Water in the Humboldt River Valley Near Winnemucca, Nevada

By PHILIP COHEN

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A summary of the water-resources studies of the interagency Humboldt River Research Project in the Winnemucca area

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CONTENTS

ILLUSTRATIONS

TABLES

WATER IN THE HUMBOLDT RIVER VALLEY NEAR WINNEMUCCA, NEVADA

By PHILIP COHEN

ABSTRACT

Most of the work of the interagency Humboldt River Research Project in the Winnemucca reach of the Humboldt River valley has been completed. More than a dozen State and Federal agencies and several private organizations and individuals participated in the study. The major objective of the project, which began in 1959, is to evaluate the water resources of the entire Humboldt River basin. However, because of the large size of the basin, most of the work during the first 5 years of the project was done in the Winnemucca area. The purpose of this report is to summarize briefly and simply the information regarding the water resources of the Winnemucca area—especially the quantitative aspects of the flow system—given in previous reports of the project.

The Winnemucca reach of the Humboldt River valley, which is in north-central Nevada, is about 200 miles downstream from the headwaters of the Humboldt River and includes that part of the valley between the Comus and Rose Creek gaging stations. Average annual inflow to the storage area (the valley lowlands) in the Winnemucca reach in water years 1949–62 was about 250,000 acre-feet. Of this amount, about 68 percent was Humboldt River streamflow, as measured at the Comus gaging station, 23 percent was precipitation directly on the storage area, 6 percent was ground-water inflow, and about 3 percent was tributary streamflow. Average annual streamflow at the Rose Creek gaging station during the same period was about 155,000 acre-feet, or about 17,000 acre-feet less than that at the Comus gaging station. Nearly all the streamflow lost was consumed by evapotranspiration in the project area. Total average annual evapotranspiration loss during the period was about 115,000 acre-feet, or about 42 percent of the total average annual outflow.

The most abundant ions in the ground and surface water in the area are commonly sodium and bicarbonate. Much of the water has a dissolved-solids content that ranges from 500 to 750 parts per million; however, locally, the dissolved-solids content of the ground water is more than 5,000 parts per million. The chemical quality of the Humboldt River, especially during periods of low flow, reflects the chemical quality of ground-water inflow from tributary areas that discharges into the river. Almost all water in the project area is moderately hard to very hard; otherwise, it is generally suitable for most uses.

Increased ground-water development, the conjunctive use of ground and surface water, and increased irrigation efficiency would probably conserve much of the water presently consumed by nonbeneficial evapotranspiration. Intensive ground-water development, especially from the highly permeable medial gravel subunit, will, however, decrease the flow of the Humboldt River to the extent

that some pumpage may not be offset by a corresponding decrease in natural evapotranspiration losses. Such streamflow depletions will therefore infringe upon downstream surface-water rights.

The results of this study indicate that the Humboldt River and ground water in the unconsolidated deposits beneath and adjacent to the river in the Winnemucca area are closely related. Somewhat similar conditions probably exist elsewhere in the Humboldt River valley. Additional detailed studies are needed—both upstream and downstream from the Winnemucca area—to adequately define the flow system and the interrelations among the components of the system in the remainder of the valley. Before proceeding with additional detailed studies, however, a 1-year overall appraisal of the water resources of the basin should be considered. A major objective of this study would be to provide information that would help select the next subarea of the valley to be studied in detail and to decide which of the methods of study used in the Winnemucca area could be most effectively used in the future studies.

INTRODUCTION

In recent years the Nation has become increasingly aware of its water problems, both current and future. In Nevada, the most arid State in the Nation, man has been keenly aware of water problems, notably the shortage of water, for at least the last several thousand years—he had to be aware of these problems to survive.

Major changes in the use of water have taken place in Nevada in the past 50 years, largely as a result of increased agricultural activity. These changes have created and are creating local water shortages and related problems. Nevertheless, the major task for man has not changed since his earliest days in the area—that of obtaining sufficient water of suitable chemical quality for his needs.

Nevada has many other water problems, including those involving water rights and related legal matters, methods of storing and transporting water, water quality and pollution, flood control, hydroelectric power, and recreational use, just to mention a few. All these problems have one fundamental feature in common: they can be solved efficiently only when sufficient scientific information is available regarding the total water supply and its environment.

THE HUMBOLDT RIVER RESEARCH PROJECT

Recognizing the need for accurate technical information about water, the Nevada State Legislature authorized the interagency Humboldt River Research Project in 1959 (Chap. 97, Statutes 1959). The major study objective was to evaluate the water resources of the Humboldt River valley as thoroughly as possible and, thus, to provide the information that would aid planning the most effective use of these resources.

CHOICE OF THE AREA TO BE STUDIED AND OBJECTIVES OF THE STUDY

The Humboldt River is the longest stream in Nevada and carries more water than any other stream that lies entirely within the State. Moreover, about 265,000 acres in the Humboldt River valley, or about one-third the cultivated land in the State, is irrigated with water diverted from the river and (or) its major tributaries. Almost the entire flow of the river has been appropriated; accordingly, any additional agricultural, industrial, or municipal development is legally possible only insofar as it does not infringe upon existing water rights. Thus, to determine how to protect the existing economy, to determine whether the available water supply is being used most effectively, and to investigate the possibily of developing additional water in this economically vital part of the State, the Humboldt River valley was chosen as the area for intensive study.

The agencies cooperating in the project decided that it would not be feasible to study the entire Humboldt River drainage basin (fig. 1) at one time because the basin comprises almost 18,000 sq mi. Accordingly, most of the work during the first 5 years of the project was done in the Winnemucca reach of the valley. This reach is in north-central Nevada and extends from a point about 2 miles east of the Comus gaging station (Humboldt River at Comus) downstream to the Rose Creek gaging station (Humboldt River near Rose Creek). The reach covers about 520 square miles and lies almost entirely in Humboldt County; only about 17 square miles of it lies in Pershing County.

ORGANIZATION OF THE STUDY

The Nevada Department of Conservation and Natural Resources, coordinating agency for the Humboldt River Research Project, requested and received the cooperation of almost every local, State, and Federal agency, and many private organizations and individuals concerned with water in Nevada. Each participating agency agreed to evaluate those features of the water situation that it was best equipped to study—best equipped in terms of experience and available funds.

Inasmuch as water occurs above, on, and within the earth, many aspects of the atmosphere, land surface, and rocks beneath the surface were studied. Specialists in hydrology, geology, meteorology, agricultural sciences, and biology were called upon to carry out these studies. The organizations participating in the project in the Winnemucca area and their principal responsibilities are outlined briefly in table 1.

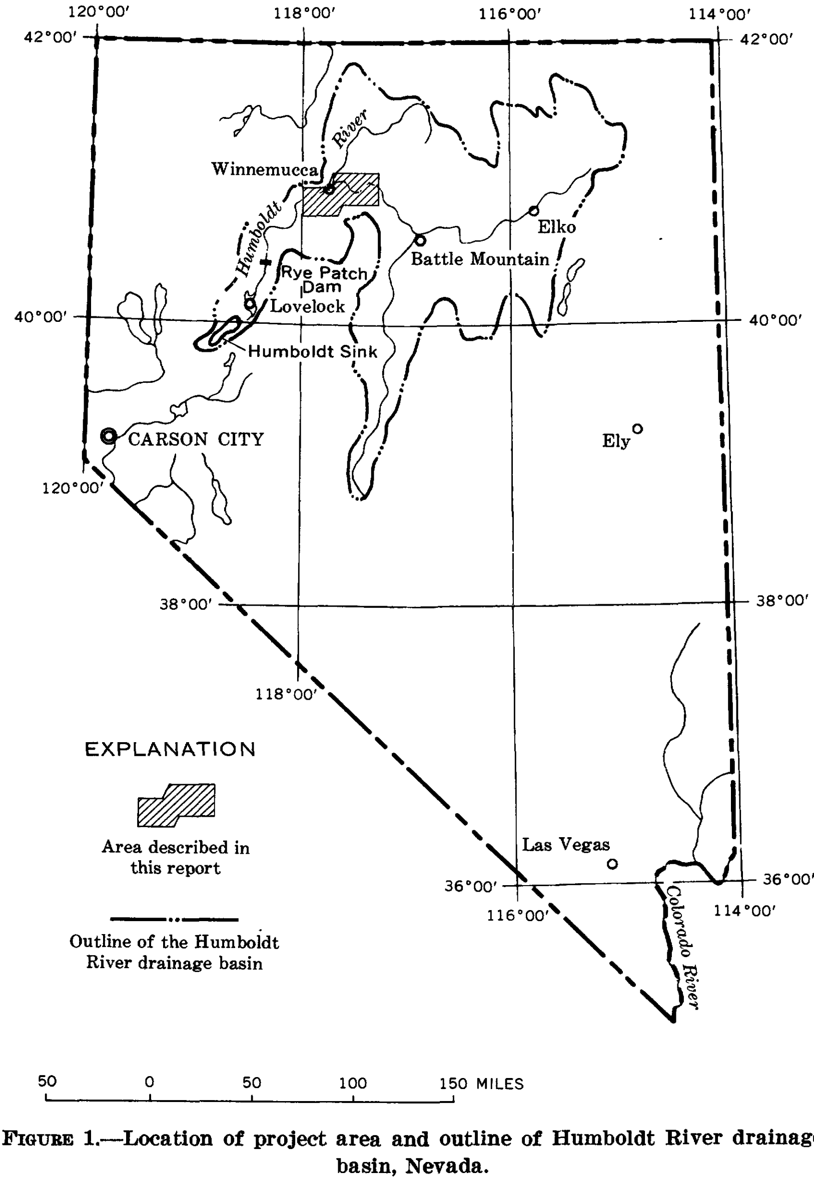

FIGURE 1.—Location of project area and outline of Humboldt River drainage basin, Nevada.

REASONS FOR REPORT; ITS CONTENT

For a research project to be truly successful, the information obtained as a result of the study must be made available to those who can benefit from it. The agencies participating in the study have accordingly completed many technical reports (some of them very long and

TABLE 1.—*Organizations participating in the Humboldt River Research Project near Winnemucca, Nev.*

Organization	Principal responsibilities
Nevada agencies	
Nevada Department of Conservation and Natural Resources.	Project coordinator; participated in field experiments involving the use of water by nonbeneficial woody phreatophytes and evaporation of water from bare soil; collected weather records.
Division of Water Resources	Supplied information on diversions for irrigation.
Division of Forestry	Gave technical advice on transplanting phreatophytes.
Nevada Bureau of Mines	Made geologic and geophysical studies.
University of Nevada:	
Department of Geology	Do.
Desert Research Institute	Do.
Federal agencies	
U.S. Agricultural Research Service	Made hydrologic studies and phreatophyte experiments.
U.S. Bureau of Land Management	Participated in replacement-vegetation studies.
U.S. Bureau of Reclamation	Cooperated in phreatophyte experiments.
U.S. Geological Survey	Made hydrologic studies, including evapotranspiration experiments.
U.S. Soil Conservation Service	Made soils and vegetation studies.
U.S. Weather Bureau	Gave technical advice regarding collection of weather data.
Other organizations	
University of Illinois, Department of Geology	Made hydrogeologic and geophysical studies.
Southern Pacific Co	Supplied topographic and geologic maps.

with great detail) that described the results of the Humboldt River Research Project in the Winnemucca area; most have been published or will be published in the near future. (See p. 67–69.) In 1962 the Nevada Department of Conservation and Natural Resources requested the U.S. Geological Survey to prepare a brief and simple summary of the results of the water-resources studies of all the participating agencies.

To ultimately achieve the most effective use of the available water supply, those individuals and agencies concerned with utilizing and managing that supply indicated their need to know as much as possible about the "flow system" in the study area—the movement of water into, within, and out of the area. They wanted to know how the system operates, how much water is in the system, what the chemical quality of the water is, and how the quality changes as it moves through the system.

The flow system in the Humboldt River valley near Winnemucca is moderately complex (fig. 2), as is described in previously prepared reports. Most surface water that reaches the area is derived from precipitation (fig. 2, item 1), Humboldt River inflow (item 2), and tributary stream inflow (item 3). Additional surface water, in the form of Humboldt River streamflow, is derived from the zone of saturation by seepage gain (item 20). Finally, ground water that is discharged from wells and by spring flow (item 21) supplies the least amount of water to the land surface.

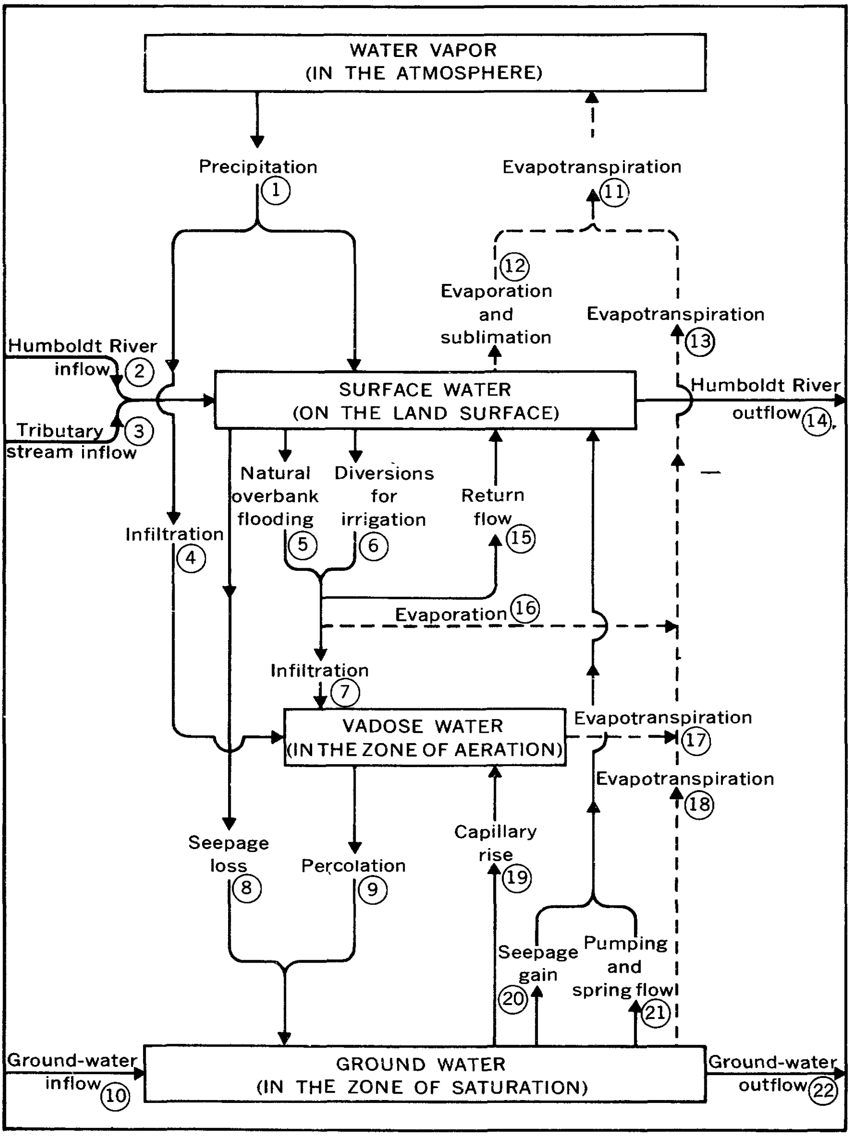

FIGURE 2.—Movement of water (the flow system) in the Humboldt River valley near Winnemucca. Numbered items are referred to in the text.

Most surface water is discharged from the area as Humboldt River streamflow at the Rose Creek gaging station (item 14). The second largest amount evaporates from free-water surfaces and is lost by sublimation (items 12, 16). The remainder of the surface water infiltrates into the zone of aeration (item 7) or seeps into the zone of saturation (item 8).

The infiltration of precipitation (item 4) and surface water (item 7), plus capillary rise from the zone of saturation (item 19), are the sources of nearly all the vadose water in the project area. Water is discharged from the zone of aeration by percolation into the zone of saturation (item 9) and by evapotranspiration (item 17).

Seepage loss of surface water (item 8) and the percolation of water from the zone of aeration (item 9) are the sources of some of the ground water in the area. The source of the remainder of the ground water is subsurface inflow (item 10). Ground water is discharged from the area mainly by evapotranspiration (item 18) and to a lesser extent by seepage to the Humboldt River (item 20), pumping and spring flow (item 21), and ground-water outflow near the Rose Creek gaging station (item 22).

Effective utilization and management of the water resources of the project area depend upon as thorough an understanding of the flow system as possible. This report therefore provides a step-by-step analysis of the flow diagram (fig. 2) and gives quantitative estimates of inflow to and outflow from the ground-water reservoir and estimates of changes in the amount of water in storage. Several aspects of the water quality of the area are reviewed briefly. Water budgets for three selected periods have also been made. The effects of man's activities on the flow system and methods to achieve the most effective use of water resources of the valley are considered.

Nearly all mathematical derivations and calculations are omitted from this report; however, the more significant results of these calculations are given. For those interested in the mathematical derivations, the supporting basic data, theoretical considerations, or a more detailed discussion of a particular phase of the study, a list of reports containing this additional information is given in the selected bibliography.

The cooperation and assistance of personnel of the organizations given in table 1 and of the residents of the project area are gratefully acknowledged. Without their help and that of my colleagues in the U.S. Geological Survey, this report could not have been written.

GENERAL GEOGRAPHIC FEATURES

Geography is the science concerned with the description of the earth and its life, especially of the land, water, and air, and of the plants and animals, including man and his activities. Many geographic features affect the water resources of the Humboldt River valley; the more significant of these are summarized in this section.

LANDFORMS AND DRAINAGE

The major landforms in the study area are four mountain ranges, two large intervening valleys, and the Humboldt River and its flood plain.

MOUNTAINS

The mountain ranges trend roughly northward; their crests range in altitude from about 7,500 to 9,500 feet. They are, in downstream order, the Osgood Mountains and their southward extension, Edna Mountain; the Sonoma Range; Winnemucca Mountain, which is the southernmost extension of the Santa Rosa Mountains; and the East Range.

The ranges are the types that are commonly referred to as fault-block mountains. They are large blocks of consolidated rock that have been uplifted along steeply dipping cracks, or faults, in the earth's crust. Earthquakes, which are common in and near the study area, are associated with movement along these faults.

PARADISE AND GRASS VALLEYS

The report area includes the south end of Paradise Valley and the north end of Grass Valley. The part of Paradise Valley included in the study area is bounded by the Osgood Mountains on the east and by Winnemucca Mountain on the west; Grass Valley is bounded by the Sonoma Range on the east and by the East Range on the west. The floors of both valleys are noticeably flat and represent the bottom of a large and deep lake, known as Lake Lahontan, which covered the area some 10–70 thousand years ago. The floor or Paradise Valley is almost horizontal, and that of Grass Valley slopes northwestward at about 3–4 feet per mile.

The maximum altitude of the level of Lake Lahontan was nearly 4,400 feet. Wave-cut terraces and scarps, beaches, gravel bars, and spits that were formed near the margins of the lake occur in both valleys at altitudes that range from about 4,260 to 4,400 feet. After the final desiccation of Lake Lahontan, wind and stream action modified the formerly featureless bottom of the lake. Because of the recent age of the deposits, the drainage systems on the floors of Paradise and Grass Valleys are poorly formed; stream channels are only a few feet deep and can carry only small amounts of runoff. (See Russell, 1885; Cohen, 1962c; and Hawley and Wilson, 1964, for additional information regarding Lake Lahontan.)

Wind action has scoured shallow depressions in the deposits of the former lake and has formed sand dunes more than 20 feet high. Most of the dunes have been stabilized by vegetation, but some in Paradise Valley are actively moving eastward.

Most of the precipitation occurs as snow in the winter and as infrequent and scattered thunderstorms in the summer. The maximum daily precipitation on record is 1.58 inches, which fell on October 24, 1951; the maximum monthly precipitation, 5.23 inches, occurred in March 1884.

Only meager data are available regarding evaporation rates in the Winnemucca area. These are summarized in other reports and cannot be used reliably to estimate the long-term average annual rate of evaporation from free-water surfaces. Data given by Kohler, Nordenson, and Baker (1959) and data obtained in other parts of Nevada suggest that the long-term average annual rate of evaporation from free-water surfaces in this area is 4–5 feet.

ALLUVIAL APRON

The alluvial apron is the intermediate slope between the steep rugged mountains and the subdued valley floors. It is largely composed of coalescing alluvial fans, which are cone-shaped deposits of clay, silt, sand, and gravel that have formed where streams discharge from the mountains onto the valley floor. Pediments, which are erosional features that superficially resemble alluvial fans, also form part of the alluvial apron, especially along the northwest slope of the Sonoma Range. (See Hawley and Wilson, 1964.)

STREAMS AND RELATED LANDFORMS

The Humboldt River is the largest stream in the area. It heads in the mountains in northeastern Nevada and flows westward for about 200 miles before it enters the Winnemucca area. From the Rose Creek gaging station, the river flows southwestward for about 40 miles to Rye Patch Reservoir; from the reservoir it continues southwestward for about 20 miles to the Humboldt Sink, which is normally a dry lake. The drainage area of the Humboldt River upstream from the Comus gaging station is 12,100 square miles; it is 15,200 square miles upstream from the Rose Creek gaging station, and 16,100 square miles upstream from Rye Patch Dam.

Probably the most striking feature of the Humboldt River channel is its winding, meandering course. The straight-line distance between the Comus and Rose Creek gaging stations is a little more than 35 miles; however, the distance measured along the meandering channel is about 92 miles. The river gradient averages about 1.7 feet per mile. The channel depth ranges from about 6 to 15 feet and averages about 10 feet; its width ranges from about 40 to about 150 feet and averages about 80 feet.

The flood plain of the Humboldt River, which is the nearly flat surface bordering the river and which is periodically covered by flood water, ranges in width from about 0.2 mile to 5 miles. The flood-plain distance between the Comus and Rose Creek gaging stations—the distance measured along straight segments parallel to the main channel of the river—is about 45 miles. The average gradient of the flood plain is nearly 3.4 feet per mile, or about twice that of the river.

Two discontinuous terraces separate the flood plain from the floors of Paradise and Grass Valleys. Locally, both terraces have been removed by erosion, and scarps about 50 feet high border the flood plain. The lower of the two terraces is best preserved downstream from Winnemucca, and the higher terrace is best preserved upstream.

The more significant tributary streams in the project area, and their drainage areas, are listed in downstream order in table 2. Although all these streams on the alluvial apron and in the valley lowlands are commonly dry during most of the year, some in the mountains contain water for short distances during the entire year.

TABLE 2.—*Smaller streams tributary to the Humboldt River valley near Winnemucca, Nev.*

Stream or canyon	*Drainage area (sq mi)*	*Point above which drainage area was measured*
Kelly Creek	300	Where it joins the Humboldt River.
Rock Creek	52	At U.S. Highway 40.
Pole Creek	13	Do.
Devils Canyon	5	Do.
Little Humboldt River	1, 800	Where it joins the Humboldt River.
Harmony Canyon	9	At U.S. Highway 40.
Water Canyon	7	At diversion ditch ¾ mile south of Winnemucca.
Thomas Canyon	11	At Grass Valley road.
Clear Creek	480	At U.S. Highway 40.
Rose Creek	8	Where it joins Clear Creek.

CLIMATE

The climate of the valley lowlands is arid to semiarid; it is characterized by low humidity and little precipitation and by an abundance of sunshine. Precipitation, which averages about 8 inches per year on the valley floor, increases with altitude (pl. 1A) and averages more than 20 inches per year on the highest peaks, where the climate is subhumid.

The U.S. Weather Bureau has collected weather records at and near Winnemucca since 1870. The significant temperature and precipitation data are summarized in table 3. The average daily temperature on the valley floor is 49°F. The highest temperature ever recorded was 108°F, on July 20, 1931; the lowest temperature was −36°F, on

January 21, 1937. Freezing temperatures have been recorded in every month of the year; however, they are not common in June, July, and August. The daily temperature commonly fluctuates 30° – 40°F and sometimes more than 50°F.

The average annual precipitation for the period 1871–1962 was 8.40 inches. In an average year nearly half the precipitation occurs in the 4-month period December–March; however, less than 2 inches, or about 20 percent of the yearly precipitation, normally falls during the growing season, May–August. All crops in the area must be irrigated, because of the small amount of precipitation.

TABLE 3.—*Summary of climatological data for area at and near Winnemucca, Nev., 1871–1962*

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

	Period (years)	Jan.	Feb.	Mar.	Apr.	May	June
Temperature (°F):							
Average monthly maximum	83	52	58	69	77	86	94
Average monthly minimum	83	−4	3	13	19	26	33
Average monthly	83	28	34	40	47	55	62
Highest of record	83	61	69	82	88	98	104
Lowest of record	83	−36	−26	−3	9	12	23
Precipitation (in.):							
Average monthly	91	1.05	.92	.90	.78	.88	.68
Maximum monthly	91	3.08	2.75	5.23	3.34	2.82	2.86
Minimum monthly	91	0	Trace	0	.06	.02	0
Maximum 24-hr	82	1.45	.99	.97	.92	1.44	1.56

	Period (years)	July	Aug.	Sept.	Oct.	Nov.	Dec.	Period of record
Temperature (°F):								
Average monthly maximum	83	99	97	90	81	67	56	78
Average monthly minimum	83	42	38	26	18	7	0	18
Average monthly	83	72	69	60	48	38	30	49
Highest of record	83	108	106	103	90	75	70	108
Lowest of record	83	29	26	12	9	−9	−27	−36
Precipitation (in.):								
Average monthly	91	.22	.18	.36	.67	.77	.99	.70
Maximum monthly	91	1.55	1.26	1.53	2.93	3.78	3.40	5.23
Minimum monthly	91	0	0	0	0	0	Trace	0
Maximum 24-hr	82	1.85	.59	1.00	1.58	1.56	1.08	1.85

VEGETATION

The native plants in the Winnemucca area are typical of those in the northern part of the Great Basin. Sagebrush and shadscale are the most abundant shrubs on the alluvial apron, and greasewood is the most abundant shrub in the valley lowlands. Native grasses cover much of the flood plain of the Humboldt River; however, willow and wildrose are locally the predominant plants on the flood plain, especially in abandoned channels of the Humboldt River. The most common varieties of trees are piñon pine and juniper, which are found mainly in the mountains, and a few scattered cottonwood on the valley lowlands.

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A vegetation map for the Winnemucca area has been prepared by the U.S. Soil Conservation Service under the supervision of E. A. Naphan (written commun., 1964). Twenty-nine types of vegetation, including the major species of plants in the area, were defined for the purpose of preparing the map.

The types of vegetation, as defined by the Soil Conservation Service, are grouped into five major units for the purpose of this report (pl. 1B) and are listed below, by unit.

Grass and willow:
- Saltgrass
- Creeping wildrye
- Cattail and bullrush
- Willow and rose
- Buffaloberry

Rabbitbrush:
- Rabbitbrush
- Rabbitbrush and greasewood

Greasewood:
- Greasewood
- Greasewood and big sagebrush
- Greasewood and shadscale
- Greasewood and saltgrass
- Greasewood and spiny hopsage
- Greasewood and budsage
- Greasewood and rabbitbrush
- Greasewood and alkalai blite

Shadscale:
- Shadscale

Sagebrush:
- Big sagebrush
- Big sagebrush and greasewood
- Big sagebrush and rabbitbrush
- Big sagebrush and spiny hopsage
- Big sagebrush and hairy horsebrush
- Big sagebrush and budsage
- Spiny hopsage
- Hairy horsebrush
- Crested wheatgrass seedings
- Annuals
- Big sagebrush and low sagebrush and shadscale
- Big sagebrush and low sagebrush
- Juniper

MAN AND HIS ACTIVITIES

Before the first white men explored the Humboldt River basin, in the early 19th century, the area was sparsely inhabited by Shoshone and Paiute Indians. The early explorers sought a westward route through the inhospitable mountains and desert of the Great Basin. By the mid-19th century, there was a well-defined emigrant trail along the Humboldt River that led to Oregon and California. Soon afterward, in the 1860's, a railroad was completed that closely paralleled the river and linked the midwest and California. By the late 19th century, mining towns, railroad junction points, and agricultural communities were well established in the valley. Winnemucca, the county seat of Humboldt County, was formerly the center of a prosperous mining industry. The principal metals recovered were gold, silver, tungsten, and mercury. Very few mines are currently in operation, and the economy of the area is based mainly on cattle raising and the tourist business. The population of Winnemucca in 1960 was about 3,500.

The activities of man that involve the use of water are, of course, of principal concern in this report. More than 95 percent of the beneficial use of water in the Humboldt River basin is for irrigation, mainly of forage crops such as meadow grasses and alfalfa. Along the main stem of the Humboldt River, diverted river water is virtually the sole source of irrigation water; ground-water development for irrigation is negligible.

In the Winnemucca area about 10,000–20,000 acres of the flood plain is irrigated with Humboldt River water. The acreage irrigated largely depends on the availability of streamflow. In 1962 nearly 2,000 acres, mostly in the mouth of Grass Valley, was irrigated with ground water. Most irrigation is accomplished by diversion of the water through a network of unlined ditches and by overbank flooding onto unimproved meadows. All diversionary structures in the project area are privately owned; the largest, Stahl Dam, is about 15 miles east of Winnemucca.

HOW AND WHERE THE WATER OCCURS

Before more consideration is given to how much water enters the project area, where it comes from, and what happens to it after it enters the area, some physicial characteristics of the water and the environment in which the water occurs should be briefly reviewed. Water occurs in three forms or phases: as a gas (water vapor), as a solid (most commonly as ice and snow), and as a liquid. The liquid phase is the one about which most people are usually concerned. All three phases are considered herein. It is also necessary to consider the three broad areas in which water occurs—beneath the earth's surface, on the land surface, and in the atmosphere.

SUBSURFACE WATER

GEOLOGIC ENVIRONMENT

According to Meinzer (1923, p. 23), subsurface water occurs in three major zones within the earth—the zone of rock flowage, the zone of saturation, and the zone of aeration. (See fig. 3.) Water in the zone of rock flowage is not considered in this report because it normally occurs at great depth and is not readily available for use by man; even if it could be recovered, it is probably not of suitable chemical quality for most uses.

To evaluate such factors as the amount of subsurface water available, the rate, direction, and quantity of ground-water flow, and the chemical quality of the water, studies were made of the distribution and the physical and chemical characteristics of rock materials on and beneath the earth's surface. In other words, many aspects of the geology of the area were studied. Results of the geologic studies, including those of a detailed test-drilling program, are described in detail in other reports listed in the selected bibliography; a brief summary of the results of some of this work is given in the following paragraphs and, where pertinent, in other sections of the report.

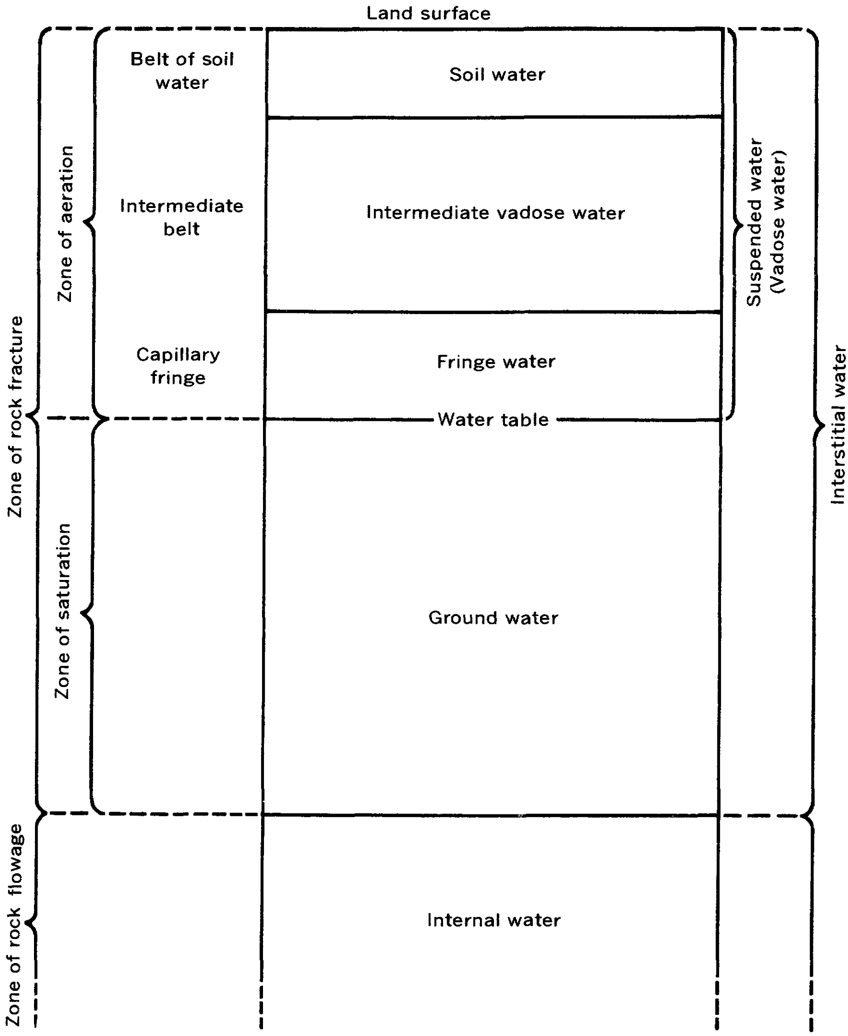

FIGURE 3.—The divisions of subsurface water. (After Meinzer, 1923, p. 23.)

For purposes of discussion in this report, the rock materials on and beneath the earth's surface are grouped into four units: consolidated rocks, older alluvium, medial alluvium, and younger alluvium (pl. 1C). The last three units are collectively termed "valley-fill deposits." The geology of the valley-fill deposits is described in considerable detail in reports by Russell (1883, 1885), Cohen (1962c, 1963a,b), and Hawley and Wilson (1964).

The consolidated rocks compose most of the mountain ranges and underlie the valley-fill deposits. These rocks are generally dense and hard and, accordingly, store and transmit only small quantities of water. Locally, however, fractures resulting from structural deformation, solution openings in some of the carbonate rocks, and primary and secondary structures in some of the lava flows transmit moderately large quantities of water through these otherwise largely impermeable rocks.

The older alluvium includes some moderately consolidated lake beds that, for the most part, are highly metamorphosed, cemented, and compacted. These deposits, therefore, do not store or transmit appreciable quantities of water. Also in the older alluvium are thousands of feet of unconsolidated and partially consolidated strata of silt, sand, and gravel, deposited mainly as alluvial fans and as stream-channel deposits in the valley lowlands, and clay and silt strata, deposited in lakes that intermittently occupied the project area. Wells in the study area that tap well-sorted and poorly compacted sand and gravel strata of the older alluvium yield more than 1,000 gpm (gallons per minute); however, wells that tap the predominately fine-grained strata or the consolidated strata of the older alluvium yield only a few gallons per minute.

The medial alluvium was deposited within and around the margins of Lake Lahontan. The unit consists of at least five recognizable subunits (Cohen, 1963b, table 3); however, only two subunits, the medial gravel and the upper silt and clay, have a significant bearing on the water resources of the area. The medial gravel subunit is saturated throughout nearly all its lateral and vertical extent (pl. 1G). The top of the subunit is at a depth that ranges from about 5 to about 20 feet below land surface on the flood plain and from about 2 to about 15 feet on the bordering terraces. Throughout most of the remainder of the project area, the medial gravel is overlain by the upper silt and clay subunit, which ranges in thickness from a few inches to about 55 feet.

The medial gravel subunit consists mainly of moderately to well-sorted lenses of coarse sand and gravel; however, locally it contains thin beds of fine sand and silt. It is almost completely saturated with ground water and is highly permeable. Thus, it could yield fairly large quantities of water to properly constructed and developed wells—at least 2,000 gpm. The upper silt and clay subunit consists of fine-grained and moderately compacted silty and clayey strata that store moderately large quantities of water; however, because of the very low permeability of these strata, the subunit transmits only small quantities of water and yields negligible quantities to wells. Locally the subunit confines water in the underlying medial gravel under artesian pressure.

The younger alluvium is entirely of post-Lake Lahontan age and includes flood-plain and terrace deposits, alluvial-fan and stream-channel deposits, windblown silt and sand, and the deposits of Gumboot Lake. Most of these deposits are less than 50 feet thick, and their texture and water-bearing character range from highly permeable stringers of sand and gravel to lenses and layers of silt and clay of very low permeability.

WATER IN THE ZONE OF SATURATION

In the Winnemucca reach of the Humboldt River valley, most water in the zone of saturation (ground water) is in the pore spaces (openings) in the unconsolidated sedimentary deposits. Some ground water also occurs in cracks and other openings in the consolidated rocks, but the amount is small as compared with that in the unconsolidated deposits. Moreover, most consolidated rocks yield little or no water to wells.

Nearly all the ground water occurs as a liquid that is under greater than atmospheric pressure. If water is held in the zone of saturation by an overlying bed or layer of material through which it cannot readily pass, it is "confined" or under artesian pressure. Where the top of the zone of saturation is not separated from the atmosphere by a confining bed, the ground water is not under artesian pressure, and the top of the zone of saturation is termed the "water table."

WATER IN THE ZONE OF AERATION

Vadose water, or water in the zone of aeration, occurs largely in the liquid phase but also partly in the vapor and solid phases. Although pore spaces in the zone of saturation are normally completely filled with water, those in the zone of aeration commonly contain small to large amounts of air, the amount depending mainly on the size of the spaces. Vadose water is also different from the ground water in that it is under less than atmospheric pressure and therefore will not enter a well. Most of the vadose water is held in the zone of aeration by capillary and molecular attraction and does not move downward in response to gravity.

The capillary fringe is the lowest part of the zone of aeration. Most water in the capillary fringe is derived from the underlying zone of saturation by capillary attraction in much the same way that water rises in a wick that is partly immersed in a glass of water. The smaller the particles and the pore spaces in the material immediately above the water table, the thicker the capillary fringe.

In the Homboldt River valley the thickness of the zone of aeration ranges from a few feet to more than several hundred feet. At times the capillary fringe locally extends to the land surface, especially on the flood plain where the zone of aeration is commonly only a few feet thick.

SURFACE WATER

Surface water is the water that occurs on the land surface; it mainly includes flowing water in streams, impounded water in lakes, ponds, and reservoirs, and ice and snow on the ground. The amount of water in the streams at a given time is referred to as the channel storage. Channel storage normally represents the largest quantity of surface water in the Humboldt River valley, and water in the Humboldt River normally represents more than 95 percent of the total channel storage in the project area.

Gumboot Lake, near the south end of Paradise Valley, is the only natural lake in the project area. Before farming began in Paradise Valley, Gumboot Lake contained water only when eastward-moving sand dunes blocked the channel of the Little Humboldt River or when the river was in flood. Most of the Little Humboldt River streamflow is currently diverted for irrigation in Paradise Valley. As a result, Gumboot Lake is dry; it was dry during this investigation.

Stahl Reservoir, the largest artificial lake in the area, covers about 600 acres and has a storage capacity of less than 1,000 acre-feet. The reservoir was formed by the construction of a dam across the channel of the Humboldt River in the NW¼ sec. 35, T. 36 N., R. 40 E. Numerous other small dams, including both permanent and temporary structures, impound and divert the flow of the Humboldt River during the irrigation season. Behind these structures are small lakes or reservoirs, which are generally considered to represent increases in the amount of water in storage in the river channel.

Although the depths of snow and ice in the project area were not measured, the snowpack that accumulates on the mountains during the winter probably contains an equivalent of at least 15–20 inches of liquid water in places. The snowpack accordingly represents an appreciable though unmeasured part of the total surface-water supply.

ATMOSPHERIC WATER

Almost all water in the atmosphere occurs as vapor. The vapor content of air is commonly expressed in terms of relative humidity, which is the ratio of the amount of water vapor in the air to the total amount that the air can contain at a given temperature. According to U.S. Weather Bureau data, the average annual relative humidity in Winnemucca in the afternoon is slightly less than 40 percent, and the humidity ranges from an average low of about 20 percent in the summer to an average high of about 60 percent in the winter.

The low summer humidity has a considerable effect on the water-supply of the area. It is one of the major factors that contribute to high evapotranspiration rates, and evapotranspiration consumes large quantities of water in the project area.

WHERE THE WATER COMES FROM

The source and quantity of water entering the Winnemucca reach of the Humboldt River valley are considered forthwith. The inflow of water to the storage area (pl. 1D) is emphasized rather than the inflow of water to the entire project area, because most inflow, most changes in the amount of water in storage, and most discharge occur in the storage area. Inflow estimates and most other quantitative estimates given in this report are for three time periods: water years 1949–62, water year 1962, and December–June of water year 1962. (The water year is defined as the 12-month period beginning October 1 and ending September 30 and is designated by the calendar year that includes 9 of the 12 months.) These three time intervals are emphasized mainly because of the availability of streamflow data and other data needed for the purpose of water-budget analysis (p. 50) and because the estimates for the three periods illustrate many significant features of the water resources of the area.

The oceans bordering the west and north coasts of North America are the sources of nearly all water in the project area. Water vapor derived from these oceans by evaporation generally moves eastward or southeastward across Nevada in response to the prevailing wind direction. Some of this moisture condenses over the Humboldt River drainage basin and falls as rain or snow. Much precipitation evaporates soon after it falls, some collects on the land surface in ponds and lakes and as streamflow, some infiltrates the zone of aeration, and some percolates downward into the zone of saturation. Eventually (perhaps after many hundreds or thousands of years) all the precipitation in the basin is returned to the atmosphere by evapotranspiration. Thus, not only is the atmosphere the medium through which all water is transported to the Humboldt River basin, but it is also the medium that transports all water discharged from the basin. Eventually the water discharged from the basin returns to the ocean, and the never-ending hydrologic cycle—the cycle of condensation, precipitation, and evapotranspiration—is repeated again.

STREAMFLOW

HUMBOLDT RIVER

The flow of the Humboldt River at the Comus gaging station is derived entirely from precipitation in the Humboldt River drainage basin upstream from the project area and is the source of most of the inflow to the storage area in the Winnemucca reach of the Humboldt River valley (fig. 2, item 2). The average annual flow at the Comus gaging station in water years 1949–62 was 172,100 acre-feet (fig. 4); the range was from a low of nearly 28,000 acre-feet in water year 1955 to a high of about 558,000 acre-feet in water year 1952.

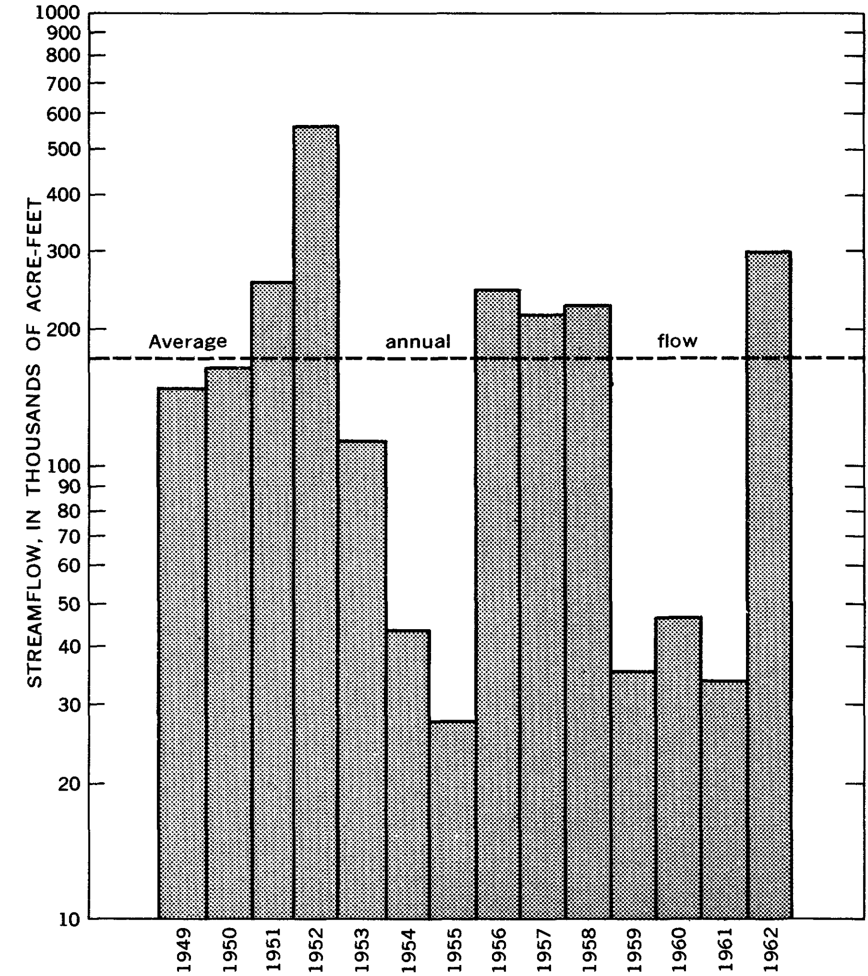

FIGURE 4.—Annual flow of the Humboldt River at the Comus gaging station, water years 1949–62.

The flow of the Humboldt River at the Comus gaging station during water years 1959–61 was markedly below average (fig. 4). However, the river inflow to the storage area in water year 1962 was 297,200 acre-feet, or about 50 percent more than the long-term average (1895–1962). Similarly, the flow of the Humboldt River at the Comus gaging station in December–June of water year 1962 was 254,300 acre-feet, which was also considerably above the long-term average.

Table 4 shows the relation between streamflow for water years 1949–62 and comparable flow for the period of record, water years 1895–

1962. The average annual flow for the 14-year period was 14 percent less than the average annual flow for the entire period of record. Overall streamflow characteristics during the 14-year period were, nevertheless, very similar to those of the long-term period. Moreover, a seemingly random distribution of years of below- and above-average streamflow characterized both the 14-year period and the long-term period.

TABLE 4.—*Summary of streamflow of the Humboldt River at the Comus gaging station for the period of record and for water years 1949–62*

Period (water years)	Average annual (acre-ft)	Water year	Maximum annual (acre-ft)	Water year	Minimum annual (acre-ft)
1895–1962 [1]	199,100	1907	688,100	1920	26,700
1949–62	172,100	1952	558,500	1955	27,530

[1] Does not include water years 1910 and 1927–45, for which data were not obtained.

No sizable storage facilities exist upstream; hence, monthly streamflow at the Comus gaging station (fig. 5) is largely a reflection of climatic conditions in the basin. The flow at the beginning of a water year is normally the lowest of the year. It increases gradually from November through January as the weather turns colder and causes the phreatophytes to consume less water and evaporation to decrease. The flow increases in January, February, and March because of winter storms, and continues to increase markedly in April when the weather begins to turn warm and melt the snowpack that accumulated during the winter. It normally reaches a peak in May. By the end of June, when the snowpack is nearly depleted the flow decreases abruptly and continues to decrease until the end of the water year. On the average, nearly 65 percent of the total yearly flow at the Comus gaging station occurs in the months of April, May, and June.

An especially notable characteristic of the flow of the Humboldt River at the Comus gaging station and for that matter, in the entire basin, is the wide range in annual and monthly flows. This, in part, reflects the lack of major upstream storage facilities but is mainly related to climatic variations. Intense thunderstorms and warm rain on frozen ground have caused severe and frequent flooding in the basin (Nevada Dept. Conserv. and Nat. Resources and U.S. Dept. Agriculture, 1962b; Thomas and Lamke, 1962). Moreover, a year or a series of years of above- or below-normal precipitation in the basin corresponds very closely to a year or years of above- or below-average streamflow (Hanson, 1963, fig. 13).

The percentage of time that the daily average rate of flow of the Humboldt River at the Comus gaging station equaled or exceeded a

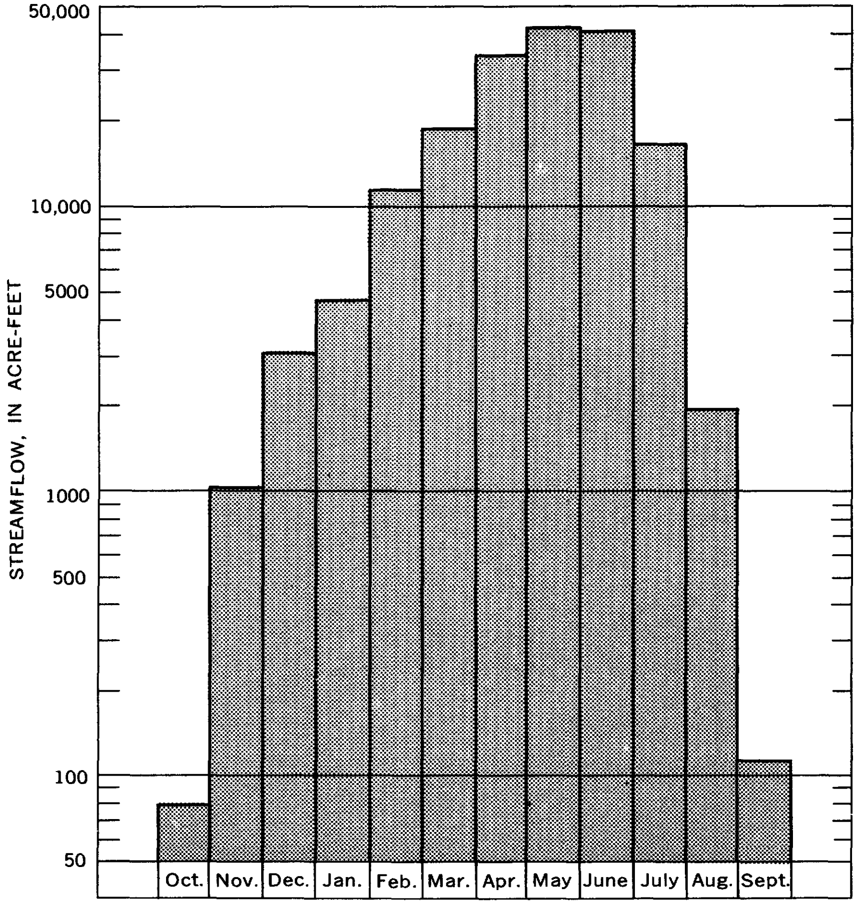

FIGURE 5.—Average monthly flow of the Humboldt River at the Comus gaging station, water years 1949–62.

given rate of flow is shown in figure 6. The graph shows, for example, that daily average flow of 70 cfs (cubic feet per second) was equaled or exceeded about 50 percent of the time. The daily average flow exceeded 2,000 cfs only about 1 percent of the time, and the river was dry at the Comus gaging station about 1 percent of the time. The maximum instantaneous flow recorded was 5,860 cfs on May 6, 1952, and the maximum daily flow of 5,810 cfs occurred on the same day.

TRIBUTARY STREAMS

Tributary streamflow supplies the least amount of water of any significant source of inflow to the storage area near Winnemucca (fig. 2, item 3). All streams in the project area, except the Humboldt

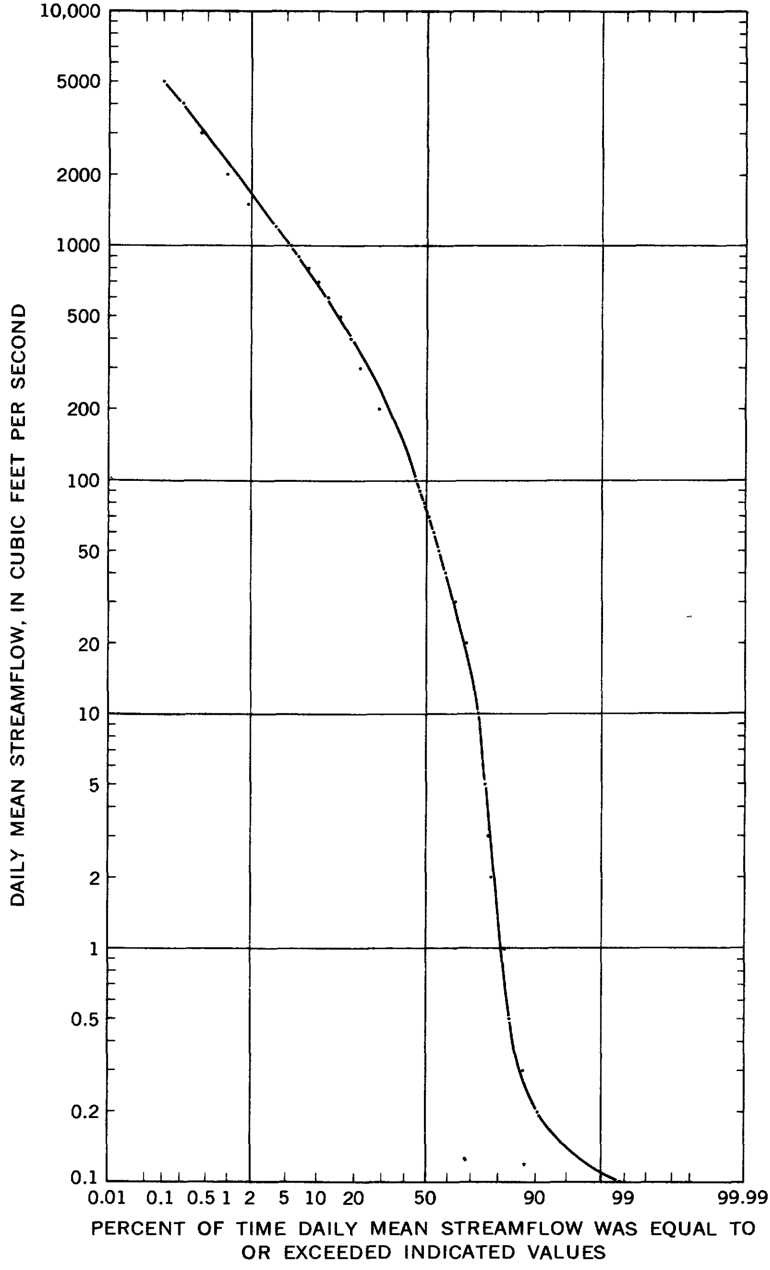

FIGURE 6.—Duration curve of daily mean streamflow, Humboldt River at Comus gaging station, water years 1918–26, and 1946–62.

River, are dry most of the time throughout most of their lengths. Some of these streams, however, flow all year for short distances in the mountains. There they receive year-round spring flow; nevertheless, even in the mountains most tributary streams normally flow only in the winter in response to increased rain and snow and in the spring and early summer in response to the melting of the snowpack.

Seldom do tributary streamflows discharge into the Humboldt River in the Winnemucca area. Rather, the flows evaporate (fig. 2, item 12), are transpired (fig. 2, item 13), infiltrate into the zone of aeration (fig. 2, item 7), or percolate downward through the zone of aeration to eventually recharge the zone of saturation (fig. 2, item 9).

Unusual weather conditions such as intense summer thunderstorms or warm rain on frozen ground may result in concentrated and large amounts of runoff in one or more of the tributary streams. Even then the amount of water that discharges into the Humboldt River in the project area is commonly negligible, especially when compared with the total annual flow of the river.

In water years 1953 and 1958, a total of about 58,000 acres-feet of flood water from the Little Humboldt River was artificially drained from Gumboot Lake to the Humboldt River. Excluding this quantity of water, the estimated average annual tributary streamflow that reached the outer margins of the storage area 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 the period December–June of that year (Hanson, 1963, p. 41). On the average, very little of this water reached the Humboldt River as surface flow.

If the water that was drained from Gumboot Lake in water years 1953 and 1958 is added to the calculated average annual inflow from other tributary streams for the period water years 1949–62, the estimated total average annual inflow from all tributary streams for that period was about 8,600 acre-feet.

PRECIPITATION

Precipitation directly on the storage area (pl. 1D) is the second largest source of water in the area (fig. 2, item 1). The average annual precipitation on the storage area in water years 1949–62 was probably almost equal to that at the Winnemucca airport—about 7.6 inches. The storge area covers about 93,000 acres. Thus, the estimated average annual precipitation on the storage area in water years 1949–62 was 59,000 acre-feet; it was 60,000 acre-feet in water year 1962 and about 47,000 acre-feet in December–June of that year. Most of this precipitation is consumed by evapotranspiration soon after it falls (fig. 2, items 12, 13), as is subsequently described in the report; and very little precipitation percolates downward to the zone of saturation.

GROUND-WATER INFLOW

The fourth major source of water in the storage area near Winnemucca is ground-water inflow—that is, the movement of water from the saturated deposits bordering the storage area to the saturated deposits within the storage area (fig. 2, item 10). Ground-water inflow to the storage area is indicated by the water-level contours on maps E and F of plate 1. These contour lines represent the altitude of water levels in observation wells and at springs and the altitude of the Humboldt River at 21 staff gages (pl. 1D). The direction of ground-water flow is perpendicular to the water-level contours, and water moves from the areas of higher water-level altitudes to areas of lower water-level altitudes.

Four subareas supply almost all the ground-water inflow to the storage area. They are, in downstream order, the Humboldt River valley upstream from the storage area, the drainage basins of Pole and Rock Creeks, Paradise Valley, and Grass Valley, including the northwestern slope of the Sonoma Range. The estimated average annual ground-water inflow from these subareas is given in table 5.

Ground-water movement into the storage area is unlike streamflow in that it is very slow (from a fraction of a foot to several feet per day) and remains almost constant. The amount of ground-water inflow to the storage area is independent of short-term climatic factors and responds only slightly to long-term climatic trends, such as several consecutive years of above- or below-normal precipitation. Accordingly, ground-water inflow to the storage area in water year 1962 was probably equal to the long-term average annual inflow of 14,000 acre-feet; inflow during the 7-month period December–June of water year 1962 was seven-twelfths of the annual inflow, or about 8,000 acre-feet.

TABLE 5.—*Estimated average annual ground-water inflow to the storage area near Winnemucca, Nev.*

[Adapted and generalized from Cohen, 1963b, table 17]

Subareas contributing ground-water inflow to storage area (pl. 1D)	*Average annual ground-water inflow (acre-ft)*
Humboldt River valley upstream from the storage area	500
Drainage basins of Pole and Rock Creeks	4, 000
Paradise Valley	3, 500
Grass Valley and the northwestern slope of the Sonoma Range	6, 000
Total	14, 000

SUMMARY OF TOTAL INFLOW

The estimated average annual inflow to the storage area near Winnemucca in water years 1949–62 and the percentage of the total represented by each of the major sources are as follows:

Source	*Average annual inflow (acre-ft)*	*Percent of total*
Humboldt River	172,100	68
Tributary streams	8,600	3
Precipitation	59,000	23
Ground-water inflow	14,000	6
Total (rounded)	250,000	100

Because of legal considerations and because of several other factors subsequently described in the report, only a small percentage of the total inflow to the Winnemucca area is available for use by man within that area.

Average annual precipitation at Winnemucca and at Elko (near the headwaters of the Humboldt River) in water years 1949–62 was about 5–10 percent less than the average annual precipitation for the past 90 years. The average annual streamflow at the Comus gaging station in water years 1949–62 was also about 14 percent less than that for the entire period of record. Thus, these figures suggest that in water years 1949–62 the average annual inflow to the storage area near Winnemucca was about 10 percent less than the average annual inflow for the past 90 years or more.

MOVEMENT AND STORAGE OF WATER

What happens to the water after it enters the storage area and before it is discharged from the area? A drop of Humboldt River streamflow at the Comus gaging station may move downstream and be discharged from the area within a few days. Another drop of Humboldt River streamflow may percolate into the ground and be stored there for tens or hundreds of years before emerging at the land surface. Similarly, raindrops or ground-water inflow may follow many diverse paths and may be stored in several different environments for various periods of time before being discharged from the area as streamflow, as ground-water outflow, or by evapotranspiration.

HUMBOLDT RIVER STREAMFLOW

The movement and storage of Humboldt River streamflow are considered first inasmuch as the Humboldt River normally supplies most of the water that moves into the area in a given year. Moreover, variations in the amount of water in the river channel generally represent the largest yearly changes in the total amount of water stored within the area.

VARIATIONS IN THE RATE AND QUANTITY OF FLOW

The rate and quantity of water flowing in the channel of the Humboldt River varies with time and with increasing distance downstream from the Comus gaging station. These variations are caused by many complex factors, some of which are closely interrelated.

The velocity at which water moves in the channel ranges from an average high of about 3 feet per second, or about 2 miles per hour, when the river is in flood, to 0 feet per second when the river is dry. During the period of record the measured rate of flow past the Comus gaging station into the project area ranged from a high of 5,860 cfs to a low of 0.

The amount of water flowing in the channel and the average velocity of flow vary seasonally. Some factors causing variations in flow at the Comus gaging station have been discussed in the section "Streamflow." These factors also affect the flow downstream from the Comus gaging station. Irrigation practices, evapotranspiration, and seepage gains and losses also significantly affect the flow of the river in the project area.

The three sets of representative streamflow measurements plotted in figure 7 show typical changes in flow of the Humboldt River during

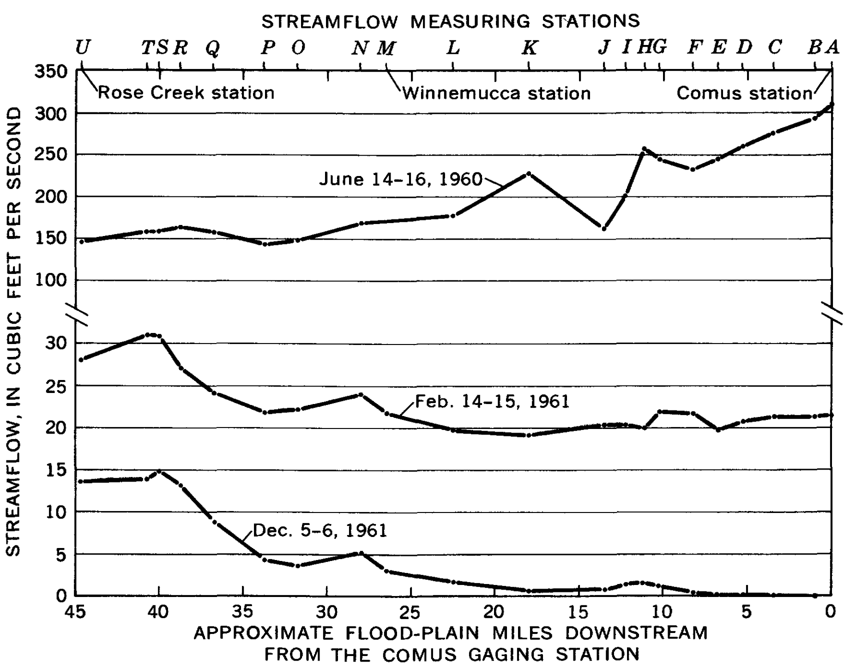

FIGURE 7.—Representative streamflow measurements of the Humboldt River between the Comus and Rose Creek gaging stations.

periods of low, moderate, and high flow. In December 1961 no tributary streamflow discharged into the river between stations *A* and *U* (pl. 1D), the stage (level of water surface) of the river was nearly constant, no water was diverted form the river, and evapotranspiration losses were negligible. Thus, the increase in flow from a fraction of a cubic foot per second at station *A* to about 14 cfs at station *U* was almost entirely the result of ground-water seepage into the river (fig. 2, item 20). In February 1961 streamflow was moderately high at station *A*—about 21 cfs—mainly as a result of snow and rain on the headwaters of the basin during the preceding few weeks. Again, as the water moved downstream the flow increased, owing to seepage of ground water into the river.

On June 14–16, 1960, the flow decreased from a little more than 300 cfs at station *A* to about 150 cfs at station *U*. The decrease in flow was caused by seepage from the river to the ground-water reservoir (fig. 2, item 8), diversions for irrigation (fig. 2, item 6), and evapotranspiration (fig. 2, item 11). In addition, part of the decrease in flow was probably caused by increases in channel storage.

VARIATIONS IN CHANNEL STORAGE

Channel storage—the volume of water in the river at any given time—is directly related to flow of the river. As the flow increases, the amount of channel storage increases. Figure 8 shows the relation of channel storage in the Humboldt River to the average of streamflow at the Comus and Rose Creek gaging station. (See Hanson, 1963, p. 55.) The average of the flow at the two gaging stations is normally the same at the beginning and at the end of a water year; hence, the average annual net change in channel storage in the Humboldt River is zero. Humboldt River streamflow at the Comus and Rose Creek gaging stations averaged 5 cfs at the beginning of water year 1962 and about 22 cfs at the end of the water year. The estimated net increase in channel storage for that period is about 1,800 acre-feet. (See fig. 8.) Flow averaged 7 cfs on December 1, 1961, and about 1,170 cfs on June 30, 1962; estimated net increase in channel storage for that period was approximately 22,000 acre-feet.

TRIBUTARY STREAMFLOW

During the spring and early summer, the flows of Rock, Pole, Thomas, and Rose Creeks and the flow of the stream in Harmony Canyon are diverted for irrigation. The flows in most of these streams are insufficient during the rest of the year to reach the outer margins of the storage area (pl. 1D). Tributary streamflow that does reach the outer margins of the storage area normally evaporates or per-

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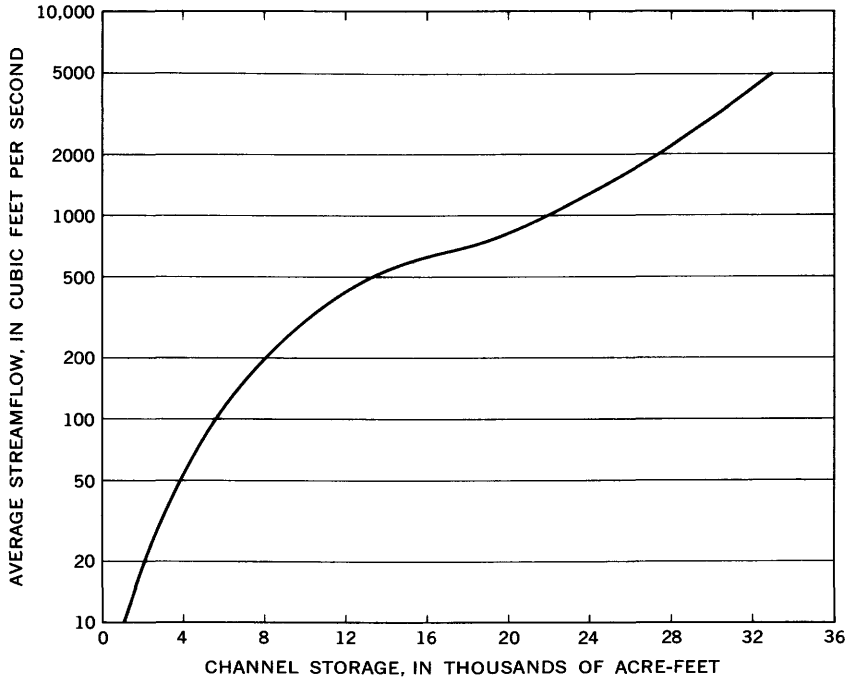

FIGURE 8.—Channel storage between the Comus and Rose Creek gaging stations related to the average of streamflow at the two gaging stations. (After Hanson, 1963, fig. 24.)

colates downward to the ground-water reservoir before reaching the Humboldt River.

Except for two farm ponds there are no facilities for storing tributary streamflow in the project area. The combined storage capacity of the two ponds is less than 50 acre-feet.

PRECIPITATION

Most rain and snow on the storage area infiltrates the zone of aeration and is stored there temporarily (fig. 2, item 4). From there it is eventually returned to the atmosphere by evapotranspiration (fig. 2, item 17). However, some precipitation percolates downward to the zone of saturation and recharges the ground-water reservoir, especially in the spring and summer when, locally, the water table beneath the flood plain is only a few feet below land surface and the capillary fringe extends up to land surface (fig. 2, item 19). The estimated average annual ground-water recharge that results from the infiltration of precipitation on the storage area is 2,000 acre-feet (Cohen, 1963b, p. 68).

On the basis of the average annual precipitation at the Winnemucca weather station and the average surface area of the Humboldt River, an estimated average of about 600 acre-feet per year of rain and snow falls directly on the Humboldt River in the storage area near Winnemucca. The moment the precipitation falls on the free-water surface of the river, it becomes part of the streamflow.

GROUND WATER

DIRECTION AND RATE OF MOVEMENT

Throughout most of the year the general direction of ground-water movement is from the outer margins of the storage area (pl. 1D) toward the Humboldt River. Some water discharges into the river, some discharges by evapotranspiration on the flood plain and bordering terraces, and some moves westward and southwestward parallel to the river (pl. 1E; fig. 9).

In the spring and early summer when the stage rises and the flow of the river increases rapidly, a ground-water ridge or mound forms along the river as a result of seepage from the stream to the ground-water reservoir (pl. 1F; fig. 10). At the same time ground water continues to move toward the river from the outer margins of the storage area; however, along most of the reach of the river in the storage area, ground water cannot discharge into the river because of the ground-water ridge. As a result, ground-water levels rise beneath the

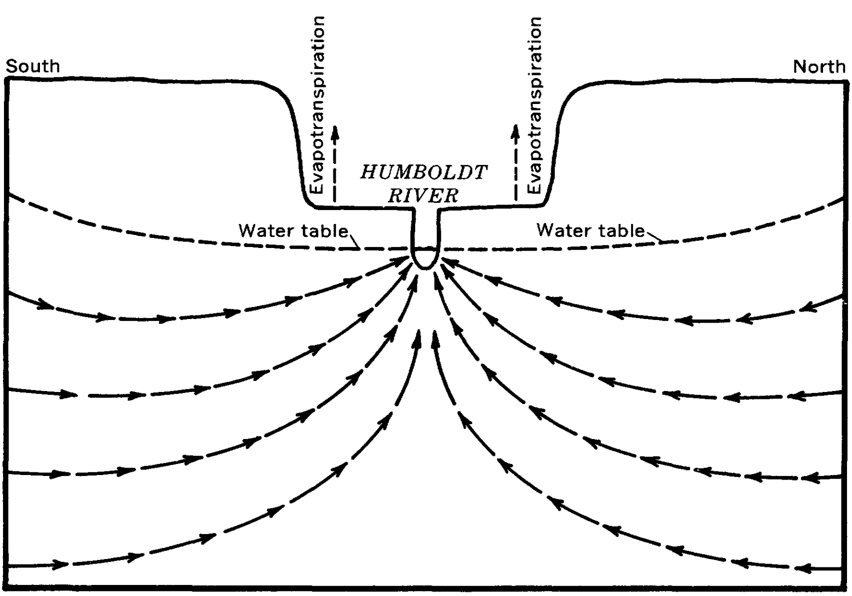

FIGURE 9.—Direction of ground-water movement in the Humboldt River valley near Winnemucca when the stage and flow of the river are low.

flood plain and the bordering terraces, and two troughs are formed in the water table, one on each side of the ground-water ridge. Ground water moves into these troughs and thence westward and southwestward downstream, parallel to the river. In the late summer the ground-water ridge subsides because of evapotranspiration and seepage to the river, and water-level contour lines, if drawn on a map, would again resemble those shown on plate 1E and in figure 9.

The velocity, or rate, of ground-water flow depends on three factors: the permeability, or the ease with which water can move through the saturated deposits; the hydraulic gradient; and the porosity, or the percentage of open spaces in the deposits. In general the flow velocity in coarse material such as sand and gravel is greater than that in fine material, such as silt and clay. Typical values for the velocity of ground-water flow in the project area range from a few tens of feet to about a thousand feet per year.

STORAGE

Ground water in storage is the water in the zone of saturation that will drain by gravity when water levels are lowered. It is less than the total amount of water in the zone of saturation because some water will be retained in the deposits by capillary and other attracting forces. The amount of water that drains from the saturated deposits, expressed as percentage of the total volume of the material, is known as the specific yield.

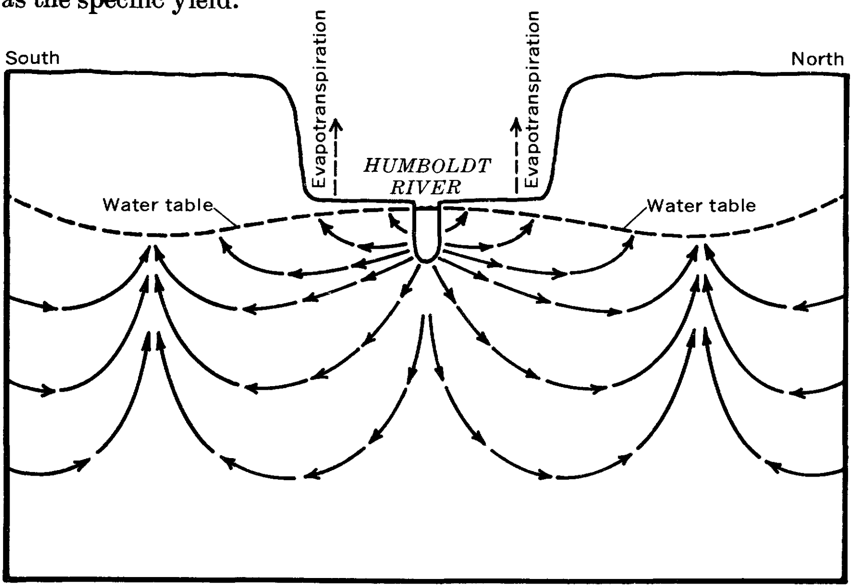

FIGURE 10—Direction of ground-water movement in the Humboldt River valley near Winnemucca when the stage and flow of the river are high.

Plate 1G shows the approximate saturated thickness of the medial gravel subunit. The total saturated volume of the subunit is about 2.5 million acre-feet, and the estimated average specific yield of the subunit is 20 percent (Cohen, 1963b, p. 81). Thus, total ground water in storage in the subunit is about 500,000 acre-feet. The volume of the upper 100 feet of saturated unconsolidated deposits adjacent to the medial gravel subunit is about 15 million acre-feet in the remainder of the project area; the average specific yield of these deposits is presumed to be 10 percent. Accordingly, these deposits contain an additional, estimated 1.5 million acre-feet of ground water in storage. Total ground water in storage in the upper 100 feet of unconsolidated deposits in the zone of saturation in the project area is therefore about 2 million acre-feet, or more than 10 times the capacity of Rye Patch Reservoir (the largest surface reservoir on the river).

The amount of ground water in storage varies seasonably and annually. Increases in the amount of ground water in storage are accompanied by rises in the ground-water levels; the converse is also true. Figure 11 shows that ground-water levels beneath the flood plain respond to and are related closely to changes in the stage of the Humboldt River; the higher the stage of the river, the higher the ground-water levels and the more ground water in storage.

The computed net changes of ground water in storage for four selected time intervals are listed in table 6. (See Cohen, 1963b, p. 81.) For the 14-year period water years 1949–62, the average annual net change of ground water in storage was zero, or very nearly zero (table 6). However, the estimated average annual net increase of ground

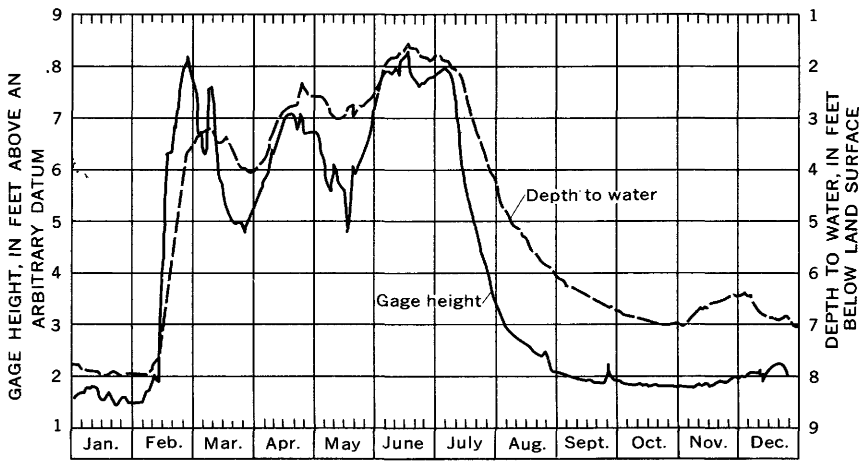

FIGURE 11.—Stage of the Humboldt River at the Winnemucca gaging station, and water level in well 36/38–19ddc1, 500 feet from river and 18 feet deep, calendar year 1962.

water in storage from December through June of water years 1949–62, when ground-water levels were at or near their yearly lows and highs, respectively, was 10,000 acre-feet.

TABLE 6.—*Estimated net increase of ground water in storage near Winnemucca, Nev., for four selected time intervals*

Period	*Net increase of ground water in storage (acre-ft)*
Water years 1949–62 (avg ann.)	0
December–June, water years 1949–62 (avg)	10,000
Water year 1962	5,000
December–June, water year 1962	26,000

Humboldt River streamflow into the storage area measured at the Comus gaging station, was about 125,000 acre-feet above average in water year 1962 (fig. 4). Ground-water levels beneath the flood plain rose markedly, locally more than 8 feet, in the late winter and spring as a result of the above-average streamflow. This, in turn, resulted in an estimated net increase of ground water in storage of 26,000 acre-feet in the period December–June of water year 1962, or about 16,000 acre-feet more than average. By the end of the water year, much of the increased ground water in storage had been consumed by evapotranspiration or had discharged into the river; however, even then there was still an estimated 5,000 acre-feet more ground water in storage than at the beginning of the water year.

Although the net increase of ground water in storage was substantial in December–June of water year 1962, it was only slightly more than 1 percent of the total amount of ground water in storage in the upper 100 feet of the zone of saturation in the project area. The average thickness of the zone of saturation is probably more than 1,000 feet, therefore, seasonal changes in the amount of ground water in storage are almost negligible as compared with the total amount of ground water in storage.

VADOSE WATER

In 1961 A. O. Waananen of the U.S. Geological Survey began an investigation designed to evaluate the effectiveness of a neutron-scattering soil-moisture meter in studying the movement and storage of water in the zone of aeration in the shallow flood-plain deposits in the Winnemucca area. (See Waananen, 1963.) Although these studies were not designed to yield quantitative answers for the entire storage area, the data obtained have provided a rough indication of the changes in moisture content in the zone of aeration (Cohen, 1963b, p. 83–84). These changes reflect differences in the amount of water moving into and out of the zone of aeration during a given period of time (table 7). When more water moves into the zone than is discharged from it, the moisture content increases; the converse is also true.

TABLE 7.—*Estimated net increase in moisture content in the zone of aeration in the storage area near Winnemucca, Nev., for three selected time intervals*

Time interval	*Net increase in moisture content (acre-ft)*
Water years 1949–62 (avg ann.)	0
Water year 1962	10, 000
December–June, water year 1962	17. 000

DISCHARGE OF WATER

HUMBOLDT RIVER STREAMFLOW NEAR ROSE CREEK GAGING STATION

The Humboldt River streamflow, as measured at the Rose Creek gaging station (fig. 2, item 14), normally represents the largest quantity of water discharged from the storage area in a given year. Since the beginning of the period of record (water yr 1949), it has ranged from a high of about 536,000 acre-feet in water year 1952 to a low of about 22,000 acre-feet in 1955 (fig. 12). The average annual flow for the period 1949–62 was 155,400 acre-feet; it was 242,900 acre-feet in water year 1962, and 187,800 acre-feet in December–June of that year.

Overall yearly streamflow characteristics at the Rose Creek gaging station (fig. 12) were very similar to those at the Comus gaging station (fig. 4). Streamflow, however, was less at the Rose Creek than at the Comus gaging station for 10 of the 14 years of common record; it ranged from nearly 5,200 acre-feet less in water year 1955 to about 54,000 acre-feet less in water year 1962 (fig. 13). In the other 4 years, streamflow was greater at the Rose Creek gaging station than at the Comus gaging station; it ranged from about 700 acre-feet more in water year 1954 to about 15,000 acre-feet more in water year 1958. In the 14-year period, water years 1949–62, the average annual streamflow at the Rose Creek gaging station was nearly 17,000 acre-feet less than that at the Comus gaging station.

On the average the flow of the Humboldt River decreased between the Comus and the Rose Creek gaging stations in the months of February–June of water years 1949–62. Table 8 shows that streamflow averaged about 28,000 acre-feet more at the Comus gaging station than at the Rose Creek gaging station during these months. The decrease in flow between the two stations in February–June was about 11,000 acre-feet more than the average annual decrease in flow.

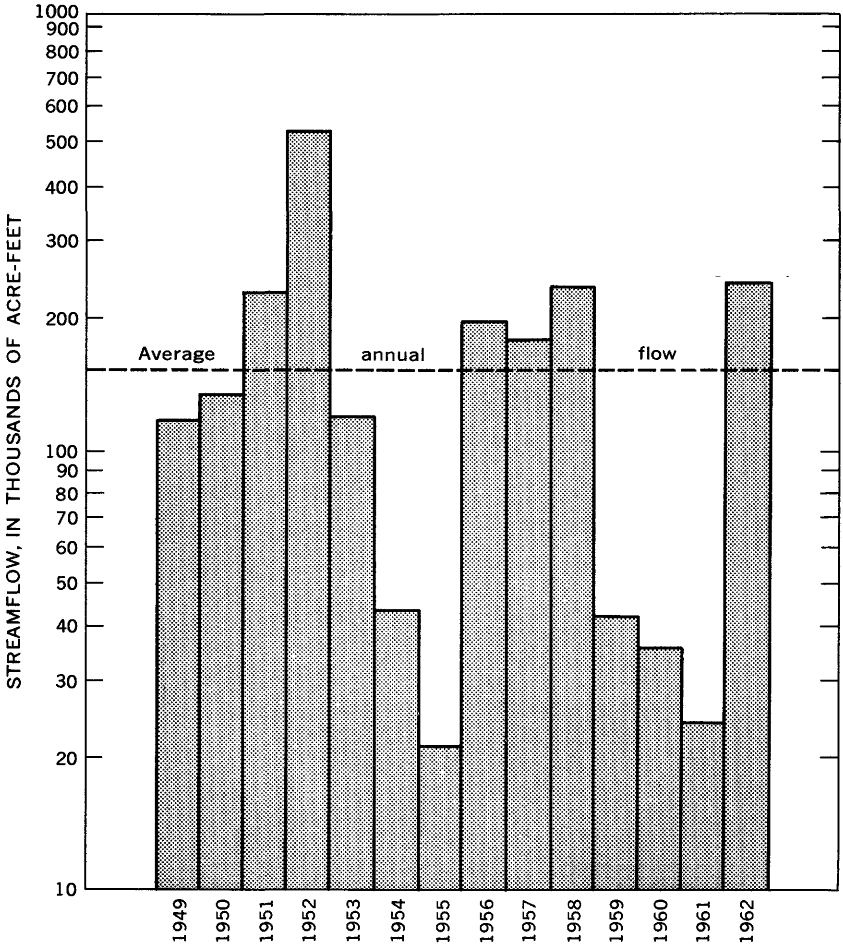

FIGURE 12.—Annual flow of the Humboldt River at the Rose Creek gaging station, water years 1949–62.

TABLE 8.—*Average decrease in flow of the Humboldt River between the Comus and Rose Creek gaging stations, February–June of water years 1949–62*

	Streamflow (acre-ft)		
	Avg at Comus gaging sta.	Avg at Rose Creek gaging sta.	Decrease
February	11, 300	8, 780	2, 520
March	18, 620	16, 950	1, 670
April	33, 560	23, 750	9, 810
May	41, 030	36, 380	4, 650
June	40, 500	31, 120	9, 380
Total (rounded)	145, 000	117, 000	28, 000

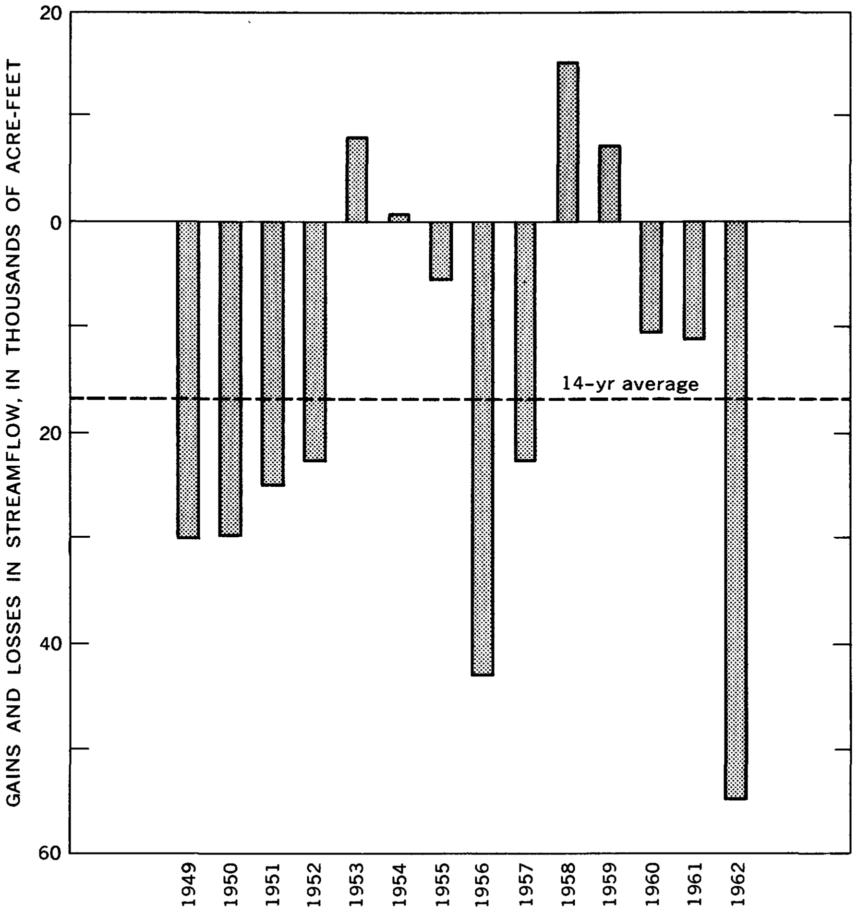

FIGURE 13.—Gains and losses in streamflow between the Comus and Rose Creek gaging stations, water years 1949–62.

On the average, the flow increased by about 11,000 acre-feet in July–January of water years 1949–62 (table 9), which thereby accounts for the difference between the average annual loss in streamflow and the loss in the months of February–June.

The decrease in flow between the Comus and Rose Creek gaging stations in February–June was a result of seepage from the river to the ground-water reservoir (fig. 2, item 8), diversions for irrigation (fig. 2, item 6), and evapotranspiration (fig. 2, item 11). Tributary streamflow was almost negligible; therefore, almost the entire increase in flow in July–December was due to ground water discharging into the river between the two stations (fig. 2, item 20). In July and August most water that seeped into the river was ground water de-

TABLE 9.—*Average increase in flow of the Humboldt River between the Comus and Rose Creek gaging stations, July–January of water years 1949–62*

	Streamflow (acre-ft)		
	Avg at Comus gaging sta.	Avg at Rose Creek gaging sta.	Increase
July	16, 220	19, 570	3, 350
August	1, 940	4, 590	2, 650
September	131	2, 100	1, 970
October	79	1, 670	1, 590
November	1, 040	2, 030	990
December	3, 080	3, 650	570
January	4, 660	4, 840	180
Total (rounded)	27, 000	38, 000	11, 000

rived mainly from the river and stored in the flood-plain deposits during the previous high-water season. As the rate of seepage to the river decreased in September and October, the proportion of ground-water inflow that discharged from tributary areas into the river increased. Normally, by December and January almost all ground water that discharges into the river is inflow from tributary areas.

EVAPOTRANSPIRATION OF PRECIPITATION

Of the approximately 59,000 acre-feet of average annual precipitation on the storage area near Winnemucca (pl. 1D), about 600 acre-feet falls on the Humboldt River and about 2,000 acre-feet recharges the ground-water reservoir, as previously noted (p. 28). Almost all the remainder of the precipitation, an average of about 56,000 acre-feet per year, evaporates from the land surface soon after it falls or is stored in the zone of aeration and subsequently consumed by evapotranspiration (fig. 2, items 12, 13). In water year 1962 about 57,000 acre-feet of precipitation was consumed by evapotranspiration in the storage area in this manner; about 40,000 acre-feet of this amount was lost during December–June (Cohen, 1963b, p. 68).

Once precipitation falls on the Humboldt River or percolates downward into the zone of saturation it cannot be distinguished from the streamflow or the ground water with which it mixes. Thus, an unknown but fairly small quantity of water originating as precipitation on the storage area probably evaporates from the free-water surface of the Humboldt River and is lost by evapotranspiration from the zone of saturation. In addition, a very small percentage of the precipitation on the storage area is probably discharged from the area as Humboldt River streamflow and as ground-water outflow near the Rose Creek gaging station. These losses of precipitation cannot be computed separately; however, they are included in the estimates given in other parts of this section.

TRANSPIRATION BY PHREATOPHYTES AND EVAPORATION FROM BARE SOIL

Phreatophytes are plants that obtain a substantial part of their water supply from the zone of saturation (fig. 2, item 18). The loss of water from areas covered by phreatophytes in the Winnemucca area, including the amount transpired by the plants and the amount evaporated from bare soil, is being intensively investigated as part of the Humboldt River Research Project. T. W. Robinson of the U.S. Geological Survey is in charge of the studies of the woody phreatophytes (Robinson, 1963), and A. S. Dylla of the U.S. Agricultural Research Service is in charge of the studies of the grasses.

The phreatophyte studies are not completed; however, the available data permit fairly accurate preliminary estimates of these evapotranspiration losses. Most precipitation on the storage area evaporates from the land surface soon after it falls; therefore, the estimates given in the following table do not include these losses. The preliminary estimates of evapotranspiration losses from the areas covered by phreatophytes listed in table 10 are based on unpublished data supplied by agencies cooperating in the project (T. W. Robinson, written commun. 1964; A. S. Dylla, written commun. 1964; and E. A. Naphan, written commun. 1964) and the interpretation and extrapolation of these data by the writer.

TABLE 10.—*Preliminary estimates of evapotranspiration losses from areas covered by phreatophytes in the storage area near Winnemucca, Nev.*[1]

Phreatophyte classes [2]	Acreage	Estimated evapotranspiration losses for water year indicated (acre-ft)		
		1949–62 (avg ann.)	1962	December–June, 1962
Grass	10, 020	13, 000	14, 000	4, 300
Willow and wildrose	5, 470	20, 000	22, 000	7, 000
Cattail and bullrush	460	2, 100	2, 300	700
Greasewood	16, 780	6, 000	6, 700	2, 100
Rabbitbrush	2, 310	3, 800	4, 200	1, 300
Total (rounded)	35, 000	45, 000	50, 000	15, 000

[1] Does not include evapotranspiration losses of precipitation from the land surface and from the zone of aeration.

[2] Major vegetation types; include lesser amounts of associated plants. Grass, willow, wildrose, cattail, and bullrush are included in the "grass and willow" vegetation unit shown on plate 1B.

EVAPORATION FROM OPEN BODIES OF WATER

The amount of water evaporated from open bodies of water (fig. 2, item 12) depends mainly on the rate of evaporation and on the area of the open bodies of water (the area of free-water surface). Hanson (1963, p. 53–55) studied the relation between the average flow of the Humboldt River at the Comus and Rose Creek gaging stations and the area of the free-water surface of the river (fig. 14). He found that, for example, when the flow of the river at the two gaging stations averaged 20 cfs, the area of the free-water surface was about 1,000 acres; when the streamflow averaged 5,000 cfs, the river was in flood, and the area of the free-water surface was 12,000 acres.

Rates of evaporation from open bodies of water were estimated on the basis of limited evaporation-pan data available for the Winnemucca area and data obtained in nearby areas. Using these data, the available streamflow data, and the relation that is shown in figure 14, Hanson computed the relation between the annual flow of the Humboldt River at the Comus gaging station and the amount of water evaporated from the free-water surface of the Humboldt River in the Winnemucca area (fig. 15). These estimated evaporation losses ranged from a high of 23,400 acre-feet in water year 1952 to a low of 4,650 acre-feet in water year 1955.

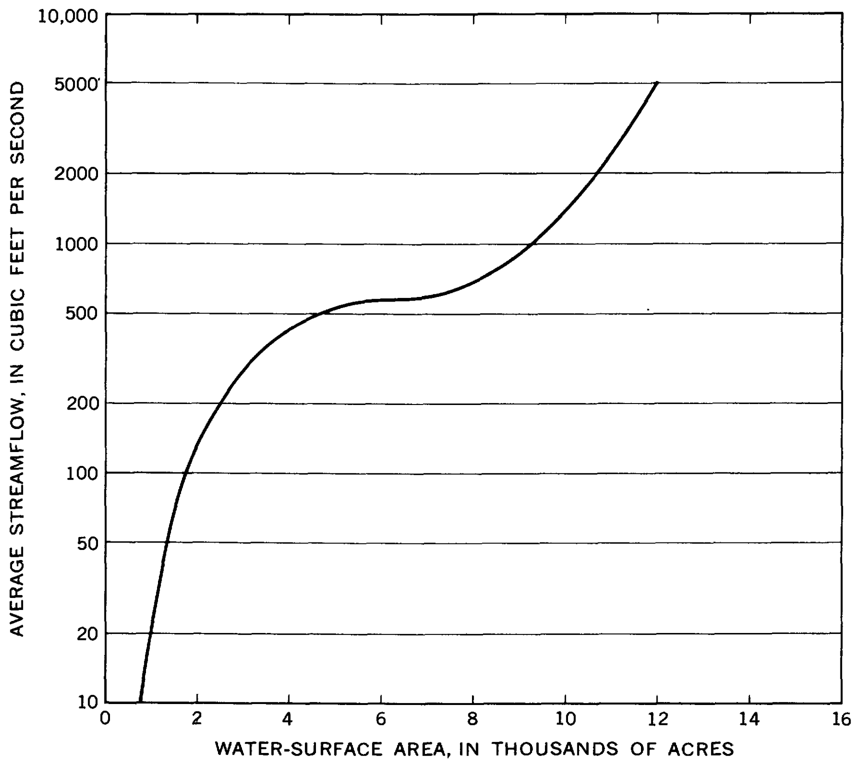

FIGURE 14.—Relation of the total free-water-surface area of the Humboldt River between the Comus and Rose Creek gaging stations to the average of streamflow at the two stations. (After Hanson, 1963, fig. 22.)

The estimated evaporation from the free-water surface of the Humboldt River for the three periods selected for water-budget analysis is summarized in table 11.

TABLE 11.—*Evaporation loss from the free-water surface cf the Humboldt River in the storage area near Winnemucca, Nev.*

Water year	*Evaporation loss (acre-ft)*
1949–62 (avg ann.)	14, 000
1962	21, 400
December–June, 1962	14, 000

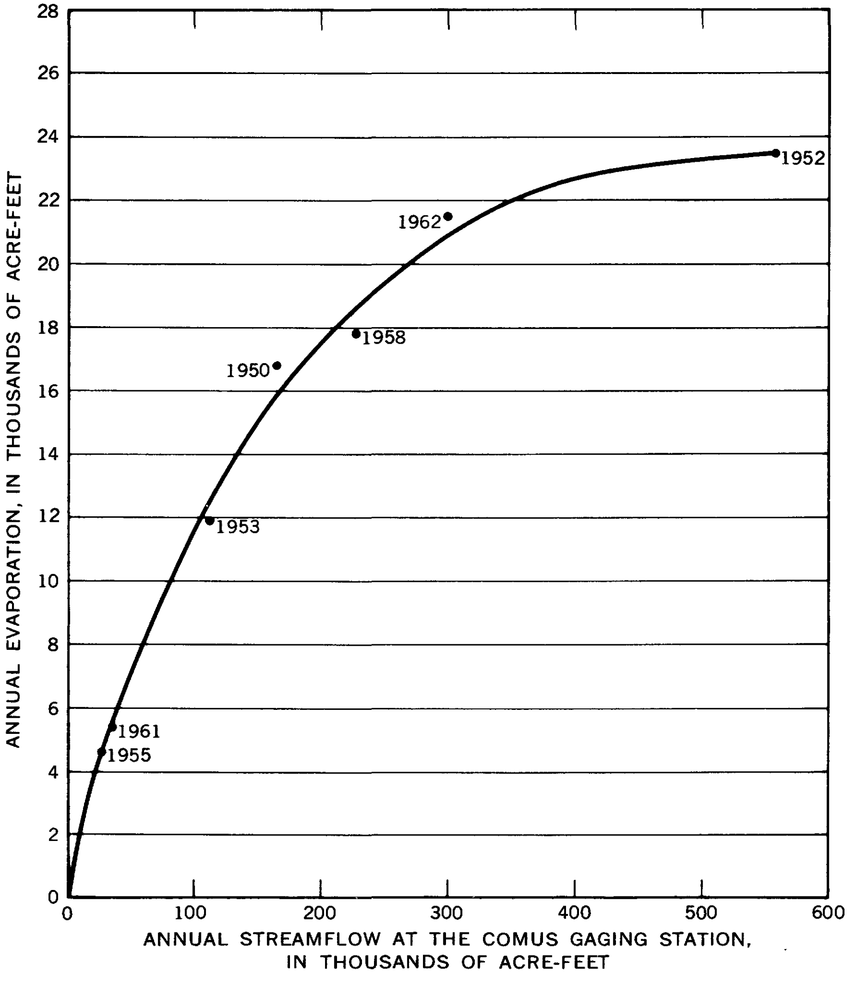

FIGURE 15.—Relation of annual streamflow at the Comus gaging station to annual free-water-surface evaporation losses between the Comus and Rose Creek gaging stations. (After Hanson, 1963, fig. 23.)

On the basis of Hanson's work, the estimates of evaporation from free-water surfaces include most but not all of the evaporation losses from free-water surfaces in the storage area. During the irrigation season thousands of acres on the flood plain are covered by water, commonly for days and sometimes for weeks at a time, as a result of artificial overbank flooding for irrigation. The amount of water lost by evaporation as a result of this method of irrigation was not studied and, thus, is not known; it probably ranges from several hundred to several thousand acre-feet per year, depending largely on the availability of Humboldt River water for irrigation.

Nearly all the remainder of the large amount of water evaporated from free-water surfaces in the storage area is lost from ephemeral pools and puddles formed as a result of infrequent rain showers. It is very difficult to compute the amount of water evaporated in this manner; however, the amount is included in the estimates of the evapotranspiration of precipitation stated previously (p. 36).

GROUND-WATER OUTFLOW

All ground-water outflow from the storage area (fig. 2, item 22) occurs at the downstream margin of the project area. Available data are insufficient to enable the direct calculation of the amount of ground-water outflow near station *U* (Rose Creek gaging sta.); however, outflow can be estimated by computing the underflow that occurs roughly parallel to the river near station *S* (pl. 1D).

Detail geophysical, geologic, and hydrogeologic studies (Dudley and McGinnis, 1962; Hawley and Wilson, 1964; McGinnis and Dudley, 1964; Cartwright, Swinderman, and Gimlett, 1964; and Cohen, 1962a) have shown that a fault bordering the west side of the East Range extends northward beneath the Humboldt River near station *S* (Pl. 1C). Owing to displacement along the fault, virtually impermeable consolidated rock underlies the flood plain at a depth of about 40–50 feet; the consolidated rock, in turn, is overlain almost solely by the medial gravel subunit. Nearly all ground-water outflow is roughly parallel to the Humboldt River near station *S* and is through the medial gravel. This outflow is about 2.5–3.5 cfs (Cohen, 1963b, table 16).

During most of the year about 1 cfs is lost between stations *S* and *U*, because water moves from the river to the ground-water reservoir as a result of the substantial increase in the cross-sectional area of the medial gravel subunit downstream from station *S*. Ground-water inflow toward the river between stations *S* and *U* is negligible. Thus, the estimated average annual underflow leaving the storage area near station *U* is equal to the underflow past station *S* plus the 1 cfs of water derived from the river by seepage loss between stations *S* and *U*, or about 3.5–4.5 cfs, which is approximately 3,000 acre-feet per year. Ground-water outflow in water year 1962 was nearly equal to the average annual ground-water outflow, and outflow in the period December–June 1962 was about 1,800 acre-feet.

PUMPAGE AND SPRING FLOW

Gross pumpage is the total amount of water removed from the ground-water reservoir through wells (fig. 2, item 21). Some pumped water returns to the ground-water reservoir by infiltration, and a few hundred acre-feet of pumped water discharges into the Humboldt River through the Winnemucca sewage plant. The remainder, termed the "net pumpage," is removed from the storage area by evapotranspiration. The estimated net pumpage for the three time intervals of interest is as follows:

Water year	*Estimated net pumpage (acre-ft)*
1949–62 (avg ann.)	1,500
1962	3,000
December–June, 1962	1,000

Average annual spring flow in the storage area is about 250 gpm, or about 400 acre-feet per year. Most of this water is consumed by evapotranspiration; however, because all the spring flow is thermal and its ultimate source is not known, spring flow is not included in either the inflow or outflow data listed in the water budgets (table 13).

SUMMARY OF TOTAL OUTFLOW

The estimated average annual outflow from the storage area near Winnemucca in water years 1949–62 and the percentage of the total represented by each major outflow items are as follows:

Outflow item	*Average annual outflow (acre-ft)*	*Percent of total*
Humboldt River	155,400	57
Evapotranspiration of precipitation	56,000	20
Transpiration by phreatophytes and evaporation from bare soil [1]	45,000	16
Evaporation from free-water surfaces	14,000	5
Ground-water outflow	3,000	1
Net pumpage	1,500	<1
Total (rounded)	275,000	100

[1] Does not include the evapotranspiration of precipitation.

CHEMICAL QUALITY OF THE WATER

Almost all the many thousands of compounds and elements above, on, and beneath the earth's surface are to some extent soluble in water. Therefore, nearly all water that occurs naturally contains dissolved solids. In the small quantities in which they commonly occur, most of these dissolved solids are harmless; in fact, many substances found in water are necessary for proper nutrition of plants and animals, including man. Some material dissolved in water can be harmful if quantities are only slightly higher than the optimum amounts needed. One of the major objectives of the water-resources studies carried on as part of the Humboldt River Research Project was, consequently, an evaluation of the chemical suitability of the water for use. (See Cohen, 1962d.)

In addition, water-quality data are commonly very helpful in evaluating many other features of the water resources of an area, such as the source and amount of water entering the area, and its rate and direction of movement. Water-quality data were used to study these and other features of the water resources of the Winnemucca area (Cohen, 1962d, 1963b).

Some significant results of the water-quality studies are summarized in the following paragraphs.

DEFINITION OF TERMS

"Dissolved solids," or "dissolved-solids content," refers to the substances dissolved in water. The values for dissolved-solids content given in this report are the sums of the constituents for which analyses were made, expressed in parts per million—the weight of dissolved material in 1 million parts of water. Water in the Winnemucca area is classified according to dissolved-solids content as follows:

Dissolved-solids content (ppm)	*Classification*
150–300	Very low
300–500	Low
500–750	Moderate
750–1,000	Moderately high
1,000–2,000	High
>2,000	Very high

Most water that occurs naturally will conduct an electrical current; its conductivity depends mainly on the number and kinds of ions in solution and on the temperature of the water. "Specific conductance" (expressed in micromhos per centimeter at 25°C) is a measure of the ease with which the electricity will pass through water and is therefore a rough measure of the dissolved-solids content of water.

Hardness of water is caused principally by dissolved calcium and magnesium and is commonly expressed in parts per million of calcium carbonate. The following numerical ranges and terms are used to classify water hardness in this report:

Hardness (ppm of $CaCO_3$*)*	*Classification*
0–60	Soft
61–120	Moderately hard
121–180	Hard
>180	Very hard

VARIATIONS IN WATER QUALITY

GROUND WATER

Plate 1H shows the dissolved-solids content of the ground water in the area, based on 176 chemical analyses. (See Cohen, 1962d, tables 1, 2, for representative chemical analyses.) Many of the wells and springs were sampled more than once (during periods of low, moderate, and high ground-water levels in 1961 and 1962) to determine whether the water quality changed with time, especially from season to season. Water samples were also obtained, where possible, from nearby wells of different depths to evaluate vertical changes in quality. Throughout most of the area the water quality did not change appreciably with depth; however, marked changes were noted locally.

The dissolved-solids content and, accordingly, the chemical quality of the ground water vary considerably from place to place within the Winnemucca reach of the Humboldt River valley (pl. 1H). Throughout almost the entire project area, most ground water beneath the flood plain of the Humboldt River and the immediately adjacent benchlands is of the sodium bicarbonate type, and its dissolved-solids content ranges from 500 to 750 ppm.

Ground water sampled from several small areas on the flood plain had a high to very high dissolved-solids content. Most of these samples reflected highly localized conditions or the fact that they were obtained from shallow test borings, or a combination of the two factors. Large amounts of salts have accumulated in many places on the flood plain as a result of evapotranspiration. Shallow wells that tap these highly saline flood-plain deposits or their subsurface equivalents yield sodium chloride or calcium sulfate water high in dissolved solids. Wells that tap deposits beneath these saline materials, however, generally yield sodium bicarbonate water of moderate dissolved-solids content.

Ground water in most of that part of Paradise Valley shown on plate 1H has a low dissolved-solids content. A small area in the northeastern part is underlain by ground water of very low dissolved-solids content; a 61-foot-deep flowing well in sec. 39, T. 37 N., R. 39 E., yields thermal sodium bicarbonate water having a high dissolved-solids content and a temperature of 158°F. Shallow wells that tap fine-grained saline lacustrine deposits near the southwest corner of Paradise Valley yield sodium chloride and mixed-type water having high to a very high dissolved-solids content.

Ground water in the drainage basins of Pole and Rock Creeks and most ground water in Grass Valley is the calcium bicarbonate type and is low in dissolved solids. This water is derived mainly from the infiltration of streamflow draining the Sonoma Range. Calcium and bicarbonate are the most abundant ions in this water because the Sonoma Range consists mainly of limestone ($CaCO_3$). Ground water in Grass Valley that had a moderate to very high dissolved-solids content (pl. 1H) was obtained from shallow wells that tap the highly saline silt and clay deposits of Lake Lahontan age.

Near the southwest margin of the project area, thermal calcium bicarbonate ground water associated with the East Range fault has a moderately high to very high dissolved-solids content. This water is very similar to the thermal water that issues from the previously described flowing well in Paradise Valley and to the water that issues from springs near the east margin of the project area. Thermal springs near the town of Golconda also discharge sodium bicarbonate water of similar chemical quality. These widely spaced sources of thermal artesian ground water of similar chemical quality suggest the possibility of a single, widespread thermal ground-water system at depth.

The chemical quality of all the thermal ground water and of much of the rest of the ground water that was sampled more than once did not change significantly with time. The quality of the water from some of the shallow wells, notably from some of the shallow wells on the flood plain, however, changed considerably with time. Most of these shallow wells are fairly close to the Humboldt River and tap deposits that are in hydraulic continuity with the river; that is, during periods of high-river stage, water moves from the river into these deposits, and during periods of low-river stage, water moves from the deposits into the river.

SURFACE WATER

The chemical quality of the Humboldt River and that of most ground water in the shallow deposits are closely related. The specific conductance varies inversely with the flow of the Humboldt River (fig. 16). Thus, during periods of high flow the dissolved-solids content of the river and of most of the ground water in the shallow deposits adjacent to the river decreases markedly. Locally, however, the dissolved-solids content of the ground water increases during these same periods because the water table rises into highly saline silty and clayey flood-plain deposits.

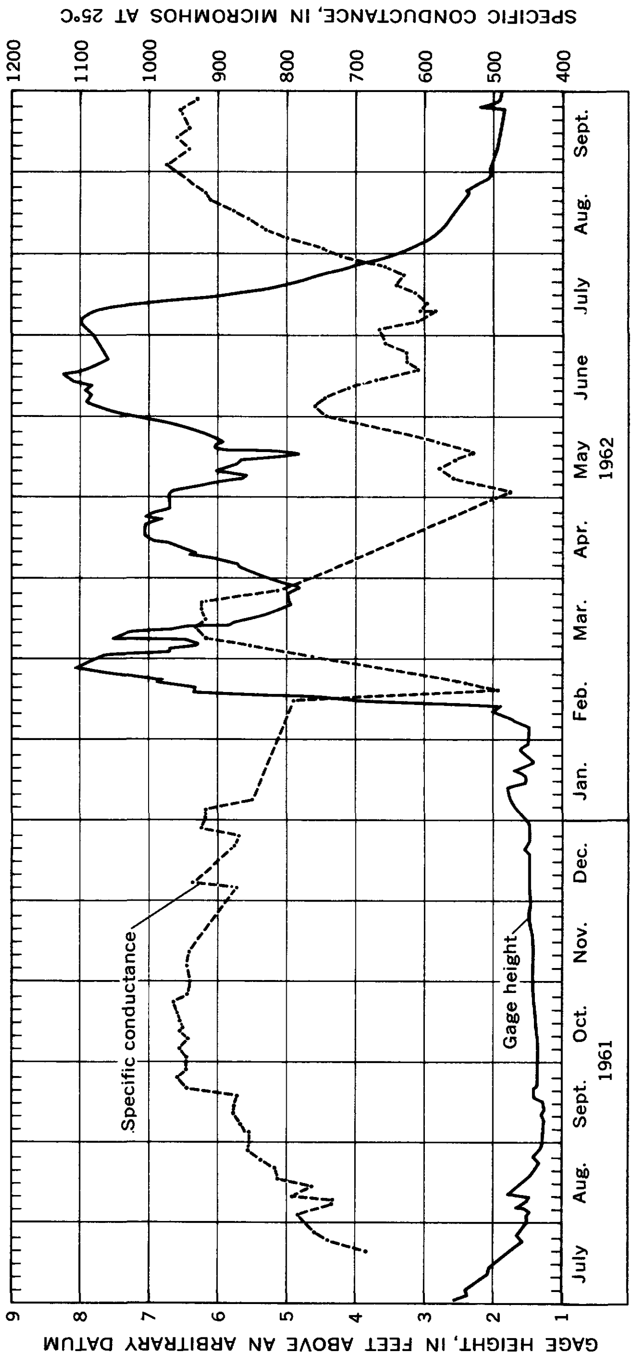

FIGURE 16.—Relation between specific conductance and gage height of the Humboldt River at the Winnemucca gaging station (sta. *M*), 1961–62.

Normally the stage and flow of the river are highest in the late winter and spring. At that time almost all streamflow is derived from rain and snowmelt runoff; therefore, the specific conductance of the water is commonly the lowest of the year—about 475–500 micromhos at the Winnemucca gaging station (sta. M, pl. 1D). In the late summer and fall when the stage and flow of the river are at or near their lowest of the year, streamflow consists almost entirely of ground-water seepage, and specific conductance is the highest of the year, about 950–975 micromhos at the Winnemucca gaging station.

During periods of low streamflow in the late fall and early winter, the chemical quality of the river water closely reflects that of underflow from the tributary areas. Downstream the flow and the chemical quality change because of interchange between the river and the ground-water reservoir. (See Cohen, 1963b, p. 89–92.)

Changes in the chemical quality of the river between the Comus and Rose Creek gaging stations in December 1961 and estimates of ground-water inflow from Grass Valley based on water-quality data are considered in detail in other reports (Cohen, 1962d, p. 18–20; 1963b, p. 89–92). The more significant of these changes are briefly summarized in the following paragraphs.

The flow of the Humboldt River at station *A* was about 0.05 cfs and was a mixture of sodium chloride and sodium bicarbonate water of moderately high to very high dissolved-solids content derived from the deposits in the vicinity of and upstream from the Comus gaging station. At station *B* the flow increased to 0.4 cfs and the dissolved-solids content decreased to 836 ppm as a result of seepage of ground water of moderate dissolved-solids content into the river. The river was dry at station *C*, but the dissolved-solids content of water from a pool in the streambed was 585 ppm. The flow and dissolved-solids content increased to 0.21 cfs and 752 ppm, respectively, at station *E*, as a result of seepage into the river of ground water of moderate to moderately high dissolved-solids content.

At station *G* the flow increased to 1.23 cfs, and the dissolved-solids content decreased to 559 ppm, mainly as a result of inflow to the river of calcium bicarbonate ground water of low dissolved-solids content from the drainage basin of Rock Creek. The flow and dissolved-solids content increased at station *H*, owing to continued ground-water inflow. At station *N* the flow increased to 5.07 cfs, and the dissolved-solids content decreased to 489 ppm, mainly because of seepage to the river of ground-water inflow from the Pole Creek drainage basin and Paradise Valley.

Between stations *N* and *O* the width of the medial gravel unit increased markedly and caused the river to lose water to the ground-water reservoir; the dissolved-solids content of the river remained almost unchanged between the two stations in December 1961. The inflow of ground water of very low to low dissolved-solids content mainly from Grass Valley caused the streamflow to increase to 14.8 cfs and the dissolved-solids content to decrease to 453 ppm between stations *O* and *S*. The flow decreased to about 13.5 cfs at station *U*, and the dissolved-solids content was almost unchanged from that at station *S*.

SUITABILITY FOR USE

The industrial use of water in the project area was negligible during the investigation. Standards for the chemical quality of water for such use are extremely variable; therefore, only the chemical suitability of the water for domestic and agricultural use was studied in detail. (See Cohen, 1962d.) Available data, however, indicate that most water in the Winnemucca area probably is chemically suitable for most industrial uses.

Table 12 summarizes the source of the chemical constituents for which analyses were made as part of the present investigation and the significance of these constituents with respect to the suitability of the water for use. Some thermal water near the Comus gaging station, the water issuing from the springs near Golconda, and much ground water near the East Range fault contain excessive amounts of boron and fluoride and are therefore not suitable for agricultural or domestic use. Some ground water in the shallow flood-plain deposits that also has a high to very high dissolved-solids content is unsuitable for many uses. Nevertheless, most ground water and almost all surface water in the area is of good to excellent quality and is chemically suitable for most agricultural and domestic uses.

TABLE 12.—*Principal sources and significance with respect to suitability for use of selected chemical constituents in the water of the Humboldt River valley near Winnemucca, Nev.*

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)	Calcium-bearing feldspars which constitute as much as 50 percent of some 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.

TABLE 12.—*Principal sources and significance with respect to suitability for use of selected chemical constituents in the water of the Humboldt River valley near Winnemucca, Nev.*—Continued

Constituent	Principal sources	Significance with respect to suitability for use
Magnesium (Mg)	Pyroxenes and amphiboles in igneous rocks. Magnesium salts in the unconsolidated deposits.	Second of the major causes of hardness.
Sodium (Na)	Sodium-bearing feldspars in acidic volcanic rock 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 give water a salty taste.
Potasium (K)	Potassic feldspars in silicic igneous rock. Potassium salts are probably scarce in the unconsolidated deposits.	Essential for proper plant nutrition.
Bicarbonate (HCO_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 impart a 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 45 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 with 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.

SUMMARY OF THE FLOW SYSTEM

The quantitative aspects of the flow system in the storage area near Winnemucca are summarized by means of three water-budget analyses (table 13). The storage area (pl. 1D) includes only about 28 percent of the project area—the area termed the "Humboldt River valley near Winnemucca"—which, in turn, represents only about 3 percent of the entire Humboldt River drainage basin. Development in this fairly small part of the basin could conceivably affect both the downstream water supply and, because of established water rights, the upstream supply.

TABLE 13.—*Three water budgets for the storage area near Winnemucca, Nev.*

Water-budget components	Water years 1949–62; 14-year average (acre-ft)	Water year 1962 (acre-ft)	December–June, water year 1962 (acre-ft)
Inflow:			
Humboldt River streamflow at the Comus gaging station (p. 18–19)	172, 100	297, 200	254, 300
Precipitation (p. 23)	59, 000	60, 000	47, 000
Ground-water inflow (p. 24)	14, 000	14, 000	8, 000
Tributary streamflow (p. 23)	[3] 8, 600	5, 800	5, 000
(1) Total inflow	253, 700	377, 000	314, 300
Outflow:			
Humboldt River streamflow at the Rose Creek gaging station (p. 33)	155, 400	242, 900	187, 800
Evapotranspiration of precipitation (p. 36) [1]	56, 000	57, 000	40, 000
Transpiration by phreatophytes and evaporation from bare soil (table 10) [2]	45, 000	50, 000	15, 000
Evaporation from open bodies of water (table 11)	14, 000	21, 400	14, 000
Ground-water outflow (p. 41)	3, 000	3, 000	1, 800
Net pumpage (p. 41)	1, 500	3, 000	1, 000
(2) Total outflow	274, 900	377, 300	259, 600
Net increase in storage:			
Surface water (p. 27)	0	1, 800	22, 000
Ground water (table 6)	0	5, 000	26, 000
Vadose water (table 7)	0	10, 000	17, 000
(3) Total increase in storage	0	16, 800	65, 000
(4) SUM (2+3)	274, 900	394, 100	324, 600
Difference (1−4)	−21, 200	−17, 100	−10, 300

[1] Mainly evaporation from land surface; includes small amount of evapotranspiration from zone of aeration.
[2] Does not include evapotranspiration losses of precipitation from land surface and from zone of aeration; mainly includes evapotranspiration of water derived from zone of saturation.
[3] Includes artificial drainage of Gumboot Lake; therefore, is 4,100 acre-feet more than the value in table 27 of Cohen (1963b).

CONCEPT OF DYNAMIC EQUILIBRIUM

The flow system in the project area as summarized in figure 2 is nearly in a state of long-term dynamic equilibrium. In this context, the term "dynamic" means a constant state of motion and refers to the fact that water in the storage area is continually moving. The rate of movement of surface water ranges from a few feet per second when the Humboldt River is in flood to almost 0 feet per second in pools of standing water. Even in these pools the water is moving. The word "equilibrium" refers to a state of balance in the flow system. Thus, when the flow system is referred to as being in a state of long-term dynamic equilibrium, it is implied that over a long period of time the amount of water entering the system is balanced by, or is equal to, the amount of water leaving the system.

The flow system in the storage area was in a state of long-term dynamic equilibrium prior to the development of water by man. The equilibrium has been disturbed only slightly, if at all, as a result of the activities of man because (1) the additional net draft has been very small as compared to the total amount of water entering and leaving the system, and (2) the additional draft has in part been compensated for by decreased natural losses from the system. Thus, the flow system of the storage area is still nearly in a state of long-term dynamic equilibrium.

WATER-BUDGET ANALYSIS

A water-budget analysis of the storage area is a quantitative evaluation of the flow system of the area—a tally of all items of inflow and outflow and of changes in the amount of water in storage. For any period of time, the water budget for a given area can be expressed by the equation:

$$I = O \pm St,$$

where I represents total inflow, O represents total outflow, and St, the net change in the amount of water in storage. If the amount of water in storage increases, that numerical amount is added to the right side of the equation; if it decreases, the numerical amount is subtracted. The flow system in the storage area is virtually in long-term dynamic equilibrium; hence, the long-term average annual net change in the amount of water in storage is almost zero.

Water-budget analyses were made for three periods: water years 1949–62, water year 1962, and December–June of water year 1962. The period 1949–62 was chosen because of the availability of Humboldt River streamflow data at both the Comus and Rose Creek gaging stations for that period. Water year 1962 was chosen because the largest measured loss in streamflow between the Comus and Rose Creek gaging stations, about 54,000 acre-feet, occurred during that year. The period of December–June 1962 was chosen because the largest measured changes in storage occurred then. The three water budgets are shown in table 13.

Not all items shown in the flow diagram (fig. 2) are included individually in the budget analyses. Rather, several are grouped together in the table. This grouping is necessary because it was impossible to estimate some items separately. For example, it was impossible to determine what proportion of the water lost from the zone of saturation was derived from the infiltration of precipitation, the infiltration of streamflow, and ground-water inflow. Similarly, the continual downstream interchange between the Humboldt River and the ground-water reservoir makes it impossible to identify the exact amounts of water in the river at the Rose Creek gaging station that are derived from the various sources contributing to the streamflow.

If all amounts listed in table 13 were accurate, the water-budget equation for each of the three periods would balance. The table shows that the estimates of inflow for each period are somewhat less than the sums of the outflow plus the net increases in storage; these estimates range from about 3 percent less for December–June of water year 1962 to about 10 percent less for the 14-year average of water years 1949–62. The imbalances reflect the cumulative errors in the estimates of all the components of the water budgets and are to be expected, inasmuch as the components of the flow system could not be studied as precisely as desired within the realm of economic and technological feasibility.

HOW MAN HAS MODIFIED THE NATURAL FLOW SYSTEM

To achieve the most effective use of the water resources of the Winnemucca area and of the entire Humboldt River valley, the present flow system may have to be changed significantly. Before describing modifications being considered and the possible results of these changes, the existing modifications of the natural flow system are considered. In addition, some legal aspects with regard to the use of water in the valley are briefly reviewed.

DIVERSIONS OF HUMBOLDT RIVER STREAMFLOW

The first and most significant modification of the natural flow system in the Humboldt River valley was the diversion of Humboldt River streamflow for irrigation. The early settlers found that the natural grasses growing on the flood plain, which were in part subirrigated and in part irrigated by natural flooding, made excellent hay for horses and cattle. Later, about 1870, as the larger cattle ranches became established and as the need for a more dependable and more substantial supply of winter feed for the expanding livestock industry increased, Humboldt River water was diverted for irrigation.

These early diversions were temporary rock and brush dams built in the channel to create artificial flooding. Eventually, a network of unlined ditches was completed. Most ditches were only a few miles long, and many were abandoned stream channels.

Gradually, more substantial and permanent diversionary structures were built. In 1912, the first and only major off-stream storage facilities—the Pitt-Taylor Reservoirs—were completed near the community of Humboldt, about 40 miles downstream from Winnemucca. The reservoirs, which have a combined storage capacity of 32,000 acre-feet, were constructed to supply supplemental irrigation water to the Lovelock area, about 30 miles farther downstream.

The largest and only major storage facility on the Humboldt River—Rye Patch Dam and Reservoir—is about 50 miles downstream from Winnemucca. It was completed in 1936, furnishes supplemental irrigation water for 38,000 acres in the Lovelock area, and has a storage capacity of 179,100 acre-feet. Since construction of Rye Patch Dam, water has only been diverted into the Pitt-Taylor Reservoirs in years of abnormally high streamflow. In these years water is released from the Pitt-Taylor Reservoirs during the irrigation season through an outlet canal into Rye Patch Reservoir, from which it is subsequently released for irrigation purposes in the Lovelock area. Water was not diverted into the Pitt-Taylor Reservoirs during the period 1958–62.

Except for construction of the moderately large reservoirs that supply irrigation water to the Lovelock area, methods of irrigation using Humboldt River water upstream from the Lovelock area have not changed much since the earliest diversions were built. Moderately frequent and severe natural flooding has discouraged most landowners from making major capital improvements on either the land or the irrigation systems. Thus, almost all the Humboldt River water, other than that used in the Lovelock area, is diverted to unimproved meadows on the flood plain by artificial overbank flooding. The water is used mainly to irrigate native grasses, which in turn are cut for hay or are used for pasture.

In 1931, the Sixth Judicial District Court of Nevada adjudicated the rights of the various ranchers to divert the waters of the Humboldt River. The court determined that as of 1931 the total area of cultivated land for which water could legally be diverted from the river was slightly more than 285,000 acres and that about 698,000 acre-feet of water was required to satisfy the irrigation rights for this land (Mashburn and Mathews, 1943, p. 27).

As part of the reclamation project which resulted in the construction of Rye Patch Dam and Reservoir, about 60,000 acres of ranching property along the Humboldt River in the Battle Mountain area (fig. 1) was purchased; owners of some of this land held decreed rights to divert Humboldt River water for irrigation, and these rights were transferred to owners of land downstream for use in the Lovelock area. Since then the purchased land in the Battle Mountain area has not been irrigated, except perhaps during the periods of natural flooding. Accordingly, the owners of about 265,000 acres along the river hold decreed rights to Humboldt River water.

Data supplied by the Assistant State Engineer of Nevada (written commun., 1964), indicate that, depending upon the availability of streamflow, a maximum of about 31,300 acre-feet of Humboldt River water may be legally diverted onto slightly less than 17,000 acres in the Winnemucca area. Very rarely is there sufficient streamflow to supply all these water rights.

GROUND-WATER DEVELOPMENT

Ground-water development for irrigation along the main stem of the Humboldt River is small as compared to the total amount of water diverted from the river. In the Winnemucca area, total (gross) ground-water pumpage was about 5,000 acre-feet in water year 1962, of which about 4,000 acre-feet was for irrigation and the remainder was for domestic and municipal use.

Data are not available to allow accurate estimation of total pumpage in the remainder of the Humboldt River basin. Along the main stem of the Humboldt River, ground-water pumpage for irrigation is probably negligible. However, a few thousand acre-feet per year is probably pumped for municipal use, as in the cities of Elko, Battle Mountain, and Lovelock. Ground-water development for irrigation in valleys tributary to the Humboldt River, especially upstream from the Winnemucca area, has rapidly increased in recent years. Such development could eventually modify the flow system of the basin.

EFFECTS OF MAN'S MODIFICATIONS OF THE FLOW SYSTEM

Under natural conditions a substantial part of the Humboldt River streamflow ultimately discharged into the Humboldt Sink; from there the water was lost by evapotranspiration. These losses were almost a complete waste, as they provided no significant economic benefits. Man's activities have severely limited the quantity of streamflow that currently reaches the sink. Almost all water that formerly flowed into the Humboldt Sink is lost by evapotranspiration upstream—by natural evapotranspiration and as a result of agricultural practices. Some increased upstream evapotranspiration losses are desirable, for the water is used to produce crops, which, in turn, provide economic return.

Manmade structures, ranging in size from Rye Patch Dam and Reservoir to small headgates and earthen dams, have increased the free-water surface of the river, which, in turn, has resulted in increased losses upstream from the Humboldt Sink. Upstream evaporation losses have also increased as a result of the artificial flooding of meadows for irrigation. Diversions for irrigation and the resultant infiltration of water to the zone of saturation beneath the flood plain cause the water table to rise to within a few feet and, locally, to within a few inches of the land surface. This results in substantial evaporation losses from bare soil and increased transpiration by phreatophytes. The increased upstream evapotranspiration losses locally have resulted in the accumulation of large amounts of salts in the soil that formerly would have been deposited in the Humboldt Sink.

Many older residents in the area report that, since the advent of intensive artificial overbank flooding for irrigation, the character of the phreatophytes locally has changed from wildrye to willow, wildrose and less nutritious grasses. These changes in the types of plants growing on the flood plain have not only decreased the productivity of the meadows, but have also increased the nonbeneficial evapotranspiration losses.

Ground-water development has locally increased the net draft on the hydrologic system. Total pumpage, however, is very small in relation to the total average annual recharge to and discharge from the system; hence, the losses from the system to date (1965) as a result of this development are negligible. Although pumpage on the flood plain has undoubtedly decreased the flow of the river locally, the amount has been so small that it was not detected in the Winnemucca area during this investigation.

LEGAL ASPECTS OF THE MODIFICATIONS OF THE FLOW SYSTEM

Many volumes of court testimony and legal decisions are available regarding man's modifications of the natural flow system of the Humboldt River valley. Much of this material deals with the rights to divert Humbolt River water for irrigation. Those legal matters that have a direct bearing on the scope and content of this report are briefly considered herein.

Two fundamental features of Nevada water law are (1) that the water is public property—hence, the State has the legal right to regulate its use—and (2) that the legal right to utilize the water resources of the State is based on the doctrine of prior appropriation, which states that the first person who beneficially uses a specific quantity of water from a given source has the highest priority for the perpetual use of that water source. (See Hutchins, 1955.)

All rights to divert Humboldt River streamflow for irrigation were adjudicated largely on the basis of these two features of the State water law. (See Mashburn and Mathews, 1943.) In the Humboldt River basin the earliest rights established and those rights having the highest priority were for the year 1861. Rights were recognized and established for each year thereafter until 1921; the later the date of a recognized water right, the lower the priority to divert water—that is, earlier rights must be satisfied before water may be diverted onto land having later rights.

The highest priority rights to divert water in the Winnemucca area are for the year 1863; the lowest rights are for 1912. Some land downstream from the Winnemucca area, notably in the Lovelock area, has an earlier priority right to divert Humboldt River water than that in the Winnemucca area. When streamflow is insufficient to irrigate all the land in the valley that has established water rights (which often happens) diversions must commonly be curtailed or discontinued in the Winnemucca area so that the higher priority water rights can be fulfilled downstream.

The Nevada Department of Conservation and Natural Resources has been empowered by the State legislature to enforce the regulatory statutes of the State water law. That agency has established several rules and regulations regarding ground-water development in the State; some are especially pertinent to the modification of the flow system in the Humboldt River valley. The Department recognized that pumping water from a well drilled near a stream may affect the flow of the stream and thereby infringe upon established surface-water rights. In an attempt to minimize this possibility, regulations have been established regarding the required distance of a well from a stream and the methods of constructing wells close to streams.

ACHIEVEMENT OF THE MOST EFFECTIVE USE OF WATER RESOURCES

Achieving the most effective use of water resources of the Winnemucca area (and the entire Humboldt River valley) depends at least in part upon general agreement as to the meaning of the phrase "the most effective use." Many people who are concerned with the economic well-being of the valley think in terms of using the available water supply more efficiently for irrigation and of possibly increasing the total amount of water available for agricultural use. Some people are primarily concerned with flood control or the development of additional facilities for recreation. A few people feel that more effective use of Humboldt River water would result if more water were allowed to discharge into the Humboldt Sink, which would then become a refuge for waterfowl again.

Obviously no general agreement exists as to how to achieve the most effective use of water resources of the valley. Suggestions have been made, however, by various individuals and agencies with regard to possible changes in the water-use pattern. The potential effect of the more commonly proposed changes to the flow system are of principal concern to the valley residents.

CHANGES UPSTREAM FROM THE WINNEMUCCA AREA

INCREASED PRECIPITATION AND RUNOFF

The Nevada Department of Conservation and Natural Resources, the coordinating agency for the Humboldt River Project, is participating in research to evaluate the effectiveness of cloud seeding as a means of increasing precipitation on the headwaters of the Humboldt River valley. The study began in 1961 and, as yet, no data are available as to the feasibility of increasing precipitation by this method. Conceivably the amount of inflow to the basin could be significantly increased in the future as a result of cloud seeding. The Humboldt River streamflow into the Winnemucca area, accordingly, might also be increased; the amount largely depends on how the increased streamflow is utilized in the upstream part of the basin. The Humboldt River streamflow supplies nearly 70 percent of the average annual inflow to the Winnemucca area; therefore, a substantial increase in this inflow would markedly affect the flow system in the area.

UPSTREAM STORAGE FACILITIES

The feasibility of constructing major upstream storage facilities in and near the headwaters of the Humboldt River is being investigated intensively by the Nevada Department of Conservation and Natural Resources and by several Federal agencies. These facilities would probably help prevent costly flood damage and could provide recreational areas. Upstream reservoirs may also significantly affect the agricultural industry by regulating the flow of the river and thereby increasing the timeliness of the delivery of irrigation water. The extent to which the operation of upstream reservoirs would infringe upon the established downstream water rights and the possibility of increased salinity of the water because of increased evaporation from the free-water surfaces of the reservoirs are being considered by several State and Federal agencies. Any significant changes in the Humboldt

River streamflow at the Comus gaging station, as the result of construction and operation of upstream reservoirs, could significantly alter the flow system in the Winnemucca area, as previously noted.

Several additional changes can be made to the flow system and the water-use pattern upstream from the Winnemucca area. These changes are similar to the possible ones that can be made in the Winnemucca area.

CHANGES IN THE WINNEMUCCA AREA

Other than increasing the total amount of inflow to the system by artificially increasing precipitation in the upper Humboldt River valley, the only legal means of increasing the total available supply of water in the Winnemucca area is to decrease evapotranspiration losses, either in the project area or upstream from the area. The other means by which water is discharged from the Winnemucca area—ground-water and surface-water outflow—cannot legally be decreased by man's activities, as this would infringe upon downstream water rights, especially in the Lovelock area.

Some modifications in the management of the water supply would also probably result in more effective use of the available supply. For example, improvement in the timeliness of the delivery of water and the conjunctive use of ground and surface water could be of significant economic value. Construction of upstream reservoirs might result in more timely delivery of Humboldt River water, as previously noted. Increased upstream ground-water development might also aid the timeliness of delivery of irrigation water.

DECREASED EVAPOTRANSPIRATION LOSSES

Beneficial evapotranspiration losses are an inherent part of growing crops. As long as farming continues in the area, some water will be consumed by evapotranspiration. Regardless of what conservation methods are employed in the foreseeable future, some precipitation will probably be lost by nonbeneficial evapotranspiration. Improved irrigation practices could, however, conserve much water currently consumed by nonbeneficial evapotranspiration. In terms of modern irrigation practices, overbank flooding onto unimproved meadows is unquestionably not the most efficient method of irrigation. If Humboldt River water were diverted onto level fields by means of a network of lined ditches, crops of higher economic value could probably be produced and less water would be lost by evapotranspiration as well.

Upstream storage facilities and the concurrent lessening of flood danger may encourage farmers to upgrade their farming activities on the flood plain—notably the improvement of irrigation practices and the leveling of fields. Consideration might also be given to channel improvement—especially the straightening of the channel. This would not only lessen the frequency and severity of floods but also decrease the area of the free-water surface; which would in turn decrease evaporation losses from the river.

Most of the substantial quantity of water transpired by the native phreatophytes, other than the grasses used as forage, is wasted, as the water provides little or no economic return. Of the estimated average of 45,000 acre-feet per year of ground and surface water lost by evapotranspiration from the areas covered by phreatophytes (table 10), only 13,000 acre-feet was consumed in areas covered by grass. At least 30,000 acre-feet could conceivably be salvaged for beneficial use. Ground-water development may help salvage some of this water. Moreover, increased efficiency in the use of Humboldt River water for irrigation will result in lower ground-water levels beneath the flood plain. This would also decrease nonbeneficial evapotranspiration losses from area covered by phreatophytes, and, if it is deemed undesirable or impractical to eradicate the native phreatophytes, it may be possible to replace these plants with more beneficial plants or crops.

As part of the Humboldt River Research Project, the U.S. Agricultural Research Service has been investigating the feasibility of replacing greasewood and rabbitbrush with more beneficial plants, such as tall wheatgrass and wildrye (Nevada Dept. Conserv. and Nat. Resources, 1964, p. 9). Some major problems yet to be resolved in addition to economic feasibility are the development of irrigation supplies to support the seedlings of the replacement plants and the correction of adverse soil conditions locally.

INCREASED GROUND-WATER DEVELOPMENT

DEVELOPMENT IN TRIBUTARY AREAS

The possibility of increased ground-water development is of major interest to almost everyone in the basin. Water users in the Lovelock area have long been aware that ground water from Grass and Paradise Valleys discharges into the Humboldt River. They are concerned that ground-water development in these valleys would decrease the amount of seepage gain in the river and thereby decrease the downstream supply of surface water.

Their concern is justified. Uncontrolled ground-water development in these valleys and in the drainage basin of Pole and Rock Creeks could eventually intercept nearly 14,000 acre-feet of ground-water inflow to the storage area (table 5; Cohen, 1963b, p. 98–100). This could conceivably result in a decrease in Humboldt River streamflow of an approximately equal amount. The decrease in ground-water inflow to the storage area and to the Humboldt River however will ultimately be less than the total pumpage in the tributary areas, to the extent that some pumped ground water will return to the ground-water reservoir, and some natural evapotranspiration losses will be salvaged because of the pumping.

The amount of natural evapotranspiration losses salvaged in the tributary areas, will depend mainly on future well locations, the amount of pumpage, and the magnitude and extent of the resultant lowering of ground-water levels. If the increased ground-water development is carefully planned and the net pumpage (the amount of water permanently removed from the ground-water reservoir) is limited to the amount of natural evapotranspiration losses that are salvaged, the decrease in ground-water inflow to the storage area and to the Humboldt River may be negligible.

DEVELOPMENT FROM THE MEDIAL GRAVEL SUBUNIT

The medial gravel subunit (pl. 1G) is highly permeable and contains a large amount of ground water in storage. Moreover, the subunit lies at shallow depth and will yield large quantities of water—at least 2,000–3,000 gpm—to adequately constructed and equipped wells. Development of the subunit could supply water to supplement the surface-water supply during periods of deficient streamflow and thus provide irrigation water at times when it is most needed.

If the medial gravel subunit were partly dewatered by pumping, at least some and perhaps much of the streamflow that is lost by nonbeneficial evapotranspiration during periods of natural flooding would recharge the subunit naturally or might be induced to recharge the subunit by artificial means. Increased ground-water development locally would also lower ground-water levels sufficiently to conserve some ground water that is now wasted by nonbeneficial phreatophytes.

Increased ground-water development from the medial gravel subunit and from somewhat similar deposits upstream from the Winnemucca area (Bredehoeft, 1963, p. 39–45) offers the possibility of significantly increasing effective use of the total water supply in the basin. In terms of present agricultural practices and legal restrictions, however, ground-water withdrawals from the medial gravel subunit that would not be compensated for by decreased natural evapotranspiration losses would ultimately decrease the flow of the Humboldt River and thereby infringe upon downstream surface-water rights. The amount of water that would be diverted from the river as a result of increased ground-water development would depend mainly on the quantity of the net ground-water withdrawal and on the

790-166 O - 66 - 5

distance of the wells from the river. (See Cohen, 1963b, p. 99–100, fig. 38.)

During the spring and early summer when ground-water levels beneath the flood plain are fairly close to the land surface, crops locally are subirrigated—that is, they derive at least some of their moisture from the water table or from the overlying capillary fringe. Increased ground-water withdrawals from the medial gravel subunit locally could lower the water table sufficiently to decrease or eliminate subirrigation of crops.

NEED FOR ADDITIONAL STUDIES

One objective of the intensive interagency studies in the Winnemucca area was to test the new and the established methods of investigation and, thus, to determine how to evaluate the water resources of the entire Humboldt River valley most effectively. Now that most studies of the Winnemucca area are completed, consideration can be directed to an orderly and efficient investigation of the water resources of the remainder of the valley.

The magnitude of the water supply must be known before an effective basin-wide plan for the most efficient use of the available water supply can be formulated. Interrelations of the components of the flow system must also be evaluated both qualitatively and quantitatively, and understood as thoroughly as possible. If these interrelations are not known, effectiveness of future water-resources planning and development activities may be less than optimum.

To take full advantage of the results of the studies of the Winnemucca area, it is suggested that an appraisal of the water resources of the entire Humboldt River valley be undertaken and completed as soon as possible. The objectives of such a study should be:

1. Accumulation and analysis of the available hydrologic data, particularly the surface-water data.
2. Evaluation of the interrelation of surface and ground water.
3. Definition of those reaches of the valley in which additional intensive studies are needed.
4. Definition of the desired degree of intensity of future studies.
5. Definition of the salt balance for the basin.
6. Establishment of the order of priority of the subareas in the valley where future studies in detail should be undertaken.
7. Decision as to the most effective methods for future studies in detail based on the results of the studies of the Winnemucca area.

Such an appraisal should provide adequate information as to the feasibility of and area for future studies in detail in the Humboldt River valley.

Much information obtained in the Winnemucca area, such as the use of water by phreatophytes and the relation of specific yield to other geologic factors, can, with a reasonable degree of accuracy, be adapted for use in and applied to other parts of the basin. Future studies in detail of the basin could then be completed in less time than was the study described in this report.

SUMMARY

The preceding sections are summarized as follows:

Introduction

1. The Nevada State Legislature authorized the interagency Humboldt River Research Project in 1959; a major objective of the project was to evaluate the water resources of the Humboldt River valley as thoroughly as possible. Most work in the first 5 years of the study was done in the Winnemucca reach of the valley—the reach of the river between the Comus and Rose Creek gaging stations.
2. The Nevada Department of Conservation and Natural Resources is coordinator of the project; other agencies and organizations participating in the study are the Nevada Bureau of Mines, the Department of Geology and the Desert Research Institute of the University of Nevada, the U.S. Agricultural Research Service, the U.S. Bureau of Land Management, the U.S. Bureau of Reclamation, the U.S. Geological Survey, the U.S. Soil Conservation Service, the U.S. Weather Bureau, the Department of Geology of the University of Illinois, and the Southern Pacific Co.
3. The flow system—the movement of water into, within, and out of the Winnemucca area—and related physical features have been described in considerable detail in reports prepared by cooperating agencies. The purpose of this report is to summarize the hydrologic information given in those reports, especially the quantitative estimates of the components of the flow system.

General geographic features

1. The project area includes parts of four fault-block mountains and two intervening valleys, Grass and Paradise Valleys, and part of the Humboldt River valley. The flat and poorly drained floors of those parts of Grass and Paradise Valleys within the project area were covered by ancient Lake Lahontan, which had a maximum altitude of about 4,400 feet.
2. The Humboldt River is the largest stream entirely within Nevada and has a total drainage area of about 18,000 square miles. Its drainage area upstream from the Rose Creek gaging station is

15,200 square miles. The distance along the meandering channel of the river in the project area is 92 miles, but the length of the flood plain is only about 45 miles; the average width and depth of the channel are about 80 and 10 feet, respectively.

3. All other streams in the project area are usually dry on the alluvial apron and in the valley lowlands; some streams are perennial for short distances in the mountains.
4. The climate of the project area ranges from arid to semiarid in the valley lowlands to subhumid in the higher mountains. The average daily temperature and average annual precipitation on the valley floor are 49° F and 8.40 inches, respectively. Evaporation from free-water surfaces averages about 4–5 feet of moisture per year.
5. Sagebrush and shadscale are the most abundant shrubs on the alluvial apron, and greasewood is the most abundant shrub in the valley lowlands. Native grasses and lesser amounts of willow, wildrose, and rabbitbrush cover most of the flood plain.
6. The area's economy is largely based on cattle raising and the tourist business. The principal crops, mainly native grasses used for forage, are irrigated almost entirely with Humboldt River water. About 2,000 acres of farmland was irrigated with ground water in 1962.

How and where the water occurs

1. Water occurs as gas, liquid, and solid beneath the earth's surface, on the land surface, and in the atmosphere. The rock materials on and beneath the earth's surface in the project area are grouped into four units in this report—consolidated rocks, older alluvium, medial alluvium, and younger alluvium. Most consolidated rocks do not store or transmit appreciable amounts of water; rather, most of the water is stored in and transmitted through the three alluvial units. The medial gravel subunit of the medial alluvium lies at fairly shallow depths beneath the flood plain and bordering terraces, is highly permeable, and will yield at least 2,000 gpm to adequately constructed and equipped wells.
2. Ground water is the water in the zone of saturation; the top of this zone is commonly termed the water table. The water table is overlain by the zone of aeration. Most water in the zone of aeration (vadose water) is held by capillary and other attraction and does not move downward in response to gravity. Water in the lowermost part of the zone of aeration—the capillary fringe—is mainly derived from the underlying zone of saturation.
3. Water in storage in the channels of the Humboldt River and its tributaries normally represents the largest quantity of surface

water in the area at any given time. The snowpack that accumulates in the mountains in the winter also represents an appreciable part of the total surface-water supply.

Where the water comes from

1. Estimates of inflow, outflow, and changes in the amount of water in storage are made for the storage area (pl. 1D) rather than for the entire project area. These estimates are made for three periods: water years 1949–62, water year 1962, and December–June of water year 1962. The estimates for water years 1949–62 are more nearly representative of the long-term averages; hence, these values are emphasized in this summary.
2. Humboldt River streamflow, as measured at the Comus gaging station, supplied most of the water to the storage area—an average of about 172,100 acre-feet per year in water years 1949–62. Precipitation directly on the storage area supplied the second largest amount of water to the storage area—an average of about 59,000 acre-feet per year in water years 1949–62. Ground-water inflow to the storage area from the Humboldt River valley upstream from the storage area, from the drainage basins of Pole and Rock Creeks, from Paradise Valley, and from Grass Valley and the northwestern slope of the Sonoma Range supplied about 14,000 acre-feet per year. Finally, tributary streamflow supplied an average of about 8,600 acre-feet of water per year to the storage area in water years 1949–62.
3. Total inflow to the storage area in water years 1949–62 averaged slightly more than 250,000 acre-feet per year.

Movement and storage of water

1. Humboldt River streamflow moves at average rates that range from almost 0 to about 3 feet per second. The amount of water in the channel of the Humboldt River varies from season to season and from place to place. In the spring and early summer when the flow is commonly high, the amount of water in storage in the channel is large, and the river loses water between the Comus and Rose Creek gaging stations. In late summer and early fall, the flow and the amount of water in storage in the river channel are commonly the lowest of the year, and the river gains water in the project area.
2. An average of about 2,000 acre-feet per year of precipitation on the storage area recharges the ground-water reservoir; about 600 acre-feet per year falls on the Humboldt River and becomes streamflow. Most of the remainder of the precipitation, about 56,000 acre-feet, is lost by evapotranspiration from the land surface and from the zone of aeration.

3. Ordinarily the direction of ground-water movement is from the outer margins of the storage area toward the Humboldt River and thence downstream roughly parallel to the river; however, in spring and early summer the hydraulic gradients are reversed locally, and water moves from the river to the ground-water reservoir.
4. Estimated total ground-water in storage in the upper 100 feet of saturated alluvium in the project area is about 2 million acre-feet. Of this amount, about 500,000 acre-feet is stored in the medial gravel subunit. The average annual net change of ground water in storage (in the storage area) in water years 1949–62 was zero, or very nearly zero.
5. Estimates based on meager soil-moisture data and on theoretical considerations indicate that the average annual net change in moisture content in the zone of aeration in the storage area was zero in water years 1949–62.
6. Most tributary streamflow that discharges into the storage area is consumed by evapotranspiration or recharges the ground-water reservoir before ever reaching the Humboldt River as surface flow.

Discharge of water

1. Humboldt River streamflow as measured at the Rose Creek gaging station represents the largest quantity of water discharged from the storage area—an average of about 155,400 acre-feet per year in water years 1949–62. Streamflow at the Rose Creek gaging station ranged from 54,000 acre-feet less than that at the Comus gaging station in water year 1962 to 15,000 acre-feet more in water year 1958; it averaged nearly 17,000 acre-feet per year less in water years 1949–62.
2. Only a few thousand acre-feet of precipitation on the storage area is discharged from the area as Humboldt River streamflow and as ground-water outflow. A small undetermined amount is also discharged from the zone of saturation by evapotranspiration. In water years 1949–62 an estimated average of about 95 percent of the total precipitation was lost by evapotranspiration from the land surface and from the zone of aeration.
3. In water years 1949–62 an average of about 45,000 acre-feet per year of water, excluding that derived from precipitation, was consumed by evapotranspiration in areas covered by phreatophytes, and the estimated average annual evaporation loss from open bodies of water was 14,000 acre-feet.
4. The estimated average annual ground-water outflow from the storage area was about 3,000 acre-feet per year in water years 1949–62,

and the estimated average annual net pumpage for that same period was about 1,500 acre-feet.

5. The computed total outflow from the storage area near Winnemucca for water years 1949–62 averaged about 275,000 acre-feet per year.

Chemical quality of the water

1. Most ground water beneath the flood plain of the Humboldt River is of the sodium bicarbonate type and has a dissolved-solids content of 500–750 ppm. Ground water in the mouth of Paradise Valley is mainly of the sodium bicarbonate type and has a low dissolved-solids content; ground water in the drainage basins of Pole and Rock Creeks and most of the ground water in Grass Valley is of the calcium bicarbonate type and has a very low dissolved-solids content.
2. The specific conductance and, therefore, the dissolved-solids content of the Humboldt River are inversely proportional to the streamflow. During periods of low streamflow, the flow and the chemical quality of the river change between the Comus and Rose Creek gaging stations because of the interchange of streamflow with water in the ground-water reservoir.
3. Most ground water and almost all surface water in the area are chemically suitable for agricultural and domestic uses.

Summary of the flow system

1. The flow system, or the movement of water into, within, and out of the storage area, is virtually in long-term dynamic equilibrium. The equilibrium may be expressed by the following equation: I (inflow) $= O$ (outflow) $\pm St$ (net change in storage).
2. Solutions of the water-budget equation for three periods, water years 1949–62, water year 1962, and December–June of water year 1962, yielded results that balanced within 3–10 percent.

How man has modified the natural flow system

1. Diversion of the Humboldt River streamflow for irrigation is the most significant of man's modifications of the natural flow system in the Humboldt River valley.
2. About 265,000 acres in the basin can legally be irrigated with Humboldt River water; nearly 700,000 acre-feet of water—more than twice the average annual flow—would have to be diverted from the river to supply all the adjudicated water to this land. A maximum of about 31,300 acre-feet of Humboldt River water can legally be diverted onto slightly less than 17,000 acres in the Winnemucca area.

3. The activities of man, mainly his agricultural practices, have decreased the nonbeneficial evapotranspiration losses in the Humboldt Sink and have increased both beneficial and nonbeneficial losses upstream from the Sink. The small amount of ground-water development has not appreciably altered the flow system in the Winnemucca area or in the basin.
4. Almost the entire flow of the Humboldt River is appropriated. Any future activities of man that might infringe upon these rights are illegal, according to the present State law and regulatory provisions.

Achievement of the most effective use of the water resources

1. Precipitation may increase in the upper Humboldt River basin as a result of future cloud seeding and may increase the downstream supply of water.
2. Increased upstream storage facilities (a) will probably decrease the hazard of floods, (b) may provide recreational facilities, and (c) may increase the timeliness of delivery of Humboldt River water for irrigation.
3. Decreased evapotranspiration losses, both beneficial and nonbeneficial, by means of more efficient methods of irrigation, the development of ground water for irrigation, and other methods of conservation are significant ways by which the total available water supply can be used more effectively. A total of at least 30,000 acre-feet could be salvaged if economically and technologically feasible methods can be found to recover the water now being wasted in areas that are covered by nonbeneficial phreatophytes.
4. Ground-water development would increase the timeliness of the delivery of irrigation water; however, ground water that is consumed and not compensated for by decreases in natural evapotranspiration losses will ultimately decrease the flow of the Humboldt River and thereby infringe upon established surface-water rights.
5. Additional studies are needed to evaluate the hydrology of the remainder of the basin. Consideration should now be given to an overall appraisal of the water resources of the Humboldt River valley. This appraisal would evaluate the need and establish the guidelines or additional studies in detail, such as the one described in this report.

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