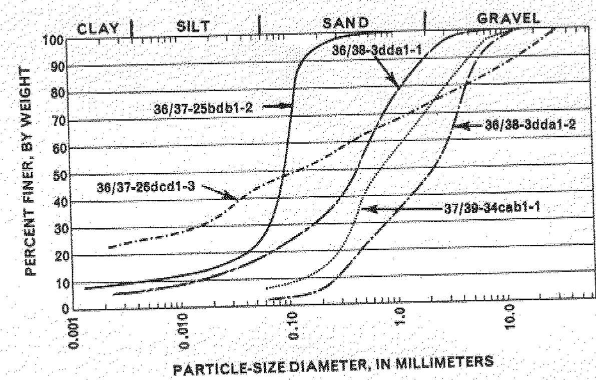

FIGURE 11.— Particle-size distribution of selected samples of terrace deposits in the Humboldt River valley near Winnemucca, Nev.

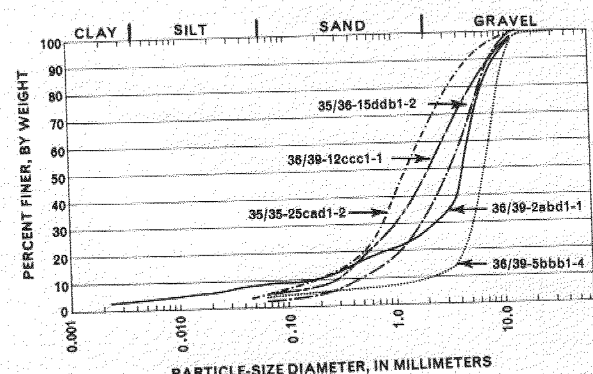

FIGURE 12.— Particle-size distribution of selected samples of the medial gravel unit in the Humboldt River valley near Winnemucca, Nev.

Values for the laboratory coefficients of permeability of the deposits ranged from 0.001 gpd/ft^2 (gallons per day per square foot) for a sample of slope wash to 7,000 gpd/ft^2 for a sample of the medial gravel unit. The laboratory coefficient of permeability is equal to the rate of flow of water, having a temperature of 60°F., through 1 square foot of material under a hydraulic gradient of 1 foot per foot. These values are only slightly higher than those of the field coefficients of permeability because the average temperature of ground water in the project area is about 58°F. (See Wenzel, 1942, p. 62.)

The coefficient of transmissibility is the rate of flow of water through a vertical strip of aquifer 1 foot wide extending the full saturated height of the aquifer under a hydraulic gradient of 1 foot per foot at the prevailing water temperature. Thus, the coefficient of transmissibility is equal to the field coefficient of permeability multiplied by the saturated thickness of the aquifer. Coefficients of transmissibility can be obtained from controlled pumping tests. Unfortunately, very few wells in the area were adequately equipped and constructed to obtain reasonably accurate and meaningful estimates of the coefficients of transmissibility. Data obtained from two tests at well 35/37–8dadl indicate that the medial gravel unit, which has a saturated thickness of about 90 to 95 feet near the well, has a coefficient of transmissibility of about 500,000 gpd/ft (gallons per day per foot). Accordingly, the estimated average field coefficient of permeability of the unit in the vicinity of the well is on the order of 5,000 gpd/

TABLE 4—HYDROGEOLOGIC PROPERTIES OF SELECTED SAMPLES FROM THE GROUND-WATER RESERVOIR IN THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEVADA

Sample number	Occurrence and mode of deposition	Lithology	Structural and textural features	Reaction with dilute hydrochloric acid	Laboratory coefficient of permeability (gpd/ft²)	Porosity (percent)	Specific retention (percent)	Specific yield (percent)	Median diameter (millimeters)	Sorting coefficient
35/35–25cadl–2	Medial gravel; fluviatile and lucustrine deposit	Sand and gravel	Subangular to rounded	Weak to moderate	-------	28.2	12.4	15.8	1.3	2.3
35/36–15ddbl–2	Medial gravel; fluviatile and lucustrine deposit	Gravel and sand	Angular to rounded	Weak to moderate	7,000	30.1	10.5	19.6	3.2	2.0
35/36–19accl–1	Flood plain of the Humboldt River; overbank deposit	Sandy silt; some clay	No evidence of bedding; numerous root holes	Weak to moderate	3	48.6	32.4	16.2	.03	3.4
35/36–19dbcl–2	Flood plain of the Humboldt River; point-bar deposit	Sand and gravel	No evidence of bedding; angular to subangular	Weak	1,400	38.3	6.0	32.3	.82	1.6
35/36–19dcal–3	Flood plain of the Humboldt River; channel deposit (?)	Sand and gravel, some silt	Angular to subangular; gravel size, angular to subrounded; poorly defined bedding	Weak	26	38.1	8.1	30.0	.19	1.5
36/37–25bdbl–2	River-cut terrace; fluviatile deposit	Sand; silty and clayey	Angular to subangular; poorly defined bedding; numerous root holes containing calcite	Moderate	5	46.9	17.8	29.1	.09	1.5
36/37–26dcdl–3	River-cut terrace; slope-wash deposit	Gravel, sand, silt, and clay	Angular to subangular; no apparent bedding; poorly sorted	Moderate	.001	63.4	56.4	7.0	.13	27.2
36/38–3ddal–1	River-cut terrace; fluviatile deposit	Sand and gravel; some silt and clay	Some bedding evident	Weak to moderate	-------	30.0	17.4	12.6	.44	2.7
36/38–3ddal–2	River-cut terrace; fluviatile deposit; reworked medial gravel	Sand and gravel	Subangular to rounded	Weak to moderate	-------	28.7	9.1	19.6	2.4	2.6
36/39–2abdl–1	Medial gravel; fluviatile and lacustrine deposit	Gravel and sand; some silt and clay	Subangular to rounded	None	-------	28.8	8.3	20.5	4.3	2.6
36/39–5abbl–4	Medial gravel; fluviatile and lacustrine deposit	Gravel and sand	Subangular to rounded; well sorted	None	-------	41.9	24.5	17.4	6.8	1.3
36/39–12cccl–1	Medial gravel; fluviatile and lacustrine deposit	Gravel and sand	Subangular to rounded	Weak	-------	35.6	12.1	23.5	2.1	2.4
36/39–19ddbl–2	Flood plain of the Humboldt River; point-bar deposit	Sand; some gravel	Angular to subrounded particles; no evidence of bedding	None	1,900	41.0	4.3	36.7	.47	1.1
37/38–34abbl–3	Flood plain of the Humboldt River; overbank deposit	Sandy silt; some clay	No evidence of bedding; numerous root holes	Weak to moderate	2	47.0	31.3	15.7	.04	2.7
37/39–31addl–3	Flood plain of the Humboldt River; overbank deposit	Sandy silt; some clay	No evidence of bedding; numerous root holes	Moderate	.004	49.2	37.3	11.9	.02	2.9
37/39–34cabl–1	River-cut terrace; fluviatile deposit; reworked medial gravel	Sand and gravel	Subangular to rounded	Moderate	-------	33.3	14.5	18.8	.76	2.6

ft^2. This agrees reasonably well with the laboratory permeability of 7,000 gpd/ft^2 for sample 35/36–15ddbl–2 (Table 4). The sample probably is representative of the most permeable facies of the gravel. Accordingly, the coefficient of permeability of about 5,000 gpd/ft^2 obtained from the aquifer tests is considered to be more nearly representative of the average permeability of the unit.

GEOLOGIC STRUCTURES

Geologic structures affect the storage and movement of water in the project area. Although there is some overlap, the structures of hydrologic significance are divided into two groups—tectonic structures and internal primary and secondary structures. Tectonic structures are those formed as a result of relatively large deformational forces within the earth's crust and include normal faults, thrust faults, joints, and other fractures. These fractures allow water to move through some of the otherwise impermeable consolidated rocks. Furthermore, many of the solution openings, which locally transmit water through some of the carbonate rocks, were formed along tectonic fractures.

Internal primary structures that store and transmit water include interflow scoracious and fractured zones in the Tertiary or Quaternary basalt flows. Inasmuch as the basalt was formed from a cooling liquid, it has practically no interstitial porosity and permeability. Accordingly, primary structures and, locally, secondary structures, afford almost the only opportunity for the storage and movement of water in these rocks.

Primary and secondary structures also affect the hydrologic properties of the unconsolidated deposits forming the ground-water reservoir. Bedding or stratification is one of the most common primary sedimentary structures. Where strata of similar lithology overlie one another, there normally are little or no marked vertical changes in hydraulic properties. However, bedding surfaces commonly demark substantial changes in lithology and, accordingly, changes in hydraulic properties. The irregular bedding surface which forms the contact between the medial gravel unit and the overlying upper silt and clay unit is an example of a marked lithologic and hydraulic discontinuity.

Commonly, the unconsolidated deposits are composed of nonequidimensional particles that tend to be oriented with their flatest surface parallel to the bedding, thus imparting anisotropic hydraulic properties to most of these deposits. Permeability ordinarily is much greater parallel to the bedding than across the bedding.

Secondary accretionary structures, formed largely by chemical precipitation, are common in the deposits of the ground-water reservoir and include nodules and layers of calcium carbonate, rosettes of calcium sulfate, and calcium carbonate root fillings. These structures decrease porosity and permeability. Other secondary structures, such as cavities formed by burrowing snails and crustaceans, cavities formed by the solution of fossil shells, and fractures formed as a result of desiccation, locally result in a high secondary porosity, especially in some of the flood-plain deposits.

GEOLOGIC HISTORY

The following brief summary of the Paleozoic geologic history largely is adapted from Ferguson, Muller, and Roberts (1951).

Most of the Paleozoic rocks of the area were deposited in a fairly shallow marine environment. A major period of orogenic deformation, characterized largely by tight folding and thrust faulting, occurred before Middle Pennsylvanian time. Another period of orogenic deformation accompanied by volcanism began in the Permian Period, as evidenced in the Sonoma Range where rocks of Carboniferous age are thrust over rocks of Permian (?) age. Orogenic deformation continued in Triassic time and probably culminated in Jurassic or Early Cretaceous time contemporaneous with the emplacement of granitic plutons of Jurassic (?) age.

Early Tertiary geologic history is not well documented in the project area. Volcanism and epeirogenic deformation characterized by gentle warping and normal faulting probably were the most significant geologic events in early Tertiary time. The oldest sedimentary deposits of the ground-water reservoir accumulated partly in a lacustrine and partly in a subaerial environment in late Tertiary time. These deposits subsequently were broken by normal faults of large vertical displacement, possibly on the order of 3,000 to 5,000 feet or more. Following and perhaps partly contemporaneous with this deformation, the Tertiary or Quaternary basalt flows were extruded.

The present gross topographic features, including the Humboldt River drainage system, were outlined during and following the last-mentioned interval of structural deformation. Coarse alluvial wedges of older fanglomerate were deposited along the bases of the newly uplifted ranges. Finer grained fluviatile and lacustrine deposits were formed in the valley lowlands. Continued relative uplift of the ranges deformed the older fanglomerate. Subsequently, the younger fanglomerate was deposited along the slopes of the ranges. Its finer grained correlative, the undifferentiated alluvium, was deposited contemporaneously in the valley lowlands.

Throughout late Tertiary and Quaternary time, intermittent uplift along normal faults disrupted the regional drainage system. The course of the Humboldt River periodically was blocked by the newly uplifted mountain ranges; lakes formed in which some of the fine-grained, relatively impermeable strata of the ground-water reservoir were deposited. Eventually, water gaps, such as those at Emigrant Canyon and the buried gaps at the Winnemucca narrows and the Rose Creek constriction, were formed.

In response to a change in climate in late Pleistocene time, Lake Lahontan covered the lowlands of the project area. As the climate became more humid, the flow of the Humboldt River and its tributaries increased and the lake encroached about as far eastward as the Comus gaging station. The lower silt and clay unit was deposited in the deeper parts of the lake. Subsequently, in response to a more arid climate, the level of the lake declined. Eventually, the lake completely receded from the project area, and alluvial material was deposited by streams flowing across the former lake bottom.

In response to increased precipitation, the flow of the Humboldt River and its tributaries again increased. The river carried large volumes of coarse material and probably channeled the underlying deposits. In time, Lake Lahontan again covered the lowlands of the project area. As the lake rose, rapidly shifting shorelines partly reworked the coarse material being transported and deposited by the Humboldt River. In addition, waves reworked some of the alluvial-fan deposits, and beaches, bars and spits were formed. All these well-sorted, highly permeable materials formed the medial gravel unit. As the lake continued to rise, the medial gravel unit was covered by the upper silt and clay unit. Most of the gravel bars exposed at land surface at present were formed near the shore of this second deep stage of the lake.

Subsequently, the climate again became more arid and Lake Lahontan receded downstream from the study area toward the Humboldt Sink. The Humboldt River then cut through the upper silt and clay unit into the upper few feet of the medial gravel unit. The river-cut terraces were formed during pauses in the decline in lake level. The present flood plain was formed on a river-cut surface that was covered by about 10 to 20 feet of largely fluviatile post-lake Lahontan deposits. The younger alluvium and wind-blown material were deposited following the final desiccation of the lake.

SCOPE AND OBJECTIVES OF THE HYDROLOGIC ESTIMATES

All the components of the hydrologic system that were studied by the Geological Survey are described in the following sections of the report. In addition, hydrologic budgets are computed for three time intervals, water years 1949–62, water year 1962, and December through June of water year 1962 (page 93). The period, water years 1949–62, was selected because Humboldt River streamflow data at both the upstream and downstream margins of the area are available only for this period. A budget is given for water year 1962 because the largest measured annual loss of streamflow and the largest measured increase of ground water in storage occurred during that year. A budget is given for December through June of water year 1962 because the largest measured seasonal increases of ground water and surface water in storage occurred during this period.

Hydrologic-budget analyses are not made for the entire project area as outlined on the maps accompanying this report; rather, they are restricted to the storage units shown on Plate 5 largely because nearly all the changes of ground water and surface water in storage and most of the evapotranspiration occurs in these areas. Accordingly, where appropriate, quantitative hydrologic estimates for the storage units and for the three time intervals are described in the following sections of the report.

Inasmuch as all the components of the hydrologic system have not been studied and because some of the studies have not been completed yet, preliminary and very approximate estimates of some components are made to develop the data needed for the hydrologic-budget analyses.

SURFACE WATER

By R. L. Hanson

The principle objectives of the surface-water studies were to determine the amount of surface-water inflow and outflow from the area, and to describe the routing and disposition of surface water within the area. These components of the hydrologic system are emphasized in this section of the report; estimates needed for the water-budget analyses are included.

Streamflow data were obtained and analyzed at three recording stream-gaging stations, and periodic streamflow measurements were made at 18 intermediate nonrecording gages along the Humboldt River within the study reach. Tributary streamflow was obtained for nine small streams entering the project area. These data were obtained at several measuring sites on each tributary and at a gaging station on Pole Creek.

The three gaging stations on the main stem of the Humboldt River are formally designated as "Humboldt River at Comus," "Humboldt River at Winnemucca," and "Humboldt River near Rose Creek." In this report these are referred to as the Comus, Winnemucca, and Rose Creek gaging stations. The 3 stations and the 18 intermediate stations are listed in Table 12 and are shown in Plate 5. The gaging station on Pole Creek is formally designated "Pole Creek Near Golconda," and is referred to as the Pole Creek gaging station. The locations of the Pole Creek station and miscellaneous streamflow measuring sites on the other tributaries are listed in Table 7.

INFLOW

Humboldt River

Surface-water inflow to the project area is mainly from the Humboldt River and has been evaluated largely on the basis of long-term streamflow data obtained at the Comus gaging station. This station is 9 miles northwest of Golconda and about 3 miles downstream from the eastern border of the project area. The drainage area of the Humboldt River above the Comus gaging station is approximately 12,100 square miles.

Monthly and yearly streamflow data for Humboldt River at Comus are available for 48 water years, 1895–1909, 1911–26, and 1946–62. Most of these data are given in the following U.S. Geological Survey Water-supply Papers:

Water year	Water-supply Paper
1895–1950	1314
1951–1960	1734 (in preparation)

Beginning with the 1961 water year, annual water-supply papers were discontinued, and streamflow records at the Comus gaging station for water years 1961 and 1962 were published in annual reports entitled, "Surface Water Records of Nevada."

Table 5 summarizes streamflow at the Comus gaging station for the 48 water years of record. The substantial difference between the mean and median annual flow, and the very large difference between the extreme years suggest that there are wide variations in annual Humboldt River inflow to the study area.

TABLE 5—SUMMARY OF ANNUAL STREAMFLOW AT THE COMUS GAGING STATION

	Water year	Streamflow (acre-feet)
Mean annual	*1895–1962	199,100
Median annual	*1895–1962	149,500
Maximum annual	1907	688,100
Minimum annual	1920	26,700

*Does not include water years 1910 and 1927–45.

Tributary Streams

Nine small streams were investigated during water years 1960–62 to estimate the average annual tributary streamflow into the project area and into the storage units, and the amount of this flow that discharges into the Humboldt River as surface flow. The tributaries investigated south of the Humboldt River were Rock Creek, Pole Creek, Devils Canyon, Harmony Canyon, Water Canyon, Thomas Canyon, and Rose Creek. Because Clear Creek, which drains Grass Valley, had no perceptible flow in the area during the period of study, a streamflow measuring site was not established. The tributaries investigated north of the Humboldt River were Kelly Creek and the Little Humboldt River.

The Pole Creek gaging station is the only tributary streamflow measuring station equipped with a water-stage recorder (Table 6). This station has been used as a basis for estimating the average annual streamflow from the other major tributaries flowing into the project area. Records for Pole Creek are available in "Surface Water Records of Nevada" for water years 1961 and 1962.

The drainage area between the Comus and Rose Creek gaging stations is about 3,100 square miles. The tributaries and valleys which comprise this area are listed in Table 6. The sum of the drainage areas of Kelly Creek, Little Humboldt River, and Clear Creek is about 2,500 square miles, or about 80 percent of the total drainage area between the Comus and Rose Creek gaging stations. However, an almost negligible amount of tributary streamflow from these three basins reaches the Humboldt River.

Kelly Creek flows into the Humboldt River about 2 miles downstream from the Comus gaging station. Almost all the flow from this stream is used upstream for irrigation and seldom reaches the river. Some flow from Kelly Creek may reach its mouth during the spring runoff or during periods of high flow when no irrigation occurs.

The Little Humboldt River, which flows into the Humboldt River about 2 miles upstream from Winnemucca, is utilized for irrigation in Paradise Valley. Most of the remaining flow is blocked by sand dunes across the valley floor about 6 miles upstream from the mouth of the Little Humboldt River and forms Gumboot Lake. Surface flows of about 0.5 cfs and less were observed near the mouth of the river in April and May of water year 1962. Most of this flow was ground-water seepage and did not discharge into the Humboldt River. Normally, the Little Humboldt River is dry within the study area throughout most of the year.

Clear Creek, which had no significant streamflow in the project area during the study period, has a well-defined channel on the floor of Grass Valley in the project area, indicating that flow has occurred in the past. A flood flow of 11,000 cfs was measured on Clear Creek about 13 miles upstream from the project area in August 1961 (Table 15). Virtually all of this flow ponded and was lost by evapotranspiration, however, before reaching the study area.

The remaining tributaries investigated, Rock Creek, Pole Creek, Devils Canyon, Harmony Canyon, Water Canyon, Thomas Canyon, and Rose Creek comprise about 105 square miles of drainage area, or about 3 percent of the total, between the Comus and Rose Creek gaging stations. Table 6 shows that, except for Rock Creek which has a drainage area of about 52 square miles, the drainage area of each of these tributaries is less than 15 square miles. This relatively minor part of the total drainage area furnishes most of the total tributary streamflow to the project area.

During the summer months, most of the streams originate at springs near their headwaters. Snow melt normally increases the flow beginning in March or April and ending in June or July. Occasional thunder showers on these watersheds result in flash floods.

Discharge measurements were made periodically along each tributary to determine approximately the point of maximum surface flow. This point, which is most easily determined during periods of low streamflow, generally ranges between an altitude 5,000 and 5,500 feet for the tributaries studied.

The tributaries above this altitude usually are gaining streams, which are replenished by springs and snow melt. Below this altitude they are losing streams, as the flows evaporate, are transpired, or percolate into the alluvial fill in the canyon floor. Table 7 lists the approximate point of maximum flow for each tributary investigated. Streamflow data for these sites in water year 1960 are listed in Water-supply Paper 1714; data for water years 1961–62 are listed in "Surface-water Records of Nevada" (U.S. Geological Survey, 1961a, 1962).

During periods of high flow most of the runoff spreads out over the alluvium into many distributary channels and percolates into the ground or is diverted into fields for irrigation. Flows of about 20 cfs or less may have reached the river from Rock Creek and Pole Creek during periods

TABLE 6—TRIBUTARY STREAMS AND VALLEYS FORMING THE TOTAL DRAINAGE AREA BETWEEN THE COMUS AND ROSE CREEK GAGING STATIONS

Tributary or valley (in downstream order)	Approximate drainage area (square miles)	Remarks
Kelly Creek	300	Above mouth
Rock Creek	52	Above U.S. Highway 40 crossing
Pole Creek	13	Above U.S. Highway 40 crossing
Devils Canyon	5	Above U.S. Highway 40 crossing
Little Humboldt River (Paradise Valley)	1,800	Above mouth
Harmony Canyon	9	Above U.S. Highway 40 crossing
Water Canyon	7	Above diversion ditch three-quarters of a mile south of Winnemucca
Thomas Canyon	11	Above Grass Valley road crossing
Clear Creek (Grass Valley)	480	Above U.S. Highway 40 crossing
Rose Creek	8	Above confluence with Clear Creek above U.S. Highway 40
Humboldt River flood-plain and foothill areas	385	Between the Comus and Rose Creek gaging stations; excludes drainage areas listed above
Total	3,070	

TABLE 7—STREAMFLOW-MEASURING STATIONS ON TRIBUTARY STREAMS AT APPROXIMATE POINTS OF MAXIMUM STREAMFLOW

Symbol*	Designation	Location	Drainage area (sq. mi.)	Altitude (feet)
....	Kelly Creek near Golconda, Nev.	W½ sec. 5, T. 37 N., R. 43 E.	†120	†5,500
....	Rock Creek near Golconda, Nev.	SE¼NW¼ sec. 1, T. 34 N., R. 34 E.	12.2	5,440
ddcl	Pole Creek near Golconda, Nev.‡	SW¼SE¼SE¼ sec. 12, T. 35 N., R. 39 E.	10.7	4,920
abal	Devils Canyon near Golconda, Nev.	NE¼NW¼NE¼ sec. 11, T. 35 N., R. 39 E.	4.4	5,080
dbcl	Little Humboldt River near Winnemucca, Nev.	SW¼NW¼SE¼ sec. 27, T. 37 N., R. 38 E.	†1,800	4,200
adcl	Harmony Canyon near Winnemucca, Nev.	SW¼SE¼NW¼ sec. 36, T. 36 N., R. 38 E.	6.2	5,190
adcl	Water Canyon near Winnemucca, Nev.	SW¼SE¼NW¼ sec. 11, T. 35 N., R. 38 E.	3.9	5,680
cdcl	Thomas Canyon near Winnemucca, Nev.	SW¼SE¼SW¼ sec. 15, T. 35 N., R. 38 E.	7.2	5,190
abbl	Rose Creek near Winnemucca, Nev.	NW¼NW¼NE¼ sec. 2, T. 34 N., R. 36 E.	5.2	5,080

*Symbols used to identify streamflow measuring stations shown in Plate 5. Kelly Creek and Rock Creek streamflow measuring stations are beyond the margins of the project area and are not shown in Plate 5.
†Approximate.
‡Pole Creek gaging station. All other streamflow measuring stations are at miscellaneous sites.

of high runoff in February, April, and May 1962. Normally, however, a negligible amount of surface flow reaches the Humboldt River.

Total tributary inflow to the project area was estimated for water years 1961 and 1962. Approximate annual hydrographs were reconstructed for each tributary stream studied by comparing streamflow data at the Pole Creek gaging station with the periodic measurements made at the approximate points of maximum flow. Based on these hydrographs, the estimated total inflow for the tributaries studied was about 2,800 acre-feet in water year 1961 and 12,000 acre-feet in water year 1962. These streams drain approximately 80 percent of total tributary drainage area contributing streamflow to the project area. Accordingly, the estimated total tributary streamflow was about 3,500 acre-feet in water year 1961 and about 15,000 acre-feet in water year 1962.

Relatively long-term records at two nearby gaging stations, Martin Creek near Paradise Valley and Little Humboldt River near Paradise Valley, indicate that streamflow at both stations was about 45 percent of the long-term average in water year 1961 and about 135 percent of the long-term average in water year 1962. It is assumed that the long-term flow characteristics of Martin Creek and the Little Humboldt River are comparable to those of the smaller streams in the project area. On this basis, the average annual tributary streamflow at the points of maximum streamflow in the project area is estimated to be between 8,000 and 11,000 acre-feet, or roughly 10,000 acre-feet per year.

The estimated average annual tributary streamflow that reached the outer margins of the storage units in water years 1949–62 was about 4,500 acre-feet; it was about 5,800 acre-feet in water year 1962, and about 5,000 acre-feet in December through June of water year 1962. On the average, very little of this water reached the Humboldt River as surface flow.

OUTFLOW

Humboldt River streamflow as measured at the Rose Creek gaging station constitutes almost all the surface-water outflow from the project area. The drainage area upstream from the gaging station is approximately 15,200 square miles. Monthly and yearly streamflow data for the station are available since 1948 and are given in Water-supply Paper 1734 (in preparation). Records for water years 1961–62 have been published in "Surface Water Records of Nevada."

Table 8 summarizes streamflow data at the gaging station for the 14 complete water years of record, 1949–62. The data show that the median annual streamflow for the period of record is about 80 percent of the mean annual flow. The maximum recorded annual streamflow occurred in water year 1952 and was about 25 times greater than the minimum annual flow which occurred in water year 1955. The outflow is less than the inflow listed in Table 5.

TABLE 8—SUMMARY OF ANNUAL STREAMFLOW AT THE ROSE CREEK GAGING STATION

	Water year	Streamflow (acre-feet)
Mean annual	1949–62	155,400
Median annual	1949–62	127,600
Maximum annual	1952	535,800
Minimum annual	1955	21,840

STREAMFLOW CHARACTERISTICS

Streamflow at the Comus gaging station is more dependent upon precipitation in the headwater area than precipitation in the project area. Because most of the headwater precipitation falls in the form of snow, most of the runoff at the Comus gaging station occurs during the snowmelt period, normally April through June. The storms producing the snowpack in the upper watershed usually are regional and cover wide areas. As a result, as shown in Figure 13, a fair correlation exists between precipitation at Winnemucca and streamflow at the Comus gaging stations. There is a relatively close correlation between precipitation and streamflow in water years 1946–62. Both streamflow and precipitation were below average in water years 1946–50, 1953–55, and 1959–61, and above average in water years 1951–52, 1956–58, and 1962. The graph also shows that streamflow in 30 years, or nearly two-thirds of the 48 water years of record at the Comus gaging station, was below average.

The percent of time that a specific daily mean rate of flow occurred or was exceeded at the gaging station can be ascertained from Figure 14, which is a flow-duration curve for the Humboldt River at Comus for water years 1918–26 and 1946–62, the period during which streamflow data were obtained at the site of the present station. The curve was prepared by the so-called "total-period" method (Searcy, 1959, p. 3). A mean annual streamflow of 275 cfs (199,100 acre-feet per year) at the Comus gaging station was equaled or exceeded about 25 percent of the time. A daily mean flow of 70 cfs was equaled or exceeded about 50 percent of the time. The daily mean discharge exceeded 2,000 cfs only about 1 percent of the time, and 4,000 cfs about 0.2 percent of the time. The river was dry at the Comus gaging station for a total of 110 days, slightly more than 1 percent of the time. During the present study, it was dry for a total of 10 days.

Average annual precipitation at Elko, Nevada (near the headwaters of the Humboldt River) for the 48 years of streamflow record at the Comus gaging station was about 10 percent more than the average annual long-term precipitation at Elko (1870–1962). On the other hand, average annual precipitation at Winnemucca for the 48 years was about 5 percent less than the average annual long-term precipitation at Winnemucca (1871–1962). On the basis of these data, it is presumed that the 48 years of streamflow record at the Comus gaging station is reasonably representative of the past 90 years or so.

Data for the 48 years of record at the Comus gaging station and for the period during which both the Comus and Rose Creek gaging stations were in operation (water years 1949–62) are summarized in Table 9. Mean annual streamflow for the common period of record was 14 percent less than that for the long-term period of record; median annual streamflow was 5 percent more than that for the long-term period. In addition, the annual maximum and minimum extremes for the common period very nearly approached the

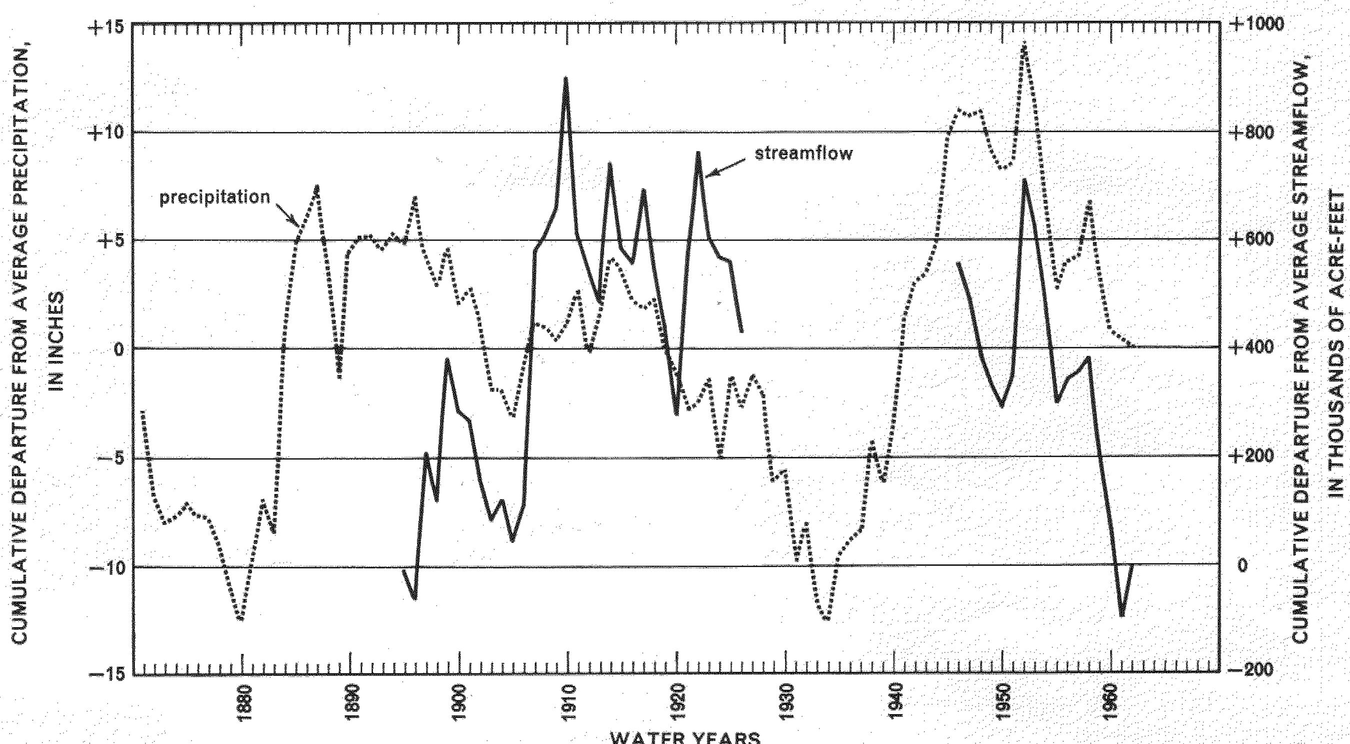

FIGURE 13.—Cumulative departure from average precipitation at Winnemucca for water years 1871-1962, and cumulative departure from average streamflow at the Comus gaging station for water years 1895-1909, 1911-26, 1946-62

long-term extremes. Accordingly, in overall aspect streamflow at the two gaging stations during the common period of record probably was reasonably representative of long-term streamflow characteristics in the study reach.

Streamflow at the Comus gaging station was about 22 percent of average in water years 1959–61 and about 160 percent of average in water year 1962. Thus, the flow of the Humboldt River in the project area was considerably below average during 3 of the 4 years of the present study and was significantly above average during the 4th year.

Figure 15 is a bar graph of annual streamflow at the Comus and Rose Creek gaging stations for the common period of record. The graph shows that streamflow at the Rose Creek gaging station generally was less than that at the Comus gaging station. Years of above average flow at the Comus gaging station corresponded with years of above average flow at the Rose Creek gaging station; the converse was also true.

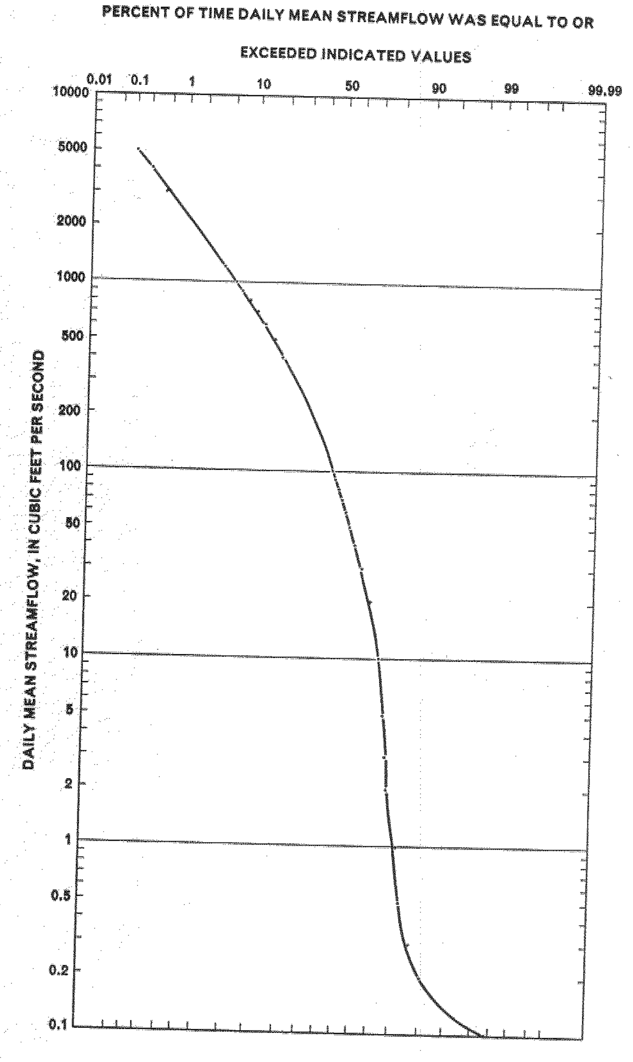

FIGURE 14.— Duration curve of daily mean streamflow, Humboldt River at Comus, Nev., water years 1918-26, 1946-62

TABLE 9—STREAMFLOW, IN ACRE-FEET, OF THE HUMBOLDT RIVER AT THE COMUS GAGING STATION

	Period of Record (Water Years) 1895–1909, 1911–26, 1946–62	1949–62
Mean annual	199,100	172,100
Median annual	149,500	156,700
Maximum annual	688,100	558,500
Minimum annual	26,700	27,530

Monthly and yearly streamflow at the Comus and Rose Creek gaging stations for the common period of record are listed in Table 10; average monthly streamflow is shown in Figure 16. The graph shows that the lowest monthly flow at both gaging stations commonly occurs in September and October. This is a result of evapotranspiration and the depletion of channel and bank storage from the previous spring runoff. Streamflow begins to increase by November, owing mainly to a reduction of evapotranspiration. By December, practically no evapotranspiration occurs and streamflow increases slightly. The flow continues to increase through January and February as a result of winter precipitation. Spring runoff from the winter's snowpack usually begins in March or April, resulting in peak flows in May and June. The flow gradually recedes following the peak as water is used for irrigation and is consumed by evapotranspiration. Normally, by July most of the winter's snowpack has been depleted, water is flowing out of channel storage, and the river is drawing from the ground-water reservoir. In August, streamflow continues to decrease as the only significant source of water is that which is supplied from the ground-water reservoir. By September or October the river again reaches its point of minimum flow.

The preceding discussion describes the monthly trends in streamflow of the Humboldt River during an average water year. Unusual weather conditions, such as prolonged periods of drought or unusual storms as exemplified by the February 1962 peak flows, however, may affect the monthly flow pattern in a given water year.

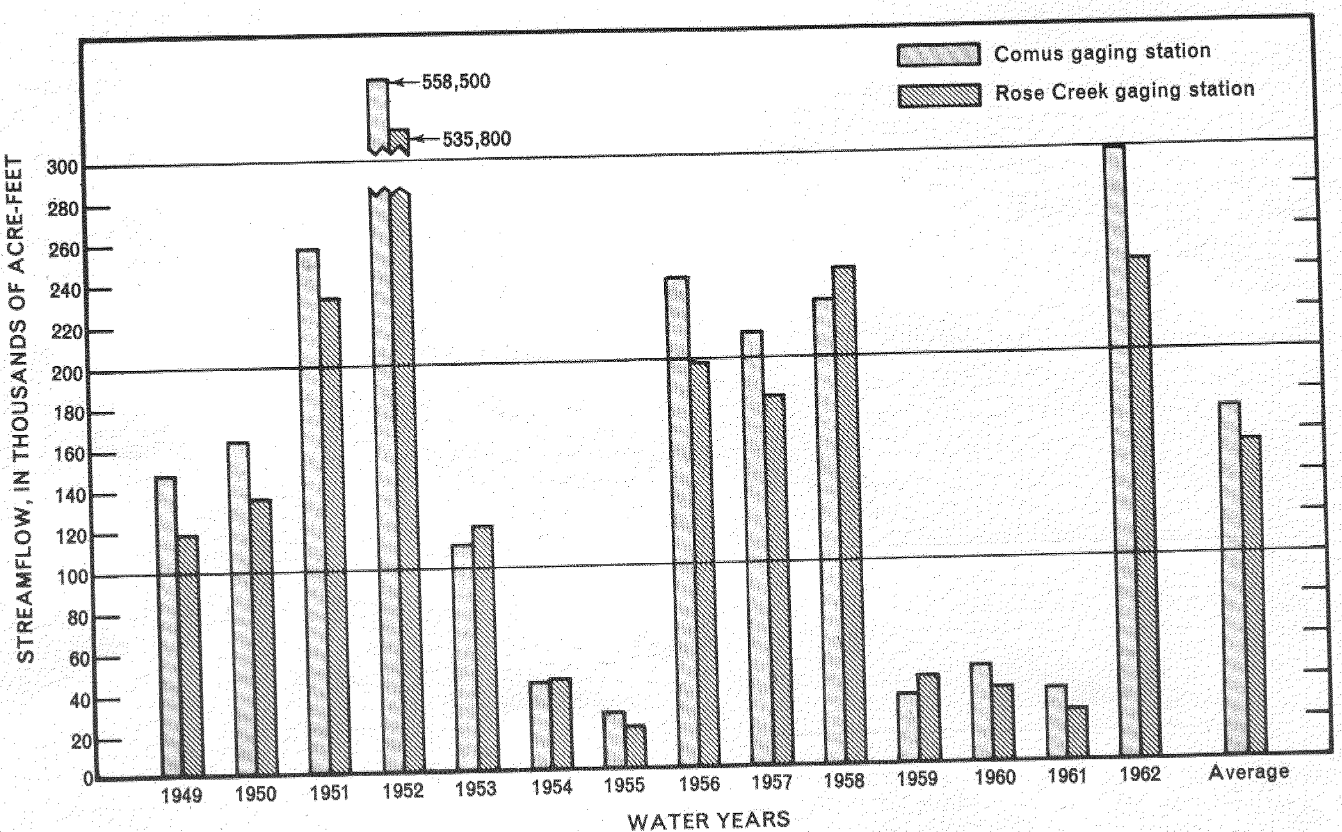

FIGURE 15.—Annual streamflow of the Humboldt River at the Comus and Rose Creek gaging stations near Winnemucca, Nev., water years 1949-62

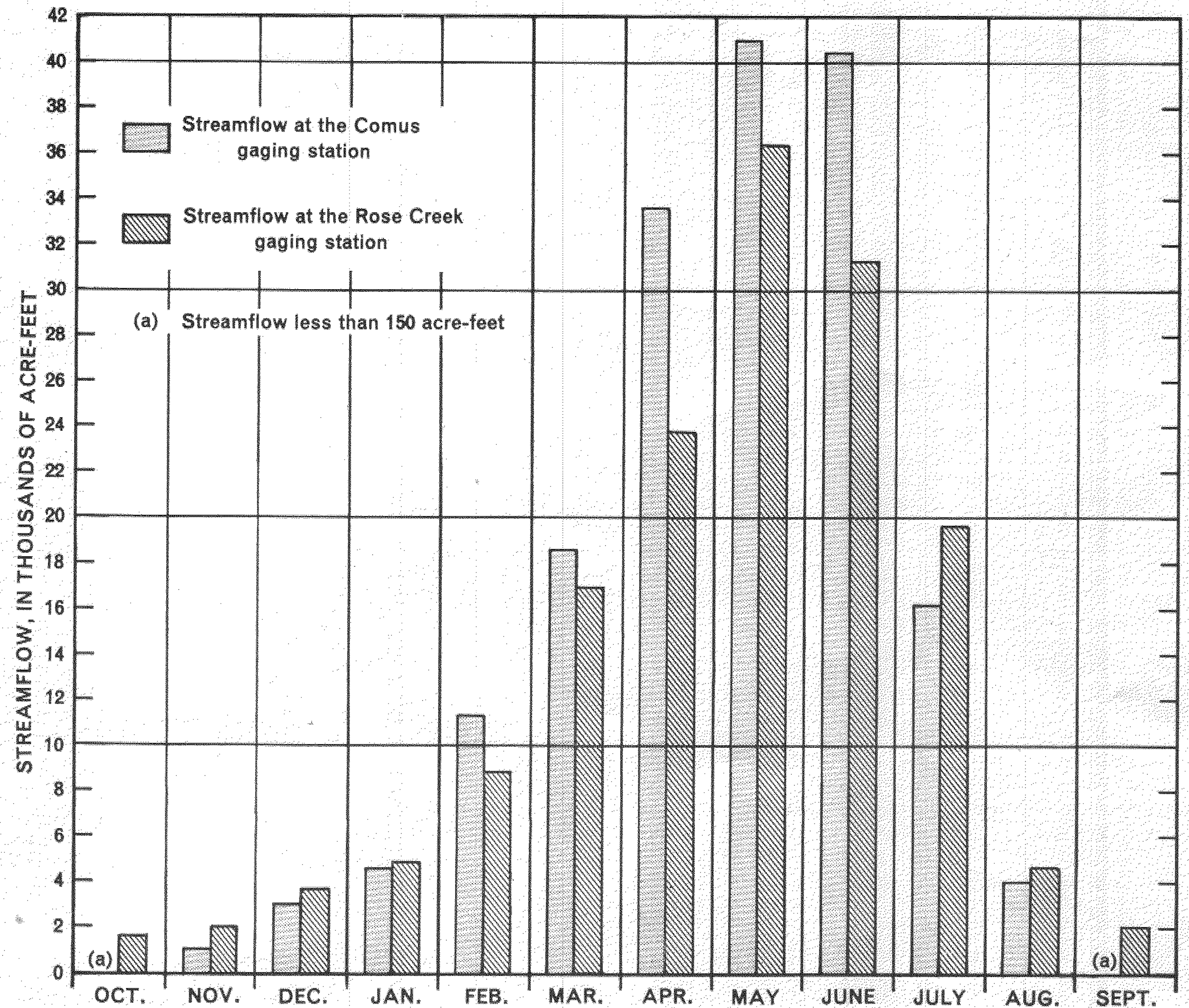

FIGURE 16.— Average monthly streamflow of the Humboldt River at the Comus and Rose Creek gaging stations near Winnemucca, Nev., water years 1949-62

TABLE 10—MONTHLY AND YEARLY STREAMFLOW, IN ACRE-FEET, OF THE HUMBOLDT RIVER AT THE COMUS AND ROSE CREEK GAGING STATIONS, WATER YEARS 1949–62

[Data from water-supply papers and unpublished records of the U.S. Geological 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	228,800
1959	86	1,780	3,930	5,550	6,170	8,160	5,600	1,900	1,640	75	9.5	6.1	34,810
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
1961	15	28	5.6	53	1,610	4,710	9,480	6,420	11,750	1,770	20	22	35,880
1962	6.1	13	165	641	36,320	32,150	55,190	50,720	79,120	38,620	4,030	247	297,200
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	79	1,040	3,080	4,660	11,300	18,620	33,560	41,030	40,500	16,220	1,936	131	172,100
Minimum	2.8	6.0	5.6	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
1961	661	752	811	850	1,430	3,220	4,260	2,690	5,790	2,770	832	595	24,670
1962	752	811	754	649	13,310	32,080	40,680	38,930	61,440	42,630	7,940	2,950	242,900
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	1,670	2,030	3,650	4,840	8,780	16,950	23,750	36,380	31,120	19,570	4,590	2,100	155,400
Minimum	633	772	760	669	1,160	2,130	3,190	2,310	1,130	827	714	541	21,840

STREAMFLOW DISPOSITION AND ROUTING

Gains and Losses

A comparison of the monthly streamflow at the Comus and Rose Creek gaging stations listed in Table 10 and summarized in Figure 16 shows periods of gains and losses in streamflow between the two main-stem stations. Some of the more significant hydrologic factors affecting these gains and losses are the amount of streamflow, available channel storage, ground-water conditions, soil-moisture conditions, and irrigation practices.

During the 14-year period of common record, about 60 to 70 percent of the total flow in the Humboldt River occurred during the spring runoff in April, May, and June. An average of about 24,000 acre-feet more water passed the Comus gaging station than the Rose Creek gaging station during this 3-month period. The loss in streamflow between the two gaging stations was caused largely by increases in channel storage, use of water for irrigation, recharge to the ground-water reservoir, evaporation from open bodies of water, and transpiration by vegetation.

Generally, the transition from a losing stream to a gaining stream between the Comus and Rose Creek gaging stations occurs quite abruptly in June or July. Considerably more water is passing the Rose Creek gaging station than the Comus gaging station by the end of the water year as water flows out of channel storage and is discharged from the ground-water reservoir. The river continues to gain into January as the result of a reduction in evapotranspiration. Normally, not until February does the river again become a losing stream, when the stage of the river rises as the result of winter precipitation. Thus, the data indicate that on the average the Humboldt River gains water between the Comus and Rose Creek gaging stations during the periods of low flow from July through January, and loses water during the periods of medium and high flow from February through June.

Table 11 lists the annual net gains and losses of streamflow between the Comus and Rose Creek gaging station during water years 1949–62, and the percent of total flow at Comus represented by the gains and losses. Net losses ranged from 54,300 acre-feet in 1962 to 5,690 acre-feet in 1955. Net gains ranged from 14,400 acre-feet in 1958 to 680 acre-feet in 1954. In the 14-year period the net loss averaged about 17,000 acre-feet, or 15 percent of the average annual flow at the Comus gaging station.

TABLE 11—ANNUAL GAINS OR LOSSES IN STREAMFLOW OF THE HUMBOLDT RIVER, BETWEEN THE COMUS AND ROSE CREEK GAGING STATIONS, WATER YEARS 1949–62

Water year	Gains (+) or losses (—) (acre-feet)	Percent of annual flow at the Comus gaging station
1949	—30,000	20
1950	—29,900	18
1951	—25,000	10
1952	—22,700	4
1953	+8,000	7
1954	+680	2
1955	—5,690	21
1956	—43,000	18
1957	—32,700	14
1958	+14,400	6
1959	+7,740	22
1960	—10,510	22
1961	—11,210	31
1962	—54,300	18
Averages	—16,700	15

Seepage Studies

In September 1959, 18 intermediate streamflow-measuring stations equipped with staff gages were established on the main stem of the Humboldt River between the Comus and Rose Creek gaging stations. Eight of the stations were at or near dams. In addition, in September 1960 the Geological Survey established the Winnemucca gaging station about 2 miles north of Winnemucca to measure Humboldt River streamflow about midway through the study reach. These stations are listed in Table 12 and are shown in Plate 5. During the study period, seepage measurements were made periodically at the intermediate stations and at the three regular recording stations to help evaluate seepage gains and losses of the river. Streamflow data for these stations are listed in Water-supply Paper 1734 and in the "Surface-water Records of Nevada" for water years 1961 and 1962.

Seventeen sets of seepage measurements were made during the period 1959–62, and the results are shown on Figures 17, 18, and 19. Each set of seepage measurements is defined by plotting the measured streamflow at each intermediate and regular gaging station. Lines sloping upward to the left indicate a gain in streamflow, whereas lines sloping downward to the left indicate a loss in streamflow.

Table 13 summarizes the results of the seepage measurements. During periods when the flow was 50 cfs or less, the river was a gaining stream. These periods commonly occurred in the late summer, fall, and early winter. The graphs show that the patterns of gains and losses during periods of low flow were very uniform. (Figures 17 to 19). The gains and losses were caused largely by the interchange of water between the river

TABLE 12—STREAMFLOW MEASURING STATIONS ALONG THE HUMBOLDT RIVER FROM THE COMUS TO ROSE CREEK GAGING STATIONS

Identification letter*	Distance Downstream From Comus Gaging Station		Station name	Location	Remarks
	River miles	Flood plain miles			
A	0	0	Humboldt River at Comus, Nev.	SE¼NE¼SE¼ sec. 14, T. 36 N., R. 41 E.	Water-stage recorder
B	1.3	1.0	Humboldt River below Comus, Nev.	SW¼SE¼SW¼ sec. 11, T. 36 N., R. 41 E.	Staff gage
C	5.6	3.5	Humboldt River above Preble, Nev.	NE¼SW¼NE¼ sec. 21, T. 36 N., R. 41 E.	Staff gage
D	8.4	5.2	Humboldt River at Preble, Nev.	SW¼SE¼SE¼ sec. 19, T. 36 N., R. 41 E.	Staff gage
E	10.6	6.7	Humboldt River above Stahl Dam, Nev.	NE¼SW¼SE¼ sec. 25, T. 36 N., R. 40 E	Staff gage
F	13.1	8.3	Humboldt River at Stahl Dam, Nev.	SW¼NW¼NW¼ sec. 35, T. 36 N., R. 40 E.	Staff gage
G	16.5	10.3	Humboldt River at Golconda, Nev.	SE¼NE¼NW¼ sec. 28, T. 36 N., R. 40 E.	Staff gage
H	18.7	11.2	Humboldt River at Eden Valley Road Bridge, Nev.	NW¼NW¼SW¼ sec. 21, T. 36 N., R. 40 E.	Staff gage
I	21.2	12.2	Humboldt River at Diamond S Ranch, Nev.	SE¼SE¼SW¼ sec. 17, T. 36 N., R. 40 E.	Staff gage
J	25.1	13.7	Humboldt River below Diamond S Ranch, Nev.	NE¼NE¼NE¼ sec. 13, T. 36 N., R. 39 E.	Staff gage
K	32.7	17.9	Humboldt River at C S Ranch, Nev.	SE¼NE¼NE¼ sec. 4, T. 36 N., R. 39 E.	Staff gage
L	43.1	22.6	Humboldt River at Kearns Ranch, Nev.	SW¼NE¼NW¼ sec. 2, T. 36 N., R. 38 E.	Staff gage
M	54.0	26.5	Humboldt River near Winnemucca, Nev.	NE¼SW¼NE¼ sec. 17, T. 36 N., R. 38 E.	Water-stage recorder
N	58.3	28.0	Humboldt River at Winnemucca, Nev.	NW¼SW¼SW¼ sec. 20, T. 36 N., R. 38 E.	Staff gage
O	67.4	31.7	Humboldt River at Harrer Ranch, Nev.	NE¼SE¼SE¼ sec. 34, T. 36 N., R. 37 E.	Staff gage
P	71.7	33.7	Humboldt River at Upper Hilyer Ranch, Nev.	NW¼NW¼NE¼ sec. 9, T. 35 N., R. 37 E.	Staff gage
Q	80.2	36.8	Humboldt River above Lower Hilyer Ranch, Nev.	NW¼SW¼SE¼ sec. 12, T. 35 N., R. 36 E.	Staff gage
R	83.0	38.7	Humboldt River at Lower Hilyer Ranch, Nev.	SW¼SW¼NW¼ sec. 14, T. 35 N., R. 36 E.	Staff gage
S	85.5	40.1	Humboldt River at Lower McNinch Ranch, Nev.	NW¼NW¼NE¼ sec. 21, T. 35 N., R. 36 E.	Staff gage
T	87.2	40.7	Humboldt River below Lower McNinch Ranch, Nev.	NW¼NW¼NW¼ sec. 21, T. 35 N., R. 36 E.	Staff gage
U	92.3	44.7	Humboldt River near Rose Creek, Nev.	NW¼SE¼NW¼ sec. 36, T. 35 N., R. 35 E.	Water-stage recorder

*Letter used to identify streamflow measuring stations on Plate 5 and elsewhere in report.

and the ground-water reservoir (pages 61–64). Increases in base flow from the fall to the winter, for example from October to December 1960 and 1961, resulted largely from seasonal reductions in evapotranspiration losses.

Medium to high flows of 50 cfs or more occurred in April and June during the irrigation season. The graphs for these months show a loss in streamflow between the Comus and Rose Creek gaging stations, which was due mainly to the diversion of water for irrigation and recharge to the ground-water reservoir. Marked decreases in flow between some of the intermediate stations during these months were largely the result of diversions for irrigation of meadow lands adjacent to the river. Increases in flow probably were the result of the return flow to the river of some of the water diverted for irrigation.

Gains and losses during periods of peak flow are related primarily to the amount of streamflow, the amount of channel and bank storage available to be filled within the study reach, and the amount of water retained behind dams for

TABLE 13—SUMMARY OF SEEPAGE MEASUREMENTS BETWEEN THE COMUS AND ROSE CREEK GAGING STATIONS, WATER YEARS 1959–63

Date of seepage measurements	Measured Streamflow Maximum (cfs)	Measured Streamflow Minimum (cfs)	Net gain (+) or loss (—) between Comus and Rose Creek gaging stations (cfs)
1959 water year—			
Sept. 29	14.8	*	+12.8
1960 water year—			
Apr. 12–13	283	112	—137
June 14–16	310	144	—164
Aug. 9–11	15.2	*	+13.7
1961 water year—			
Oct. 18–19	13.5	0	+11.4
Dec. 13–15	16.2	0.07	+14.9
Feb. 14–15	31.0	19.0	+6.3
Apr. 11–12	208	79.7	—128
June 12–14	278	105	—107
Aug. 8–9	17.9	.20	+17.1
1962 water year—			
Oct. 9–10	11.8	0	+10.3
Dec. 5–6	14.8	0	+13.4
Apr. 30–May 2	855	731	—79.0
June 13–17	1,270	1,070	—200
Aug. 27–31	67.8	13.4	+46.1
1963 water year—			
Nov. 5–7	31.1	.17	+28.6
Dec. 17	48.4	27.8	+19.6

*Less than 0.01 cfs.

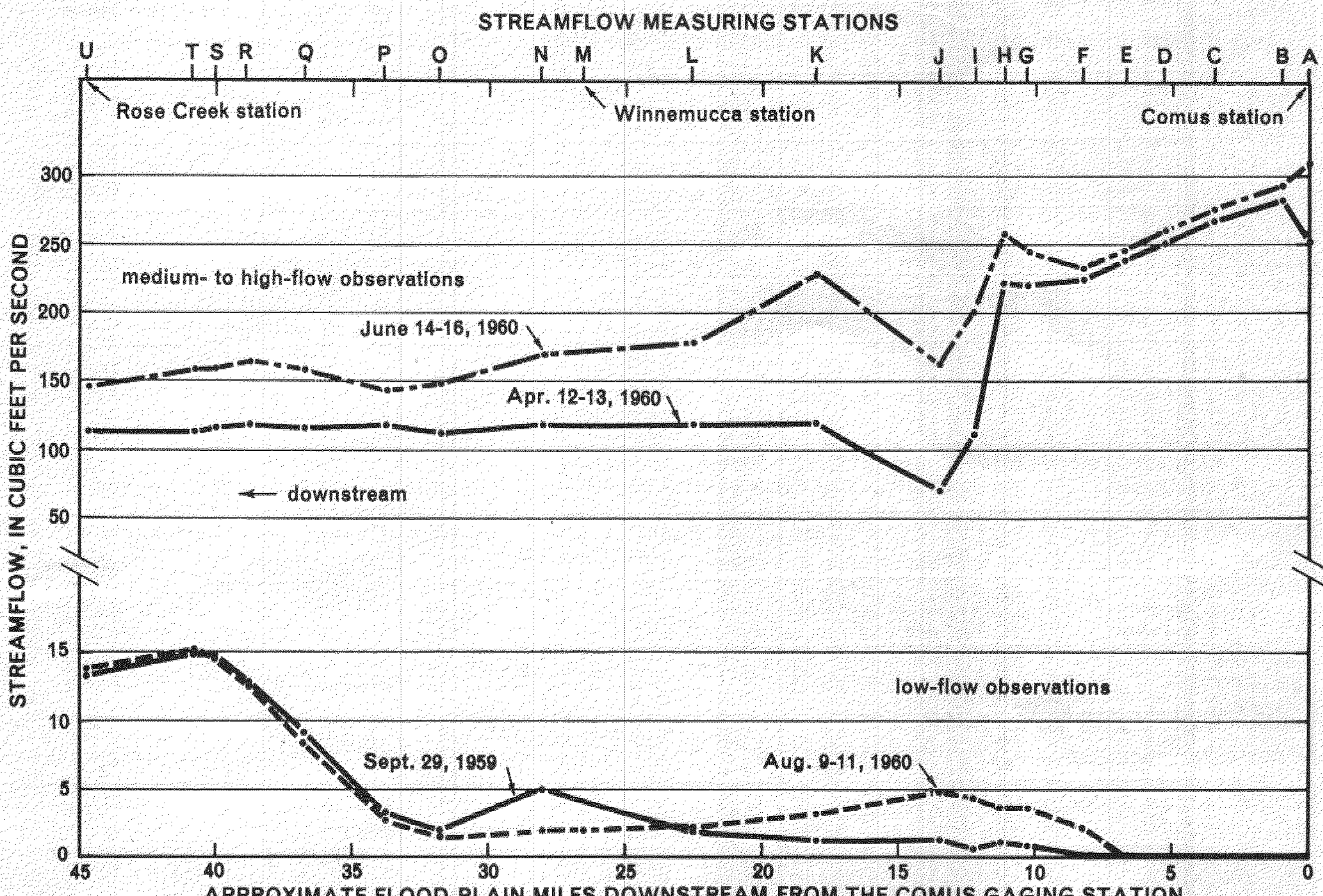

FIGURE 17.— Streamflow measurements along the Humboldt River between the Comus and Rose Creek gaging stations near Winnemucca, Nev., water years 1959-60

irrigation. Gains and losses during these periods are affected to a lesser degree by evaporation from open bodies of water and transpiration by vegetation.

Variations in the gains and losses during periods of high flow are shown by the hydrographs in Figure 20 for the Comus, Winnemucca, and Rose Creek gaging stations during the period February through July of water year 1962. Table 14 compares the four major peak flows shown in the figure and lists the peak-flow travel time between stations.

The rapid increase in flow in February, reaching a peak flow at Comus on February 21, was caused by heavy rains on snow upstream from the study area. By the time the peak reached the Winnemucca gaging station, it had been reduced by nearly 35 percent of the peak flow at Comus. By the time the peak reached the Rose Creek gaging station, it had been reduced by nearly 50 percent of the peak flow at Comus. This large reduction in flow was due primarily to retention of water behind irrigation dams and storage of water in the channel and banks. A second peak

TABLE 14—SUMMARY OF FOUR PEAK FLOWS AT THE COMUS, WINNEMUCCA, AND ROSE CREEK GAGING STATIONS, WATER YEAR 1962

Gaging station	Date of peak	Daily mean peak flow (cfs)	Loss in peak flow between gaging station (cfs)	Travel time between gaging station (days)
Comus	Feb. 21	1,690		
Winnemucca	Feb. 28	1,120	570	7
Rose Creek	Mar. 2	875	245	2
Comus	Apr. 14	1,120		
Winnemucca	Apr. 19–20	915	205	5½
Rose Creek	Apr. 22	808	107	2½
Comus	June 5–6	1,440		
Winnemucca	June 16	1,220	220	9½
Rose Creek	June 17–18	1,150	70	2½
Comus	June 29	1,360		
Winnemucca	July 4–5	1,130	230	5½
Rose Creek	July 7	1,070	60	2½

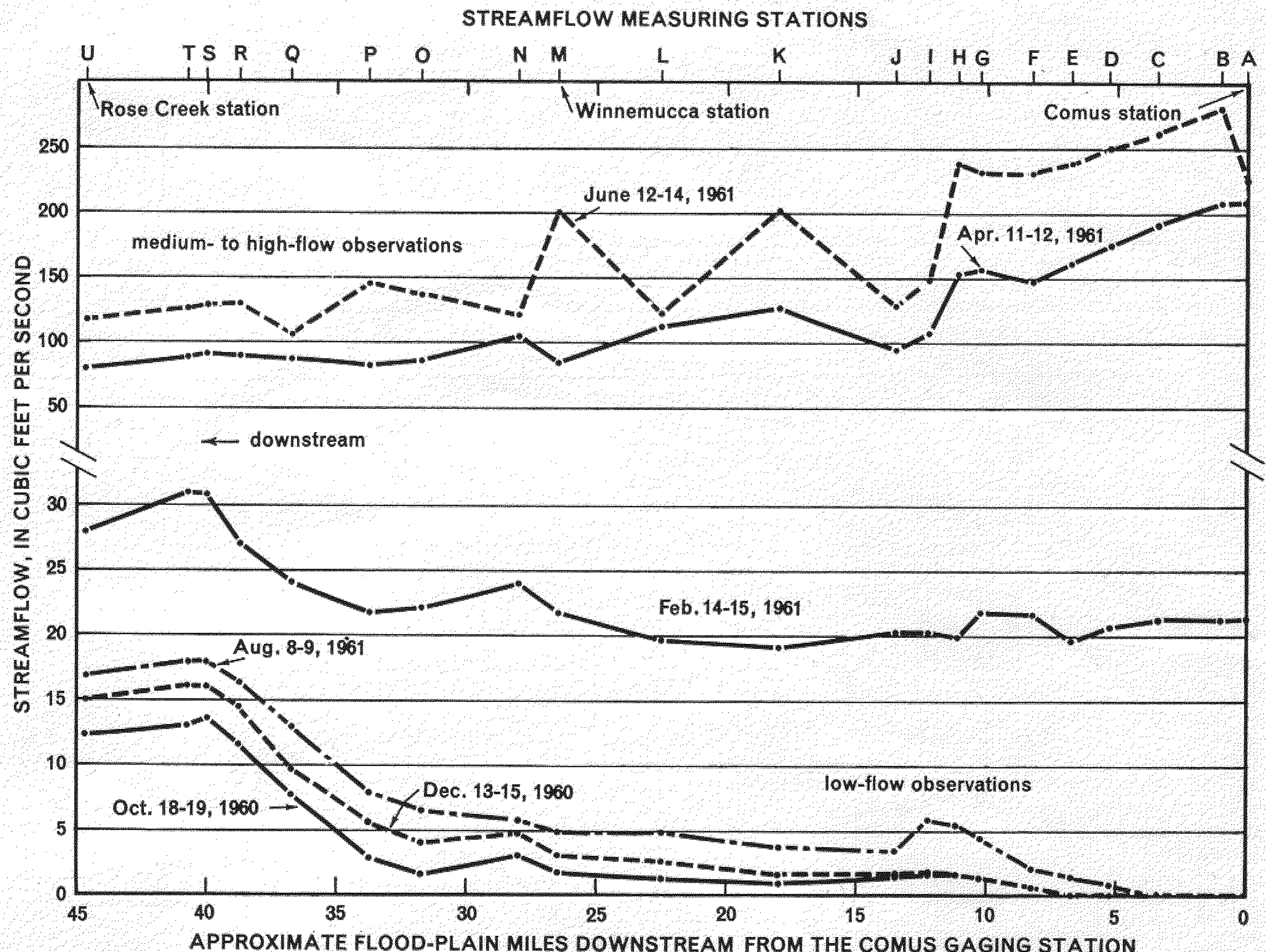

FIGURE 18.— Streamflow measurements along the Humboldt River between the Comus and Rose Creek gaging stations near Winnemucca, Nev., water year 1961

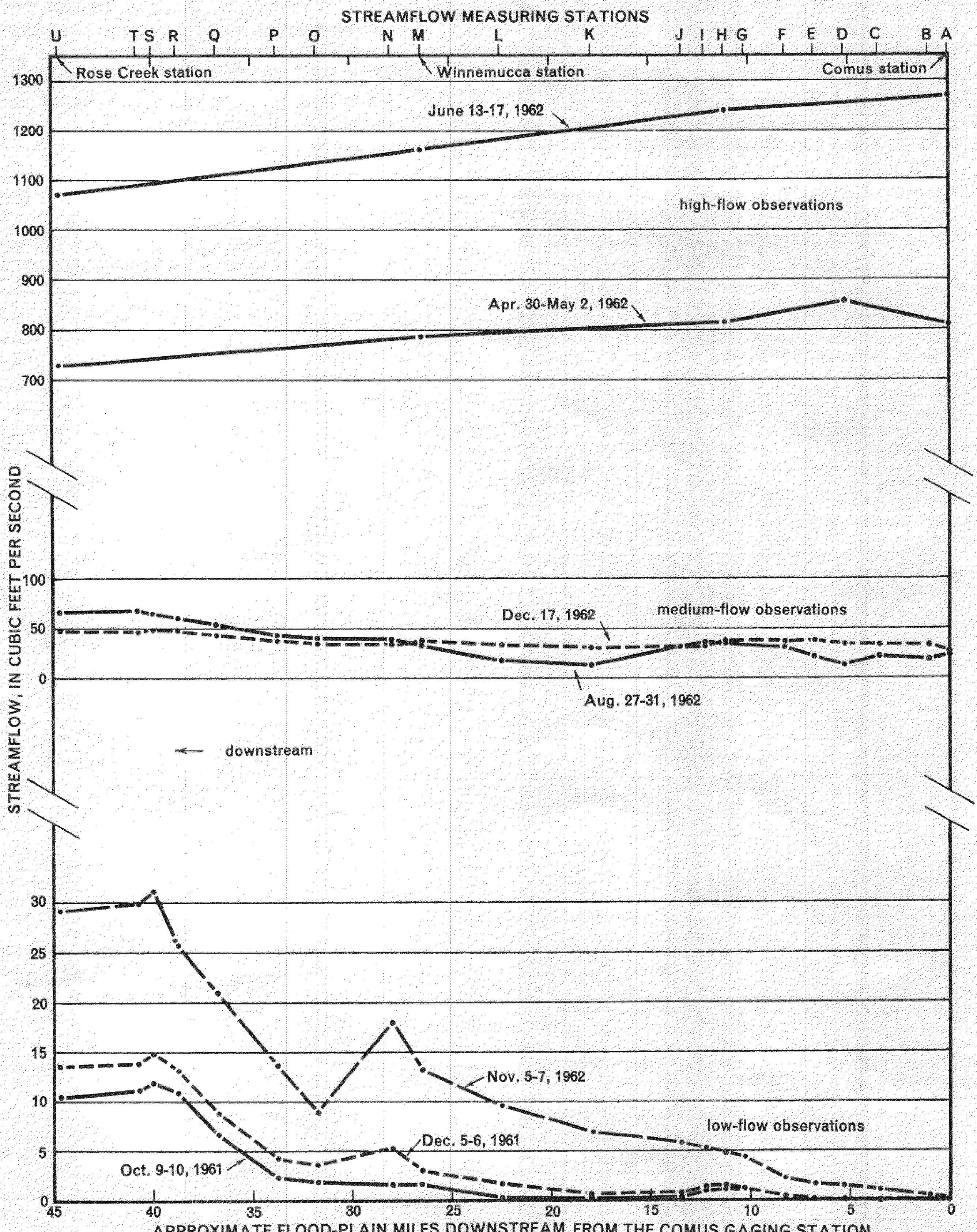

FIGURE 19.— Streamflow measurements along the Humboldt River between the Comus and Rose Creek gaging stations near Winnemucca, Nev., water years 1962-63

flow occurred at the Winnemucca gaging station on March 8 and 9. Because this peak did not appear upstream at the Comus gaging station, it probably was the result of the release of water stored behind dams between the two stations.

The hydrographs also show that the February peak was followed by three other significant peaks during the spring runoff in April, June, and July. Preceding the three peaks, the flow increased at a slower rate than that preceding the February peak. This slower rate of increase in flow is typical of spring-runoff characteristics of the Humboldt River in the study reach. The peak flows during February and March filled much of the available channel storage within the flood plain, leaving little storage space available for the subsequent peaks. As a result the losses in streamflow for these three peaks, as shown in Table 14, were less than the losses which occurred during the February peak, and were due primarily to the diversion of water for irrigation, evapotranspiration, and recharge to the ground-water reservoir.

The hydrographs show that the highest peak at the Comus gaging station for the 1962 water year occurred in February, whereas the highest peak at the Rose Creek gaging station occurred in July. Because much of the available channel storage was filled by the February peak, the lower subsequent peaks retained much of their volume in their progress downstream.

Travel Time

A correlation between travel time and streamflow requires a very complex analysis of the channel and flow characteristics of a study reach. In this report consideration of streamflow travel time is limited to a brief analysis of the travel time of wave fronts of peak flows (Rantz, 1961). Some of the factors which affect streamflow travel time within the study reach are amount of streamflow, amount of available channel storage, amount of water retained behind dams, roughness, slope, and shape of the channel, and rate of increase or decrease in streamflow.

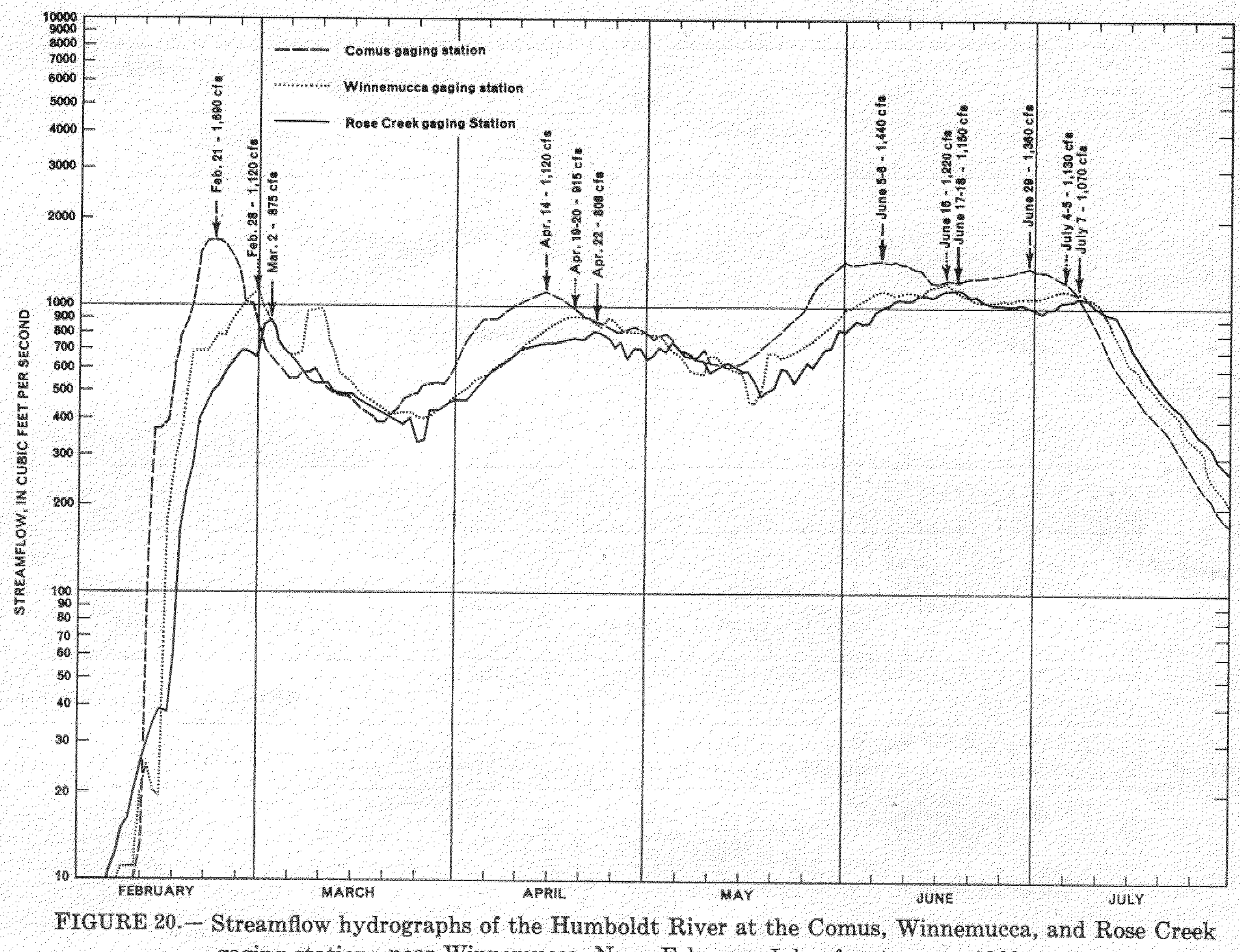

FIGURE 20.— Streamflow hydrographs of the Humboldt River at the Comus, Winnemucca, and Rose Creek gaging stations near Winnemucca, Nev., February-July of water year 1962

The wave front of a peak flow normally travels downstream at a faster rate than the volume of water contained in the peak. The travel time for the February, April, June, and July peaks during water year 1962 are shown in Table 14. The table shows that travel time of waves (or peaks) between the Comus and Winnemucca gaging stations ranges between 5½ to 9½ days, or 6 to 10 miles per day, for peak flows of about 1,000 cfs. Travel time between the Winnemucca and Rose Creek gaging stations ranges between 2 and 2½ days, or on the order of 15 to 20 miles per day, for peak flows of the same magnitude.

Evaporation Losses From Open Bodies of Water

Man has increased water-surface evaporation losses within the project area by placing various constrictions across the valley floor. Numerous road and railroad crossings between the Comus and Rose Creek gaging stations cause back water and additional flooding during high flows. In addition, about 16 small dams store water for irrigation purposes. Evaporation from water behind the dams and evaporation resulting from natural flooding are evaluated in the following paragraphs; however, no attempt is made in this report to evaluate surface-water evaporation losses from irrigated fields that often are almost completely inundated artificially for several weeks at a time.

To estimate the evaporation losses from open bodies of water, the water-surface area and its relation to the amount of streamflow, and the rate of evaporation from these surface areas were evaluated. Flood-plain profiles were drawn at 18 of the 21 intermediate and recording gaging stations utilizing large-scale topographic maps prepared by the Soil Conservation Service. Four typical profiles (Figure 21) show that the width of the flood plain varies considerably, and that the flood plain is characterized by numerous side channels and depressions. Each of the 18 profiles was assumed to be typical of the flood plain halfway between the adjacent upstream and

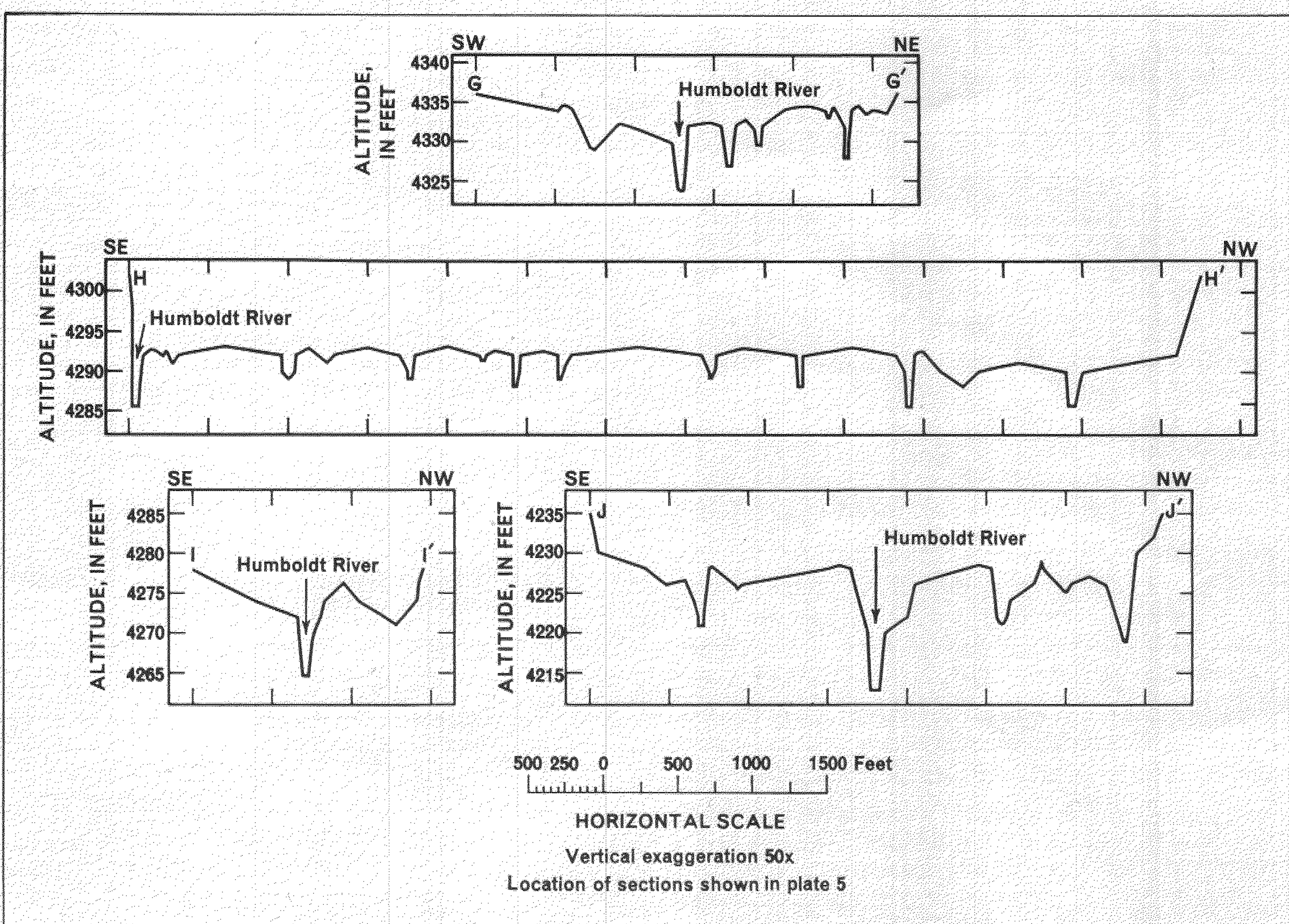

FIGURE 21.— Flood plain profiles across the Humboldt River near Winnemucca, Nev. View is downstream

downstream cross-sections. Based on the stage-discharge relation of the main channel at each profile, a relation between discharge and water-surface area was determined. The total water-surface area between the Comus and Rose Creek gaging stations could then be computed. Figure 22 shows a curve relating the total water-surface area between the two gaging stations to the average of streamflow at the two gaging stations. The figure shows that the surface area increases from about 1,000 acres for an average flow of 20 cfs to about 12,000 acres for an average flow of 5,000 cfs.

Wide variations in evaporation rates and water-surface areas occur throughout the year. Therefore, water-surface evaporation losses were

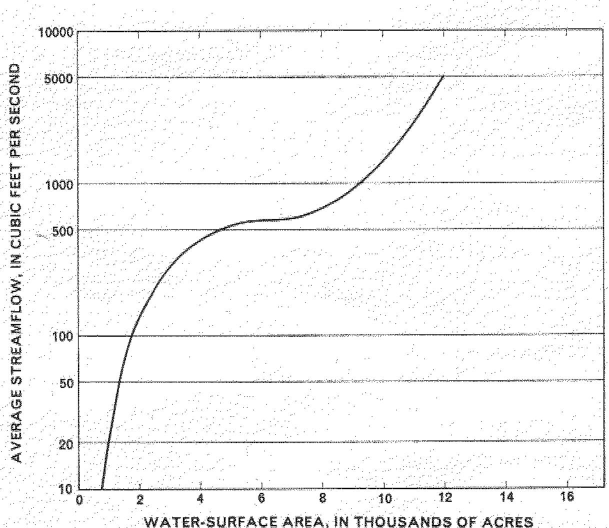

FIGURE 22.— Relation of total water-surface area between the Comus and Rose Creek gaging stations to the average of streamflow at the two gaging stations

determined on a monthly basis rather than a yearly basis. The average monthly streamflow of the river was estimated by averaging monthly streamflow data at the Comus and Rose Creek gaging stations. Monthly water-surface areas were then obtained from the discharge surface-area curve in Figure 22. Monthly evaporation rates from free-water surfaces were estimated on the basis of partial short-term evaporation data near Winnemucca and more complete yet partial evaporation data at Rye Patch Reservoir, 45 miles southwest of Winnemucca, and at the Fallon experimental station, 115 miles southwest of Winnemucca. The water-surface evaporation loss for a given month is the product of the water-surface area and the evaporation rate for that month. The annual water-surface evaporation loss for a given year is the summation of the monthly water-surface evaporation losses for that year.

The relation of annual streamflow at the Comus gaging station to the estimated annual evaporation losses from free-water surfaces between the Comus and Rose Creek gaging stations is shown in Figure 23. Evaporation from free-water surfaces was on the order of 5,000 acre-feet, or 17 percent of the total flow, when the annual flow at

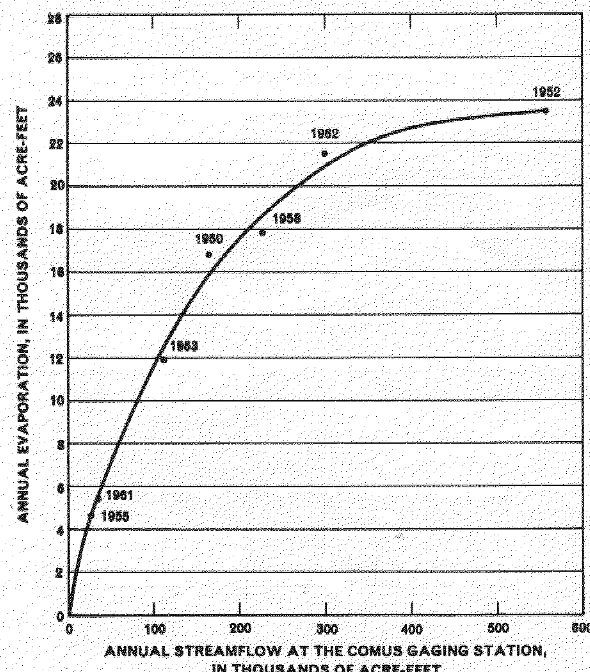

FIGURE 23.— Relation of annual streamflow at the Comus gaging station to annual water-surface evaporation losses between the Comus and Rose Creek gaging stations, water years 1950, 1952-53, 1955, 1958, 1961-62

the Comus gaging station was about 30,000 acre-feet; it was about 9 percent when the annual streamflow was about 200,000 acre-feet, and about 5 percent when the annual streamflow was about 500,000 acre-feet.

The following table shows a comparison of the estimated annual water-surface evaporation losses and annual gains or losses in streamflow between the Comus and Rose Creek gaging stations for the 7 water years and for the common period of record. There does not appear to be a close correlation between water-surface evaporation losses and annual gains or losses in streamflow. The table indicates, however, that water-surface evaporation losses are significant when compared with the annual gains and losses in streamflow.

Water year	Water-surface evaporation losses (acre-feet)	Annual gain (+) or loss (—) between the Comus and Rose Creek gaging stations (acre-feet)
1950	16,800	—29,900
1952	23,400	—22,700
1953	11,900	+8,000
1955	4,650	—5,690
1958	17,800	+14,400
1961	5,400	—11,210
1962	21,400	—54,300
Averages, 1949–62	14,000	—17,000

The estimated average annual water-surface evaporation losses for water years 1949–62 is on the order of 14,000 acre-feet. The estimated evaporation losses from free-water surfaces in December through June of water year 1962 is 14,000 acre-feet.

Some of the factors affecting water-surface evaporation losses which were not investigated in this analysis are irrigation flooding, vegetal cover over flooded areas, relation between depth of water and evaporation rates, and increased water-surface areas based on daily mean streamflow rather than monthly mean streamflow. A more complete evaluation of these factors would require the collection of considerably more data and a more detailed and comprehensive analysis of the data. However, the results obtained in this study probably are a reasonable indication of the order of magnitude of evaporation losses from free-water surfaces and the extent to which this evaporation affects the total water budget.

Surface-water Storage

Channel storage has a significant effect on the flow characteristics and disposition of streamflow throughout the study reach. As a result of increased channel storage, peak flows are reduced as they move downstream, surface-water evaporation losses increase, and the ground-water reservoir is replenished.

The normal channel-storage capacity of the river is greatly increased by the numerous dams in the main channel. Diversions at the dams flood meadow lands, side channels, and other depressions, further increasing the surface-water storage capacity. The amount of surface water in storage varies widely during the irrigation season when flash boards are added to or removed from the dams, and diversion structures are opened or closed. No attempt is made to analyze changes in the amount of surface water in storage as a result of irrigation practices.

Channel storage was determined in a manner similar to water-surface area (page 53); that is, a relation between discharge and cross-sectional area was obtained at each topographic profile. From this, the relation of the total surface water in storage between the Comus and Rose Creek gaging stations to the average of streamflow at the two gaging stations was determined to define the curve shown in Figure 24. The graph shows that surface water in storage between the two gaging stations increases from about 1,000 acre-feet for an average streamflow of 10 cfs to about 33,000 acre-feet for an average streamflow of 5,000 cfs.

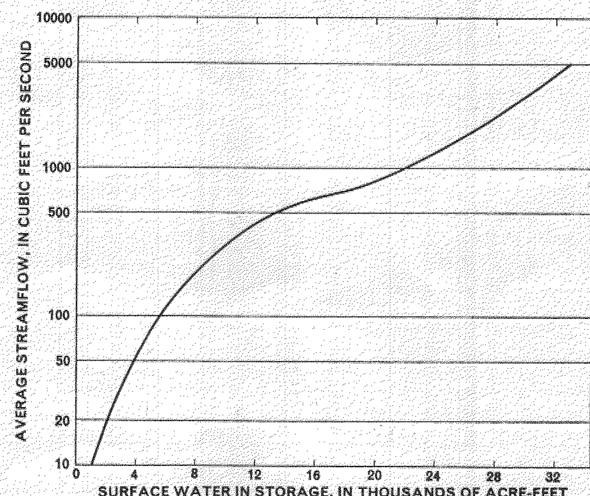

FIGURE 24.— Relation of total surface water in storage between the Comus and Rose Creek gaging stations to the average of streamflow at the two gaging stations

On the average, the stage and flow of the river is the same at the beginning and end of a water year. Accordingly, the net change of surface water in storage from the beginning to the end of a water year normally is zero or very nearly so. However, the flow of the Humboldt River averaged about 5 cfs at the Comus and Rose Creek gaging stations at the beginning of water year 1962 and about 22 cfs at the end of the water year. Thus, the estimated net increase of surface water in storage for this period was about 1,800 acre-feet. The flow averaged 7 cfs on December 1, 1961, and 1,170 cfs on June 30, 1962; the estimated net increase of surface water in storage during this period was on the order of 22,000 acre-feet.

FLOODS

Floods in the Humboldt River and its tributaries are characterized by several different weather conditions. Peaks of extreme magnitude usually occur during the winter, spring, and early summer. Floods during the winter usually are caused by rain on snow or heavy rain on frozen ground. Floods during the spring normally are the result of runoff from the winter's snowpack. The magnitudes of peak flows are dependent largely on the amount of snow pack in the mountains and on the amount of rain. Heavily concentrated rain showers may occur at any time and cause floods of unusually high magnitude from tributaries having relatively small drainage areas.

Extreme high flows of the Humboldt River usually inundate much of the flood plain resulting in loss of livestock and damage to bridges, roads, railroads, and irrigation structures. Mud and sheet flows from tributaries occasionally block or wash out roads and railroads.

A flood-frequency study was made of the Humboldt River at the Comus gaging station to evaluate the flood potential of the river in that area. This study involved the determination of the magnitude of peak flows and their frequency, or recurrence interval. The recurrence interval may be defined as the average interval of time within which a peak flow of a given magnitude will be equaled or exceeded once.

A method developed by the U.S. Geological Survey (Dalrymple, 1960, p. 16) was used to draw the flood-frequency curve on Figure 25, which shows the relation between the annual peak flows and the recurrence interval. The curve shows that the February 21, 1962 peak flow of 1,690 cfs at the Comus gaging station has a recurrence interval of about 4.3 years. In other words the peak flow which occurred in water year 1962 theoretically would be expected to occur once every 4.3 years.

The mean annual flood or the peak flow which may be expected to occur 50 percent of the time is, by definition (Dalrymple, 1960, p. 29), that flood having a recurrence interval of 2.33 years. From Figure 28, the mean annual flood at the Comus gaging station is about 1,070 cfs.

The magnitude of floods in the upper Humboldt River basin is not always an indication of the magnitude of floods in the lower basin. For example, the February 1962 peak flows at many gaging

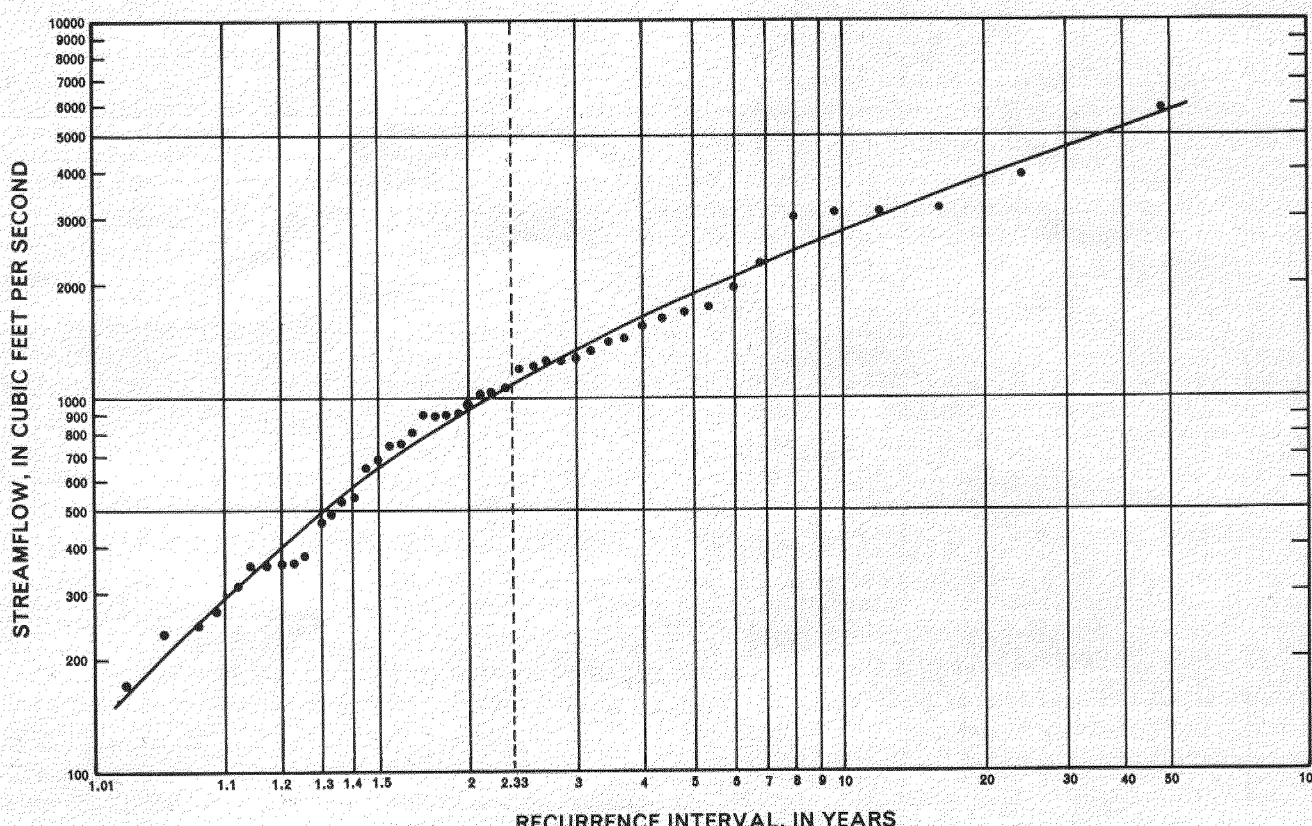

FIGURE 25.— Frequency of annual floods, Humboldt River at Comus, Nev., water years 1895-1909, 1911-23, 1925-26, 1946-62

stations in the upper basin were the highest of record, whereas the highest peak flow of record at the Comus gaging station occurred during water year 1955.

Relatively few additional data are available on the magnitude and frequency of floods in the study area. Old newspaper reports indicate that unusually high floods occurred throughout the Humboldt River basin during water year 1910. No data are available, however, to establish the magnitude of this flood. Unusually high flows from tributaries in the Winnemucca area occurred in July and August 1961 as the result of heavily concentrated thunder showers. Peak-flow measurements were made by indirect methods on Pole Creek, Thomas Canyon, and Clear Creek, which drain the Sonoma Range. A summary of these peak flows is listed in Table 15. The relatively small drainage areas above the measuring sites on these tributaries contributed a very high unit runoff. Flood flows from the tributaries carried considerable mud and debris which were deposited on the alluvial aprons. The Pole Creek gaging station and an earth fill dam on Clear Creek were washed out.

A nearly complete summary of floods in the Humboldt River basin during the period 1861 to 1962 is available in a report published by the Nevada Department of Conservation and Natural Resources and the U.S. Department of Agriculture entitled, "Chronology of Flood Years and High Water Years, 1962." A description of the February 1962 flood on the Humboldt River is given in U.S. Geological Survey Circular 467 entitled, "Floods of February 1963 in Southern Idaho and Northeastern Nevada."

TABLE 15—SUMMARY OF PEAK FLOWS ON POLE CREEK, THOMAS CANYON, AND CLEAR CREEK, WATER YEAR 1961

Stream	Location	Drainage area (sq. miles)	Date	Peak flow (cfs)
Pole Creek	At the Pole Creek gaging station near Golconda, Nevada	10.7	Aug. 6, 1961	4,000
Thomas Canyon	About 2½ miles upstream from the Grass Valley Road crossing and 4½ miles south of Winnemucca, Nevada	8.4	July 3 or 4, 1961	1,320
Clear Creek	About ½ mile upstream from Clear Creek Ranch and 17 miles south of Winnemucca, Nevada	32.4	Aug. 5, 1961	11,400

GROUND WATER

Those aspects of the ground-water system of the project area studied by the U.S. Geological Survey are emphasized in this section of the report. Quantitative estimates of recharge to, discharge from, and changes of ground water in storage in the storage units outlined in Plate 5 are stressed for the purpose of developing the data needed for the water-budget analyses. Preliminary estimates of several components of the hydrologic system are included.

THE GROUND-WATER RESERVOIR

Nearly all the economically recoverable ground water in the project area and virtually all the ground water closely associated with the flow of the Humboldt River is in the unconsolidated and partly consolidated Tertiary and Quaternary sedimentary deposits. Where saturated, these deposits and a few basalt flows collectively are termed the ground-water reservoir. Stratigraphic units in the ground-water reservoir capable of yielding significant quantities of water to wells are termed aquifers. Some ground water probably occurs in the consolidated rocks of the area in addition to the basalt flows; however, in overall aspect most of the older consolidated rocks have little or no interstitial porosity and permeability and therefore are not considered part of the ground-water reservoir.

Partly because of erosion but largely as a result of displacement along normal faults, the bedrock surfaces underlying and bordering the ground-water reservoir are highly irregular. Accordingly, the range in thickness of the ground-water reservoir is considerable. In the mouth of Grass Valley, it is at least several thousand feet thick. In other areas, such as Emigrant Canyon and the Rose Creek constriction, the reservoir is only about 40 to 50 feet thick. Along the margins of the basin where saturated deposits overlap the rocks of the bordering mountains, it thins to a feather edge.

OCCURRENCE OF GROUND WATER

Water in the ground-water reservoir occurs almost entirely in the interstices or pore spaces between granular sedimentary particles and chemical precipitates. The porosity and permeability of the deposits largely are related to the size and shape of the particles and the degree of compaction and cementation of the material. All other factors being equal, well-sorted material has the most numerous pore spaces, and coarse-grained material has the greatest permeability. Accordingly, well-sorted, coarse-grained strata normally store and yield the most water and poorly-sorted, fine-grained strata normally store and yield the least water. Because of the plate-like shape of some of the fine-grained particles, because of the loose compaction, and because of primary and secondary sedimentary structures, some of the fine-grained deposits in the project area are moderately to highly porous and consequently contain relatively large amounts of water. Nevertheless, because they are fine-grained, these deposits have a low permeability and yield little water to wells.

Little is known about the occurrence of water in the deeper parts of the ground-water reservoir because no wells in the area are more than about 600 feet deep. Presumably, deposits similar to the Miocene or Pliocene deposits (Table 3) occur at depth; however, it is difficult to predict at what depth they occur, because they are broken by faults of large vertical displacement and have been deeply eroded. Loeltz, Phoenix, and Robinson (1949, p. 26 and Plate 1) indicate that the older Miocene or Pliocene deposits consist largely of fine-grained material having low permeability and underlie most of the floor of Paradise Valley below a depth of about 300 feet. The older deposits apparently were not penetrated by any of the wells in the mouth of Grass Valley or along the Humboldt River. It is surmised that the older Miocene or Pliocene deposits transmit only small quantities of water largely because they are fine grained, structurally deformed, moderately compacted, and partly cemented.

During the drilling of most of the test borings at nearly 175 sites, ground-water levels did not change with depth, indicating that ground water occurs under water-table (unconfined) conditions in most of the shallow deposits. Locally, however, artesian (confined) conditions occur where lenses of relatively permeable sand and gravel are interbedded with or overlain by less permeable material in the alluvial-fan deposits and in the flood-plain deposits.

Beneath the flood plain and river-cut terraces, ground water occurs under water-table conditions in the medial gravel unit during most of the year.

In the mouth of Grass Valley, artesian conditions probably occur in the medial gravel unit where it is overlain by the clay facies of the upper silt and clay unit. (See Section E-E′, Plate 2.) Locally, water-table conditions probably occur in the sand facies of the upper silt and clay unit.

Thermal springs and two flowing wells, one thermal and one nonthermal, define five additional, relatively small areas where water occurs under artesian conditions. A ground-water mound of thermal water about 100 feet above the regional water table occurs along the East Range fault. (See Plates 3 and 4.) The mound is defined by water levels at springs 35/36–28abal and 35/36–28dccl, and by the water level in well 35/36–27bbbl. Flowing well 36/38–19dcal, which is in the city of Winnemucca, reportedly penetrated mostly fluviatile deposits to a depth of 499 feet and basalt to depth of 525 feet; reportedly, it has an artesian head of about 10 to 12 feet above land surface. Well 37/39–3dccl is the only flowing well in the mouth of Paradise Valley, and reportedly is the only well discharging thermal water in Paradise Valley (Loeltz, Phoenix, and Robinson, 1949, pp. 33–34). The well is 61 feet deep, flows at a rate of about 2 gpm, and discharges water having a temperature of about 158°F. Thermal water having a maximum temperature of 148°F. forms a ground-water mound just west of Golconda. The mound, which is about 50 feet above the regional water table, is defined by the levels of spring pools and by the water level in well 36/40–29cdal. The fifth area of artesian flow occurs about 2 miles north of the Comus gaging station, where springs 36/41–2aacl and 36/41–2aac2 discharge thermal water.

SOURCE AND MOVEMENT OF GROUND WATER

Infiltration of precipitation within the Humboldt River drainage basin is the ultimate source of nearly all the ground water in the project area. As described subsequently in the report the direct infiltration of precipitation probably contributes only a small part of the average annual ground-water recharge. Rather, the source of most of the ground water is seepage of streamflow, the ultimate source of the streamflow being precipitation.

The source of the apparently small amount of thermal water in the area is not known. That the water is hot suggests possible deep circulation through fractured zones in the consolidated rocks.

Direction of Movement

Ground water moves in the direction of least hydraulic head, perpendicular to water-level contours, from recharge areas to discharge areas. Plates 3 and 4 show water-level contours based largely on the altitude of water levels in wells that penetrate only the upper few feet of the zone of saturation and on the altitude of the Humboldt River at 21 staff gages. Accordingly, the maps do not necessarily indicate the precise direction of ground-water movement at any appreciable depth below the top of the zone of saturation, especially in areas underlain by confined aquifers. However, as previously indicated, most of the aquifers in the area probably contain unconfined water; therefore, the maps probably indicate the general horizontal component of the direction of ground-water movement to a depth of several hundred feet in most parts of the project area. Loeltz, Phoenix, and Robinson (1949, Plate 1) show water-level contours in the mouth of Paradise Valley, based on the altitude of water levels in moderately deep wells. In overall aspect, these contours are similar to those shown in Plates 3 and 4. This suggests that the general direction of the horizontal component of ground-water movement at depth probably is similar to that in the shallow aquifers.

Plate 3 shows water-level contours in December 1961. Contours showing artesian heads near the East Range fault and near Golconda are shown; however, inasmuch as only meager data are available relative to the extent of other artesian aquifers in the area, artesian heads in the two flowing wells in the area and of the springs near the Comus gaging station are not shown. Although the shape of the contours change from day to day and season to season, their overall shape during most of the year (normally from about late July to mid-April) remains about the same. Thus, during most of the year, the gross direction of ground-water movement is, as shown in Plate 3, toward the Humboldt River and thence westward and southwestward roughly parallel to the river.

Rate of Movement

Most of the ground water in the project area moves at rates ranging from a small fraction of a foot to a few hundred feet per year, depending on the porosity, permeability, and hydraulic gradient. Except under special circumstances, such as flow through large fractures or solution openings in consolidated rocks or flow through highly permeable unconsolidated aquifers having unusually steep hydraulic gradients (as in the vicinity of pumping wells), the quantity of ground-water flow or underflow can be computed by the equation

$$Q = PIA, \qquad (1)$$

where Q = the quantity of ground-water flow in gallons per day,
P = the field coefficient of permeability in gallons per day per square foot,
I = the hydraulic gradient in feet per mile, and
A = the cross-sectional area through which the flow occurs.

The rate of flow in feet per day, V, through a given section having a cross-sectional area, A, can be computed from the equation

$$V = \frac{Q}{7.48n} = \frac{PIA}{7.48n}, \qquad (2)$$

where n is porosity expressed in percent and 7.48 is a factor for converting gallons to cubic feet.

The following data and computations illustrate the method of calculating the velocity of ground-water flow. Sample 35/36–19dbcl–2 had a laboratory coefficient of permeability of 1,400 gpd/ft^2 and a porosity of about 38 percent (Table 4). The estimated field coefficient of permeability of the material is about 1,350 gpd/ft^2. The hydraulic gradient in the aquifer near the well from which the sample was obtained normally is about 4 feet per mile. For convenience, the cross-sectional area through which the flow occurs may be taken as 1 square foot. Substituting these data in equation 2

$$V = (1{,}350) \left[\frac{4}{5{,}280}\right]\left[\frac{1}{7.48 \times 0.38}\right] = 0.36 \text{ feet per day,}$$

or about 130 feet per year. Because the field coefficient of permeability of most of the flood-plain deposits probably is somewhat less than 1,350 gpd/ft^2, and because the hydraulic gradient commonly is not more than 4 feet per mile, the average velocity of ground-water flow in these deposits is assumed to be somewhat less than 130 feet per year.

The estimated average field coefficient of permeability of the medial gravel unit is 5,000 gpd/ft^2 (page 32). Its estimated average porosity is about 30 percent. Thus, where the hydraulic gradient is 4 feet per mile the velocity of ground-water flow in the unit is

$$V = (5{,}000) \left[\frac{4}{5{,}280}\right]\left[\frac{1}{7.48 \times 0.30}\right] = 1.7 \text{ feet per day,}$$

or about 600 feet per year. Where the hydraulic gradient is steeper the velocity is proportionately greater.

GROUND-WATER MOVEMENT AND ITS RELATION TO THE FLOW OF THE HUMBOLDT RIVER

As described in a subsequent section of the report (page 64), ground-water movement and its relation to the flow of the Humboldt River in December are highly significant with respect to the quantitative analysis of ground-water inflow from tributary areas. Moreover, many of the observed hydrologic features of the project area can be explained on the basis of interrelations between the river and the ground-water reservoir.

Normally in December, very little water is diverted directly from the river, no tributary streamflow discharges into the river, no significant changes in channel storage occur, and virtually no decreases in streamflow occur as a result of evaporation and transpiration. Pumping in December is almost entirely for domestic and municipal use in Winnemucca. In the past 10 years, pumpage in the vicinity of Winnemucca in December probably averaged about 0.5 cfs. Much of this water and some springflow (page 74) was discharged into the river through the municipal sewage plant in the NW¼SE¼NE¼ sec. 30, T. 36 N., R. 38 E. The estimated rate of sewage effluent discharging into the river was slightly less than the pumpage and spring discharge used in Winnemucca. Some of the pumpage probably was indirectly diverted from the river (page 99). For the sake of simplicity, it is assumed that the amount of water diverted from the river by pumpage was approximately equal to the amount of return flow to the river through the sewage plant. Inasmuch as the sewage plant is less than 0.5 mile downstream from the principal area of pumpage, the effects on the flow of the river of pumpage and the discharge of sewage effluent into the river in December are presumed to cancel each other.

The shape of the water-level contours, as they cross the Humboldt River, indicates the relations between the river and the ground-water reservoir. Figure 26 shows the diagrammatic shape of water-level contours as they cross the stream for various conditions along the Humboldt River. Figure 26a shows ground-water seepage to the river where the hydrostatic head in the aquifers is greater than that in the river. Figure 26b shows seepage from the river to the aquifers where the head in the aquifers is less than that in the river. Figure 26c shows ground-water flow parallel to the river where the head and gradient in the aquifers is the same as that in the river. Figure 26d shows a reach of the river where ground water moves obliquely across the trend of the river because the head in the aquifers on one side of the river is greater than that in the

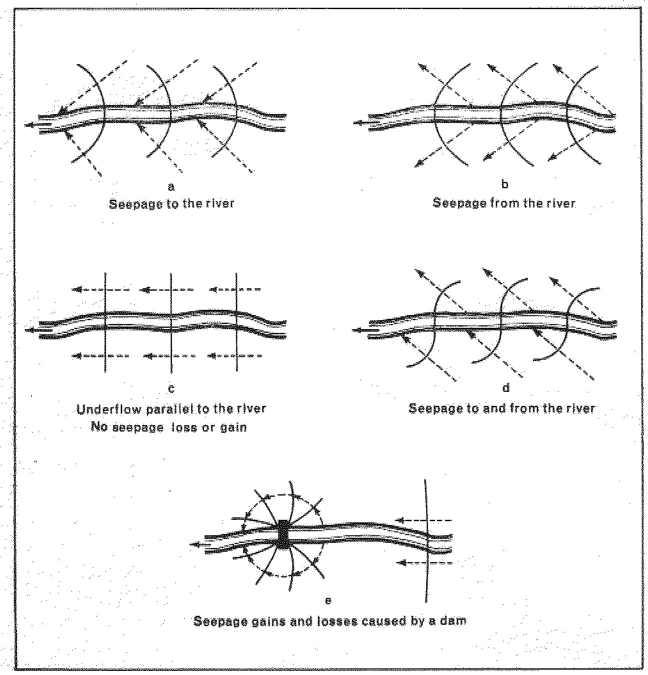

FIGURE 26.— Diagrammatic shape of water-level contours as they cross the Humboldt River for various conditions along the river. Solid arrows indicate the direction of streamflow; dashed arrows indicate the horizontal component of the direction of ground-water movement.

river, and the head in the aquifers on the other side of the river is less than that in the river. Figure 26e shows the shape of water-level contours at a dam. Some distance upstream from the dam, ground-water movement is roughly parallel to the river; immediately upstream, ground-water movement is away from the river; immediately downstream, ground-water movement is toward the river.

Streamflow measurements along the Humboldt River in December 1961 are shown in Figure 19. The flow at the Comus gaging station (station A) was 0.15 cfs, and increased to about 0.5 cfs at station F as a result of ground-water seepage to the river. This is verified by the shape of the water-level contours between stations A and F (Plate 3) which were slightly concave downstream, indicating ground-water movement toward the river. The flow increased to about 1.4 cfs at station H. As suggested by the shape of the water-level contours of Plate 3, the increase in flow was a result of ground-water seepage from the deposits adjacent to the river near the Stahl Dam (station F), and ground-water underflow to the river from the drainage basin of Rock Creek. A small part of the increase in flow may have been the result of subsurface inflow to the river of thermal water from the hot spring system near Golconda. Streamflow decreased to 0.7 cfs at station K. In this reach, the contours were oblique to the general trend of the river suggesting ground-water movement from the southeast toward the river (probably largely from the Pole Creek drainage basin), and ground-water movement away from the river toward the northwest. Apparently, streamflow decreased because the rate of movement away from the river toward the northwest was greater than the rate of movement toward the river from the southeast.

Streamflow increased to about 5.1 cfs at station N. The increase in flow was partly a result of ground-water underflow to the river from the north and northeast, and partly a result of a decrease in the cross-sectional area of the ground-water reservoir in the Winnemucca narrows. The width of the medial gravel unit at station O is several times the width of the unit in the Winnemucca narrows. (See Plate 2.) The increased width resulted in seepage losses from the river between stations N and O.

The increase in streamflow from about 3.7 cfs at station O to 14.8 cfs at station S was partly the result of ground-water underflow from Grass Valley and the northwestern slope of the Sonoma Range discharging into the river and partly the result of a partial barrier to ground-water movement at the Rose Creek constriction. The contours of Plate 3 indicate that some ground water moved southwestward from the mouth of the valley parallel to the river as ground-water underflow. In the vicinity of station S, the cross-sectional area of the medial gravel unit decreases markedly where it overlies consolidated rock in the Rose Creek constriction (Section F-F′, Plate 2) causing ground water to move upward and laterally into the river. The abrupt flattening of the hydraulic gradient immediately upstream from station S probably is related to the partial bedrock barrier which functions as a subsurface dam. Seemingly, the relatively flat hydraulic gradient is analogous to a pond upstream from a surface-water dam. The steep hydraulic gradient downstream from station S is comparable to the spillway of a surface dam.

Streamflow decreased about 1.3 cfs between stations S and U in December 1961. Virtually all of the decrease occurred between stations S and T where the cross-sectional area of the medial gravel unit increases markedly downstream from the bedrock barrier.

Because the shape of the contours shown in Plate 3 remains about the same during low-flow periods, ground-water movement and the resulting changes in the flow of the river during most of the year are similar to those already described. However, during periods of high streamflow, which normally occur during the spring runoff, the shape of the water-level contours and, accordingly, the direction of ground-water movement near the river changes markedly. Plate 4 shows the shape of water-level contours in June 1962. Streamflow in the spring of 1962 was above normal (Table 10). Accordingly, the altitude of the contours probably was somewhat higher than average for June.

In June 1962, a pronounced ground-water ridge developed along the Humboldt River. As a result of the rapidly rising and relative high stage of the river, ranging from about 3 to 7 feet above the stage in December 1961, water moved from the river to the ground-water reservoir. A loss of streamflow of about 200 cfs was measured between the Comus and Rose Creek gaging stations on June 13–17, 1962 (Figure 19). However, because of diversions for irrigation, evaporation, transpiration, and increases in channel storage, only a small part of the measured loss entered the ground-water reservoir.

The fact that the average rate of ground-water movement in the flood-plain deposits probably is less than 130 feet per year (page 61) bears directly on the character of the ground-water ridge formed along the Humboldt River in June 1962. In places the ridge was more than a mile wide. Obviously, if the river functioned as a line source of recharge, ground water could not have moved this far from the river during the few months it took for the ridge to form. If the saturated flood-plain deposits were largely confined, that is, if the water were under artesian pressure, the ground-water ridge largely would reflect an increase in artesian pressure which would occur in a relatively short period of time. Some aspects of the ground-water ridge shown in Plate 4 may have been related to increased artesian pressure; however, in overall aspect the ridge probably was indicative of a rise in the water table and the actual movement of water to the ground-water reservoir rather than merely a transmission of pressure. In addition to the river functioning as a line source of ground-water recharge, it also supplies water to many of the depressions on the flood plain as a result of natural flooding or diversions for irrigation. Each of the filled depressions serves as a source of ground-water recharge. Because the depressions occur throughout virtually the entire flood plain and because they are closely spaced, ground water actually moves relatively short distances from the sources of recharge.

During the period of high river stage in June 1962, ground water continued to move toward the Humboldt River valley from tributary areas. At the same time, the hydrostatic head in the river was above that in the immediately adjacent aquifers causing ground-water movement from the river to the ground-water reservoir. This resulted in the formation of two troughs in the water-level surface, one on each side of the river, parallel to the ground-water ridge along the river. The troughs were especially well-defined in the mouth of Grass Valley and north of the river opposite the mouth of Grass Valley. Ground water apparently moved into the troughs and thence southwestward parallel to the river. Exceptions occurred in the reach of the river extending about a mile downstream from station Q and in the vicinity of station H where ground water probably discharged into the river.

Ground-water levels in June 1962 were at or very close to land surface in the flood plain of the Humboldt River between the Stahl Dam and station C. In other words, the ground-water reservoir was nearly full. As a result, virtually no water moved from the river to the ground-water reservoir. Accordingly, the water-level contours in this reach were practically perpendicular to the river.

The average rise of ground-water levels from December 1961 to June 1962 in the flood-plain deposits near the western margin of the project area was 2.8 feet. (See Table 23.) A few miles upstream, the average rise was 5.7 feet. The increase in the stage of the river and the geology of the flood-plain deposits in both areas are comparable. The difference in the average rise of water levels was largely a result of irrigation practices; a comparatively small amount of water was diverted for irrigation in the former area, whereas a considerable amount was diverted in the latter area. Thus, it seems that the ground-water ridge was formed partly by the infiltration of irrigation water diverted from the river, and in large part probably reflected a rise in the water table rather than an increase in artesian pressure.

In the late summer of water year 1962 after the stage of the river declined following the spring runoff, the ground-water ridge and the parallel troughs dissipated largely as a result of the return flow of bank storage to the river. The shape of the water-level contours again closely resembled that of the contours shown in Plate 3.

RECHARGE

Practically all the ground-water recharge to the storage units outlined in Plate 5 results from subsurface ground-water inflow, infiltration of streamflow and diverted irrigation water, and the direct infiltration and deep percolation of precipitation.

Subsurface Ground-water Inflow

The areas that contribute most of the subsurface ground-water inflow to the storage units are, in upstream order, Grass Valley and the northwestern slope of the Sonoma Range, Paradise Valley, the drainage basins of Pole Creek and Rock Creek, herein referred to as the Pole Creek-Rock Creek area, and the Humboldt River valley upstream from the storage units. Subsurface inflow from the remaining parts of the project area is considered negligible because of the comparatively small watersheds of these areas and because of the shape of the water-level contours in Plates 3 and 4.

Total subsurface inflow and that from each of the major tributary areas was computed on the basis of increases in the flow of the Humboldt River and differences between underflow through key sections perpendicular to the river. Although seasonal changes in ground-water levels of as much as 10 feet occur near the Humboldt River, ground-water levels commonly fluctuate within a comparatively narrow range, commonly only a fraction of a foot, near the margins of the storage units. Accordingly, hydraulic gradients, and therefore the amount of subsurface inflow to the storage units, remain nearly constant.

In December of most years very little ground water was discharged by pumping and virtually none by evapotranspiration. In water years 1955, 1960, and 1961, ground and surface water in storage remained nearly constant. Accordingly, in those years virtually all the subsurface inflow to the storage units discharged into the Humboldt River or discharged out of the project area near the Rose Creek gaging station (page 73). The average increase in flow between the Rose Creek and Comus gaging station in December of water years 1955, 1960, and 1961 was about 900 acre-feet, or 15 cfs. Because of the preceding years of drought, little or none of the gain in streamflow in these years was caused by the returnflow of bank storage. Furthermore, streamflow at the Comus gaging station was nearly constant during the preceding few months. Thus, the sum of the average increase in streamflow of about 15 cfs plus the estimated underflow out of the project area near the Rose Creek gaging station, about 4 cfs (page 73) probably is a reasonably accurate estimate of the amount of subsurface ground-water inflow to the storage units. Because the hydraulic gradients near the margins of the storage units remain virtually constant throughout the year, the estimated average annual recharge to the storage units by subsurface ground-water inflow was about 19 cfs, or about 14,000 acre-feet per year.

Subsurface inflow to the storage units from each of the major tributary areas was estimated separately by evaluating the increase in flow of the Humboldt River in December of water years 1960 and 1961 (Figures 17 and 18) and differences in the amount of underflow moving through cross-sections perpendicular to the river at station C, half a mile downstream from station K, at station O, and half a mile downstream from station S. Most of the underflow through these sections probably occurs in the highly permeable medial gravel unit and can be estimated by means of the following equation:

$$Q = TIW, \qquad (3)$$

where Q and I are as previously defined (page 61), T is the coefficient of transmissibility in gpd/ft. (page 32), and W is the width, in miles, of the saturated deposits perpendicular to the direction of flow.

The water-level contours shown in Plate 3 were practically identical to those in December of water years 1960 and 1961. Accordingly, values for the hydraulic gradient and width of the cross sections were obtained from Plate 3. Values for the coefficient of transmissibility were estimated largely on the basis of the estimated average field coefficient of permeability of 5,000 gpd/ft^2 (page 32) multiplied by the average thickness of the medial gravel unit at each section. These data and computations and the estimates of underflow through the four key sections across the Humboldt River valley are listed in Table 16. Ranges are given for the estimated coefficients of transmissibility because of the limited data on permeability and thickness. The ranges in the coefficients of transmissibility are believed to be sufficiently large to allow for underflow occurring in the deposits adjacent to and beneath the medial gravel unit.

Grass Valley and the Northwestern Slope of the Sonoma Range

As suggested by the relation between ground water and the Humboldt River in December (page 61) and by the water-level contours shown in Plate 3, most of the subsurface inflow to the storage units from Grass Valley and the northwestern slope of the Sonoma Range discharged into the Humboldt River between stations O and S in December of water years 1960 and 1961. Thus, subsurface inflow from Grass Valley and the northwestern slope of the Sonoma Range was equal to the increase in streamflow between stations O and S in December of water years 1960 and 1961, which averaged about 11 cfs (Figures 17 and 18), minus the decrease in underflow moving parallel to the Humboldt River near stations O and S. The estimated underflow past station O was 2.5 to 4 cfs more than the underflow past station S (Table 16); therefore, total subsurface inflow from Grass Valley and the northwestern slope of the Sonoma Range was 11 cfs minus 2.5 to 4 cfs, or 7 to 8.5 cfs. Accordingly, the estimated average annual subsurface inflow from Grass Valley and the northwestern slope of the Sonoma Range is about 5,000 to 6,000 acre-feet per year.

This estimate is less than that given by Robinson, Loeltz, and Phoenix (1949, pp. 60–63), who observed that the flow of the Humboldt River increased an average of about 23 cfs between stations O and T in September and October 1947. Most of the increase in flow was attributed to subsurface inflow from Grass Valley. Largely on this basis, it was presumed that the average annual subsurface inflow from Grass Valley was somewhat less than 16,700 acre-feet. This estimate is considered too large because the results of this study indicate that the increase in the flow of the river between stations O and T in September and October 1947 probably resulted not only from subsurface inflow from Grass Valley but also from the return flow of bank storage.

Paradise Valley

Most of the subsurface inflow from Paradise Valley in December of water years 1960 and 1961 probably discharged into the Humboldt River between stations K and O. The increase in streamflow between the two stations averaged about 2.7 cfs (Figures 17 and 18). The estimated underflow parallel to the Humboldt River near station K was 1.5 to 2 cfs less than underflow near station O (Table 16). Thus, the estimated inflow from Paradise Valley was about 4 to 5 cfs or about 3,000 to 3,500 acre-feet per year. This agrees closely with the estimate of 3,200 acre-feet made by Loeltz, Phoenix, and Robinson (1949, p. 42).

Pole Creek—Rock Creek Area

Virtually all the subsurface inflow from the Pole Creek-Rock Creek area discharged into the Humboldt River valley between stations C and K in December of water years 1960 and 1961. The increase in streamflow between the stations averaged about 1.1 cfs (Figures 17 and 18). The estimated underflow parallel to the Humboldt River was 3 to 4.5 cfs greater near station K than near station C (Table 16). Therefore, the estimated subsurface inflow from the Pole Creek-Rock Creek area was about 4 to 5.5 cfs, or about 3,000 to 4,000 acre-feet per year.

TABLE 16—ESTIMATED UNDERFLOW THROUGH SELECTED SECTIONS PERPENDICULAR TO THE HUMBOLDT RIVER

(1) Location of sections perpendicular to the Humboldt River	(2) Estimated average coefficient of transmissibility (gallons per day per foot)	(3) Approximate water-table gradient (ft. per mile)	(4) Approximate width of section (miles)	(5) Estimated Underflow* (cubic feet per second) (rounded)	(acre-feet per year) (rounded)
At station C	100,000 to 200,000	3	1	0.5 to 1	350 to 700
Half a mile downstream from station K	200,000 to 300,000	4	3	3.5 to 5.5	2,500 to 4,000
At station O	400,000 to 600,000	4	2	5 to 7.5	3,500 to 5,500
Half a mile downstream from station S	200,000 to 300,000	8	1	2.5 to 3.5	2,000 to 2,500

*Column 5 is the product of columns 2, 3, and 4.

Humboldt River Valley Upstream From the Storage Units

Practically no ground water was discharged between station A, near the upstream margin of the study area, and station C in December of water years 1960 and 1961. The change in streamflow of the Humboldt River between the stations was negligible. Therefore, underflow near station C was a measure of subsurface inflow to the storage units near station A. The estimated underflow near station C and, accordingly, the estimated subsurface inflow derived from the Humboldt River valley upstream from the project area, was 0.5 to 1 cfs (Table 16), or about 350 to 700 acre-feet per year.

Summary of Estimated Ground-water Inflow to the Storage Units

The estimated average annual ground-water inflow from major tributary areas to the storage units in the project area is shown in Table 17. The estimated total average annual subsurface inflow obtained by adding the inflow from each of the areas agrees reasonably well with the estimated total average annual inflow of 14,000 acre-feet calculated on page 64.

TABLE 17—ESTIMATED AVERAGE ANNUAL RECHARGE FROM SUBSURFACE GROUND-WATER INFLOW TO THE STORAGE UNITS

Areas contributing ground-water inflow	Ground-water Inflow cfs	Ground-water Inflow Acre-feet per year
Grass Valley and the northwestern slope of the Sonoma Range	7 to 8.5	5,000 to 6,000
Paradise Valley	4 to 5	3,000 to 3,500
Pole Creek—Rock Creek area	4 to 5.5	3,000 to 4,000
Humboldt River valley upstream from the storage units	0.5 to 1	350 to 700
Totals (rounded)	15 to 20	11,000 to 14,000

Infiltration of Streamflow

Tributary Streamflow

In the mountains, part of the tributary streamflow infiltrates into fractures and other openings in the consolidated rocks. Some of this water is discharged by springs and by evapotranspiration and some moves valleyward as ground-water underflow toward the Humboldt River. Seepage measurements along the tributary streams indicate that streamflow normally decreases progressively downslope on the alluvial aprons (page 40). Much of the decrease in flow, especially during the spring and summer, results from evapotranspiration. However, that part of the streamflow that infiltrates into the deposits in excess of field capacity percolates downward to the ground-water reservoir.

Insufficient data are available to determine the amount of recharge from tributary streams; however, recharge occurring in this manner and recharge resulting from the infiltration of some of the tributary streamflow diverted for irrigation are the source of most of the ground-water inflow to the storage units and are included in the estimates listed on page 64 and in Table 17.

In water years 1949–62 an estimated average of 4,500 acre-feet per year of tributary streamflow discharged into the storage units and virtually none of it discharged into the Humboldt River. Thus, nearly all of this water either was lost by evapotranspiration or recharged the ground-water reservoir beneath the storage units. Insufficient data are available to evaluate this element of ground-water recharge to the storage units. It may have averaged about 1,500 to 2,000 acre-feet per year.

Humboldt River Streamflow

Figure 27 shows hydrographs of the stage of the Humboldt River at the Winnemucca gaging station and ground-water levels in well 36/38–30ddcl. In overall aspect, the deposits tapped by the well are in hydraulic continuity with the river. As the stage of the river rises, ground-water levels rise, and the converse is true. Although seepage losses to the ground-water reservoir occur along some reaches of the Humboldt River throughout most of the year, most of the recharge resulting from the infiltration of Humboldt River water commonly occurs in April, May, and June when the stage and flow of river normally are at their yearly highs.

Natural flooding, but more commonly, flooding resulting from the installation of temporary dams and headgates for irrigation, recharges the ground-water reservoir. Some of the flood water flows into oxbow lakes, floodflow channels, and other depressions on the flood plain. During the spring and early summer, these depressions commonly intersect the water table, and flood water flowing into the depressions directly enters the ground-water reservoir. Infiltration losses from irrigation ditches and the downward percolation of some of the excess irrigation water diverted onto cultivated fields and meadows also recharges the ground-water reservoir. Some of the surface water applied for irrigation is consumed by vegetation, some evaporates from the land surface,

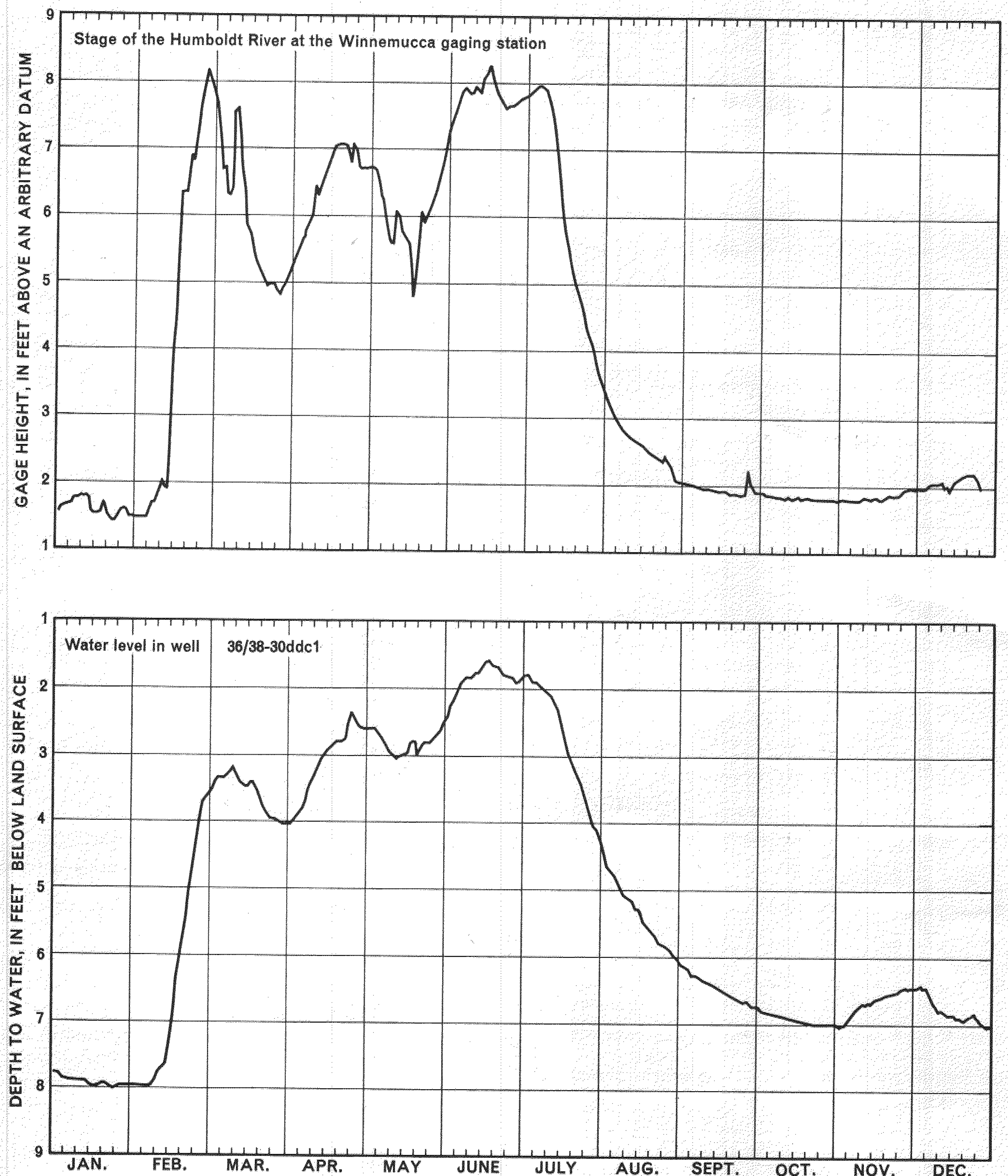

FIGURE 27. — Hydrographs of the stage of the Humboldt River at the Winnemucca gaging station and the water level in well 36/38-30ddc1, calendar year 1962

and some evaporates from the zone of soil moisture. The amount that enters the ground in excess of field capacity percolates to the water table.

Virtually all the ground-water recharge resulting from the infiltration of Humboldt River water normally occurs in the storage units outlined on Plate 5 in April, May, and June. The average annual measured loss of streamflow between the Comus and Rose Creek gaging stations during those months was 24,000 acre-feet. However, as previously noted not all of this water recharged the ground-water reservoir. Although much of it probably did, only the net amount could be identified. Based on the estimated net average annual increase of ground water in storage in the spring and early summer, the estimated net average annual ground-water recharge from the Humboldt River is on the order of 10,000 acre-feet.

Direct Infiltration of Precipitation

Average annual precipitation at the Winnemucca weather station in water years 1949–62 was about 7.6 inches. The total area of the storage units is about 93,000 acres (Table 23). Thus, the average annual precipitation on the storage units in water years 1949–62 was about 59,000 acre-feet. Most of this precipitation evaporated from land surface soon after it occurred or was stored in the zone of aeration and subsequently was lost by evapotranspiration.

Practically all the recharge resulting from the direct infiltration of precipitation on the storage units probably occurred on the flood plain during the spring and early summer when the water table and the overlying capillary fringe locally were at or close to land surface. Because (a) these areas were comparatively small, ranging from about 10,000 to 20,000 acres, (b) the length of time during which ground-water levels were fairly close to land surface normally was not more than 3 months (April, May, and June), (c) precipitation during those months averaged only about 2 inches, and (d) evapotranspiration rates were moderately high during this time, the estimated average annual ground-water recharge from this source in water years 1949–62 was only about 2,000 acre-feet.

Most of the deposits at land surface in those parts of the storage units other than the flood plain are fine grained and have a high field capacity. Moreover, ground-water levels averaged more than 10 to 15 feet below land surface and locally were more than 50 feet below land surface. Accordingly, nearly all the precipitation on these areas probably evaporated from land surface soon after it occurred or was stored in the upper few feet of the zone of aeration and subsequently was consumed by evapotranspiration.

In addition to the 2,000 acre-feet of precipitation that recharged the ground-water reservoir, about 600 acre-feet fell on the Humboldt River and was discharged from the storage units as streamflow. Thus, in water years 1949–62, it is estimated that about 56,000 acre-feet of precipitation on the storage units was lost by evapotranspiration from land surface and from the zone of aeration.

About 7.7 inches of precipitation, or about 60,000 acre-feet, fell on the storage units in water year 1962. It is estimated that about 2,000 acre-feet recharged the ground-water reservoir and that about 1,000 acre-feet fell on the Humboldt River and was discharged from the project area as streamflow. The remainder, about 57,000 acre-feet was consumed by evapotranspiration. About 6 inches of precipitation, 47,000 acre-feet, fell on the storage units in December through June of water year 1962. It is assumed that most of the precipitation during this period, about 40,000 acre-feet, was consumed by evaporation; most of the remainder was stored in the zone of aeration and subsequently consumed by evapotranspiration in July, August, and September.

The soil mantle is comparatively permeable in most of the project area outside the storage units, especially in the mountains and on the alluvial aprons. Moreover, larger amounts of precipitation occur in these areas. Accordingly, the amount of recharge resulting from the direct infiltration of precipitation is considerably larger than that occurring in the storage units. This aspect of the hydrology was not studied quantitatively; however, nearly all the resulting recharge moves downgradient as subsurface ground-water inflow to the storage units and thus is included in the estimates listed on page 64 and in Table 17.

DISCHARGE

Ground water is discharged from the project area by seepage to the Humboldt River, evapotranspiration, subsurface outflow near the Rose Creek gaging station, springflow, and pumping.

Discharge Into the Humboldt River

When and where the hydrostatic head in the ground-water reservoir adjacent to or beneath the Humboldt River is higher than the stage of the river, ground water discharges into the river. Table 18 shows that on the average the flow of the Humboldt River increased between the Comus and Rose Creek gaging stations from July through January in water years 1949–62. Inasmuch as virtually no surface water discharged into this reach of the river, nearly the entire increase in flow during these months was the result of ground water discharging into the river. On the average, during the remaining months of the year, February through June, water moved from the river to the ground-water reservoir and the flow of the river decreased.

The average increase in the flow of the Humboldt River between the Comus and Rose Creek gaging stations in July through January of water years 1949–62 was 11,300 acre-feet. A few hundred acre-feet of the increase resulted from precipitation directly on the river. Thus, the estimated net average annual ground-water discharge into the river in water years 1949–62 was about 11,000 acre-feet.

TABLE 18—AVERAGE JULY THROUGH JANUARY MONTHLY INCREASE IN THE FLOW OF THE HUMBOLDT RIVER BETWEEN THE COMUS AND ROSE CREEK GAGING STATIONS, WATER YEARS 1949–62

Month	Average streamflow at the Comus gaging station (acre-feet)	Average streamflow at the Rose Creek gaging station (acre-feet)	Increase in Streamflow (acre-feet)	Increase in Streamflow (cubic feet per second)
July	16,220	19,570	3,350	55
Aug.	1,936	4,590	2,660	43
Sept.	131	2,100	1,970	33
Oct.	79	1,670	1,590	26
Nov.	1,040	2,030	990	17
Dec.	3,080	3,650	570	9
Jan.	4,660	4,840	180	3
Totals	27,150	38,450	11,300	....

The largest increase in flow between the Comus and Rose Creek gaging stations usually occurred in July when the hydraulic gradient from the ground-water reservoir toward the river was steepest and consequently the rate of seepage to the river was highest. Nearly all the ground water discharging into the river in July normally was bank storage derived from the river during the preceding spring runoff. However, not all the water stored in the deposits adjacent to the river returned to the river; some evaporated from the capillary fringe, some was transpired by vegetation, and a small amount was discharged by pumping.

As the ground-water ridge dissipated in late summer, the gradient toward the river decreased, and consequently the rate of return flow of bank storage to the river decreased. After the ground-water ridge declined sufficiently, on the average in mid-August, ground-water inflow from tributary areas began to discharge into the river. Thus, in the fall, ground water discharging into the river normally included both bank storage derived from the river during the spring runoff and subsurface inflow from tributary areas. The proportion of subsurface inflow from tributary areas discharging into the river increased as the ground-water ridge dissipated. Normally, by December nearly all the ground water discharging into the river was derived from the tributary areas.

Evapotranspiration

Most of the ground-water discharge in the area results from evaporation from bare soil and evapotranspiration from areas occupied by phreatophytes. Phreatophytes are plants that obtain water principally from the zone of saturation or the capillary fringe. Transpiration by native grasses is being evaluated by the Agricultural Research Service. The Geological Survey is studying transpiration by the woody phreatophytes and evaporation from bare soil. The evapotranspiration studies have not yet been completed; however, preliminary results of the work of the Geological Survey are given in the following section of the report.

Water-use Studies Utilizing Evapotranspiration Tanks

By T. W. Robinson

One of the large unknowns in the comprehensive study of the water resources of the project area is the evaportranspiration loss. Of particular concern is that portion of the evapotranspiration loss that results from the draft on the ground-water reservoir by nonbeneficial woody phreatophytes. Phreatophytes are plants that depend upon ground water for their water supply. The common nonbeneficial woody phreatophytes in the Humboldt River basin are greasewood, willow, rabbitbrush, and wildrose. Of these, greasewood and willow are the most prominent and widespread.

The existing information on the use of water by both greasewood and willow is not only meager but was obtained under environmental conditions that were different from those of the Humboldt River basin. For this reason studies were started in late 1959 and early 1960 to obtain water-use data on greasewood and willow, and later were expanded to include wildrose and rabbitbrush, and also evaporation from bare soil. The studies are being made by growing the plants under controlled conditions in large evapotranspiration tanks. Insofar as possible, water-use data are being obtained under conditions and in terms that can be used to evaluate the evapotranspiration discharge in naturally occurring areas of growth. However, in growth areas where the depth to the water table is greater than can be maintained in the tanks, about 10 feet, it will be necessary to extrapolate water use at the greater depth.

The tanks are in a test site about 4 miles southwest of Winnemucca, partly on the lower terrace and partly on the flood plain of the Humboldt River. The test site is a parcel of land 300 feet by 600 feet composed about equally of low-lying meadow land covered with grasses and some willow, and an adjacent portion about 4 feet higher covered largely with greasewood.

Twelve tanks have been installed at the site since the work began in 1959. The time of construction, number and size of the tanks, and the species grown are:

Construction date	No. of tanks	Size (feet)	Species	Planting date
Nov. 1959	2	30x30x10.5	Greasewood	April 1960
Mar. 1960	3	10x10x 7.5	Willow	April 1960
May 1961	3	10x10x7	Wildrose	June 1961
May 1961	1	10x10x7	Bare soil	----------
Oct. 1961	3	20x20x10	Rabbitbrush	April 1962

Construction of the tanks involved the use of a polyvinyl chloride membrane of a weight and size that was specially fabricated at the factory. The tanks were constructed by lining a pit, excavated to the proper size, with the membrane, installing a water distribution system, and backfilling with the excavated material.

The water-supply system for the tanks consists of a 6-inch diameter well, 25 feet deep, equipped with a jet pump, that supplies water to a 450-gallon pressure tank. From the tank, in which the pressure is maintained at about 30 pounds per square inch, water is distributed through 1,200 feet of buried line to five 350-gallon and seven 100-gallon gravity water tanks.

The water level in each evapotranspiration tank is controlled by a float-operated valve. Water is measured into the tanks through water meters that can be read to one-fourth gallon. In the greasewood and willow tanks the water level was maintained at 5 feet below the surface, and in the bare-soil tank, during most of the 1962 season, at 4 feet below the surface. The water level in the wildrose and rabbitbrush tanks was kept at a higher level, and adjusted downward as the plants became established.

Beginning on August 1, 1961, water-use data were obtained for greasewood and willow for the remainder of the season and during the 1962 growing season. However, no water-use data were obtained for wildrose and rabbitbrush, as the plants were not yet established. Due to flooding of the willow tanks in June and July 1962 by excessively high ground-water levels resulting largely from flood irrigation on the flood plain of the Humboldt River, water-use data were obtained for only one willow tank for the growing season; data were obtained from the three willow tanks for the period August 1 to October 20, the end of the growing season.

Beginning in July 1962, signs of distress were observed in the greasewood plants in tank 2, and to a lesser extent in tank 1, followed in August and September by considerable defoliation. During this time the rate of water use decreased. The difficulty probably was caused by a high concentration of boron salts in the root zone. The salts, which had been leached from the soil in the tanks were found to be concentrated in the 2- to 4-foot depth range as the result of capillary action and evaporation.

As a regular part of the water-use study, records of plant growth and measurements of cover density and plant height were made at periodic intervals. During each of the growing seasons, a photographic record of plant growth in each tank was made at 4- to 6-week intervals. The cover density and plant height, from which foliage volumes were computed, were measured in the middle and latter part of the growing season.

Foliage Volume

The volume of foliage was determined by the line intercept or transect method (Horton, Robinson, and McDonald, in preparation). Foliage volume is the product of the cover intercept and the thickness or height of foliage. Cover intercept is the amount of ground covered or shaded by the vegetation foliage and is expressed in percent. It is the summation of the vertical projections of the crown of the plant onto a tape stretched on the ground, expressed in percent of the transect length. The canopy of the plant is considered solid within the perimeter of the outer branches. Where the plants have interlocking branches the canopy is considered as complete cover. Thickness or height of foliage was measured at the same time as the cover intercept. In all cases this was equal to the height of the plants.

The measurements from which the volumes of foliage were obtained are based on the average of four transects in the case of the large greasewood tanks and two transects for the willow and wildrose tanks. These data are shown in Table 19.

Measurements of foliage volumes serve two purposes. First, they provide a basis for expressing the use of water on a volume of foliage basis and, secondly, they provide a means for periodic comparison of plant growth. Thus, the increase in growth of the greasewood and willow plants from 1961 to 1962 is readily apparent from the data in Table 19. The lack of growth in greasewood tank 2 between June and August 1962, which resulted from the deleterious effect of boron salts in the root zone, is also quite apparent.

TABLE 19—FOLIAGE MEASUREMENTS OF PLANTS GROWN IN EVAPOTRANSPIRATION TANKS IN THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEVADA

Date	Cover intercept (percent)	Average height of plants (ft.)	Foliage volume (cu. ft.)
Greasewood Tank 1			
Sept. 14, 1961	26.0	1.37	321
June 13, 1962	49.6	1.38	610
Aug. 8, 1962	55.4	1.58	784
Greasewood Tank 2			
Sept. 14, 1961	29.5	1.36	390
June 11, 1962	39.1	1.43	503
Aug. 8, 1962	38.9	1.43	501
Willow Tank 1			
Sept. 14, 1961	81.6	3.26	266
June 14, 1962	84.8	3.28	278
Aug. 30, 1962	96.8	4.25	411
Willow Tank 2			
Sept. 14, 1961	77.9	2.82	220
Aug. 30, 1962	86.9	4.38	381
Willow Tank 3			
Sept. 14, 1961	77.0	2.75	212
Aug. 30, 1962	94.7	4.32	409
Wildrose Tank 1			
Aug. 8, 1962	63.5	1.73	110
Wildrose Tank 2			
Aug. 8, 1962	24.1	1.20	29
Wildrose Tank 3			
Aug. 8, 1962	63.8	1.70	108

Water in the Zone of Aeration

Water in the zone of aeration in the tanks may represent a significant part of the water budget. Consequently, information on differences in the amount of water in this zone at the beginning and end of the growing season are pertinent to evapotranspiration studies. To obtain this information, access tubes were installed in all tanks and a program of observation with a neutron-scattering soil-moisture meter was begun in September 1961.

The extent of moisture depletion by evapotranspiration during the 1962 growing season is indicated by the records for greasewood tanks 1 and 2 and willow tank 1. The reduction in water content in the zone of aeration was equivalent to a depth of 0.47 foot and 0.40 foot of water, respectively, over the two greasewood tanks, and to a depth of 0.43 foot over the willow tank. Except for the period August 1 to October 1961, data are available relative to changes in water content in the zone of aeration and have been used in computing total water loss from the tanks.

Water Use by Greasewood and Willow

Commonly the use of water by species of phreatophytes and other vegetation is expressed as depth of water over an area, usually in acre-feet or acre-inches per acre. When expressed in units of depth there is no indication of the growth conditions under which the use has been determined; that is, there is no indication of the density or number of plants per unit area, or size of the plants. As growth conditions may vary from place to place, use values expressed in this way can be applied with confidence only where growth conditions are similar. However, when the cover density and height of the plants are known, water use may be expressed in terms of foliage volume. When expressed in this manner, water-use values may be applied on the same basis to different growth conditions with confidence. A unit of foliage volume is a better index of leaf area, and hence the area from which water is transpired, than a unit of land-surface area. In the studies of water use by greasewood and willow in the evapotranspiration tanks, both methods are used to express the results.

Seasonal values of water use are available only for the two greasewood tanks and one willow tank for the period April 3 to October 20, 1962 (Table 20). This period is slightly shorter than the growing season, which is defined as the season that is warm enough for plants to grow (Robinson, et al., 1962). Although the growing season ended about October 20, there was some growth and water use prior to April 3. The amount, however, is believed to have been small.

During this period, rainfall in the form of scattered and infrequent showers amounted to 1.36 inches. The largest single shower occurred on

October 14 and amounted to 0.29 inch; other showers ranged from 0.01 to 0.24 inch. Rain falling on the dry surfaces of the tanks was quickly evaporated, and there was little if any opportunity for use by the plants or recharge to the water in the tanks. Rainfall during the growing season is not included in the following water-use figures. However, changes in water content in the zone of aeration are included.

TABLE 20—USE OF WATER BY GREASEWOOD AND WILLOW GROWN IN EVAPOTRANSPIRATION TANKS, APRIL 3 TO OCTOBER 20, 1962
(Depth to water maintained at 5 feet below tank surface)

Tank No.	Acre-feet per acre	Cubic feet of water per cubic foot of foliage
Greasewood 1	1.61	1.84
Greasewood 2	1.18	2.16
Willow 1	3.95	.96

Comparative values of water use by the plants in the greasewood and willow tanks are available for two periods, from August 1 to the end of the growing season in 1961 and 1962. Water use during these periods is believed to be approximately one-half of the use for the full growing season. Water use by the two species by individual tanks is given in Table 21.

TABLE 21—USE OF WATER BY GREASEWOOD AND WILLOW GROWN IN EVAPOTRANSPIRATION TANKS, AUGUST 1 TO OCTOBER 20, 1961 AND 1962*

Tank No.	Acre-feet per Acre 1961†	Acre-feet per Acre 1962‡	Cubic Feet of Water per Cubic Foot of Foliage 1961†	Cubic Feet of Water per Cubic Foot of Foliage 1962‡
		Greasewood		
1	0.47	0.58	1.51	0.66
2	.49	.40	1.23	.72
Average	.48	.49	1.37	.69
		Willow		
1	1.18	2.12	0.45	0.52
2	.80	1.87	.36	.49
3	.78	1.87	.37	.46
Average	.92	1.95	.39	.49

*Rainfall of 1.98 and 0.51 inches (0.16 and 0.04 foot) respectively in the periods August to October 20, 1961 and 1962 is not included.
†Data not obtained to correct for changes in water content in the zone of aeration.
‡Includes loss of water from the zone of aeration.

The values of water use in 1961 are not a measure of the use by the same species growing in the Humboldt River basin because the plants in the tanks were immature and were becoming established. Neither are the values for the greasewood tanks during 1962 representative because of the deleterious effect of the boron salts in the root zone and because the depth to water in the tanks was less than the depth to water in much of the area covered by greasewood. However, the use of water in 1962 in the three willow tanks, where there were no deleterious effects and where the plants were well established even though not quite mature, should approximate water use by willow on the Humboldt River flood plain where the depth to water and vegetation density are comparable to those in the tanks.

The estimated seasonal use of water by willow in 1962, based on the use in the period April 3 to October 20, is 4 acre-feet per acre. This estimate is supported by the average use in the three tanks during the partial period which is considered to be approximately one-half that for the season. Accordingly, the use by willow growing on the flood plain of the Humboldt River would be on the order of 4 acre-feet per acre. This is equal to one cubic foot of water for each cubic foot of foliage.

Relation of Water Use by Willow to Evaporation From Free-water Surfaces

Evaporation from a Standard Weather Bureau evaporation pan at the test site for the period April 3 to October 20, 1962, was about 60 inches. The amounts by months are given below:

Period	Inches
April 3 to 30	*7.05
May	7.51
June	10.66
July	11.27
August	10.75
September	8.41
October 1 to 20	4.19
Total	59.84

*Adjusted.

According to the U.S. Weather Bureau (Kohler, Nordenson, and Baker, 1959), the coefficient for lake evaporation at Winnemucca is 0.73 of the pan evaporation. Thus, the lake evaporation during the growing season would be about 44 inches, or 3.7 feet. Based on these data, willow growth in the Humboldt River flood plain use about one-third of an acre-foot of water per acre more than would be lost by evaporation from a lake of equivalent area.

Evaporation From the Bare-soil Tank

The water level in the bare-soil tank declined from a depth of 1.5 feet on April 3, 1962, to a depth of 4.0 feet on June 11, 1962, during which time no water was added to the tank. From June 11 to October 20, 1962, the water level was maintained at a depth of 4.0 feet. Approximately

0.4 foot of water evaporated from the tank during the period April 3 to October 20, 1962.

In the period April 3 to June 11, virtually the entire loss of water by evaporation from the surface of the tank was from the zone through which the water level declined; that is, from the zone between 1.5 and 4 feet below tank surface. From June 11 to October 20 practically all the water loss by evaporation was from the zone of saturation or from the overlying capillary fringe.

Rainfall during the period April 3 to October 20, 1962, occurred as scattered and infrequent showers and amounted to 1.36 inches. These showers appeared only to wet the surface of the soil and apparently did not percolate downward to the zone of saturation in the tank. If rainfall is included, the total evaporation loss from the tank during the period April 3 to October 20 was about 0.5 foot. It should be emphasized that this total figure includes evaporation from the zone of saturation plus evaporation from the zone of aeration.

Preliminary Estimates of Evapotranspiration of Ground Water and Vadose Water

The evapotranspiration data given in the immediately foregoing section of the report are preliminary and incomplete. Moreover, evapotranspiration studies and vegetation maps being prepared by other agencies have not yet been completed. However, crude preliminary estimates of total evapotranspiration of ground water and vadose water are given to indicate the possible order of magnitude of these features and to develop preliminary data for the water-budget analyses. These estimates do not include evapotranspiration of precipitation from land surface and from the zone of aeration which are estimated separately (page 68). They include only evapotranspiration of ground water from the water table and the overlying capillary fringe, and evapotranspiration of water in the zone of aeration derived from the downward percolation of Humboldt River water—including that derived from natural overbank flooding and diversions for irrigation.

Preliminary evapotranspiration rates developed by Robinson (pages 69 to 73) and by the Agricultural Research Service (Nevada Department of Conservation and Natural Resources, 1962) range from about 1 to 4 acre-feet per acre per year on the flood plain and the lower terrace. The author estimates that the area of evapotranspiration on the flood plain and the lower terrace, where the depth to water ranges from less than a foot to about 12 feet, is roughly 25,000 acres; the area of evapotranspiration in the remainder of the storage units, where the depth to water ranges from about 20 to more than 50 feet and where evapotranspiration rates are considerably less, may be about 25,000 to 45,000 acres. Based on these preliminary data, the estimated average annual evapotranspiration of ground water and vadose water in the storage units, excluding precipitation, in water years 1949–62 is 25,000 to 50,000 acre-feet. Evapotranspiration of ground water and vadose water in water year 1962 may have been somewhat larger, about 30,000 to 60,000 acre-feet, owing to above-average streamflow and the resulting above-average ground-water levels during the year. Evapotranspiration losses of ground and vadose water in December through June of water year 1962 may have been about 10,000 to 20,000 acre-feet.

Subsurface Outflow Near the Rose Creek Gaging Station

Subsurface outflow from the project area near station U is evaluated on the basis of underflow parallel to the Humboldt River near station S. The estimated average annual underflow near station S is 2.5 to 3.5 cfs (Table 16). During periods of low flow, about 1 cfs is lost from the river to the ground-water reservoir between stations S and U (Figures 17–19). Underflow toward the river, derived from precipitation on the northern slope of the East Range and on the drainage area north of the river between stations S and U, is assumed to be negligible (page 64). Accordingly, the estimated average annual subsurface outflow from the project area is about 3.5 to 4.5 cfs, or about 3,000 acre-feet.

Springflow

Numerous small springs in the mountains discharge ground water. Most of these probably are gravity springs; that is, they appear to occur where the water table or where perched ground-water bodies intersect the land surface. All the apparent gravity springs observed had a flow of less than 50 gpm and most had flows of 1 to 2 gpm. Springs 35/36–28abal and 35/36–28dccl along the East Range fault are artesian and have a combined flow of about 2 gpm. Thermal artesian springs near Golconda, including 36/40–29dcal, flow at an estimated combined rate of about 200 gpm, and thermal springs 36/41–2aacl and 36/41–2aac2 near the Comus gaging station flow at a combined rate of about 25 gpm.

Springs in Water Canyon and an unnamed

canyon about 2 miles northeast of Water Canyon reportedly supply an average of about 0.6 cfs used as part of the Winnemucca municipal water supply. Much of this water normally evaporates or is transpired, but some discharges into the Humboldt River as sewage effluent after passing through the municipal water system. Except for the amount discharged through the municipal sewage plant, virtually all the remainder of the springflow occurring outside the storage units is lost by evapotranspiration or seeps back to the ground-water reservoir and moves laterally toward the outer margins of the storage units as ground-water underflow.

The estimated average annual springflow in the storage units is about 250 gpm. All of this springflow is thermal and its ultimate source is not known. The flow is not included in the estimates of subsurface inflow to the storage units given in a previous section of the report. Moreover, almost all the springflow is consumed by evapotranspiration in the immediate vicinity of the springs. Because the quantity is small, it is disregarded in the water-budget analyses.

Pumpage

Prior to 1946, pumping for irrigation in the study area was negligible and probably averaged only a few hundred acre-feet per year. Since then, it has increased gradually and at a fairly uniform rate. In water year 1962 about 1,700 acres, mostly in the mouth of Grass Valley and on the terraces bordering the Humboldt River, was irrigated with ground water. Some of this land also was partly irrigated with surface water. The estimated total ground-water pumpage for irrigation in water year 1962 was on the order of 4,000 acre-feet. The estimated average annual pumpage for irrigation in water years 1949–62 was about 2,000 acre-feet. Pumpage for domestic and municipal use in water year 1962 was on the order of 1.5 cfs, or about 1,000 acre-feet. In water years 1949–62, pumpage for domestic and municipal use ranged from about 0.5 to 1.5 cfs and averaged about 1 cfs, or about 750 acre-feet per year. Accordingly, total pumpage was on the order of 5,000 acre-feet in water year 1962, and averaged about 2,500 to 3,000 acre-feet per year in the water years 1949–62.

Most of the pumped water evaporates and is transpired by crops and phreatophytes. The remainder percolates downward to the ground-water reservoir, and several hundred acre-feet per year discharges into the river though the Winnemucca sewage plant. The estimated net pumpage, or the amount permanently removed from the ground-water system, averaged about 1,500 acre-feet per year in water years 1949–62, was about 3,000 acre-feet in the 1962 water year, and was about 1,000 acre-feet in December through June of water year 1962.

CHANGES OF GROUND WATER IN STORAGE

Ground water in storage is water that will drain by gravity from a given volume of the ground-water reservoir. Ordinarily, it also is equal to the volume of water required to resaturate the deposits after they are drained. Ground water in storage is less than the total amount of water in the zone of saturation, because some water is held in the reservoir against the pull of gravity, principally by molecular and capillary attraction. Changes in storage occur when the hydrostatic head in the reservoir changes. Such changes result in fluctuations of ground-water levels.

Fluctuations of Ground-water Levels

Short-term and Seasonal Fluctuations

Nearly all the observed short-term and seasonal fluctuations of ground-water levels are related to changes in the stage of the Humboldt River, the diversion and application of surface water for irrigation, evapotranspiration, and precipitation. Because pumpage in the area as of 1962 was small, pumping effects have been minor, and except for drawdown effects very close to pumping wells, ground-water levels commonly fluctuate less than 10 feet from season to season and year to year.

Ground-water levels beneath the flood plain and terraces bordering the Humboldt River respond to changing river stage. As the river stage declines hydraulic gradients toward the river increase and ground-water levels decline; as the stage rises gradients toward the river flatten or are reversed and ground-water levels rise. The magnitude of the response commonly increases with time and decreases with distance from the river. As shown in Figures 28 and 29, rises of about 6 to 8 feet in river stage resulted in rises of about 4 to 6 feet in wells a few hundred feet from the river, and rises of about 2 to 5 feet in wells 0.2 and 0.4 mile away.

Diversions from the Humboldt River for irrigation also cause ground-water levels to rise beneath the flood plain of the river (page 63). Inasmuch as nearly all such rises occur in areas where water levels respond to changing river stage and inasmuch as the river stage normally fluctuates considerably during most of the irrigation season, it is difficult to discern how much of the rise in a given area results from either one of the phenomena.

Diurnal fluctuations of ground-water levels have long been recognized as being related to transpiration by phreatophytes (White, 1932, and Robinson, 1958). In a manner similar to a discharging well, such plants withdraw ground water from storage and cause water levels to decline during the day. At night, when transpiration virtually ceases, ground-water levels recover. These fluctuations are somewhat analogous to those caused by pumping a well intermittently. If the water table and overlying capillary fringe are near land surface, as on the flood plain of the Humboldt River, evaporation also causes diurnal

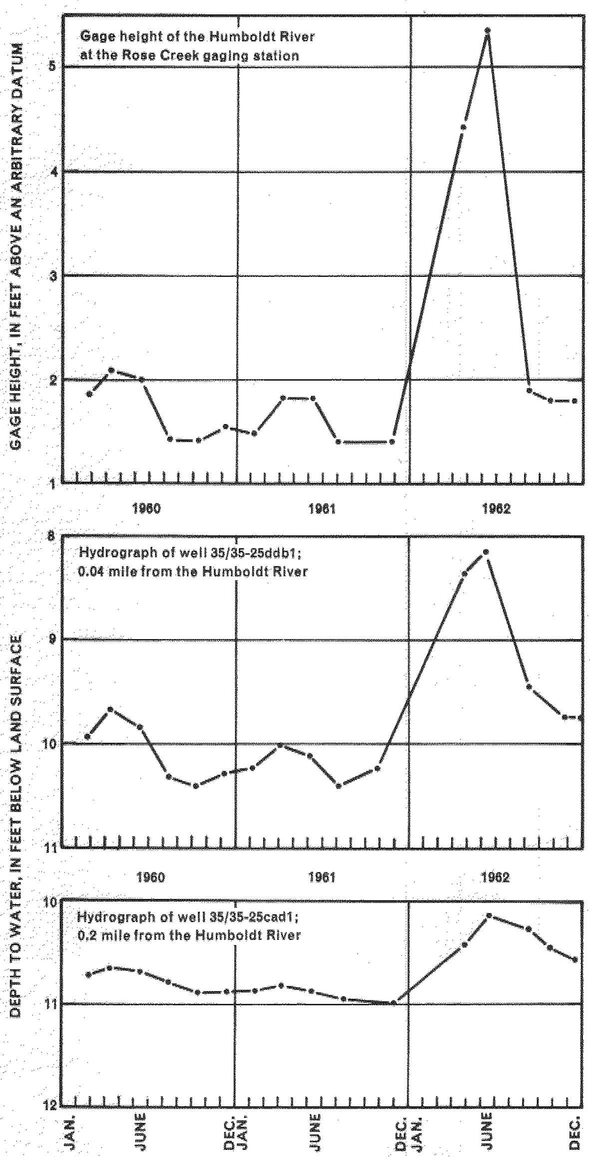

FIGURE 28.— Hydrographs of two selected wells near the Rose Creek gaging station as compared to the daily mean gage height of the Humboldt River

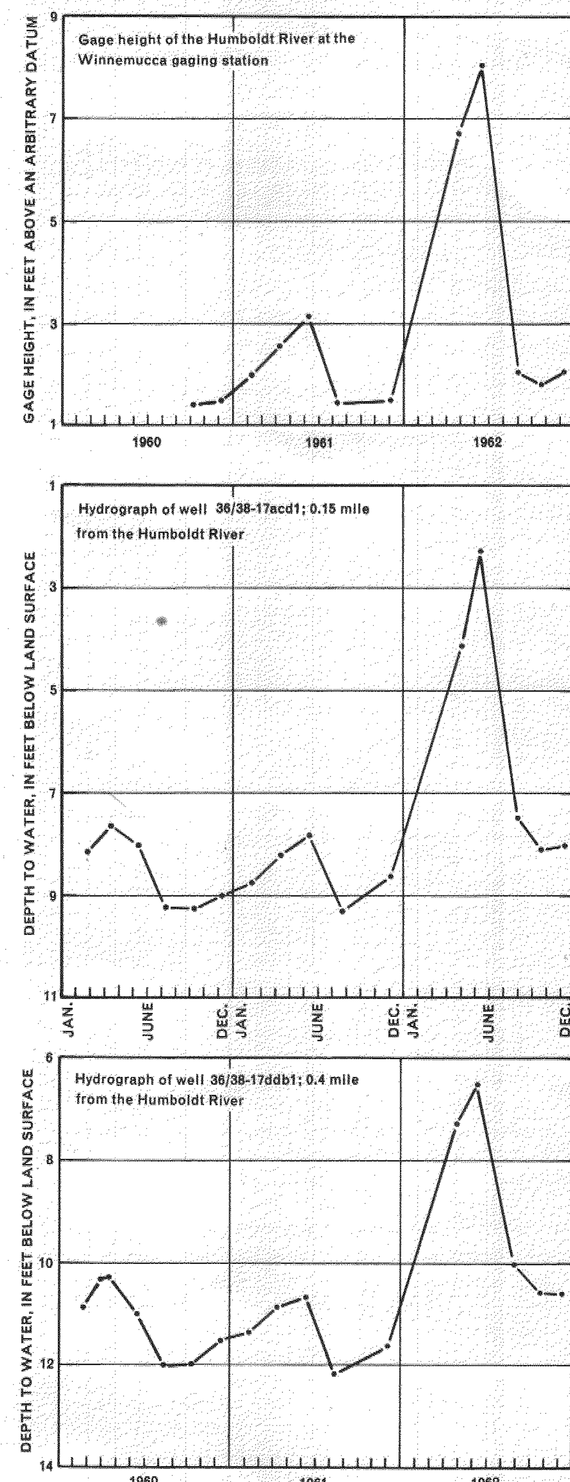

FIGURE 29.— Hydrographs of two selected wells near the Winnemucca gaging station as compared to the daily mean gage height of the Humboldt River

water-level fluctuations. Diurnal fluctuations caused by evaporation and transpiration are closely related to temperature and sunlight, and locally the effects of each phenomena are superimposed upon each other resulting in composite water-level fluctuations.

Diurnal water-level fluctuations probably attributable to evapotranspiration were not common in wells equipped with recorders on the flood plain and bordering terraces. Such fluctuations were noted during short periods of time in three wells and were most pronounced during periods of declining water levels. A maximum daily fluctuation of about 0.06 foot that probably was attributable to evapotranspiration was noted in well 36/38–19ddcl. (See Figure 30.) Diurnal fluc-

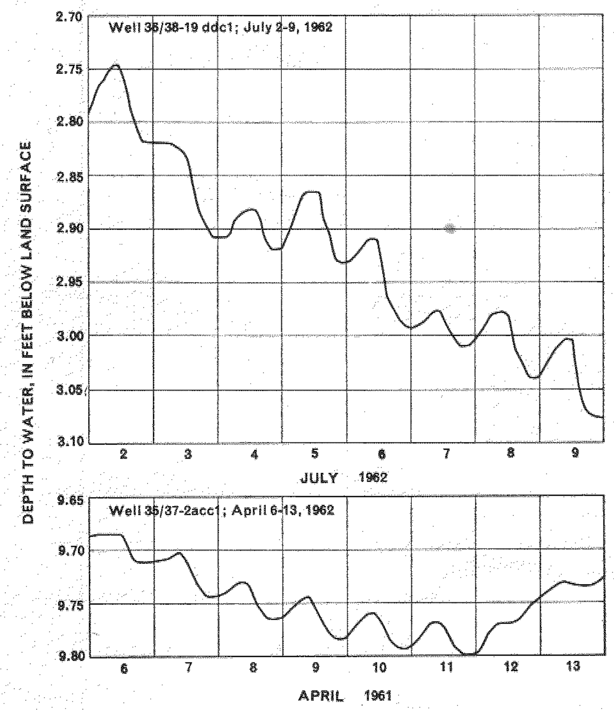

FIGURE 30.— Diurnal fluctuations of the water table near Winnemucca, Nev.

tuations in well 35/37–2accl averaged about 0.04 foot. The reasons for the relatively poor manifestation of diurnal water-level fluctuations caused by evapotranspiration are not known.

Short-term water-level fluctuations attributable to the direct infiltration of precipitation were not recognized in the study area. Locally, unusually large amounts of precipitation may cause the water table to rise; however, the rise normally is masked by an increase in the stage of the Humboldt River, which in turn causes ground-water levels to rise. In addition, at times large amounts of precipitation may cause a temporary decrease in evapotranspiration, which in turn may cause ground-water levels to rise.

Long-term Fluctuations

Water levels in several observation wells in the area have been measured periodically since 1946, and hydrographs for two wells, 35/36–14cdbl and 35/37–34adbl, are shown in Figures 31 and 32. In addition, the figures include the monthly mean gage height of the Humboldt River during the months in which the observation wells were measured. Well 35/36–14cdbl is an unused well, 18 feet deep, about 0.3 mile from the Humboldt River, and taps the unit mapped as younger alluvium. Well 35/37–34adbl, is an unused well in the mouth of Grass Valley about 5 miles south of the river. It is 83 feet deep and taps the medial gravel unit.

Figures 31 and 32 show that in overall aspect both wells respond to the stage of the Humboldt River. Water-level fluctuations in the two wells probably are reasonably representative of long-term fluctuations of ground-water levels fairly close to the river and in the mouth of Grass Valley. Accordingly, long-term fluctuations of ground-water levels throughout much of the project area seem to be related largely to the stage and flow of the Humboldt River similar to short-term and seasonal fluctuations.

Ground-water levels in the mouth of Grass Valley probably respond to changes in the stage of the Humboldt River because some of the aquifers are confined. The average rate of ground-water movement in the project area is on the order of a fraction of a foot to several feet per day. Accordingly, the water level in well 35/37–34adbl, which is about 5 miles from the river, could not respond to seasonal or even yearly changes in the stage of the river unless the well tapped one or more artesian aquifers. The well taps the medial gravel unit, and water in the unit, which is overlain and underlain by silt and clay beds of Lake Lahontan age in the vicinity of the well, probably is under artesian pressure.

In some years, as in 1952, the stage of the river declined from March to September but ground-water levels rose during the same period. In most years, ground-water levels were lower in September than in March, reflecting normal seasonal streamflow characteristics (Table 10). Streamflow in water year 1952, however, was far above normal and ground-water levels in September 1952 reflected the above normal spring runoff. That is, even though the stage of the river in September 1952 was lower than the stage of the river in March 1952, ground-water levels were higher in September owing to a large increase in the amount of ground water in storage related to the unusually high streamflow during the year.

Relation of Water-level Fluctuations to Changes in Storage

Under natural conditions and over the long-term period the ground-water system of the project area was in dynamic equilibrium—that is, the amount recharged equalled the amount discharged. For practical purposes the system is still in dynamic equilibrium owing to the small amount of pumpage. Any phenomenon which disrupts the equilibrium may cause ground-water level fluctuations and accompanying changes in the amount of ground water in storage. The magnitude and extent of the water-level fluctuations and changes in storage are related to the magnitude and extent of the disrupting phenomenon and the coefficients of transmissibility (page 32) and storage of the deposits forming the ground-water reservoir. The coefficient of storage of an aquifer is defined as "* * * the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface," (Ferris and others, 1962, p. 74).

In unconfined aquifers, water-level fluctuations normally reflect changes in the amount of ground water in storage. In confined or artesian aquifers, water-level fluctuations may or may not be accompanied by changes in the amount of ground water in storage. Where changes in the amount of ground water in storage occur in artesian aquifers, the amount of change per unit decline in hydraulic head per unit area commonly is thousands of times less than that in unconfined aquifers. The largest water-level fluctuations and virtually all the significant changes of ground water in storage occur in the unconfined aquifers beneath and adjacent to the Humboldt River.

Specific Yield

Under water-table conditions, the coefficient of storage is virtually identical to the specific yield

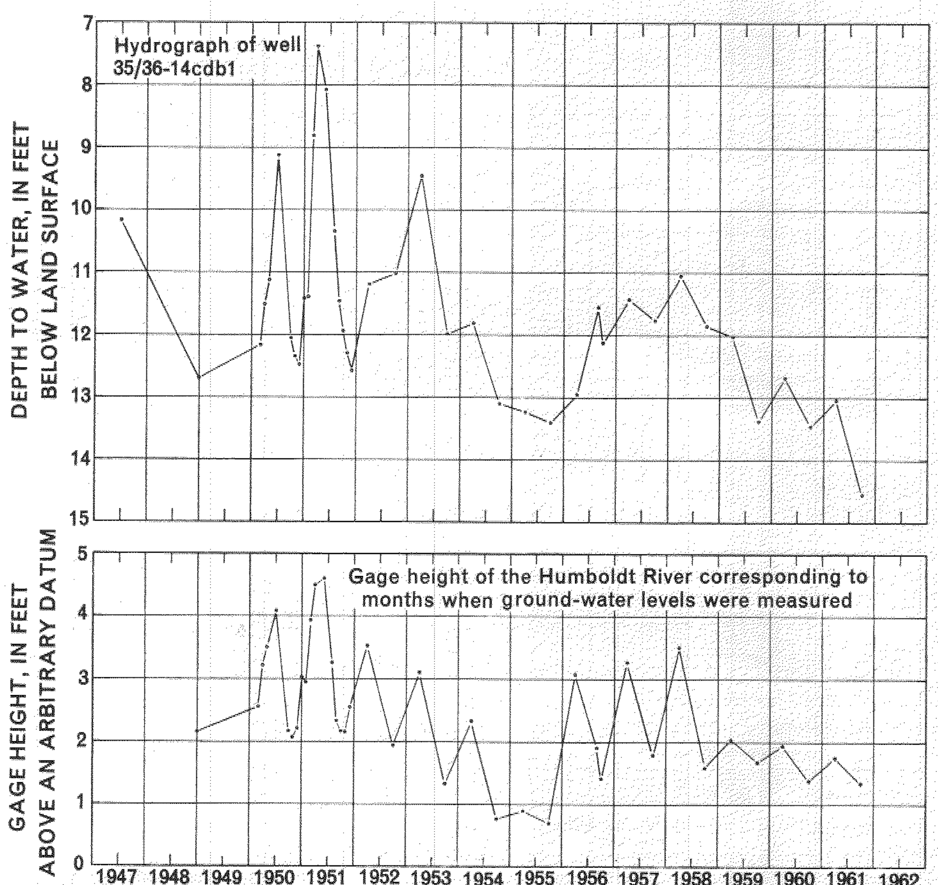

FIGURE 31.— Long-term water-level fluctuations in well 35/36-14cdb1 as compared to the monthly mean gage height of the Humboldt River at the Rose Creek gaging station near Winnemucca, Nev., 1947-62

of an aquifer. Specific yields of 323 samples were determined in the laboratory by the centrifuge-moisture-equivalent method. The centrifuge-moisture-equivalent method and the relations among specific yield and other hydrogeologic data in the Humboldt River valley are described in other reports (Cohen 1961c, and Cohen, 1963). Briefly, specific yield of a rock or sediment sample is, "* * * the ratio of (1) the volume of water which, after being saturated, it will yield by gravity to (2) its own volume" (Meinzer, 1923, p. 28). This ratio multiplied by 100 expresses specific yield as a percentage. Specific yield also may be expressed as porosity minus specific retention, where porosity is the percentage by volume of the total void spaces in a sample, and specific retention is the amount of water, expressed as percentage of the total volume of the saturated sample, retained by the sample against the pull of gravity. In the laboratory, specific yield was calculated by determining the difference between porosity and specific retention. Porosity was determined by the pycnometer method. (See Krumbein and Pettijohn, 1938, pp. 500–513.) Specific retention was determined from centrifuge-moisture-equivalent data by a method described by Piper and others (1939, pp. 118–119).

Table 22 summarizes the laboratory porosity, specific-retention, and specific-yield data. It is apparent that there is a large range in specific yield within each median particle-size class. The large range probably is caused by differences in primary and secondary sedimentary structures especially in some of the finer deposits, differences in the degree of compaction and cementation of the deposits, and complex interrelations among specific yield, specific retention, porosity, median particle size, and degree of sorting (Cohen, 1963).

Theoretically, specific yield determined by the centrifuge-moisture-equivalent method is a measure of either the amount of water that drains from saturated material during a long period of

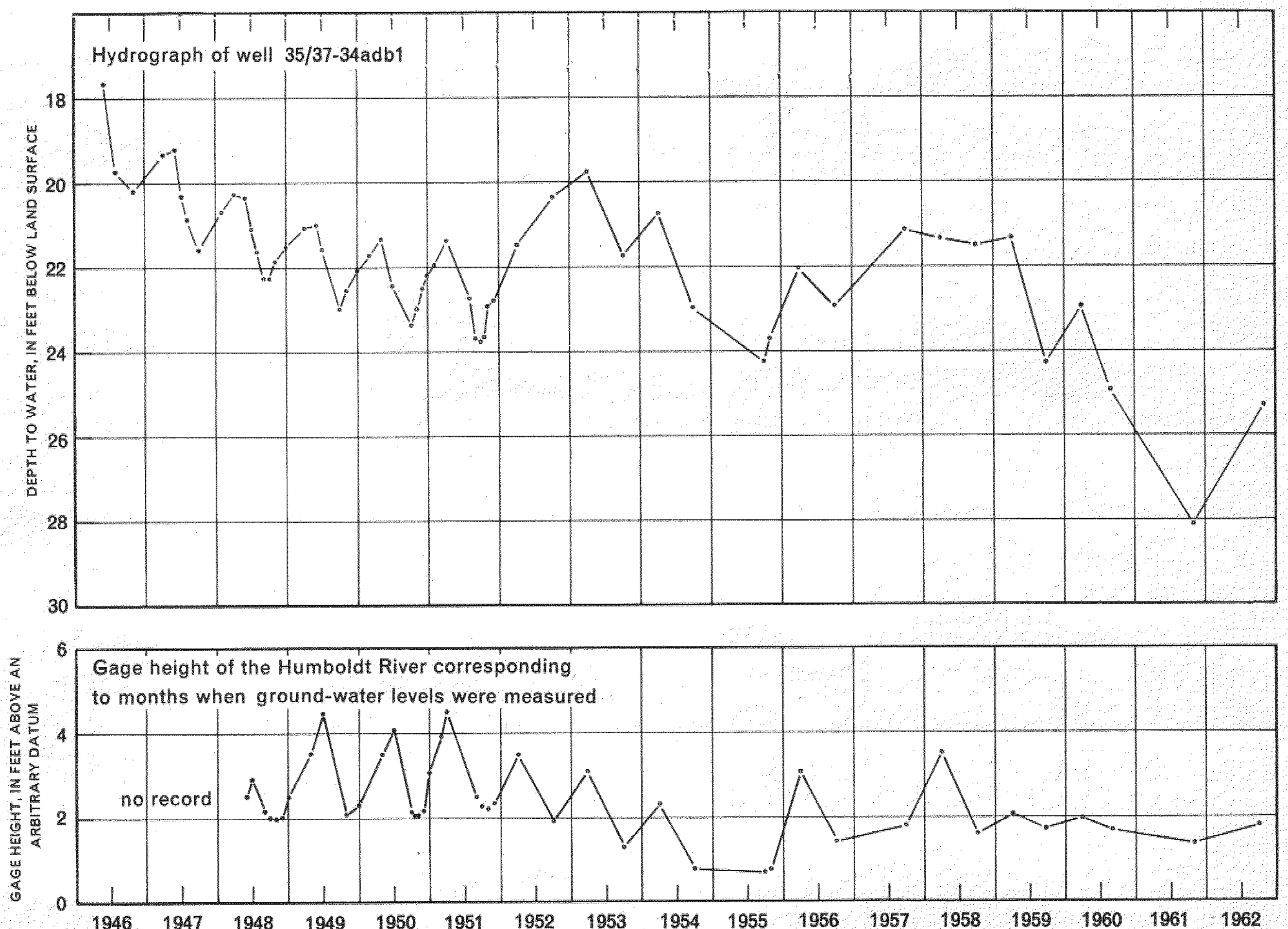

FIGURE 32.— Long-term water-level fluctuations in well 35/37-34adb1 as compared to the monthly mean gage height of the Humboldt River at the Rose Creek gaging station near Winnemucca, Nev., 1946-62

TABLE 22—SUMMARY OF LABORATORY SPECIFIC-YIELD DATA FOR SAMPLES FROM THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEVADA

Range of median diameters (millimeters)	Number of samples	Porosity Percent by Volume				Specific Retention Percent by Volume				Specific Yield Percent by Volume			
		Maximum	Median	Mean	Minimum	Maximum	Median	Mean	Minimum	Maximum	Median	Mean	Minimum
Less than 0.004 (clay)	1	....	....	48.1	....	....	....	47.6	....	....	....	0.5	....
.004–.0625 (silt)	174	67.4	53.4	52.5	33.0	44.5	33.8	33.4	10.5	34.1	19.1	19.1	1.0
.0625–.125 (very fine sand)	22	52.1	43.4	43.9	37.6	34.2	23.3	23.7	9.4	39.2	20.3	20.2	0.3
.125–.25 (fine sand)	33	63.4	42.3	42.2	32.8	56.4	14.1	16.2	5.9	40.9	29.2	26.0	4.3
.25–.5 (medium sand)	38	53.3	39.2	38.7	29.0	30.9	8.2	10.4	4.3	40.6	28.4	28.3	7.2
.5–1 (coarse sand)	14	41.9	37.9	35.9	28.3	17.9	7.6	9.4	5.5	35.9	29.3	26.5	10.7
1–2 (very coarse sand)	23	43.7	31.7	32.3	23.5	31.0	9.9	11.8	5.6	36.2	21.4	20.5	4.6
2–4 (very fine gravel)	12	42.7	28.8	30.0	26.3	22.7	11.2	12.0	7.3	27.4	18.8	18.0	4.9
4–8 (fine gravel)	6	42.7	28.8	32.6	26.4	28.0	8.3	13.4	5.4	37.3	19.5	19.2	.7
All sizes	323	67.4	45.9	45.8	23.5	56.4	28.6	24.5	4.3	40.9	20.9	21.3	.3

time or the amount needed to resaturate these materials after long-term drainage. For most materials it is presumed to be approximately equal to the total amount of water that will drain by gravity. The amount of time required for complete gravity drainage differs for different materials. Complete, or nearly complete, gravity drainage probably occurs rapidly in the medial gravel unit, perhaps within a few days. On the other hand, many months or years probably are required for complete, or nearly complete, gravity drainage of strata of the upper silt and clay unit. The time required for complete gravity drainage of most of the deposits in the project area probably ranges between these limits.

If the moisture content remains constant following gravity drainage, that is, if the moisture content remains equal to the specific retention, then and only then is the amount of water needed to resaturate the deposits equal to the amount that drained from the deposits. In many of the deposits beneath the flood plain and bordering river-cut terraces, evapotranspiration occurs from the zone of water-level fluctuations. As a result, during and following seasonal declines in the water table, the moisture content of many of the deposits formerly in the zone of saturation decreases below the specific retention. Before being resaturated, as ground-water levels begin to rise in the spring, the moisture content of the deposits in the zone of aeration first must increase to the specific retention. Such increases are not considered changes of ground water in storage inasmuch as the increased moisture will not drain by gravity. Accordingly, the estimated specific-yield values (Table 23) used to compute changes of ground water in storage locally may be considerably less than the total amount of water needed to resaturate deposits beneath the flood plain and bordering terraces.

The total amount of water added to the flood-plain deposits in the spring and early summer undoubtedly is considerably more than the net increase of ground water in storage. It is equal to the net increase of ground water in storage, plus the amount of water evaporated and transpired from the zone of saturation as the water table rises, plus the increase in moisture content in the zone of aeration. Sufficient data are not available to evaluate all of these elements. However, preliminary experimental data were obtained relative to changes in the moisture content in the zone of aeration. These are described in subsequent sections of the report.

TABLE 23—NET INCREASE OF GROUND WATER IN STORAGE IN THE STORAGE UNITS IN THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEVADA, DECEMBER THROUGH JUNE OF WATER YEAR 1962

(1) Storage unit	(2) Area (acres)	(3) Average rise of ground-water levels (feet)	(4) Estimated specific yield (percent)	(5) Net increase of ground water in storage* (acre-feet)
Toby Ranch	4,340	1.1	12	600
Lower McNinch Ranch	3,340	2.8	8	800
Lower Hillyer Ranch	1,400	0.7	12	100
Clear Creek	2,520	.7	10	200
Krum	6,900	1.7	10	1,200
Airport	7,800	1.6	2	200
Harrer Ranch	6,590	3.9	20	5,100
Upper Hillyer Ranch	3,920	5.7	6	1,300
Western Pacific	1,550	2.8	20	900
Harmony Creek	4,270	†1.5	10	600
Winnemucca	1,820	6.3	6	700
Weso	2,680	4.7	20	2,500
Kearns Ranch	5,510	5.8	6	1,900
Prospect West	1,470	†.6	10	100
Little Humboldt River	1,510	2.1	4	100
Prospect East	1,320	.6	10	100
Bliss	3,720	2.6	15	1,500
Paradise Valley	5,820	.7	10	400
Pole Creek	4,550	2.3	10	1,000
Bull Head	1,670	2.8	20	900
Diamond S Ranch	4,810	5.9	6	1,700
Eden Valley	7,020	1.2	10	800
Rock Creek	1,050	6.6	10	700
Golconda	1,050	8.2	6	500
Preble	820	5.7	5	200
Stahl Dam	390	7.4	4	100
Edna Mountain	540	†3.5	5	100
Comus	2,750	5.5	6	900
Bains Ranch	2,100	2.9	10	600
Total (rounded)	93,300	....	....	26,000

*Column 2x3x4, rounded. †Estimated.

Computation of Storage Changes

Based on several hydrogeologic features (Cohen, in press), those parts of the project area in which nearly all the changes of ground water in storage associated with the changing stage of the Humboldt River occur were divided into 29 storage units (Plate 5). The average specific yield of the deposits in the zone of rising ground-water levels in each storage unit was estimated partly on the basis of the laboratory data and partly on the basis of other hydrogeologic factors. (See Table 10 in Cohen, in press.) The estimated net increase of ground water in storage in each unit was equal to the product of the average net rise in water levels multiplied by the area of the storage units multiplied by the estimated average specific yield. Table 23 lists the data used to compute the net increase of ground water in storage from December through June of water year 1962.

As listed in Table 23 the estimated net increase of ground water in storage from December through June of water year 1962 was about 26,000 acre-feet. In water years 1949–62, the average net increase of ground water in storage during these months was about 10,000 acre-feet (Cohen, in press). During years of abnormally low streamflow, as in 1960 and 1961, the estimated corresponding net increases of ground water in storage were about 5,000 acre-feet.

The net increase of ground water in storage at the end of water year 1962 as compared to the beginning of the water year was on the order of 5,000 acre-feet. Because the hydrologic system was not appreciably affected by pumping, the long-term average annual net change of ground water in storage and the average annual net change in water years 1949–62 was zero.

Total Ground Water in Storage

A large amount of ground water in storage occurs in the medial gravel unit and in the adjacent and underlying deposits of the ground-water reservoir. The medial gravel unit is virtually completely saturated. Plate 6 shows its approximate saturated thickness and areal distribution. Its volume is about 2.5 million acre-feet and its long-term specific yield is at least 20 percent. (See specific yields in Table 22 for samples having median particle-size diameters in the coarse-sand to gravel-size ranges.) Accordingly, the total amount of ground water in storage in the unit is on the order of 500,000 acre-feet, or about three times the capacity of Rye Patch Reservoir.

The volume of the upper 100 feet of saturated deposits adjacent to the medial gravel unit in the project area is about 15 million acre-feet. Assuming that the average longterm specific yield of these deposits is 10 percent, they contain an additional 1.5 million acre-feet of ground water in storage.

Locally, highly permeable deposits occur beneath those in the upper 100 feet of the zone of saturation. The average thickness of these and other less permeable deposits forming the ground-water reservoir may be 1,000 feet or more. Thus, the total amount of ground water in storage in the project area may be 5 to 10 times greater than that in the upper 100 feet of the ground-water reservoir.

WATER–CONTENT CHANGES IN SHALLOW FLOOD–PLAIN DEPOSITS AT THREE SITES

By A. O Waananen

Water stored in the flood-plain deposits during periods of rising river stage and subsequently released as the river stage falls is one of the principal sources of water that sustains low flows in the Humboldt River. The water may be stored as soil moisture in the unsaturated zone, including the capillary fringe, and as ground water in the saturated zone. The term "total water content" is used in this and the immediately following section of the report to describe the amount of water in the unsaturated and saturated zones in the shallow flood-plain deposits.

When the water table is at shallow depth, water may be discharged by evaporation from land surface, by transpiration by riparian and flood-plain vegetation, commonly phreatophytes, and by underflow to stream channels. Seasonal changes in ground-water levels in the Humboldt River flood plain in the study reach exceed 5 feet in some years. Accompanying changes in moisture content in the unsaturated zone may be as much as half an acre-foot per acre or more. All the water going into storage in a given season may not be released in the subsequent low-water season, and the storage carry over to the next season may be substantial. The amounts of water stored and released seasonably, or carried over, appear great enough to justify consideration in annual water-budget studies.

The neutron-scattering method for measuring soil moisture provides a means for determining changes in the moisture content of soils. It is helpful also in determining specific-yield characteristics of saturated deposits. During 1962, soil-moisture data were obtained at three sites in the Humboldt River flood plain in the study reach to observe the changes in water content in the shallow flood-plain deposits. These sites were each less than 500 feet from channels of the river. Data obtained during a high water year such as 1962 should provide some indication of the storage potential of the deposits, and perhaps the short-term specific yield. On the basis of the results, the method appears satisfactory but more sampling is needed to provide more than an approximation of the soil-moisture changes and the specific yield. The data obtained, however, are useful toward a better understanding of some of the hydrologic processes.

Moisture contents were determined with a neutron-scattering soil-moisture meter using access tubes installed at the following sites:

Location	Depth of profile observed, in inches
Kearns Ranch, 6½ miles NE of Winnemucca (adjacent to well 36/38-2bbc1)	90
Winnemucca (adjacent ot well 36/38-19ddc1)	100
Test site, 4 miles SW of Winnemucca	81

The access tubes at these sites extend to and bottom in a layer of fine-grained nearly impervious volcanic ash at or a little above the minimum observed level of the water table.

The procedure used in the moisture determinations is consistent with general practice (Van Bavel, 1958). The same procedure was used to determine the water-content in the evapotranspiration tanks at the test site (page 71). The soil-moisture meter, which utilizes the neutron energy absorption technique, is equipped with a 28 milligram actinium source and has demonstrated a high degree of replicability of results.

Data were obtained in April, June, July, August and October 1962 at each of the sites, and also in September 1961 at the test site. The resulting water-content profiles and the corresponding ground-water levels are shown in Figure 33 together with a graphic log of the materials penetrated in each access hole. The water content in the observed profiles, expressed as depth of water both in inches and feet, together with the net change between observation periods are given in Table 24. In addition, the average daily depletion rate in water content, in feet, is shown for the recession period.

The profiles show the changes in water content during 1962. The additional 1961 data at the test site demonstrate the difference between water content at the end of a below average water year (1961) with that for a year of high water and overbank flow (1962). The data at the test site also indicate, for example, that the total water content in the measured profile increased from the 1961 low of about 18 percent by volume to the 1962 high of about 38 percent, the difference representing an increase in water content of 20 percent, by volume, or 16 inches of water. The increase in water content took place principally in the upper 4 feet of this profile where the average change was 25 percent, representing 12 inches of water. The increase in water content in the deposits at this site, which was more than an acre-foot per acre between September 1961 and July 1962, is an index of the increase that may be expected in deposits in the study reach having similar lithologic characteristics and in a similar hydrologic environment.

By October 1962 the water content in the upper 80 inches of the three profiles had declined 9, 11, and 13 percent by volume, respectively, from the season's maximums at the Kearns Ranch, Winnemucca, and test-site locations. The water content in the deposits at the test site in October 1962 was about 7 percent by volume higher than in September 1961, or a net increase of almost 0.5 acre-foot per acre. Relationships at the other two sites may be presumed to be similar, but the amounts and distribution of changes in water content at the other locations in the basin, of course, are dependent on many factors including the character of the local materials and the depths to water.

It is of interest to note from Figure 33, that significant parts of the changes in water content with changes in the ground-water levels occur in the zone of aeration. When water levels change gradually, as on a declining stage, the changes in water content are related to the hydrologic characteristics of the materials in both the zone of aeration and the zone of saturation. Thus, the water released may be ground water from the zone of saturation (perhaps 1 or 2 percent moisture, by volume) and vadose moisture from the zone of aeration. This becomes significant in the evaluation of probable yields when deposits having different characteristics occur in overlying layers.

The data indicate a depletion rate of nearly 0.01 foot per day during the recession from the high water level in July 1962. The depletion in water content resulted from evapotranspiration and underflow to the Humboldt River. There is a coincidental agreement with the approximate rate of water use by phreatophytic vegetation. However, the density and extent of such vegetation is low at the Kearns Ranch and Winnemucca sites and the decline in the water table probably is attributable to both evapotranspiration losses and underflow to the river. In areas where the water table is well below the root zone of most phreatophytes, the water-table decline would be related more closely to the lateral movement of ground water to streams or to other adjacent discharge areas.

PRELIMINARY ESTIMATES OF CHANGES IN MOISTURE CONTENT IN THE ZONE OF AERATION

Very few data are available to calculate net changes in moisture content in the zone of aeration. Crude preliminary estimates can be made by utilizing the preliminary data developed by Waananen in the preceding section of the report and by the writer in the section on changes of ground water in storage. It is assumed that the most significant changes in moisture content in the zone of aeration of the storage units occurred in the flood-plain deposits because of irrigation practices and natural overbank flooding. In addition, it is assumed that the net changes in total water content (vadose water and ground water in storage) that occurred in the shallow flood-plain deposits at the test site were representative of the changes that occurred on the entire flood plain.

Total water content in the flood-plain deposits increased about 0.5 acre-foot per acre in water year 1962 (page 82). Thus, it can be computed that the net increase in total water content in these deposits in water year 1962 was about 12,000 acre-feet. The estimated net increase of ground water in storage in these deposits during the same period was only 2,000 acre-feet. Accordingly, the estimated net increase in moisture content in the zone of aeration in water year 1962 was equal to the net increase in total water content minus the net increase of ground water in storage, or about 10,000 acre-feet.

The net increase in total water content from December to June of water year 1962 may have been about 1 acre-foot per acre (page 82) or about 25,000 acre-feet. The estimated net increase of ground water in storage in the flood-plain deposits during the same period was 8,000 acre-feet. Accordingly, the estimated net increase in moisture content in the zone of aeration from December to June in water year 1962 was about 25,000 acre-feet minus 8,000 acre-feet, or about 17,000 acre-feet. The estimated average annual

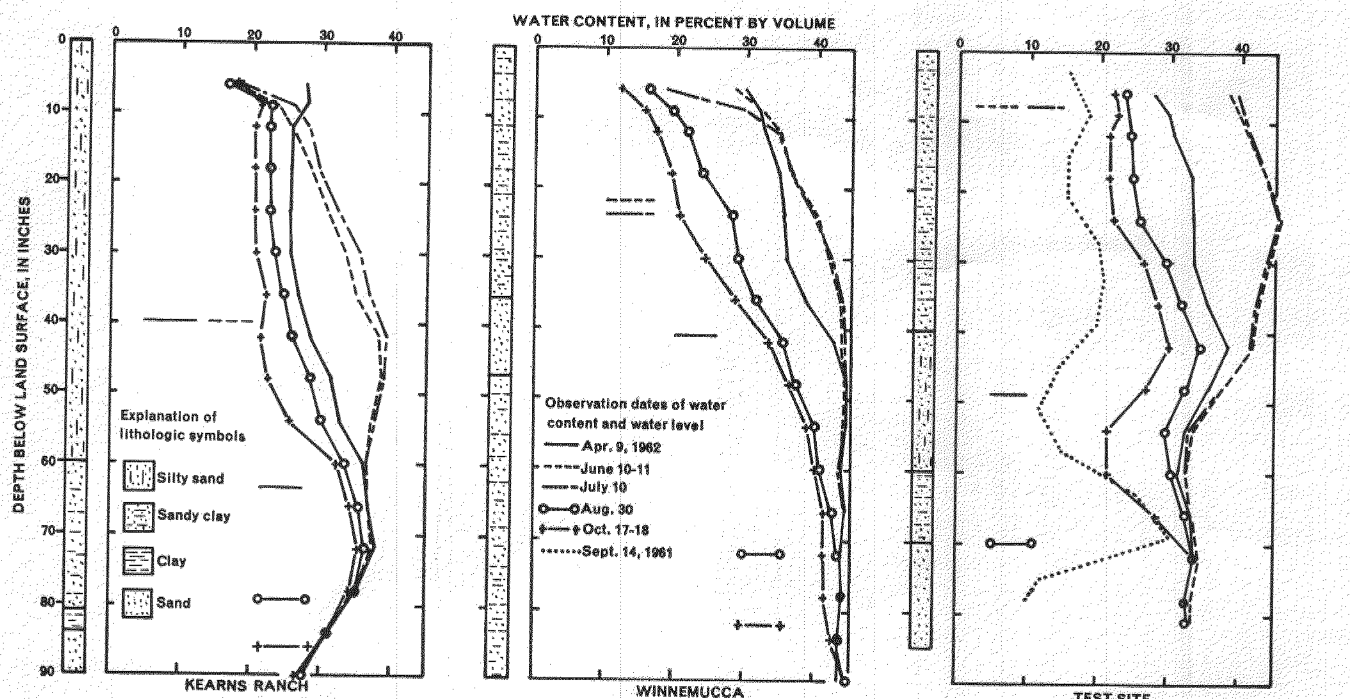

FIGURE 33.—Water content and access-hole logs at three sites in the flood plain of the Humboldt River near Winnemucca, Nev., 1961-62

net change in moisture content in the zone of aeration in water years 1949–62 was zero. This estimate probably is accurate within a few percent; however, the preliminary estimates for water year 1962 and for December through June of water year 1962 may be in error by as much as 50 percent.

TABLE 24—WATER-CONTENT CHANGES IN THE SHALLOW DEPOSITS AT THREE SITES IN THE HUMBOLDT RIVER FLOOD PLAIN NEAR WINNEMUCCA, NEVADA, 1962

	Apr. 9		June 10–11		July 10		Aug. 30		Oct. 17–18
KEARNS RANCH—									
Depth to water (in.)	*63.6		39.36		38.76		79.08		85.92
Depth of moisture in 90-inch profile (in.)	27.43		29.04		29.70		24.58		22.83
Change (in.)		+1.61		+0.66		—5.12		—1.75	
Change (ft.)		+.13		+.06		—.43		—.15	
Depletion (ft./day)		....		....		.0084		.0031	
WINNEMUCCA—									
Depth to water (in.)	40.68		22.08		24.60		72.12		82.08
Depth of moisture in 100-inch profile (in.)	39.64		40.70		39.86		34.56		32.12
Change (in.)		+1.06		—.84		—5.30		—2.44	
Change (ft.)		+.09		—.07		—.44		—.20	
Depletion (ft./day)		....		....		.0086		.0042	
TEST SITE—									
Depth to water (in.)	48.84		7.68		8.04		69.60		†
Depth of moisture in 81-inch profile (in.)	26.68		31.20		31.20		23.74		20.76
Change (in.)		+4.52		.00		—7.46		—2.98	
Change (ft.)		+.38		.00		—.62		—.25	
Depletion (ft./day)		....		....		.012		.0051	

*Estimated. †More than 84.0.

CHEMISTRY OF THE HYDROLOGIC SYSTEM

The principal objectives of the hydrogeochemical studies were (1) to determine the suitability of the water of the area for use, (2) to evaluate lateral and vertical differences in water quality and changes in water quality with time, and (3) to utilize water-quality data to make a qualitative and, where possible, a quantitative evaluation of the source and movement of water. Much of the basic water-quality data, a moderately detailed analysis of the suitability of the water for use, and a preliminary evaluation of water quality and its relation to the hydrologic system are given in a previous report (Cohen, 1962d). Variations in water quality and the relation between water quality and the source and movement of water are emphasized in the present report. The hydrogeochemical studies are based on more than 225 chemical analyses made of ground and surface water in the project area. Samples were obtained in July and August 1961, November and December 1961, and April and May 1962.

UNITS USED IN REPORTING DATA

Dissolved-solids content is a term used to refer either to the residue of a known quantity of sample dried at 180°C. or to the sum of the determined constituents. Dissolved-solids-content values given in this report are the sums of determined constituents expressed in parts per million (ppm) or equivalents per million (epm). Parts per million are the number of milligrams of solute in 1 kilogram of solution. Equivalents per million are the number of milligram equivalents of solute in 1 kilogram of solution and are calculated by dividing the concentration of an ion in parts per million by its combining weight, which is defined as the atomic or molecular weight of an ion divided by its valence. For the purpose of this report the waters have been classified according to dissolved-solids content as follows:

Dissolved-solids content (ppm)	Classification
150 to 300	Very low
300 to 500	Low
500 to 750	Moderate
750 to 1,000	Moderately high
1,000 to 2,000	High
Greater than 2,000	Very high

Specific conductance, expressed in micromhos per centimeter at 25°C., is a measure of the ease with which an electrical current will pass through a solution. It is a rough measure of dissolved-solids content. Hardness of water, which is caused principally by calcium and magnesium ions and which, if excessive, adversely affects the suitability of water for domestic and other uses, is expressed in parts per million of calcium carbonate.

The U.S. Gelogical Survey uses the following numerical ranges and adjective ratings for classifying water hardness:

Hardness range (ppm)	Classification
0– 60	Soft
61–120	Moderately hard
121–180	Hard
Greater than 180	Very hard

SOURCE AND SIGNIFICANCE OF DISSOLVED CONSTITUENTS

About 100 elements and thousands of compounds of these elements occur in the consolidated rocks and unconsolidated deposits of the area. Virtually all of these elements and compounds are, in varying degree, soluble in water. Nearly all the water enters the hydrologic system of the project area either as precipitation or as streamflow. Precipitation commonly contains trace amounts of the major chemical constituents and some minor chemical constituents. As it moves through the hydrologic system, water originating as precipitation commonly contains progressively more dissolved solids largely as a result of coming into contact with additional soluble mineral matter. Solution of carbon dioxide from the soil, increasing temperature and pressure with increasing depth, changes in pH, and other factors may increase the chemical reactivity of the water and cause it to dissolve additional mineral matter.

The dissolved-solids content of the Humboldt River, which contributes most of the water to the project area, is considerably higher than that of precipitation. As this water moves through the hydrologic system of the study area it also dissolves additional mineral matter; however, because of complex interrelations with other aspects of the system, the dissolved-solids content of Humboldt River water locally increases and locally decreases with increasing distance downstream from the Comus gaging station. In addition, the chemical quality of the Humboldt River changes seasonally.

Table 25 lists the principal sources and significance with respect to use of the determined constituents, and Plates 7 and 8 show the concentration of the major chemical constituents in equivalents per million of most of the samples obtained during the study. The diagrams, which are modified after those first introduced by Stiff (1951), permit a rapid although somewhat generalized evaluation of the chemical quality of the water.

Most of the water in the project area has a moderate to very low dissolved-solids content and is sodium bicarbonate water—that is, sodium and bicarbonate, expressed in equivalents per million, constitute more than 50 percent of the major cations and anions, respectively. Calcium is the next most abundant cation, and the chloride and sulfate anions are about equally abundant. Although otherwise suitable for most purposes, nearly all the water is moderately hard to very hard. Locally some of the water is not suitable for some uses. (See Cohen, 1962d, pages 20–24.)

TABLE 25—PRINCIPAL SOURCES AND SIGNIFICANCE WITH RESPECT TO SUITABILITY FOR USE OF SELECTED CHEMICAL CONSTITUENTS IN THE WATERS OF THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEVADA

Constituent	Principal sources	Significance with respect to suitability for use
Silica (SiO_2)	Silicate minerals abundant in nearly all the consolidated rocks and in all the unconsolidated deposits.	May form scale in pipes and boilers.
Iron (Fe)	Iron-bearing minerals that occur, at least in small amounts, in nearly all the consolidated rocks and in all the unconsolidated deposits.	More than about 0.3 ppm may stain laundry, utensils, and kitchen fixtures. Larger quantities may color and impart objectionable taste to water.
Calcium (Ca)	Calicum-bearing feldspars which constitute as much as 50 percent of some of the basic volcanic rocks such as basalt, andesite, and diorite; limestone. Calcium salts, especially $CaCO_3$ and $CaSO_4$ in the unconsolidated deposits.	Principal cause of hardness. Commonly a major constituent in scale deposits.
Magnesium (Mg)	Pyroxenes and amphiboles in igneous rocks. Magnesium salts in the unconsolidated deposits.	Second most important cause of hardness.
Sodium (Na)	Sodium-bearing feldspars in the acidic volcanic rocks such as granite and rhyolite. Sodium salts, especially NaCl, Na_2CO_3, $NaHCO_3$, and Na_2SO_4 in the unconsolidated deposits. Ion exchange with sodium-bearing clay minerals.	Excessive amounts may reduce soil permeability. In combination with chloride, may cause water to taste salty.
Potassium (K)	Potash feldspars in acidic igneous rocks. Potassium salts probably are comparatively rare in the unconsolidated deposits.	Essential for proper plant nutrition.
Bicarbonate (HCO_3) and Carbonate (CO_3)	End products of the weathering of feldspars and many other common rock forming minerals. $CaCO_3$, Na_2CO_3, and $NaHCO_3$ salts in the unconsolidated deposits.	Causes carbonate hardness in combination with calcium and magnesium. May be precipitated from boiling water to form scale and yield corrosive carbon dioxide. Locally forms "black alkali" (Na_2CO_3) crusts on the soil which are injurious to many plants.
Sulfate	Oxidation and hydration of sulfide minerals in the consolidated rocks. Solution of gypsum from the unconsolidated deposits.	May be precipitated from boiling water to form scale. Excessive amounts may have a laxative effect on humans and animals.
Chloride	Chloride salts, largely NaCl, in the unconsolidated deposits, especially in the lacustrine and flood-plain deposits.	Excessive amounts (more than 250 ppm) may cause salty taste. Precipitates locally on the Humboldt River flood plain where it is injurious to most plants.
Fluoride	Occurs in trace amounts in various consolidated rocks. Associated with thermal water near the East Range fault and near the Comus gaging station.	Essential for proper human nutrition. Excessive amounts (more than about 1.7 ppm) may cause mottled tooth enamel in children.
Nitrate (NO_3)	Nitrates in the soil and, locally, organic pollutants.	Nitrate in drinking water in excess of about 44 ppm may cause cyanosis, the so-called "blue-baby" disease, in infants.
Boron	Occurs in trace amounts in some of the consolidated rocks of the area. Associated with thermal water near the East Range fault and water of high dissolved-solids content near the Comus gaging station.	Essential for proper plant nutrition in small amounts. Toxic to many plants in amounts only slightly more than the needed amounts. Unsuitable in quantities of more than 3.75 ppm for even the most tolerant crops.

VARIATIONS IN WATER QUALITY

In a complex hydrogeologic environment such as that of the Humboldt River valley, marked variations in water quality occur—both vertical and lateral variations and variations with time. To evaluate these phenomena, where possible samples were obtained from nearby wells tapping different lithologic units at different depths; ground-water samples were obtained during periods of low, intermediate, and high water levels; the Humboldt River was sampled during periods of low and high streamflow.

Vertical and Lateral Variations

Largely on the basis of water quality, the project area is divided into seven subareas, six of which are outlined on Plate 9. The seventh subarea is the Humboldt River flood plain and bordering river-cut terraces except where they occur in the other subareas. The map shows the sum of the major anions and cations in the ground water in the project area. Vertical and lateral variations in the chemical quality of ground water in each subarea are described in detail in a previous report (Cohen 1962d, pages 12–16), and are summarized in Table 26.

Variations With Time

As the flow and stage of the Humboldt River change with time, the hydraulic relations between the river and the ground-water reservoir change. In general, when the stage and flow of the river are high, the river loses water to the ground-water reservoir; when the stage and flow of the river are low, the river gains water from the ground-water reservoir. Figure 34 shows the relation between specific conductance and gage height of the Humboldt River at the Winnemucca gaging station. In overall aspect the specific conductance is inversely proportional to the stage of the river. During periods of high streamflow, the water has a very low dissolved-solids content, and some of it recharges the ground-water reservoir beneath and adjacent to the river. During periods of low streamflow, ground water of low to high dissolved-solids content seeps into the river and constitutes most, or commonly all, of the streamflow.

Plate 7 shows the chemical quality of water in the project area in July-December 1961 when streamflow was low, ranging from about 10 to 20 cfs at the Rose Creek gaging station, and when ground-water levels throughout most of the area were at or near record-low stages. Plate 8 shows the water quality in April and May 1962 when the flow of the river was about 750 cfs at the Rose Creek gaging station and when ground-water levels were nearly as high and the shape of the water-level contours were very similar to those shown in Plate 4. In the spring of 1962, generally the most marked changes in water quality, as

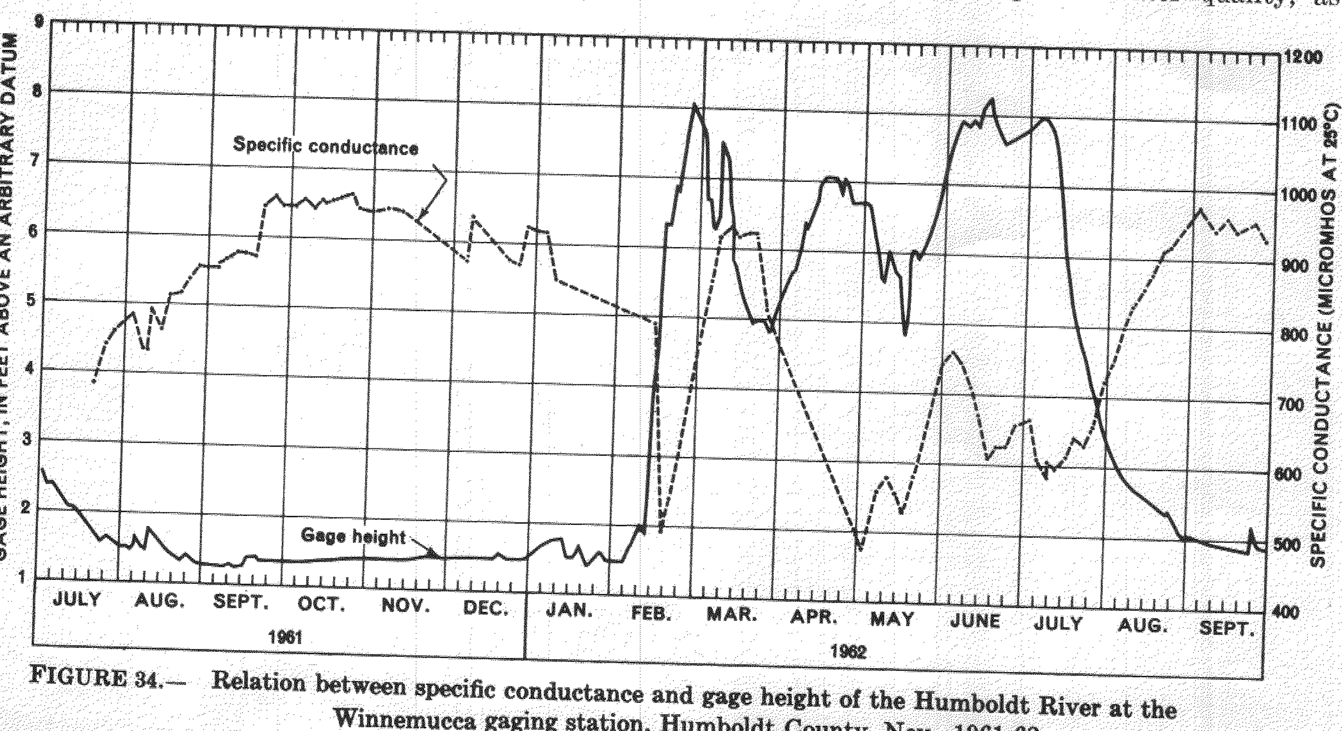

FIGURE 34.— Relation between specific conductance and gage height of the Humboldt River at the Winnemucca gaging station, Humboldt County, Nev., 1961-62

TABLE 26—SUMMARY OF THE VERTICAL AND LATERAL VARIATIONS IN CHEMICAL QUALITY OF GROUND WATER IN THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEVADA

Subarea*	Source of ground water	Variations in chemical quality
Comus	Chiefly seepage from the Humboldt River and underflow from the Humboldt River valley upstream from the subarea; small amount from a deeply circulating spring system.	Three distinct types of water occur in the subarea—sodium chloride and sodium bicarbonate water and mixtures thereof; all have a moderately high to very high dissolved-solids content. Some sodium bicarbonate water is associated with the thermal spring system (samples 36/41–2aacl–1, 2). Sodium chloride water, most of the sodium bicarbonate water, and the mixed water are largely associated with highly saline and relatively impermeable flood-plain deposits.
Golconda	Largely seepage from the Humboldt River and underflow from the Rock Creek drainage basin.	Sodium bicarbonate water of moderately high to high dissolved-solids content occurs in the shallow flood-plain deposits near the eastern margin of the subarea. Most of the remainder of the subarea contains ground water of low dissolved-solids content. The Golconda Hot Springs are characterized by sodium bicarbonate water having a maximum temperature of 152°F. and a moderate dissolved-solids content (samples 36/40–29dcal–1, 2).
Paradise Valley	Largely underflow from Paradise Valley and seepage from the Humboldt River.	Ground water in the relatively permeable deposits beneath the Lake Lahontan strata is calcium bicarbonate and sodium bicarbonate water of low to very low dissolved-solids content. Sodium bicarbonate water having a high dissolved-solids content and a temperature of 158°F. issues from a flowing well, 61 feet deep, near the center of the subarea (samples 37/39–3dccl–1, 2). Mixed water in the highly saline upper silt and clay unit and in the flood-plain deposits of the Little Humboldt River has a moderate to very high dissolved-solids content.
Sonoma Range	Recharge from the Pole Creek drainage basin.	Calcium bicarbonate water of very low dissolved-solids content derived from the Sonoma Range.
Grass Valley	Infiltration of streamflow draining the western and northwestern slopes of the Sonoma Range; underflow from Grass Valley.	Calcium bicarbonate water of very low dissolved-solids content occurs in the alluvial fans bordering the Sonoma Range, in the medial gravel unit, and in the alluvium underlying the lower silt and clay unit. Wells tapping the highly saline upper silt and clay unit yield sodium chloride water of high to very high dissolved-solids content.
East Range Fault	Source not known. Water may be moving through fractured zones related to the fault, or may be moving through alluvium and being forced to the surface by a permeability barrier related to the fault.	Most of the water in the subarea is a sodium bicarbonate type of high to very high dissolved-solids content seemingly associated with and downgradient from the East Range fault. Thermal sodium bicarbonate water having a maximum temperature of 83°F. and a high to very high dissolved-solids content issues from spring 35/36–28abal and 35/36–28dccl.
Humboldt River flood plain and bordering river-cut terraces (except where they occur in the other subareas)	Seepage from the Humboldt River and underflow from tributary areas.	Most of the flood-plain deposits, the medial gravel unit, and the underlying deposits contain sodium bicarbonate water of moderate to low dissolved-solids content. Locally, highly saline flood-plain deposits contain sodium chloride and calcium sulfate water of moderately high to very high dissolved-solids content.

*See Plate 9.

compared to the water quality in December 1961, occurred in the Humboldt River and in the shallow aquifers beneath and immediately adjacent to the river. The dissolved-solids content of water in most of the shallow wells tapping flood-plain deposits or the underlying medial gravel unit, such as water in wells 35/36–19dca1, 36/40–36bbb1, and 36/41–14dcd1, decreased. Water levels in these wells rose markedly as a result of the high river stage. The dissolved-solids content of the river was 250 to 300 ppm when sampled in April and May 1962. Accordingly, the decrease in dissolved-solids content of ground water in the shallow aquifers probably was a result of dilution by seepage of Humboldt River water of very low dissolved-solids content to the ground-water reservoir.

The dissolved-solids content of some of the shallow ground water resampled in the spring of 1962 increased. For example, the dissolved-solids content of water from well 37/38–34abb1 increased from 970 ppm in August 1961 when the water level was about 5.4 feet below land surface to 4,320 ppm in April 1962 when the water level was about 2.2 feet below land surface. The dissolved-solids content of water in this well and in some of the other shallow wells probably increased because the water table rose into near-surface highly saline deposits associated with areas of substantial ground-water discharge by evapotranspiration.

Thermal water in the project area showed no significant and consistent seasonal changes in water quality. This water may be part of a single large and deeply circulating system. If this is correct, the chemical quality of the thermal water should remain fairly constant and should not respond to short-term seasonal influences.

THE RELATION OF WATER QUALITY TO THE SOURCE AND MOVEMENT OF WATER

In overall aspect the geochemistry of the hydrologic system corroborates the hydrogeologic observations and interpretations given in previous sections of this report. In detail, water-quality data help refine some aspects of the interrelations among various components of the hydrologic system, especially interrelations between the Humboldt River and the ground-water reservoir. The relation of water quality to the source and movement of water is evaluated by analyzing the data shown in Plate 3 and Figure 35, which show water-level contours and the chemical quality and flow of the Humboldt River, respectively, when ground-water levels and the stage and flow of the river were low.

In December 1961 water-level contours were slightly concave downstream between stations A and B. Accordingly, in this reach of the river most of the ground-water movement was toward the river. Flow in the Humboldt River at station A was about 0.15 cfs and was a mixture of sodium chloride and sodium bicarbonate water of high to moderately high dissolved-solids content derived largely from the shallow aquifers upstream from the Comus gaging station. The flow increased to about 0.4 cfs at station B and the dissolved-solids content decreased about 440 ppm. The increase in flow between the two stations was a result of ground-water seepage to the river, the dissolved-solids content of which can be estimated by the equation:

$$(Q_{ha})\ (C_{ha}) + (Q_u)\ (C_u) = (Q_{hb})\ (C_{hb}), \quad (4)$$

or

$$C_u = \frac{(Q_{hb})\ (C_{hb}) - (Q_{ha})\ (C_{ha})}{Q_u}, \quad (5)$$

where Q_{ha} = rate of flow of the Humboldt River at station A, in cubic feet per second,
C_{ha} = dissolved-solids content of the Humboldt River at station A, in parts per million,
Q_u = rate of ground-water seepage into the Humboldt River between stations A and B, in cubic feet per second,
C_u = dissolved-solids content of the ground-water seepage, in parts per million,
Q_{hb} = rate of flow of the Humboldt River at station B, in cubic feet per second, and
C_{hb} = dissolved-solids content of the Humboldt River at station B, in parts per million.

The dissolved-solids content and rate of flow of the Humboldt River at station A were 1,280 ppm and 0.15 cfs, respectively; the dissolved-solids content and rate of flow at station B were 836 ppm and 0.4 cfs, respectively. Thus, the rate of ground-water seepage to the river between the two stations was 0.25 cfs. Substituting these data in equation 4:

$$C_u = \frac{(0.4)\ (836) - (0.15)\ (1280)\ \text{ppm}}{0.25} = 570\ \text{ppm}$$

Accordingly, the calculated dissolved-solids content of ground water discharging into the Humboldt River between stations A and B in December 1961 is about 570 ppm.

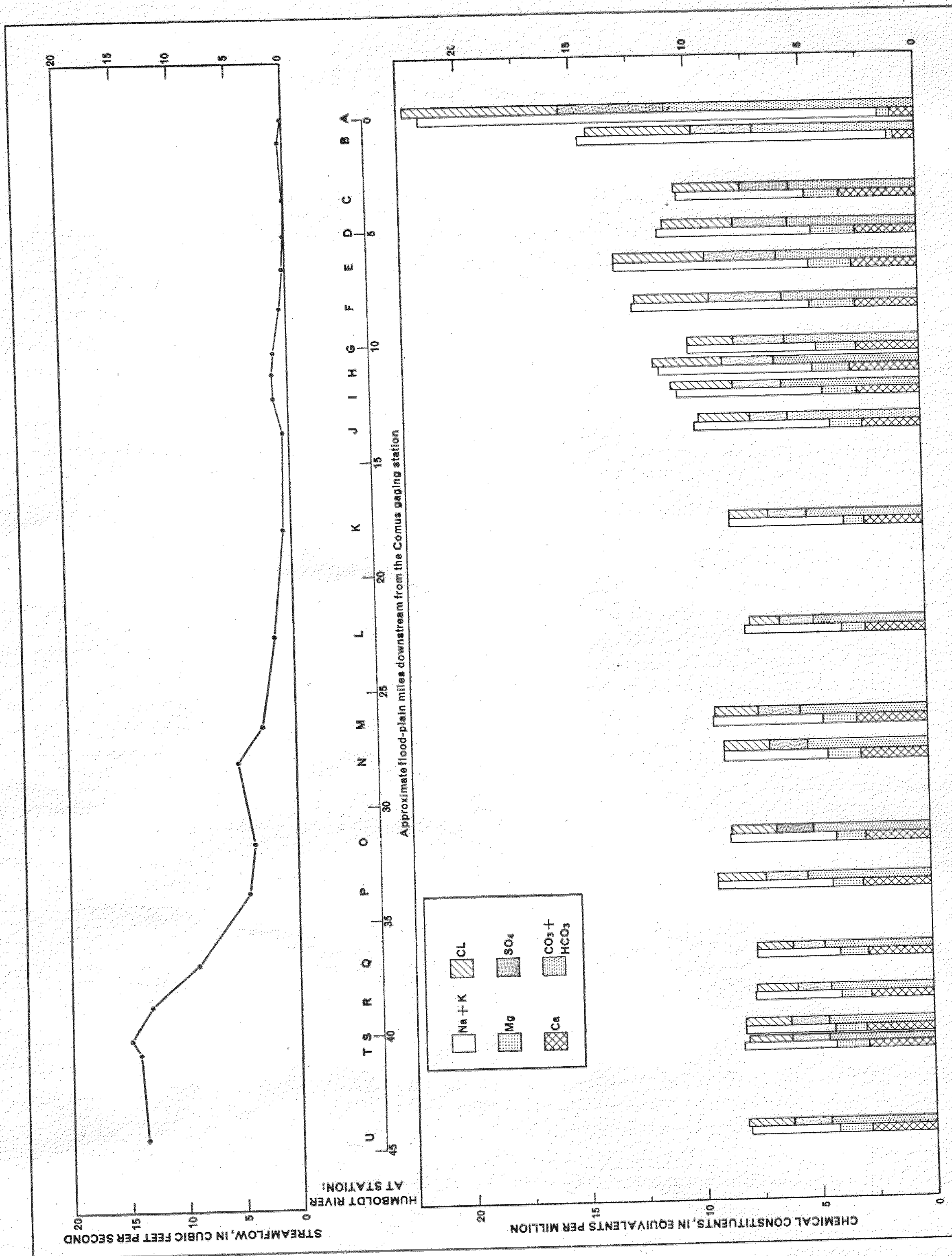

FIGURE 35.—Streamflow and chemical quality of the Humboldt River near Winnemucca, Nev., Dec. 4-6, 1961

The river was virtually dry at station C, but the dissolved-solids content from a pool near the station was 585 ppm. The pool was caused by the intersection of the bed of the river and the water table, and the quality of the water from the pool probably was very similar to that of the water discharging into the river between stations A and B. The calculated dissolved-solids content of the ground water discharging into the river, about 570 ppm, agrees closely with the dissolved-solids content of the water from the pool near station C.

The flow and dissolved-solids content of the river increased to about 0.2 cfs and about 750 ppm, respectively, at station E. Nearly the entire increase in flow and most of the increase in dissolved-solids content occurred between stations D and E where the width of the relatively permeable alluvium decreases to about a quarter of a mile causing ground water to discharge into the river. Ground water discharging into the river between stations C and E had a higher dissolved-solids content than that discharging into the river between stations A and B largely because the deposits in this area are highly saline owing to the normally very shallow water table and the resulting above average evapotranspiration rates which results in a concentration of salts.

The flow of the Humboldt River increased to about 1.2 cfs at station G and the dissolved-solids content decreased to about 560 ppm. The increase in streamflow and the decrease in dissolved-solids content probably was largely a result of the underflow of calcium bicarbonate ground water of low dissolved-solids content from the drainage basin of Rock Creek. (See Plates 3 and 9.)

At station H, the flow of the Humboldt River increased to about 1.4 cfs and the dissolved-solids content increased to about 640 ppm. The increase in flow was a result of underflow from the Pole Creek-Rock Creek area, from the Humboldt River valley upstream from station H, and perhaps from the hot springs near Golconda. Underflow from the Pole Creek-Rock Creek area had a low to very low dissolved-solids content; underflow from the Humboldt River valley had a moderate to moderately high dissolved-solids content; and underflow from the Golconda hot springs system had a moderate dissolved-solids content (Plate 9). These relations preclude the possibility of using available water-quality data to evaluate the relative amounts of underflow discharging into the river from each of the three sources.

Streamflow and dissolved-solids content decreased to about 0.6 cfs and 450 ppm, respectively, at station J. As previously indicated (page 62), streamflow decreased between stations H and K apparently because ground-water movement away from the river toward the northwest was greater than that toward the river from the southeast. The dissolved-solids content probably decreased because ground water discharging into the river from the southeast was mostly calcium bicarbonate water of low to very low dissolved-solids content from the Pole Creek-Rock Creek area.

The flow of the Humboldt River increased from about 0.6 cfs at station J to about 5 cfs at station N. The dissolved-solids content decreased to 467 ppm at station K, decreased to 426 ppm at station L, increased to 509 ppm at station M, and again decreased to 444 ppm at station N. The decrease in dissolved-solids content and the increase in streamflow between stations J and L were a result of underflow to the Humboldt River of calcium bicarbonate water of low to very low dissolved-solids content from the Pole Creek-Rock Creek area and underflow to the river of sodium bicarbonate water of moderate to low dissolved-solids content from the eastern part of the Paradise Valley subarea. The dissolved-solids content and flow of the river increased between stations L and M largely because of underflow to the river of ground water of moderate to very high dissolved-solids content from the western part of the Paradise Valley subarea. Underflow of calcium bicarbonate water of low dissolved-solids content from the northern slope of the Sonoma Range and a decrease in the width of the medial gravel unit caused the flow of the river to increase and the dissolved-solids content to decrease between stations M and N.

Surface water draining northwestward into Grass Valley is the source of most of the recharge to the ground-water reservoir of Grass Valley, and is largely calcium bicarbonate water of very low dissolved-solids content (Plate 9). The water-level contours for December 1961 indicate that most of the underflow from Grass Valley and the northwestern slope of the Sonoma Range moved toward the Humboldt River and discharged into the river between stations N and S. Prior to discharging into the river, most of the calcium bicarbonate water of very low dissolved-solids content mixed with sodium bicarbonate water of moderate dissolved-solids content in the shallow aquifers beneath and adjacent to the Humboldt River. Accordingly, most of the water that discharged into the river between stations N and S, about 9.7 cfs, was a mixture of the two waters.

As a result, the dissolved-solids content of the river decreased from 489 ppm at station N to 453 ppm at station S. Plates 3 and 9 suggest that relatively unmixed calcium bicarbonate water of very low dissolved-solids content discharged into the river between stations P and Q. This is verified by the fact that the dissolved-solids content of the river decreased to 415 ppm at station Q.

Although ground water of moderate to very high dissolved-solids content occurs in a fairly large area in the East Range fault subarea and although the water-level contours of Plate 3 suggest that most of this water probably moved toward the Humboldt River in December 1961, the dissolved-solids content of the river showed only a slight increase down-gradient from the ground-water mound along the fault. This suggests that the amount of ground water discharged into the river from the East Range fault system is very small.

By utilizing the following equation, water-quality data can be used to verify that the estimates of ground-water inflow from Grass Valley and the northwestern slope of the Sonoma Range derived on page 65 are of the correct order of magnitude:

$$(Q_{ho})(C_{ho}) + (Q_{uo})(C_{uo}) + (Q_{ug})(C_{ug}) = (Q_{hs})(C_{hs}) + (Q_{us})(C_{us}) \qquad (6)$$

or

$$Q_{ug} = \frac{(Q_{hs})(C_{hs}) + (Q_{us})(C_{us}) - (Q_{ho})(C_{ho}) - (Q_{uo})(C_{uo})}{C_{ug}} \qquad (7)$$

where Q_{ho} = rate of flow of the Humboldt River at station O, in cubic feet per second,

C_{ho} = dissolved-solids content of the Humboldt River at station O, in parts per million,

Q_{uo} = rate of ground-water underflow roughly parallel to the Humboldt River at station O, in cubic feet per second,

C_{uo} = dissolved-solids content of underflow at station O, in parts per million,

Q_{ug} = rate of ground-water inflow from the Grass Valley subarea, in cubic feet per second,

C_{ug} = dissolved-solids content of ground-water inflow from the Grass Valley subarea, in parts per million,

Q_{hs} = rate of flow of the Humboldt River at station S, in cubic feet per second,

C_{hs} = dissolved-solids content of the Humboldt River at station S, in parts per million,

Q_{us} = rate of underflow roughly parallel to the Humboldt River near station S, in cubic feet per second, and

C_{us} = dissolved-solids content of underflow near station S, in parts per million.

The rate of flow and dissolved-solids content of the Humboldt River at station O in December 1961 were about 3.7 cfs and 480 ppm, respectively. The estimated rate and dissolved-solids content of ground-water underflow roughly parallel to the Humboldt River at station O were 5 to 7.5 cfs (Table 17) and about 550 ppm, respectively. The estimated average dissolved-solids content of the calcium bicarbonate water from Grass Valley and the northwestern slope of the Sonoma Range was about 250 ppm. The rate of flow and the dissolved-solids content of the Humboldt River at station S were about 14.8 cfs and 450 ppm, respectively. The estimated rate and dissolved-solids content of ground-water underflow roughly parallel to the Humboldt River near station S were 2.5 to 3.5 cfs (Table 17) and about 460 ppm, respectively. Assuming that the rate of underflow past stations O and S were 6 and 3 cfs, respectively, and substituting these data in equation 7 yields the following estimate of inflow:

$$Q_{ug} = \frac{(14.8)(450) + (3)(460) - (3.7)(480) - (6)(550)}{250} = 12 \text{ cfs.}$$

The estimated ground-water inflow from Grass Valley and the northwestern slope of the Sonoma Range of 12 cfs, derived from water-quality data, is larger than the estimate of 7 to 8.5 cfs derived on page 65. Largely because the water-quality data are insufficient to determine precisely the average chemical quality of the ground-water underflow and because the chemical quality of the underflow doubtlessly changes somewhat as the water moves downgradient, the range of estimates of ground-water inflow from Grass Valley and the northwestern slope of the Sonoma Range derived on page 65 probably is more accurate than the estimate derived from the water-quality data. Accordingly, the estimate obtained from the water-quality data merely verifies that the ground-water inflow estimates derived on page 65 are of the correct order of magnitude.

SUMMARY OF THE RELATIONS AMONG THE COMPONENTS OF THE HYDROLOGIC SYSTEM

Qualitative and quantitative relations among the components of the hydrologic system have been described in previous sections of the report. In this section of the report preliminary hydrologic budgets are given for three periods, December through June of water year 1962, water year 1962, and for water years 1949–62, to summarize the quantitative relations among the components of the hydrologic system. In addition, qualitative and quantitative hydrologic features in water year 1962 are described separately, largely because the availability of data permits a moderately detailed summary of the flow of the Humboldt River and its relation to other components of the system, especially the ground-water reservoir.

HYDROLOGIC–BUDGET ANALYSIS

The hydrologic budget for an area can be expressed by the equation:

$$I = O \pm St, \qquad (8)$$

where I is inflow, O is outflow, and St is the net change in storage. If there is a net increase in storage, it is added to the right side of the equation; if there is a net decrease, it is subtracted.

Table 27 lists data for the three preliminary water-budget analyses for the storage units outlined in Plate 5. If all the data were accurate and if ranges were not given for transpiration by phreatophytes and evaporation from bare soil, equation 8 should balance. Table 27 shows that the estimated total inflow ranges from 2,900 acre-feet more to 30,300 acre-feet less than the sum of the estimated total outflow plus the net increase in storage. In other words, the estimated inflow ranges from about 1 percent more to 11 percent less than the outflow plus the net increase in storage.

The imbalance reflects the cumulative errors in the estimates of all the components of the water budgets. Because of the few available data, it is probable that the estimates of evapotranspiration of precipitation from land surface and from the zone of aeration, transpiration by phreatophytes and evaporation from bare soil, and changes in the amount of vadose water in storage are subject to the largest errors. When additional data on evapotranspiration and changes in moisture

TABLE 27—DATA FOR PRELIMINARY WATER–BUDGET ANALYSES, IN ACRE–FEET, FOR THE STORAGE UNITS IN THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEVADA

Water-budget components	December through June, water year 1962	Water year 1962	Water years 1949–62, 14-year average
INFLOW:			
Humboldt River streamflow at the Comus gaging station (Table 10)	254,300	297,200	172,100
Tributary streamflow (p. 41)	5,000	5,800	4,500
Ground-water inflow (p. 64)*	8,200	14,000	14,000
Precipitation (p. 68)	47,000	60,000	59,000
(1) Total inflow	314,500	377,000	249,600
OUTFLOW:			
Humboldt River streamflow at the Rose Creek gaging station (Table 10)	187,800	242,900	155,400
Ground-water outflow (p. 73)*	1,800	3,000	3,000
Evaporation from open bodies of water (p. 55)	14,000	21,400	14,000
Evapotranspiration of precipitation from land surface and the zone of aeration (p. 68)	40,000	57,000	56,000
Transpiration by phreatophytes and evaporation from bare soil (p. 73)†	10,000 to 20,000	30,000 to 60,000	25,000 to 50,000
Net pumpage (p. 74)	1,000	3,000	1,500
(2) Total outflow	254,600 to 264,600	357,300 to 387,300	254,900 to 279,900
NET INCREASE IN STORAGE:			
Surface water (p. 55)	22,000	1,800	0
Ground water (p. 81)	26,000	5,000	0
Vadose water (p. 83)	17,000	10,000	0
(3) Total increase in storage	65,000	16,800	0
(4) SUM: (2) + (3)	319,600 to 329,600	374,100 to 404,100	254,900 to 279,900
DIFFERENCE: (1) — (4)	—5,100 to —15,100	+2,900 to —27,100	—5,300 to —30,300

*Ground-water inflow and outflow in the 7-month period December through June of water year 1962 is estimated to have been about seven-twelfths of the annual ground-water inflow and outflow.
†Range in values cannot be narrowed until the final results of the studies of all the cooperating agencies are available.

content in the zone of aeration become available, the preliminary hydrologic-budget analyses can be refined. Equation 8 probably will not balance even when all the data become available. This is to be expected inasmuch as all the components of the hydrologic system have not been studied with the same degree of intensity. Moreover, some of the components could not be evaluated as precisely as desired within the realm of economic and technological feasibility.

Relation of Water Years 1949–62 to the Long-term Period

As suggested by the records at Winnemucca and Elko, average annual precipitation in water years 1949–62 was about 5 to 10 percent less than the average annual precipitation in the past 90 years. This deficiency is further confirmed by streamflow at the Comus gaging station, which was about 14 percent less in water years 1949–62 than the long-term average. These data suggest that in water years 1949–62 total inflow to and outflow from the project area probably was less than the long-term average; however, sufficient data are not available to determine precisely how much less.

HYDROLOGIC FEATURES IN WATER YEAR 1962

Largely because water year 1962 was a year of above-average streamflow following 3 years of drought, the magnitude and extent, both in space and time, of some of the hydrologic phenomena that occurred during the year were above average. Inasmuch as hydraulic gradients toward the Humboldt River near the margins of the storage units remained nearly constant, it is presumed that ground-water underflow into the area was about average. Further, the ground-water gradients, and hence underflow out of the area near the Rose Creek gaging station, were about average.

At the beginning of water year 1962, the Humboldt River was nearly dry at the Comus gaging station, having a flow of about 0.1 cfs, and the flow at the Rose Creek gaging station ranged from about 10 to 14 cfs and averaged about 12 cfs (Figure 36). Virtually the entire increase in flow between the two stations was the result of ground-water inflow from tributary areas discharging into the river. Ground-water levels throughout most of the area were at or near record low stages for October. In November and December 1961, streamflow ranged between 0.1 and 8.1 cfs at the Comus gaging station and between about 10 and 15 cfs at the Rose Creek gaging station. The variations in streamflow were caused largely by precipitation and ice effects. Ground-water levels in most wells rose slightly in November, owing largely to the virtual cessation of evapotranspiration; levels remained nearly constant in December and January.

In January 1962 streamflow increased to an average of about 10.4 cfs at the Comus gaging station and averaged about 10.9 cfs at the Rose Creek gaging station. The increase in streamflow at the Comus gaging station was largely a result of increased precipitation upstream from the project area. Streamflow at the Rose Creek gaging station remained virtually unchanged largely because of increases in channel storage between the upstream and downstream margins of the project area.

An unusually large amount of precipitation in February 1962 caused streamflow to increase markedly throughout much of the Humboldt River drainage basin. Flooding occurred in many parts of the basin and serious property damage occurred upstream from the project area, especially in the city of Battle Mountain (Thomas and Lamke, 1962). A peak daily mean streamflow of 1,690 cfs occurred at the Comus gaging station on February 21, 1962, and a peak daily mean streamflow of 875 cfs occurred at the Rose Creek gaging station on March 2, 1962. As a result of the rapidly rising stage of the river, ground-water gradients were reversed and water seeped from the river to the ground-water reservoir causing ground-water levels locally to rise as much as 7 feet.

Streamflow decreased to about 400 cfs in mid-March and ground-water levels declined. Streamflow then began to increase again owing to the beginning of the spring runoff, and ground-water levels also began to rise again. The peak daily mean streamflow during the spring runoff at the Comus gaging station of 1,440 cfs occurred on June 5, 8, and 10, 1962. The peak daily mean streamflow at the Rose Creek gaging station of 1,150 cfs occurred on June 17, 1962.

The maixmum daily mean streamflow at the Comus gaging station occurred during the February flood; however, the maximum daily mean streamflow at the Rose Creek gaging station occurred during the spring runoff. This resulted largely because more water went into channel storage between the two gaging stations in February than in June. Prior to the February flood,

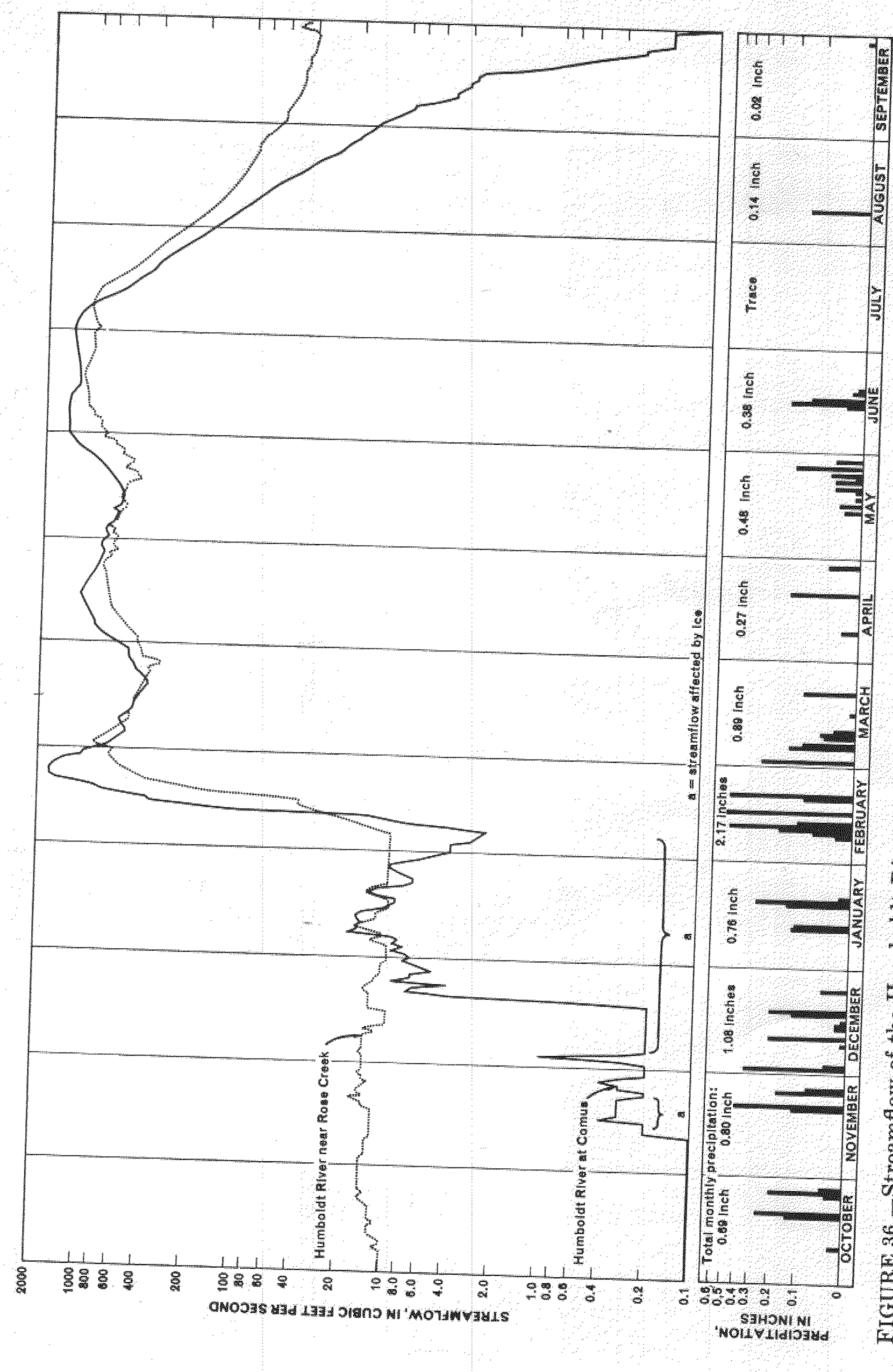

FIGURE 36.—Streamflow of the Humboldt River at the Comus and Rose Creek gaging stations near Winnemucca, Nev., and precipitation at the Winnemucca airport; water year 1962

the river stage was very low and virtually all the abandoned meander scrolls and flood-flow channels were dry. Most of these depressions were filled during the flood, causing a marked depletion of streamflow between the Comus and Rose Creek gaging stations. When the river crested in June, the channel was nearly full, owing to the high streamflow during the previous months. Further, many of the depressions on the flood plain contained water either as a result of overbank flooding for irrigation or because of high ground-water levels. Accordingly, the decrease in flow between the two gaging stations was not as marked as it was in February causing the peak daily mean flow at the Rose Creek gaging station to be greater in June than in February.

In the period October through June 1962, the total measured streamflow at the Rose Creek gaging station was about 65,000 acre-feet less than at the Comus gaging station. The decrease in streamflow resulted from increased surface water in storage, increased ground water in storage, increased water content in the zone of aeration, and discharge by evapotranspiration.

From early July, when the stage of the river began to decline, to the end of the water year, streamflow at the Rose Creek gaging station was more than that at the Comus gaging station. The increase in streamflow between the two gaging stations was largely a result of ground-water discharge to the river, much of which was return-flow of bank storage, but some of which was inflow from tributary areas.

For the entire water year, the total measured streamflow at the Rose Creek gaging station was about 54,000 acre-feet less than that at the Comus gaging station. The total measured decrease in streamflow in the project area in water year 1962 was about 11,000 acre-feet less than the measured decrease in streamflow in the period October through June, largely because of seepage of bank storage and ground-water inflow from tributary areas into the river. In addition, heavy precipitation in February melted a thin layer of snow on the valley floor, and some of the resulting runoff may have discharged into the river.

MANAGEMENT OF WATER

Sound long-term management of water is related closely to an adequate knowledge of the hydrologic system. The amount of water in the system and its suitability for use should be known. In addition, the system should be evaluated to determine whether the available supply can be used more efficiently. The preceding text describes the amount and chemical quality of water in the project area and the interrelations among various components of the hydrologic system. Possible modifications of the hydrologic system and the effects of these modifications are emphasized in this section of the report. Because water in the project area is part of a single large hydrologic system encompassing the entire Humboldt River basin, many aspects of water management must take into consideration the entire basin. Upstream use of water has and will continue to affect the available water supply in and downstream from the project area. Furthermore, modifications of the hydrologic regimen in the project area could significantly alter the available water supply downstream.

USE OF WATER AS OF 1963

In the entire basin: Probably about 95 percent or more of the beneficial use of water in the Humboldt River basin is for irrigation. Virtually all of the remainder of the beneficial water use is for domestic and municipal purposes. Along the main stem of the Humboldt River nearly all the irrigation water is diverted from the river and the water is fully appropriated; that is, under existing State law new irrigation developments or other new uses of Humboldt River water are possible only if existing water rights are transferred.

Upstream from Rye Patch reservoir, much of the irrigation using Humboldt River water is accomplished by overbank flooding largely on unimproved meadows. During the irrigation season tens of square miles are flooded for as long as a week or so at a time as part of the normal method of irrigation.

Less than 10 percent of the cultivated land along the main stem of the river is irrigated with ground water. Most of this development has occurred in the past decade or so.

In the project area: Depending on the availability of water, about 10,000 to 20,000 acres of the flood plain in the project area is irrigated with Humboldt River water; nearly 2,000 acres, largely in the mouth of Grass Valley, is irrigated with ground water. About 1,000 acre-feet of ground water is used for domestic and municipal purposes.

At present increased ground-water development for municipal use in Winnemucca is being considered. Moreover, additional development of ground water for irrigation, especially from the medial gravel unit, is contemplated.

UPSTREAM DEVELOPMENT

Increased storage facilities: Several private and governmental agencies are investigating the feasibility of sizeable upstream storage facilities on the Humboldt River and its major tributaries. These would offer some degree of flood control, the capacity to partly regulate streamflow, facilities for the production of electric power, and recreational benefits. Flood control could be of substantial benefit in the entire basin; costly flood damage would be minimized, and ranchers might be more apt to upgrade agricultural practices on the flood plain. The possible benefits resulting from additional hydroelectric power and recreational facilities are self-evident; those derived from the regulation of streamflow, however, are somewhat more complex. Water can be stored during years of above-average streamflow and released during years of below-average streamflow. In addition, seasonal variations in streamflow can be dampened and the irrigation season in much of the Humboldt valley, which depends largely upon Humboldt River water and which normally ends in June to mid-July, might be extended to take advantage of the entire growing season. The possible benefits of extending the irrigation season are obvious; however, many ranchers in the area contend that this would be of no substantial economic value. Their current method of operation is to harvest one crop of hay in late June or early July and then to use the flood plain for pasture. Accordingly, the full benefits resulting from the extension of the irrigation season as a result of the utilization of upstream storage facilities may depend upon the ranchers modifying their present methods of operation.

Some ranches along the river depend solely or largely on flood water for irrigation. Thus, flood control might deprive these ranches of considerable irrigation water. In addition, decreased overbank flooding would decrease recharge to the ground-water reservoir. This would not be of immediate significance because of the fairly small amount of pumpage at present. However, if ground-water development increases substantially in the future, decreased recharge resulting from decreased overbank flooding may become a significant factor.

Evaporation from newly impounded reservoirs is another factor being considered as part of the evaluation of the feasibility of increased upstream storage facilities. Evaporation increases in proportion to the area of a reservoir and, if the area is large, it is conceivable that the accrued benefits of upstream storage facilities may partly or entirely be offset by evaporation losses and attendant increased salinity.

Increased ground-water development: Substantial amounts of ground water may be developed in the future in the Humboldt River valley upstream from the project area. Numerous hydrologic and economic benefits could result from increased upstream ground-water development. These might be such interrelated benefits as the availability of additional water, utilization of the ground-water reservoir to stabilize the flow of the Humboldt River, and decreased evapotranspiration losses. Negative aspects of increased upstream ground-water development might be depletion of streamflow and deterioration of water quality.

In general, the possible effects of increased upstream ground-water development are similar to those of increased ground-water development in the project area which are described in the following paragraphs.

Increased precipitation: Weather modification experiments currently are being made by State agencies in the Humboldt River basin near Elko. If these experiments are successful, the resulting increased precipitation may increase the available water supply and thereby modify the hydrologic system of the project area. The extent to which additional precipitation modifies the hydrologic regimen and benefits the water users in the basin depends upon many interrelated factors, a discussion of which is beyond the scope of this report.

MANAGEMENT OF WATER IN THE PROJECT AREA

The availability of water probably will be one of the limiting factors in future agricultural, industrial, and possibly even municipal development in the project area. Because practically all the available surface water is fully appropriated, the hydrologic limitations on economic expansion in the area can be modified only to the extent that more water can be made available or to the extent that the currently available water can be used for other purposes or can be used more efficiently. Assuming that the amount of water entering the hydrologic system is not significantly increased in the future, but recognizing that it may be if weather modification or other conservation methods are successfully employed upstream, then increased ground-water development, decreased evapotranspiration, or the reuse of water offer the only possibilities of a significantly increased usable water supply.

Effects of increased ground-water development on ground-water levels: The immediate effect of increased ground-water development will be a decline in ground-water levels in the vicinity of pumping wells. Water levels will continue to decline unless the amount of water discharged from a well is offset by a corresponding decrease in natural discharge from the aquifer or unless an additional source of recharge, such as a stream, is intercepted by the cone of depression caused by a pumping well. If natural discharge does not decrease as a result of pumping and if the cone of depression does not intercept an additional source of recharge, the magnitude and extent of the cone of depression is solely a function of the rate and duration of pumping and the coefficients of transmissibility and storage of the deposits intersected by the cone of depression. If these data are known, drawdown in a pumping well tapping a so-called ideal aquifer and the effects of pumping on water levels in the aquifer at any given distance for any period of time can be evaluated by use of the nonequilibrium formula developed by Theis (1935).

Much of the future ground-water development probably will be from the medial gravel unit. Moreover, of all the aquifers in the project area the medial gravel unit comes closest to having the hydrologic properties needed for the formula to be applicable. Figure 37 shows the theoretical relation between drawdown caused by a pumping well tapping the medial gravel unit, distance from the pumping well, and time since pumping started. The graphs are based on the Theis nonequilibrium formula and on the assumptions of the idealized conditions under which the formula is applicable. The average coefficients of transmissibility and storage of the medial gravel unit are estimated to be about 200,000 gpd/ft and 0.20, respectively. The illustrations show the drawdown effects of a continually pumping well discharging at a rate of 1,000 gpm. Similar theoretical solutions are possible for any given rate of discharge (Ferris and others, 1962). A rate of discharge of 1,000 gpm was chosen as an illustrative example, because adequately constructed and equipped wells tapping the medial gravel unit would readily yield this amount of water.

Within the limits of the theoretical assumptions on which the formula is based, a well pumping 1,000 gpm from the medial gravel unit for a period of 6 months will cause a drawdown of about 5.7 feet in a well 50 feet away, a drawdown

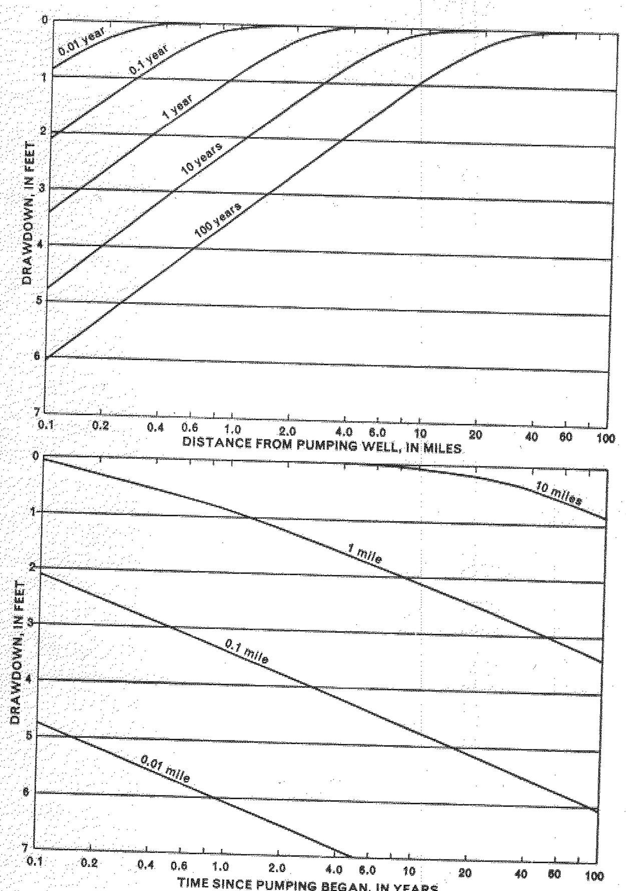

FIGURE 37.— Drawdown in an ideal aquifer caused by a well continuously discharging 1,000 gpm. (Coefficients of transmissibility and storage are 200,000 gpd/ft and 0.20, respectively. Time represents time since pumping started; mileage indicates distance from the pumping well.)

of about 3 feet in a well 500 feet away, and a drawdown of about 0.6 foot in a well 5,000 feet away. If a well tapping the medial gravel unit is allowed to pump 1,000 gpm continually, for industrial or municipal purposes for example, drawdown in a well 500 feet away would be 2.1 feet in about a month, 3 feet in about 6 months, 3.4 feet in about a year, 4.8 feet in about 10 years, and only about 6 feet in 100 years.

In several respects the medial gravel unit is not an ideal aquifer. However, nearly all the discrepancies between actual field conditions and those needed for the solution based on the nonequilibrium formula to be valid will cause drawdowns related to pumping the medial gravel unit to be somewhat less than the calculated values. Accordingly, mutual interference between pumping wells, which in some areas can cause excessive pumping lifts, should not present serious problems in the project area if wells tapping the unit are spaced several hundred or more feet apart.

Effects of increased ground-water development on the flow of the Humboldt River: Increased ground-water development in the project area may affect the flow of the Humboldt River. The amount of underflow discharging into the river may decrease, or water may be diverted from the river because of pumping. For example, some of the underflow moving toward the Humboldt River from Paradise Valley may be intercepted by wells in the mouth of Paradise Valley. Further, it is possible that all the underflow from Paradise Valley could be intercepted by a sufficient number of properly spaced wells.

In general, underflow from tributary areas will decrease as ground-water withdrawals in these areas increase. The decrease in underflow, however, will not necessarily be proportional to the increased pumpage, because increased pumpage may cause ground-water levels to decline in areas of evapotranspiration and thereby decrease natural discharge from the ground-water reservoir. In addition, some of the water pumped in tributary areas probably will seep into the ground and percolate downward to the ground-water reservoir. Accordingly, the decrease in ground-water underflow toward the Humboldt River will be less than the total pumpage in tributary areas to the extent that some evapotranspiration losses may be salvaged and to the extent that some of the pumped ground water may return to the ground-water reservoir.

The possible decrease in ground-water inflow from tributary areas to the Humboldt River cannot be computed mathematically with currently available information. Much will depend upon the location and pumping regimen of future wells in the tributary areas, and upon the use of the pumped water. Even if these factors could be predicted accurately, considerable hydrologic information would have to be obtained to provide the basis for a mathematical solution, and much of the information could be obtained within the realm of economic feasibility only after considerably more intensive ground-water development.

Because of the complexities of the hydrologic system, the amount of water diverted from the

Humboldt River as a result of increased ground-water development cannot be computed mathematically unless several simplified assumptions are made. A theoretical mathematical solution based on a modification of the nonequilibrium formula is possible if these assumptions are made. (See Theis, 1941.) The curves in Figure 38, which

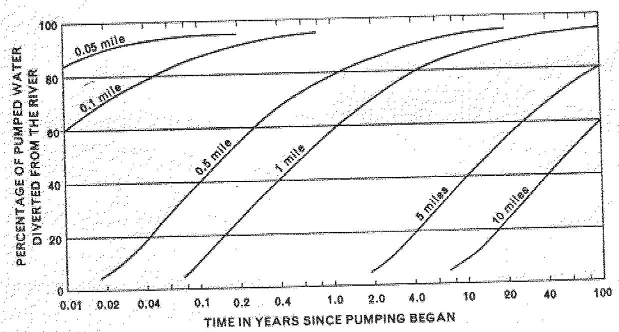

FIGURE 38.— Percentage of water diverted from the Humboldt River by a continuously discharging well penetrating an ideal aquifer in hydraulic continuity with the river. (Coefficients of transmissibility and storage are 200,000 gpd/ft and 0.20, respectively. Mileage represents distance between the well and the river.)

are based on solutions of the formula, show the theoretical relations between pumping the medial gravel unit and the resulting percentage of the pumpage diverted from the river. For example, after about 70 days of continuous pumping, 95, 90, 55, and 25 percent of the amount of water discharged from wells 0.05, 0.1, 0.5, and 1 mile from the Humboldt River, respectively, theoretically will be derived from the river.

Nearly all the discrepancies between actual field conditions and those needed for the theoretical mathematical solution to be precisely valid probably will result in the actual percentage of water diverted from the river being less than the values indicated in Figure 38. In addition, lowering of water levels as a result of pumping from the medial gravel unit will decrease evapotranspiration losses. This may make additional ground water available to wells and thereby further decrease the percentage of pumped water diverted from the river. Thus, the theoretical solution probably indicates the upper limit of the percentage of pumped water that may be diverted from the river.

In summary, it should be emphasized that any ground-water withdrawals in the project area that are not compensated for by decreased nonbeneficial evapotranspiration losses ultimately may decrease the flow of the Humboldt River. For example, even if a well is not pumped long enough or at a sufficiently large rate to directly influence the flow of the river during the pumping period, the loss of water from the system ultimately will cause a decrease in streamflow. The decrease in streamflow may, however, be so small and so distributed in time that it may not be noticeable.

Conjunctive use of ground water and surface water: Development of some of the large volume of ground water in storage, especially from the medial gravel unit, could supply additional water or could be used to supplement the surface-water supply during periods of drought. Furthermore, if the medial gravel unit is partly dewatered by pumping, considerable streamflow that normally is lost by nonbeneficial evapotranspiration during periods of uncontrolled natural flooding will recharge the unit naturally or might be induced to recharge the unit by artificial methods. On the other hand, as previously noted, increased development from the ground-water reservoir may decrease the flow of the Humboldt River and thereby decrease the available downstream supply of surface water. In addition, increased ground-water development locally may lower ground-water levels sufficiently to decrease or eliminate the subirrigation of crops. Accordingly, careful consideration should be given to the possible economic implications of the conjunctive use of ground water and surface water to determine whether it is in the best interest of all the water users. Conjunctive use probably would be a more efficient way of utilizing the available water supply, but it might necessitate major changes in the present methods of farming and stock raising.

Salvage of surface water consumed by evapotranspiration: Evapotranspiration of some of the surface water diverted for irrigation cannot be avoided. However, increased irrigation efficiency would conserve much of the surface water currently lost by nonbeneficial evapotranspiration.

Salvage of ground water consumed by evapotranspiration: Evapotranspiration of ground water from bare soil and by native phreatophytes yields virtually no economic returns. If ground-water levels were lowered to an average depth of 30 or 40 feet below land surface by pumping much of the wasted water would be salvaged. However, it may be infeasible or undesirable to decrease ground-water levels to this depth. If so, it may be desirable to replace the native phreatophytes with more beneficial vegetation. The Agricultural Research Service is investigating the feasibility of this method of utilizing the available water supply more efficiently.

SUMMARY AND CONCLUSIONS

General features: Manipulation of any aspect of the hydrologic system in the Winnemucca Reach of the Humboldt River valley, such as increased ground-water development or modifications in the use of Humboldt River water, may change the hydrologic regimen. Some changes probably are desirable to achieve the most effective use of the available water supply, especially changes that result in decreased nonbeneficial evapotranspiration losses which consumed about 40 to 50 percent of the average annual inflow to the lowlands (storage units) of the project area in water years 1949–62. (In this section of the report all quantitative estimates are for water years 1949–62 except as noted.)

Source and quantity of inflow: Average annual inflow into the lowlands of the Humboldt River valley near Winnemucca was about 250,000 acre-feet. About 68 percent of this inflow was Humboldt River streamflow; about 24 percent was precipitation; about 6 percent was sub-surface ground-water inflow; only about 2 percent was tributary streamflow.

Disposition of Humboldt River water: Much of the Humboldt River streamflow that entered the project area at the Comus gaging station discharged from the area at the Rose Creek gaging station; however, the flow at the Rose Creek gaging station averaged about 17,000 acre-feet less than that at Comus gaging station. Most of this water was consumed by evapotranspiration.

Disposition of precipitation: On the average about 2,000 acre-feet per year, less than 4 percent of the average annual precipitation on the storage units, recharged the ground-water reservoir. Nearly all of the remainder was consumed by evapotranspiration.

Disposition of ground-water inflow: Most of the ground-water inflow was consumed by evapotranspiration in the valley lowlands; however, some discharged into the Humboldt River in the late fall and winter. Average annual net ground-water discharge into the river, including lateral inflow from tributary areas and bank storage, was about 11,000 acre-feet.

Disposition of tributary streamflow: An average of about 10,000 acre-feet per year of tributary streamflow discharged into the project area. Nearly half of this flow recharged the ground-water reservoir, evaporated, or was stored in the zone of aeration and subsequently was consumed by evapotranspiration in the mountains and foothills. Accordingly, an average of only about 4,500 acre-feet per year discharged into the storage units. Most of it was diverted for irrigation and subsequently recharged the ground-water reservoir or was consumed by evapotranspiration.

Changes in storage: The average annual net changes of ground water in storage, surface water in storage, and water stored in the zone of aeration was zero. Net seasonal changes of ground water in storage averaged about 10,000 acre-feet. These changes were negligible as compared to the total amount of ground water in storage in the project area, which is on the order of 2 million acre-feet in the upper 100 feet of the zone of saturation.

Outflow: Average annual outflow from the storage units was about 255,000 to 280,000 acre-feet; about 55 to 60 percent was Humboldt River streamflow at the Rose Creek gaging station; about 1 percent was discharged as ground-water outflow; virtually all of the remainder was consumed by evapotranspiration.

Water quality: Although somewhat hard, nearly all the water in the area is suitable for most uses. Locally, small quantities of thermal ground water are unsuitable for some uses. During periods of low flow, changes in the chemical quality of the river reflected the chemical quality of lateral subsurface inflow from tributary areas.

Water management: The Humboldt River is the source of most of the irrigation water. Large supplies of additional irrigation water can be developed from a highly permeable gravel aquifer beneath the flood plain of the Humboldt River; however, development of ground water from the aquifer may partly deplete the flow of the Humboldt River and thus infringe on established downstream surface-water rights. Nevertheless, the conjunctive use of ground water and surface water probably would result in the more effective use of the total water supply.

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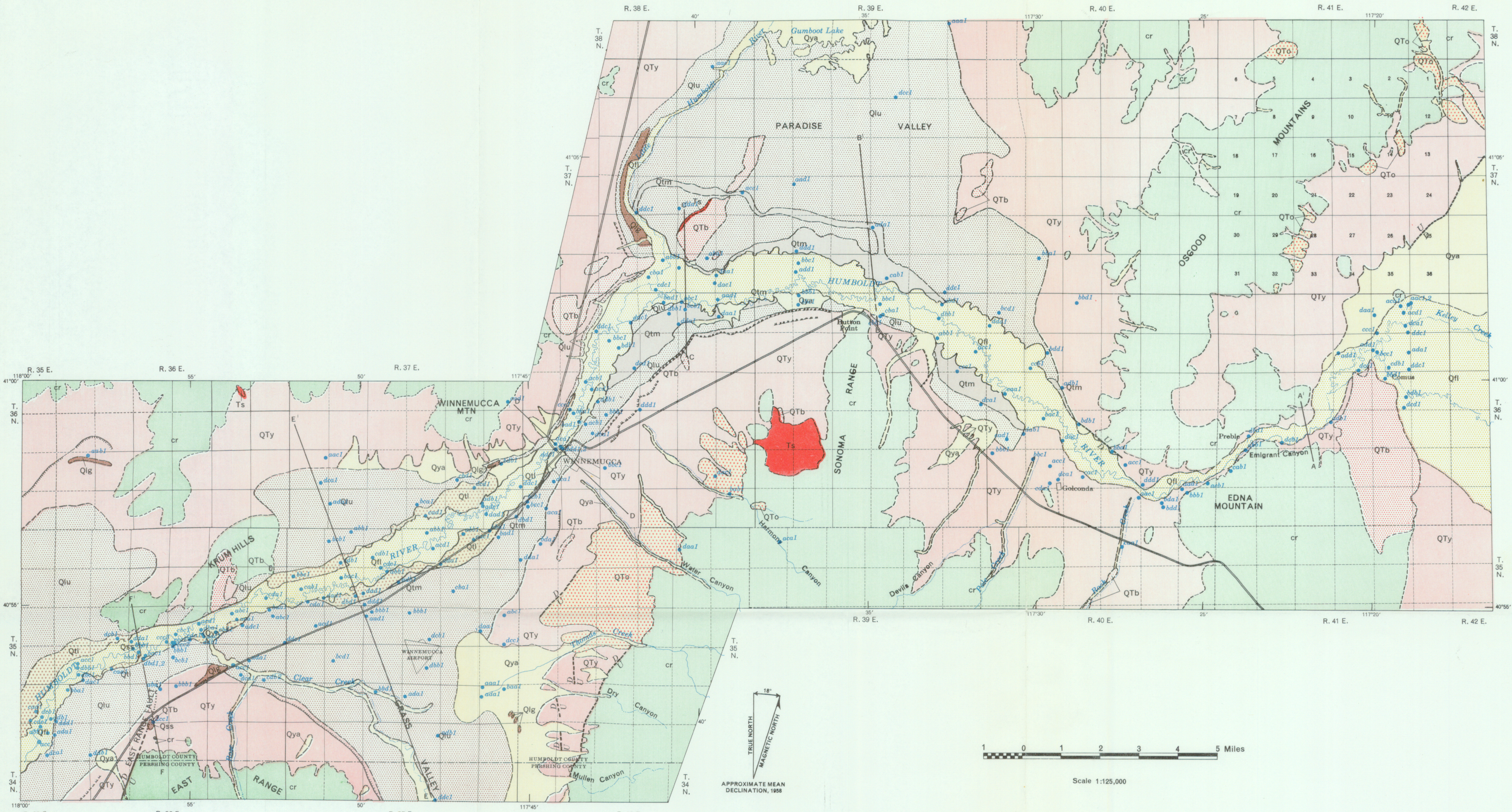


EXPLANATION

(Lithology, thickness, occurrence, hydrologic features and other pertinent characteristics are listed in table 3)

QUATERNARY

Recent

Qya — Younger alluvium

Qfl — Flood-plain deposits

Qtl, Qtm — Terrace deposits

Qtl, deposits of the lower terrace
Qtm, deposits of the middle terrace; also includes deposits in the abandoned channel in the mouth of Paradise Valley

Pleistocene or Recent

Qss — Spring sinter

Pleistocene — *Lake Lahontan deposits*

Qlu — Upper silt and clay

Qlg — Gravel-bar deposits

Qlm — Medial gravel
Recognized only in the subsurface

Qla — Older alluvium
Recognized only in the subsurface

Qll — Lower silt and clay
Recognized only in the subsurface

TERTIARY OR QUATERNARY

Pliocene or Pleistocene

QTy — Younger fanglomerate

QTo — Older fanglomerate

QTb — Basalt

QTa — Alluvium, undifferentiated
Recognized only in the subsurface

TERTIARY

Miocene or Pliocene

Ts — Older sedimentary deposits

CAMBRIAN TO TERTIARY

cr — Consolidated rocks, undifferentiated

A — A′ Location of geologic sections shown on plate 2

Contact
Dashed where approximately located

Wave-cut scarp
Dashed where questionable

U/D Fault
Dashed where approximately located, dotted where concealed and inferred. U, upthrown side; D, downthrown side

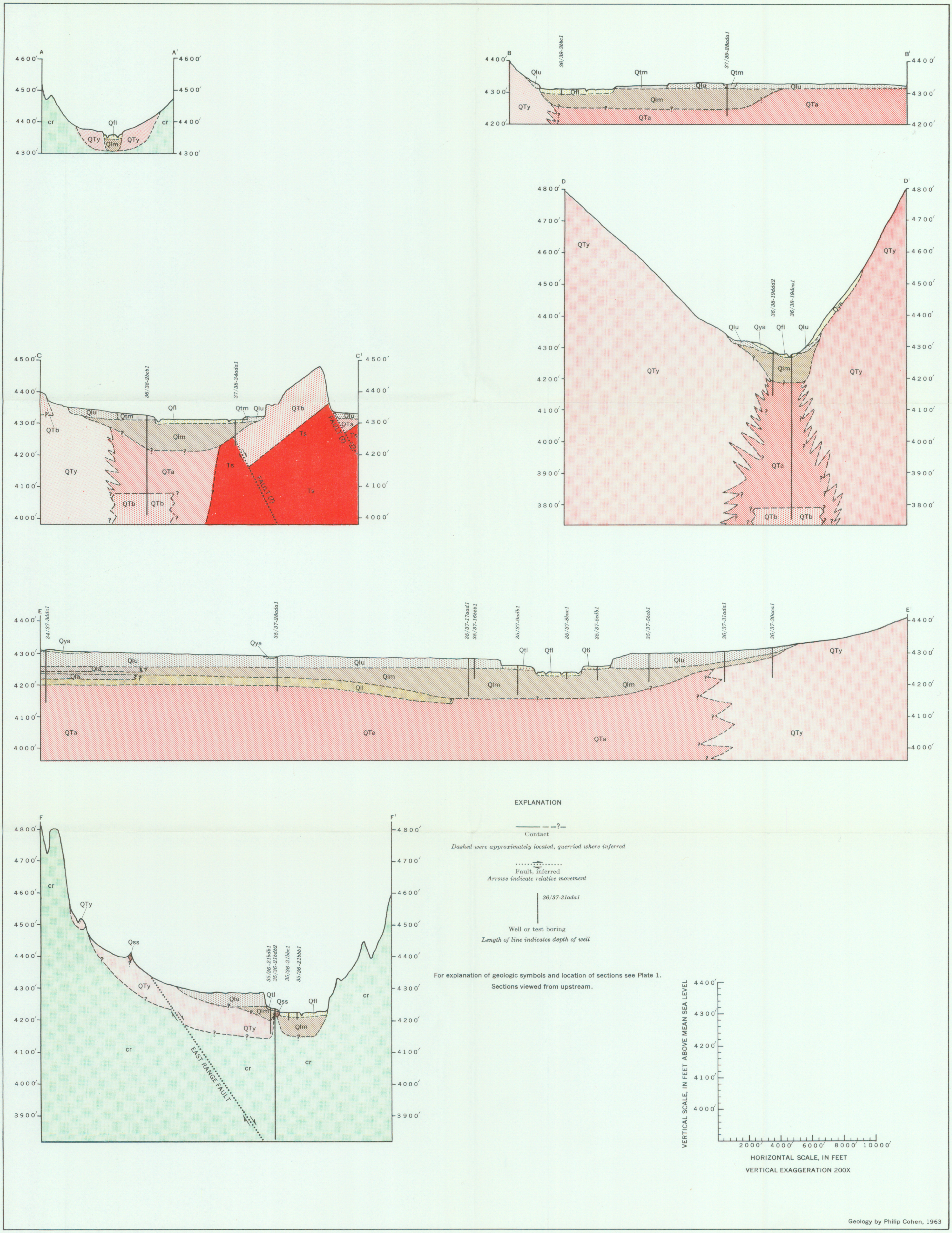
dda1 Well or test boring

cad1 Spring

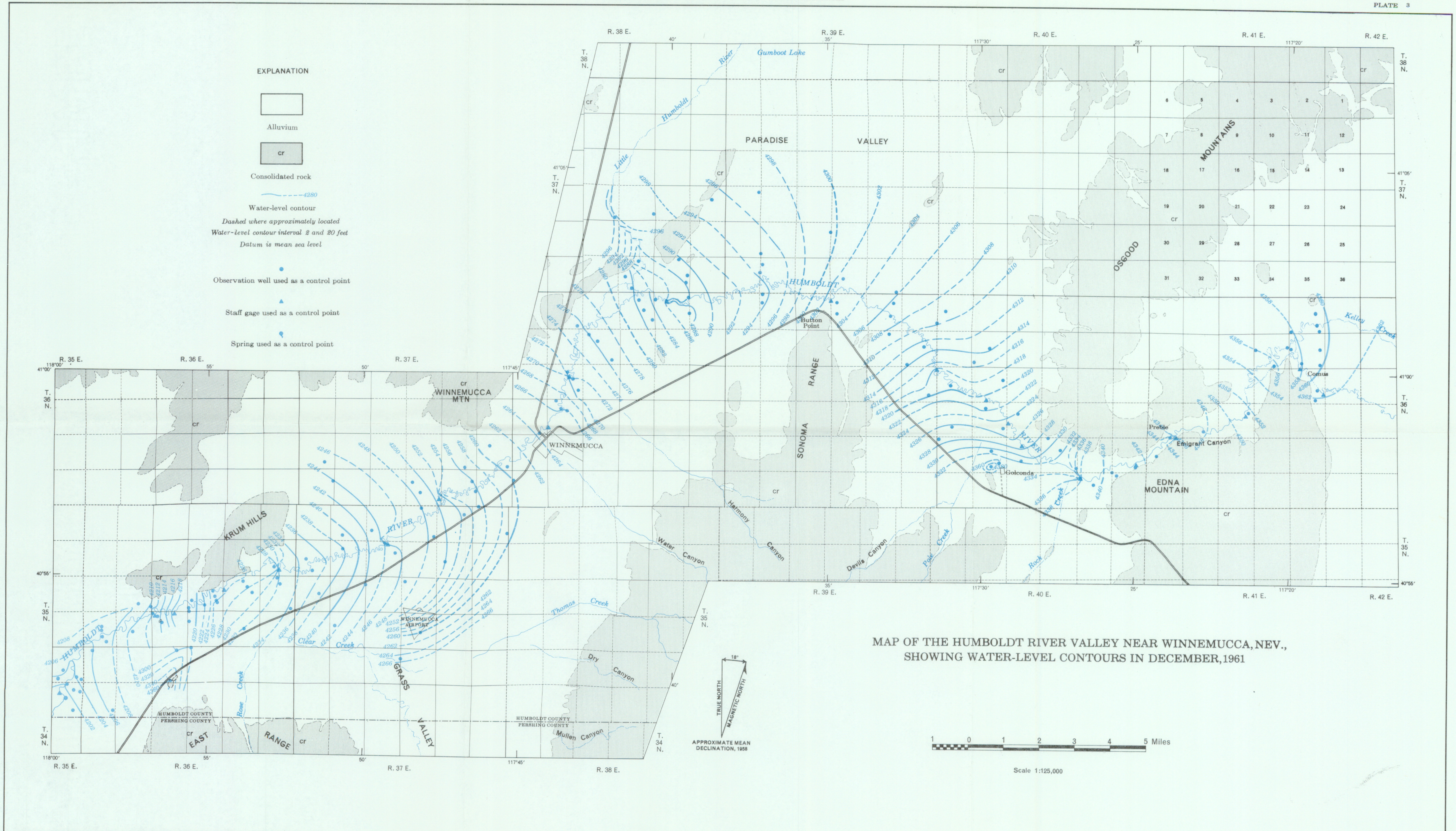
GENERALIZED GEOLOGIC MAP OF THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEV.

Base from U.S. Geological Survey topographic maps and from the Southern Pacific Company

Geology by Philip Cohen, 1963; in large part adapted from Cartwright, Keros (1960); Ferguson, H. G., Muller, S. W., and Roberts, R. J. (1951); Ferguson, H. G., Roberts, R. J., and Muller, S. W. (1952); Hawley, J. W. (1962); Hotz, P. E., and Willden, Ronald (1961); Maxey, G. B., and Shamberger, H. A. (1961); Willden, Ronald (1961); and Wilson, W. E. (1962)



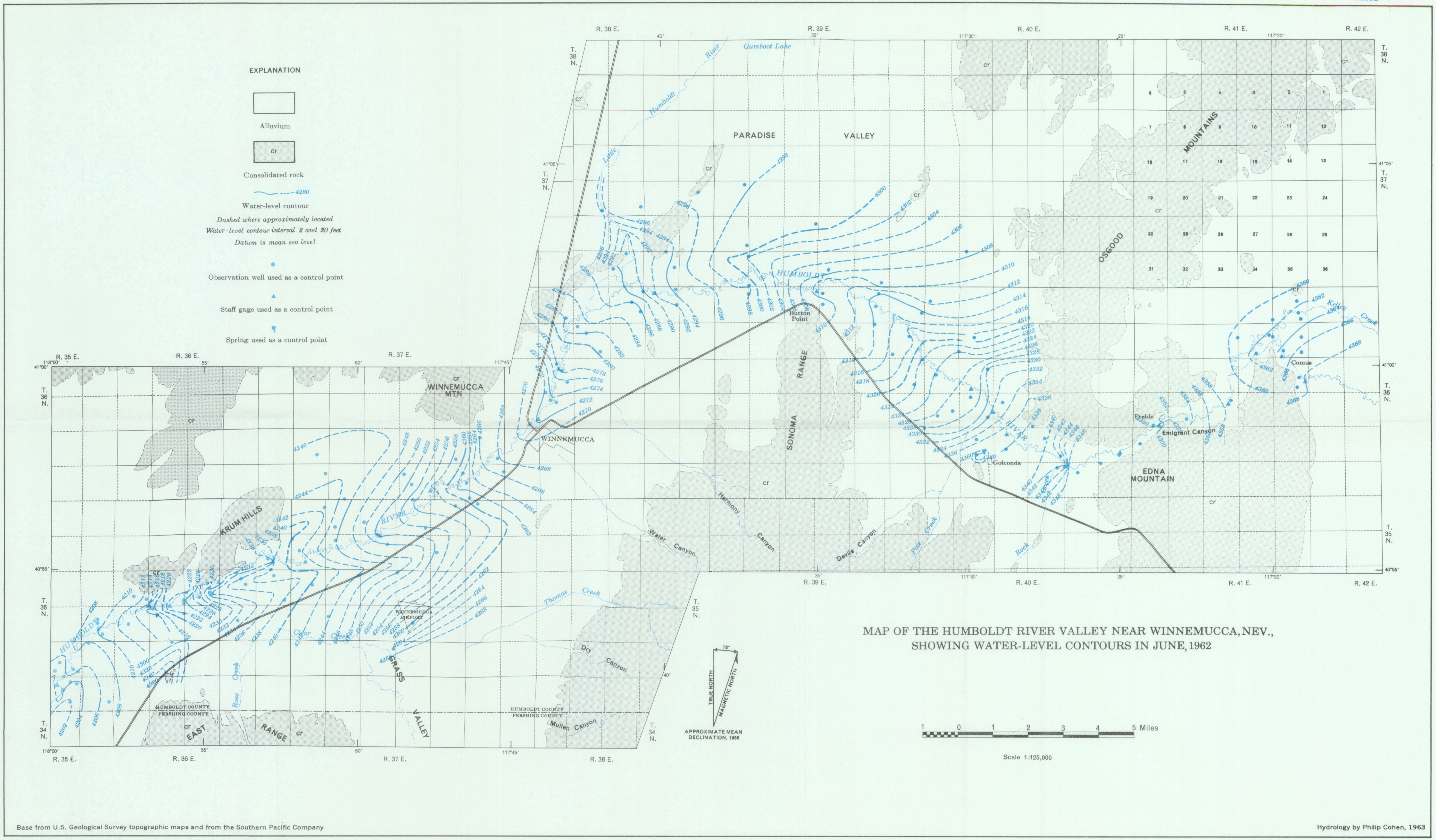
GENERALIZED GEOLOGIC SECTIONS IN THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEV.



MAP OF THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEV., SHOWING WATER-LEVEL CONTOURS IN DECEMBER, 1961

Base from U.S. Geological Survey topographic maps and from the Southern Pacific Company

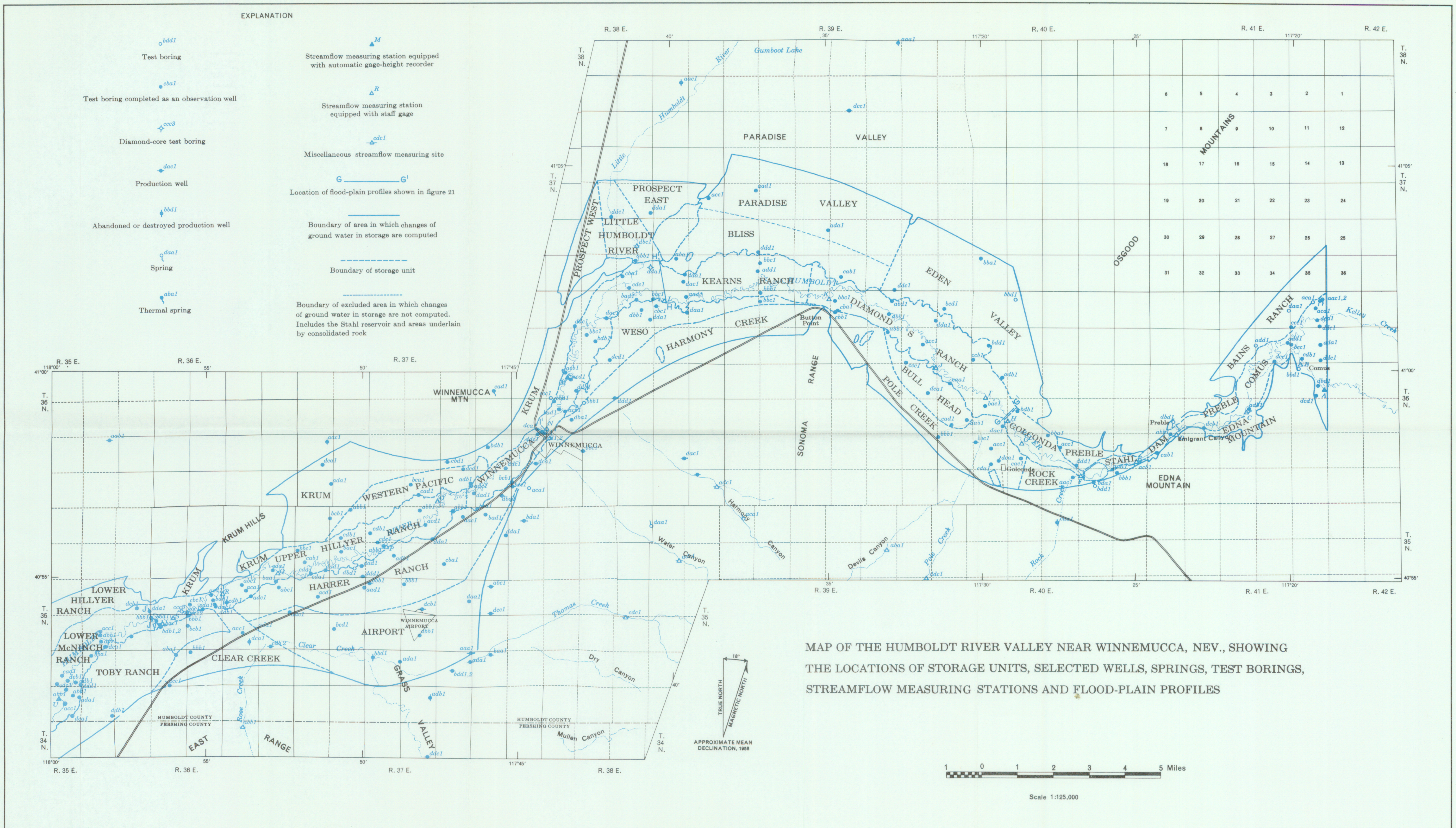
Hydrology by Philip Cohen, 1963



MAP OF THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEV., SHOWING WATER-LEVEL CONTOURS IN JUNE, 1962

Base from U.S. Geological Survey topographic maps and from the Southern Pacific Company

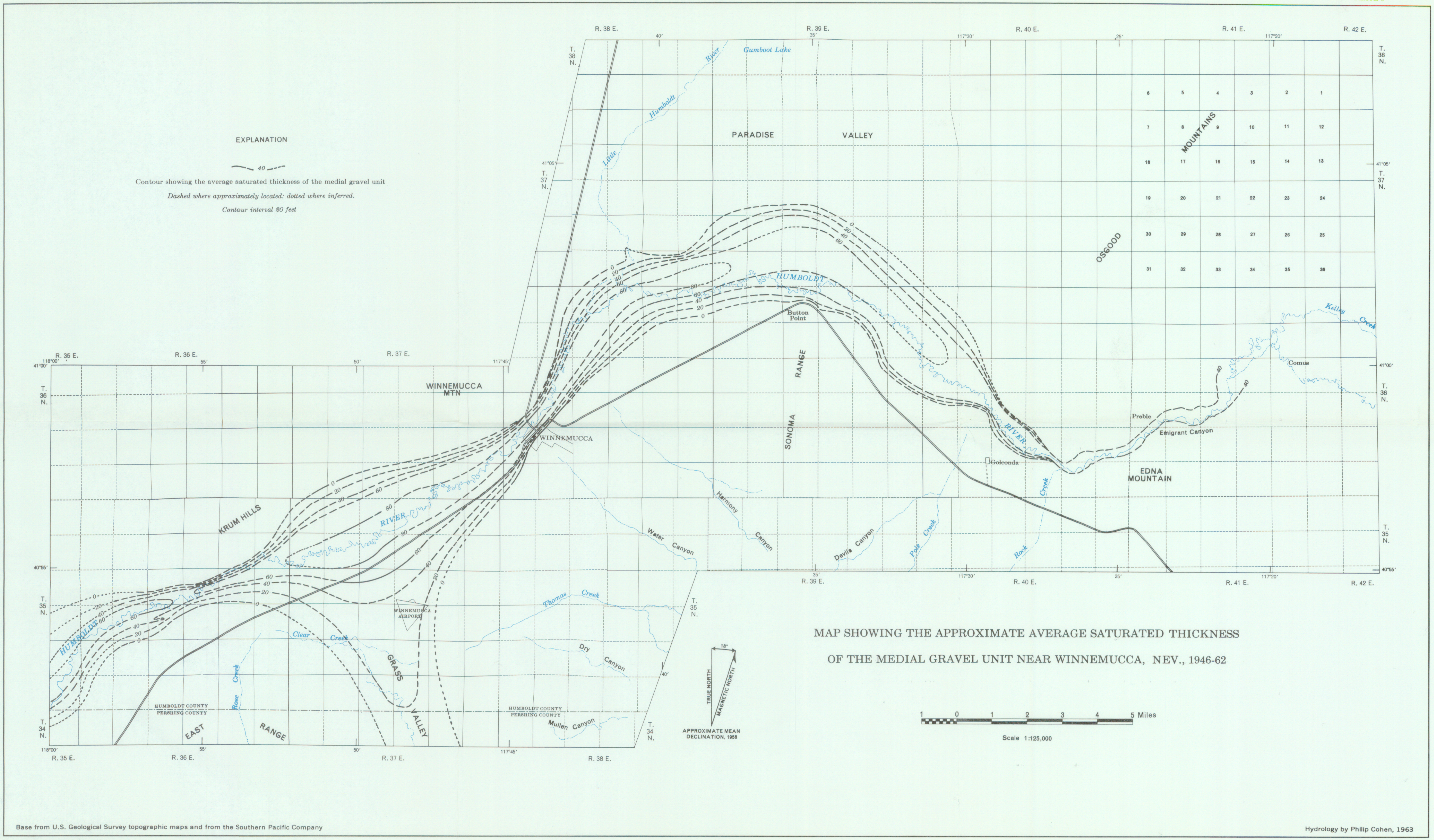
Hydrology by Philip Cohen, 1963



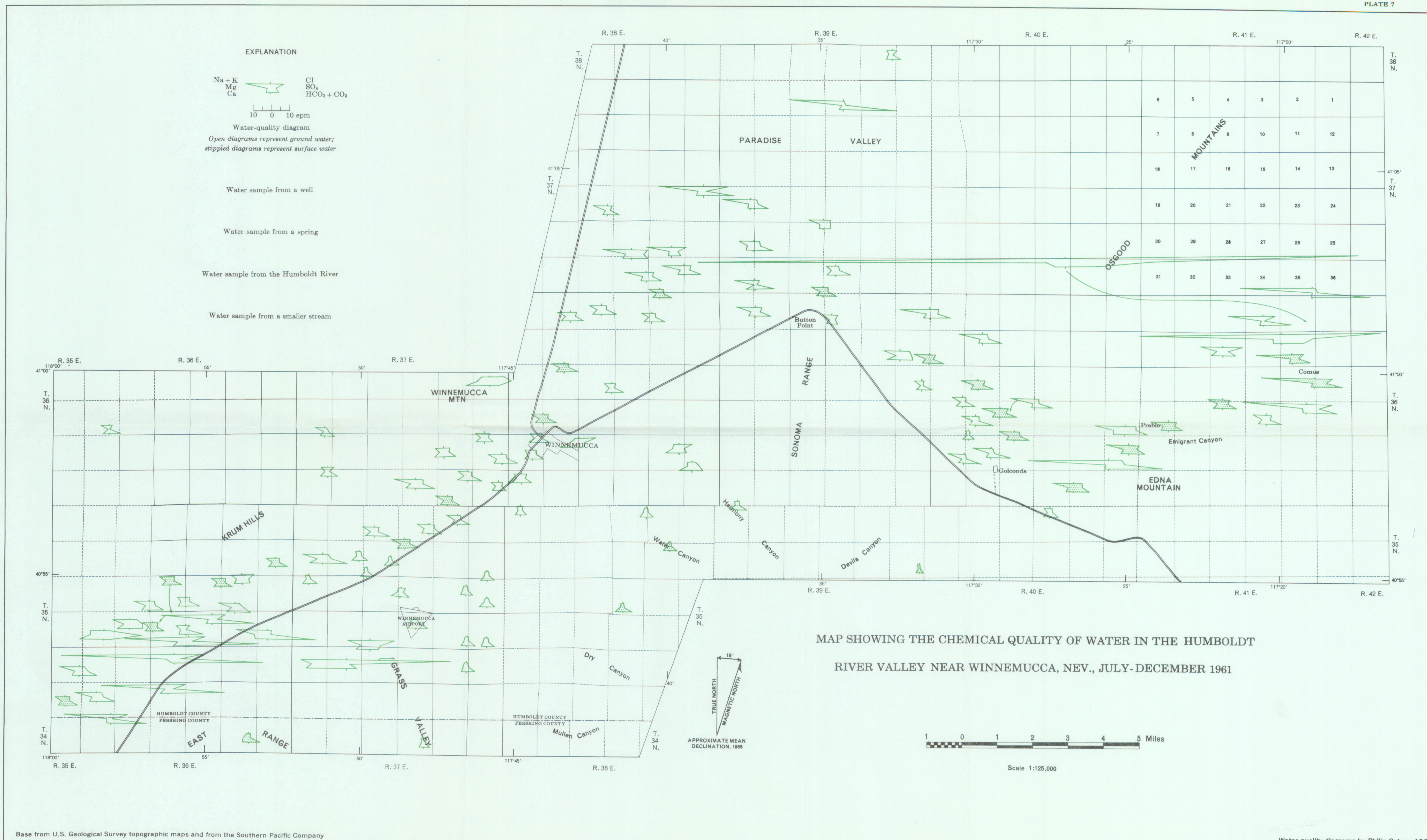
MAP OF THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEV., SHOWING THE LOCATIONS OF STORAGE UNITS, SELECTED WELLS, SPRINGS, TEST BORINGS, STREAMFLOW MEASURING STATIONS AND FLOOD-PLAIN PROFILES

Base from U.S. Geological Survey topographic maps and from the Southern Pacific Company

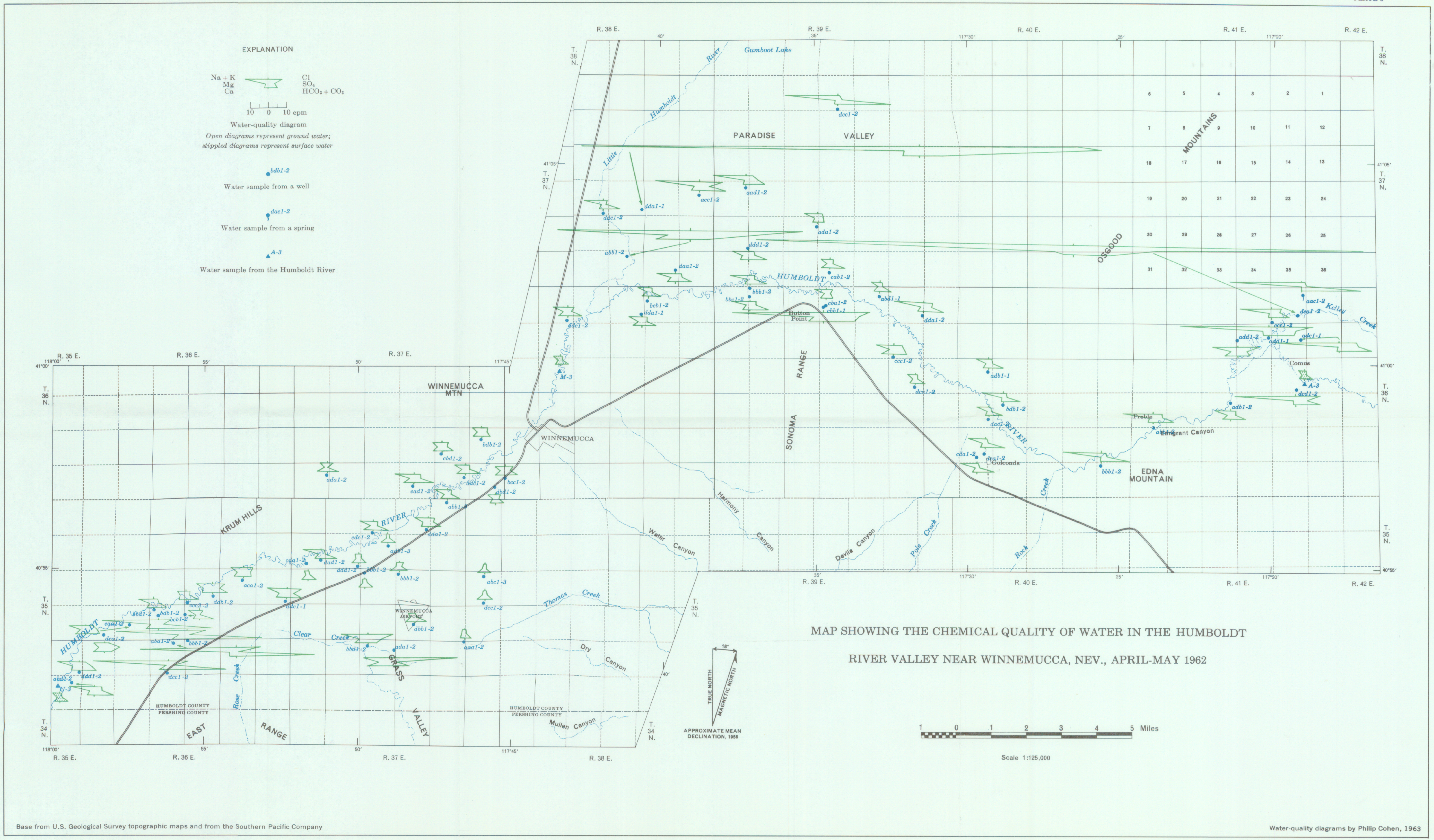
Hydrology by Philip Cohen, 1963



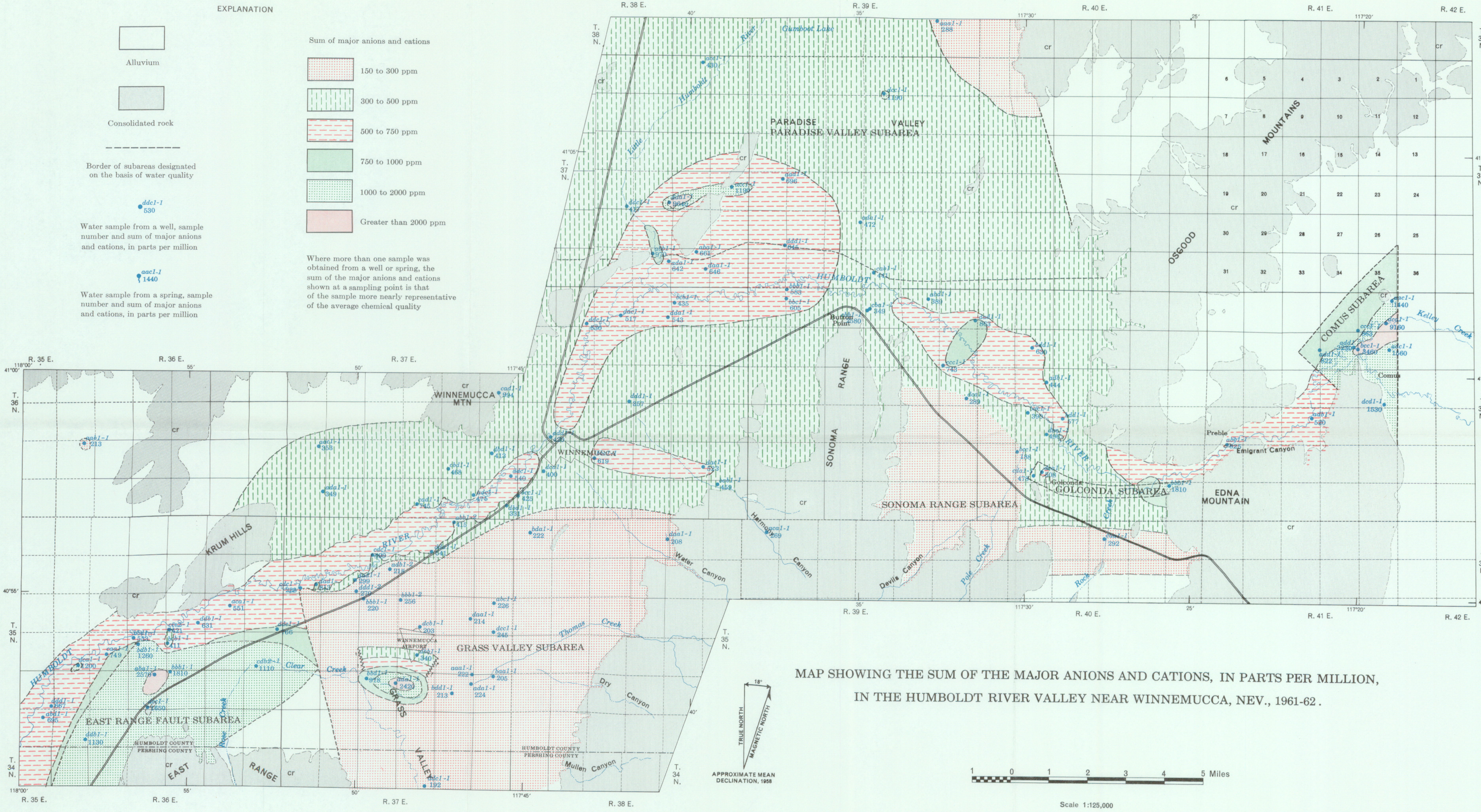
MAP SHOWING THE APPROXIMATE AVERAGE SATURATED THICKNESS OF THE MEDIAL GRAVEL UNIT NEAR WINNEMUCCA, NEV., 1946-62



MAP SHOWING THE CHEMICAL QUALITY OF WATER IN THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEV., JULY-DECEMBER 1961



MAP SHOWING THE CHEMICAL QUALITY OF WATER IN THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEV., APRIL-MAY 1962



MAP SHOWING THE SUM OF THE MAJOR ANIONS AND CATIONS, IN PARTS PER MILLION, IN THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEV., 1961-62.

Base from U.S. Geological Survey topographic maps and from the Southern Pacific Company

Hydrology by Philip Cohen, 1963