Water Resources and Effects of Changes in Ground-Water Use Along the Carlin Trend, North-Central Nevada

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CONVERSION FACTORS, VERTICAL DATUM, AND METRIC WATER-QUALITY AND GEOPHYSICAL UNITS

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	0.001233	cubic hectometer
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot per foot (ft/ft)	1.000	meter per meter
foot per mile (ft/mi)	0.1894	meter per kilometer
foot per year (ft/yr)	0.3048	meter per year
foot squared per day (ft^2/d)	0.0929	meter squared per day
inch (in.)	25.40	millimeter
inch per year (in/yr)	25.40	millimeter per year
mile (mi)	1.609	kilometer
square foot (ft^2)	0.0929	square meter
square mile (mi^2)	2.590	square kilometer

Temperature: Degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by using the formula °F = [1.8(°C)]+32.

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929, formerly called "Sea-Level Datum of 1929"), which is derived from a general adjustment of the first-order leveling networks of the United States and Canada.

Metric water-quality and geophysical units:

g/cm^3 (gram per cubic centimeter)
mmol/kg (millimole per kilogram)
pCi/L (picocurie per liter)
µS/cm (microsiemens per centimeter)
L (liter)
ntu (nephelometric turbidity unit)
µg/L (microgram per liter)
mg/L (milligram per liter)
permil (part per thousand)
µm (micrometer)

Water Resources and Effects of Changes in Ground-Water Use Along the Carlin Trend, North-Central Nevada

By Douglas K. Maurer, Russell W. Plume, James M. Thomas, and Ann K. Johnson

Abstract

The Carlin trend is a structural alignment of gold deposits in north-central Nevada. Pumping of ground water for mining and milling has caused concern regarding potential effects on the surface-water and ground-water resources of the region. This study describes the surface-water and ground-water resources of six hydrographic areas along the Carlin trend, ground-water conditions and budgets for two large flow systems, chemical quality of surface water and ground water, and the effects of pumping from 1990 to 1993.

Most mines along the Carlin trend are north of the Humboldt River in or near the Susie Creek, Maggie Creek, and Marys Creek Areas, east of the Tuscarora Mountains, and Willow Creek Valley, Rock Creek Valley, and Boulder Flat west of the mountains. Each hydrographic area is underlain by a structural basin containing basin-fill deposits as thick as several thousand feet. Bedrock beneath each structural basin consists of carbonate rocks, siltstones, volcanic rocks, and granitic rocks. The principal aquifers in the area are found in carbonate rocks, volcanic rocks, and basin-fill deposits.

All streams in the study area are tributary to the Humboldt River, which forms the southern boundary of the area. The Humboldt River gains about 38,000 acre-feet per year (acre-ft/yr) as snowmelt runoff (26,000 acre-ft/yr) and ground-water discharge (12,000 acre-ft/yr) from the Susie Creek, Maggie Creek, and Marys Creek Areas. In Boulder Flat, the river loses about 40,000 acre-ft/yr as infiltration of streamflow to the underlying aquifer and irrigation diversions.

Infiltration of precipitation into bedrock of the Independence and Tuscarora Mountains and unnamed mountains on the north side of Willow Creek Valley is the principal source of recharge to carbonate-rock, volcanic-rock, and basin-fill aquifers. However, faulting and differences in the fracture permeability of bedrock result in zones of perched ground water in mountain blocks that probably are not connected to these aquifers. Water levels near mines indicate that ground-water flow in bedrock is complex and can be restricted to separate hydrologic domains or compartments by faults, low-permeability rocks, and mineralized zones.

Two separate ground-water flow systems underlie the study area. East of the Tuscarora Mountains, ground water from the Susie Creek, Maggie Creek, and Marys Creek Areas discharges as evapotranspiration in lowlands and as inflow to the Humboldt River. West of the Tuscarora Mountains, ground water from Willow Creek Valley, Rock Creek Valley, and Boulder Flat discharges as evapotranspiration in lowlands and as subsurface flow to the Clovers Area west of the study area. Subsurface flow between hydrographic areas in each of the flow systems is common.

Ground-water recharge to the flow system in the Susie Creek, Maggie Creek, and Marys Creek Areas is an estimated 35,000 acre-ft/yr, and discharge is an estimated 27,000 acre-ft/yr. Recharge to the ground-water flow system in Willow Creek

Valley, Rock Creek Valley, and Boulder Flat is an estimated 88,000 acre-ft/yr, and discharge is an estimated 83,000 acre-ft/yr. Imbalances in these two water budgets result mostly from uncertainties in the methods used to compute the different budget components.

Streamflow in the Humboldt River and its tributaries is a mixed-cation bicarbonate water with dissolved-solids concentrations of about 250 to more than 500 mg/L (milligrams per liter). Proportions of sodium are higher in Rock Creek and the Humboldt River below Palisade because volcanic rocks are more common in these parts of the study area than in upstream parts.

Most sampled ground water in the study area is a mixed-cation bicarbonate type. Measured dissolved-solids concentrations in most of the sampled water range from 200 to 600 mg/L. Two geochemical models suggest that ground-water flow paths between Willow Creek Valley, Rock Creek Valley, Boulder Flat, and the Clovers Area are geochemically feasible.

Stable-isotope compositions of ground water do not differ over much of the study area. The principal exception is deep water from basin-fill deposits in the Maggie Creek Area upstream from Maggie Creek Canyon. This water, which is isotopically lighter than other ground water in the study area, contains only 4 percent modern carbon, and may have been recharged during cooler climatic conditions several thousand years ago.

From 1991 through 1993, pumping of ground water for mining and milling and for dewatering (more than 100,000 acre-feet in 1993) resulted in water-level changes and removal of ground water from storage. Water levels in siltstones and carbonate rocks declined 800 feet at the Post Betze mine and 200 feet at the Gold Quarry mine. Northwest-southeast-trending cones of depression have developed parallel to the Carlin trend zone of mineralization and have created zones of perched ground water in overlying basin-fill deposits. Near the Gold Quarry mine, water levels in basin-fill deposits and volcanic rocks have not declined, which suggests a poor hydraulic connection between these rocks and dewatered carbonate rocks and siltstones. Near the Post Betze mine, the cone of depression has extended through volcanic rocks of the Sheep Creek Range into Rock Creek Valley. Infiltration of water from the holding reservoir at Post Betze mine has increased ground-water in storage and has caused water levels in northern Boulder Flat to reach land surface. As a result, the rate of southward ground-water flow in this part of Boulder Flat has increased.

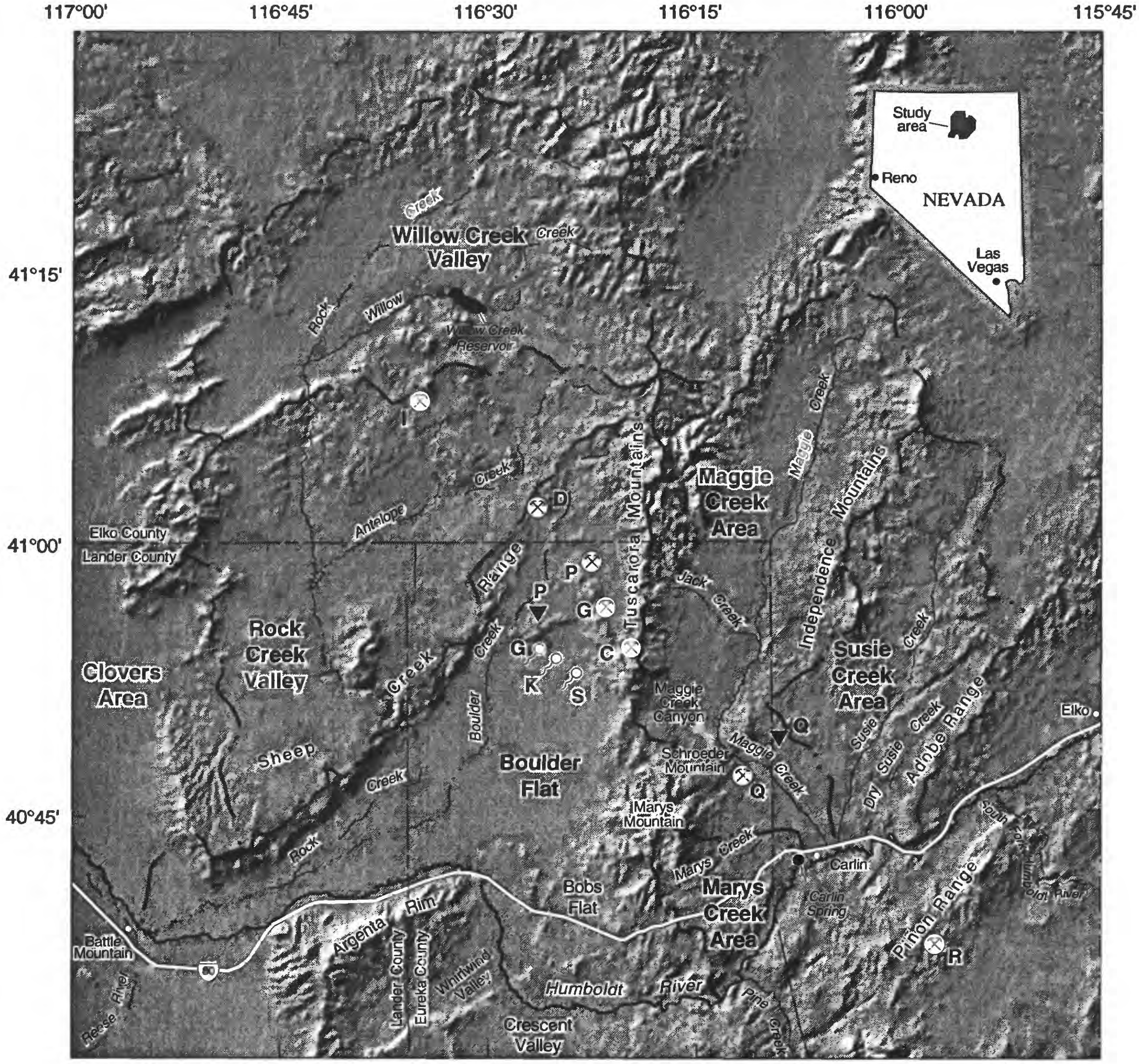
Water-level changes caused by mining activities show that faults, mineralized zones, and differences in fracture permeability and bedrock lithology control ground-water flow in the mountain blocks, creating complex flow paths. The effects of geologic structures on ground-water flow are not apparent until large stresses are placed on the system. The structures that controlled emplacement of the ore deposits appear to control ground-water flow and the response of the ground-water system to large-scale withdrawals.

INTRODUCTION

Background

This report describes the results of a hydrologic study made in and near six hydrographic areas that are tributary to, and north of, the Humboldt River in north-central Nevada (fig. 1). From east to west, the six areas are the Susie Creek, Maggie Creek, and Marys Creek Areas east of the Tuscarora Mountains, and Boulder Flat, Rock Creek Valley, and Willow Creek Valley west of the mountains. The combined area is about 2,100 mi^2.

The Carlin trend, a northwest-trending structural alignment of gold deposits (Knutsen and Wilson, 1990, p. 66), crosses part of the study area. The Carlin trend includes several active open-pit mines (fig. 1) and additional deposits that are undergoing differing stages of exploration and development. It extends from the Rain mine south of the Humboldt River to the Ivanhoe mine about 45 mi to the northwest (fig. 1). Between these two relatively small mines are the Carlin mine, the original deposit developed along the trend, and the Gold Quarry and Post-Betze mines, two of the largest gold mines in North America.



Base from U.S. Geological Survey digital data, 1:100,000 scale, 1977-88; Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000 scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

0 10 20 MILES

0 10 20 KILOMETERS

EXPLANATION

Hydrographic-area boundary—Modified from Rush (1968); not shown where coincident with Humboldt River

Mine—Letter is abbreviation for mine name as follows: **D**, Dee mine; **G**, Genesis and Bluestar mines; **I**, Ivanhoe mine; **P**, Post-Betze mine; **C**, Carlin mine; **Q**, Gold Quarry mine; and **R**, Rain mine. Rain mine, south of Humboldt River, not in study area

Reservoir—Used to store excess water from Post-Betze (**P**) and Gold Quarry (**Q**) mines

Spring—Recharge source is infiltration from reservoir used to store water from Post-Betze mine. Letter indicates informal name: **S**, Sand Dune spring; **K**, Knob spring; and **G**, Green spring

Figure 1. Location and features of Carlin trend area, north-central Nevada

The open pits at the Gold Quarry and Post-Betze mines have extended below local ground-water levels and must be dewatered. Total annual pumpage at the two mines increased from about 5,000 acre-ft in 1988 to more than 100,000 acre-ft in 1993 (fig. 2). By the year 2000, pumpage could be in excess of 135,000 acre-ft/yr (U.S. Bureau of Land Management, 1993, chap. 2, p. 31, and Anton Mayer, Barrick Goldstrike Mines Inc., oral commun., 1995).

Pumping of such large quantities of ground water has resulted in growing concerns over the potential effects on the water resources of the region. Concerns include changes in ground-water levels over large areas, changes in the flow of the Humboldt River and its tributaries, changes in the flow of springs, and changes in the quality of ground water and surface water.

An initial water-resources investigation by the U.S. Geological Survey (USGS) began in 1988 to define the water resources of the Maggie, Marys, and Susie Creek drainage basins and to characterize any effects that may have resulted from pumping at the Gold Quarry mine. Results of this study,

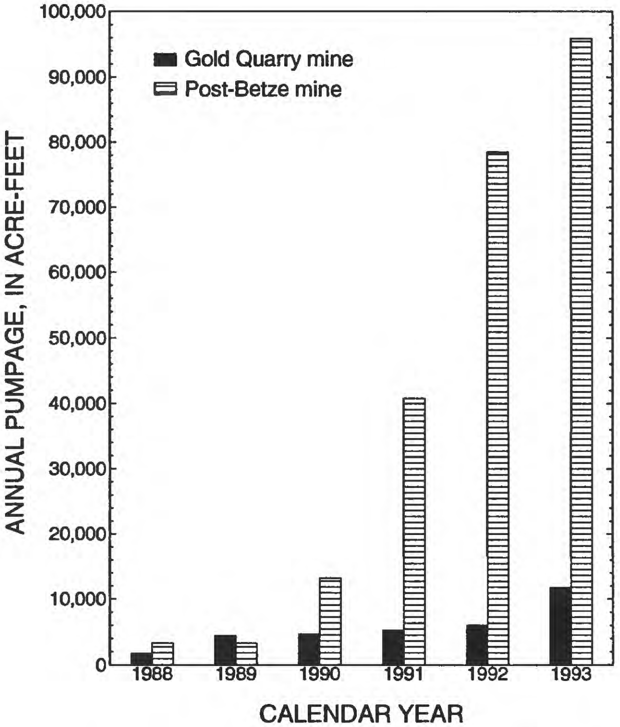


Figure 2. Ground-water pumpage at Gold Quarry and Post-Betze mines near Carlin, Nev., 1988-93 (data from D.A. Moody, Barrick Goldstrike Mines, Inc., and P.M. Pettit, Newmont Gold Co., written communs., 1994).

done in cooperation with the Nevada Division of Water Resources, are documented in a report by Plume (1995).

Development and expansion of mines along the Carlin trend continued during the initial study. As a result, the USGS, the Nevada Division of Water Resources, Nevada Division of Environmental Protection, and the mining companies recognized the need for a more regionally comprehensive study of the water resources of the Carlin trend and adjacent areas. This regional study, called the Carlin trend study, began in 1990 and was made by USGS, in cooperation with the Nevada Division of Water Resources.

Purpose and Scope

The Carlin trend study was divided into two phases. The purpose of phase one was to describe the hydrogeologic setting and the hydrologic effects of mining activities in six hydrographic areas along the Carlin trend. The purpose of phase two was to design and operate a network of sites for regional monitoring of hydrologic conditions during mining operations. Both phases began in August 1990. Interim results of phase one were published in 1992 (Plume and Stone, 1992). Final results of phase one are documented in this report. Phase two currently (1995) is scheduled to continue through the period of active mining along the Carlin trend and at diminishing levels after mining has ceased.

This report describes the hydrogeologic setting and ground-water and surface-water resources in and near the study area. The report also presents a conceptualization of the hydrologic system in the study area and describes the observed hydrologic effects of mining activities from 1990 through 1993. Existing geologic reports and maps, geophysical data, and information from drillers' logs were used to describe the geologic setting of the study area. Surface-water resources and the interaction of surface water and ground water are described using records collected by the USGS from 1896 through 1994 at 12 stream-gaging stations and additional streamflow measurements made at about 45 sites by the USGS and Newmont Gold Company. Water levels in about 180 wells, measured by USGS and the mining companies from 1989 through 1993, were used to define ground-water conditions and flow directions. Water-quality data for streamflow at eight gaging stations and ground water at 48 wells and springs were collected by the USGS from 1989 through 1994. These data were used to characterize baseline water quality during the study period and to evaluate ground-water flow paths and ages. Estimates of ground-water recharge and discharge in the study area were made by using data collected and analyzed as part of the study. These estimates were used to compile water budgets for the two ground-water flow systems in the study area.

Acknowledgments

The study documented in this report was made in cooperation with the Nevada Division of Water Resources. The study could not have been completed successfully without the assistance of many groups and individuals. Barrick Goldstrike Mines Inc. and Newmont Gold Company drilled numerous monitoring wells in the study area. Information from these wells, including lithologic logs and water-levels, provided the basis for much of the discussion of ground-water conditions presented in this report. D.A. Moody and Anton Mayer with Barrick Goldstrike Mines Inc., and C.J. Zimmerman and P.M. Pettit with Newmont Gold Company were always helpful sources of information and assistance. Owners and managers of the Horseshoe, Maggie Creek, Muleshoe, Rhodes, Squaw Valley, Taylor, TS, 26, and Tomera Ranches provided access to lands controlled by these ranches.

GEOGRAPHIC SETTING

The Carlin trend study area is sparsely populated. The only incorporated towns in the area are Carlin, with a population of 2,220, and Battle Mountain, with a population of 3,542 (U.S. Bureau of the Census, 1992). Besides mining, agriculture is a major part of the economy in the area. Diversions from the Humboldt River and its tributaries historically have been used for irrigating crops and pastures. Until recently, ground water also was pumped for irrigation of crops and pastures near Maggie Creek and in Boulder Flat. However, this pumping had ceased by 1993, and irrigation requirements are now met by part of the water being pumped from the Gold Quarry and Post-Betze open-pit mines. Much of the area is used for open-range cattle grazing, and stock water is provided by streamflow and sparsely distributed wells.

Physiography

The Carlin trend study area is in north-central Nevada along the northern margin of the Great Basin (fig. 1). The study area consists of six hydrographic areas[1], all tributary to the Humboldt River, which forms the southern boundary of the study area. Each of the six areas generally consists of a single drainage basin (exceptions are noted in the discussion below). Characteristics of each area are summarized in table 1. Data also were collected in adjacent hydrographic areas to the south and west.

The Susie Creek Area (fig. 1) consists of the Susie Creek drainage basin and the smaller Dry Susie Creek drainage basin to the east. The area is bounded to the east by the Adobe Range and to the west by the Independence Mountains and unnamed hills northeast of Maggie Creek Canyon. Altitudes in the area range from about 4,900 ft above sea level where Susie Creek joins the Humboldt River to more than 7,000 ft in the Adobe Range and more than 8,000 ft in the Independence Mountains. The Susie Creek drainage basin is about 25 mi long, 3-10 mi wide, and its area is about 180 mi^2. The Dry Susie Creek drainage basin is a small watershed of about 40 mi^2.

The Maggie Creek Area encompasses about 410 mi^2 (table 1) and consists of two reaches. One reach is upstream and the other is downstream from the Maggie Creek Canyon where the stream course changes direction from southwest to southeast (fig. 1). The upper Maggie Creek reach is bounded on the west by the Tuscarora Mountains and on the east by the Independence Mountains. Altitudes in the upper Maggie Creek reach range from 5,200 to 5,700 ft along the Maggie Creek flood plain to more than 8,000 ft in the adjacent mountain ranges.

The lower Maggie Creek reach is bounded to the east and west by low, poorly defined topographic divides that separate the basin from the Susie Creek and Marys Creek Areas, respectively. Maggie Creek joins the Humboldt River near the town of Carlin.

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[1]Formal hydrographic areas in Nevada were delineated systematically by the U.S. Geological Survey and Nevada Division of Water Resources in the late 1960's (Cardinalli and others, 1968, and Rush, 1968). These areas have been the basic units for assembling hydrologic data and for regulating water use in the State since 1968. The official hydrographic area names, numbers, and geographic boundaries continue to be used in Geological Survey scientific reports and Division of Water Resources administrative activities.

Table 1. Area, altitude, and estimated precipitation for hydrographic areas, Carlin trend area, north-central Nevada

[Abbreviation: --, not computed]

Hydrographic area [1]	Area [2]		Average altitude[2] (feet above sea level)	Annual precipitation	
	Square miles	Acres		Average [3] (inches per year)	Total [4] (acre-feet per year)
Susie Creek Area	220	140,000	5,980	12.4	150,000
Maggie Creek Area	410	260,000	6,080	12.7	280,000
Marys Creek Area	60	38,000	5,650	11.2	35,000
Willow Creek Valley	420	270,000	5,950	12.3	280,000
Rock Creek Valley	450	290,000	5,540	10.8	260,000
Boulder Flat	560	360,000	5,260	9.8	290,000
Totals	2,100	1,400,000	--	--	1,300,000

[1] See Rush (1968) and figure 1.

[2] Computed from digital elevation model for each hydrographic area (see text).

[3] Computed from precipitation-altitude relation, $P = 0.00356A - 8.56$, where P is average annual precipitation, in inches, and A is average land-surface altitude in hydrographic area, in feet.

[4] Computed as area, in acres, multiplied by average annual precipitation, in feet.

The Marys Creek Area consists of the Marys Creek drainage basin and a relatively small area to the south adjacent to the Humboldt River (fig. 1). The hydrographic area encompasses about 60 mi^2 (table 1). The Marys Creek drainage basin is bounded on the west by the southern end of the Tuscarora Mountains, on the north by the alluvial divide with the lower Maggie Creek reach, and on the south by a low range of hills between the basin and the Humboldt River. Marys Creek is normally a dry desert wash except for the reach about 1 mi above the Humboldt River. Flow of this reach of the stream is sustained by discharge of Carlin spring (fig. 1).

Rock Creek and its tributaries drain much of the study area west of the Tuscarora Mountains (fig. 1). The headwaters of Rock Creek are in the unnamed mountain range on the northern side of Willow Creek Valley. Rock Creek is joined by Willow Creek and flows southward in a rugged canyon to Rock Creek Valley. Rock Creek is then joined by Antelope Creek, cuts through the Sheep Creek Range by way of another rugged canyon, and enters Boulder Flat. Rock Creek is joined by Boulder Creek in the lowlands between the Sheep Creek Range and Argenta Rim and then enters the Humboldt River about 2 mi east of Battle Mountain.

Willow Creek Valley encompasses about 420 mi^2 and is bounded on the north, south, and west by unnamed mountain ranges and on the east by the Tuscarora Mountains (fig. 1). Altitudes range from about 5,100 ft in the lowlands to more than 8,000 ft in the adjacent mountains.

Rock Creek Valley encompasses about 450 mi^2 and is bounded to the north and west by unnamed mountain ranges and to the south and east by the Sheep Creek Range and Tuscarora Mountains, respectively (fig. 1). Altitudes range from about 4,900 ft along Rock Creek in the southern part of the hydrographic area to more than 7,000 ft in the Sheep Creek Range and the unnamed mountain range on the north side of the area.

Boulder Flat consists of several drainage basins that total about 560 mi^2 in area. The largest part of the hydrographic area is Boulder Flat, a triangular-shaped basin narrow to the north and wide to the south. The basin is bounded to the east by the Tuscarora Mountains and to the west by the Sheep Creek Range (fig. 1). The Humboldt River forms the southern boundary. Altitudes range from 4,500 to 4,600 ft along the Humboldt River flood plain to more than 7,000 ft in the adjacent mountain ranges. The southeastern part of the hydrographic area consists of several relatively small drainage basins, including Bobs Flat, along the southern end of the Tuscarora Mountains. All of these basins are tributary to the Humboldt River.

Vegetation

Vegetation in the study area is dominated by shrubs at most altitudes. In the higher parts of the mountain blocks, aspens are found near stream channels and near the heads of drainages. Sagebrush is the dominant vegetation over most of the mountain blocks. Low-lying areas of the Maggie Creek Area are covered by rabbitbrush, grasses, willows, and sedge meadows (Stone and others, 1991, p. 10, and U.S. Bureau of Land Management, 1993, sec. 3, p. 58). In contrast, low-lying areas of Boulder Flat are covered by greasewood and mixed stands of greasewood, big sage, rabbitbrush, and grass. In Rock Creek Valley, stands of big sage, rabbitbrush, and greasewood are found along stream channels. In Willow Creek Valley, low-lying vegetation consists of willow, rabbitbrush, big sage, and grass.

Many of the plants in low-lying areas are phreatophytes, which are defined as plants that obtain their water from below the water table (Freeze and Cherry, 1979, p. 201). Evapotranspiration of ground water by phreatophytes accounts for a large part of ground-water discharge.

Climate

An understanding of the water resources of the study area begins with an analysis of climate because the source of all water in the area—streamflow and ground water—is precipitation, which falls as rain or snow. The study area spans two climate zones in northern Nevada—the mid-latitude steppe and subhumid continental zones (Houghton and others, 1975, p. 3).

The mid-latitude steppe zone has a semiarid climate. Summers in this zone are warm to hot and winters are cold; annual precipitation, as rain and snow, is 6-7 in. (Houghton and others, 1975, p.69). The subhumid, continental zone has cool to mild summers and cold winters. Annual precipitation in this zone, mostly as snow, is as much as 25 in. (Houghton and others, 1975, p. 71). The boundary between the two zones in northern Nevada (Houghton and others, 1975, p. 3) is at an altitude of about 6,000 ft.

The seasonal distribution of precipitation in northern Nevada depends largely on the directions of westerly winds. West and northwest winds during the winter bring moisture as rain and snow to lowland areas and snow to the higher areas. The westerly winds are from the south during the summer and bring warm, moist air from the tropical Pacific Ocean and Gulfs of California and Mexico (Houghton and others, 1975, p. 10). Summer storms can be sudden and intense, and produce large amounts of precipitation, mostly as rain; however, precipitation from summer storms does not constitute a large part of the annual total because such storms typically affect only small areas.

The study area has been affected by a regional drought since about 1985 (fig. 3). The effects of the drought appear to have been cumulative and to have increased in severity as the drought continued. For example, total flow of the Humboldt River about 15 mi southwest of Elko (Carlin gaging station) was about 40 percent of normal in water year 1987 (Pupacko and others, 1989, p. 146) when total precipitation for the year was about 60 percent of normal at Elko (fig. 3). Total flow of the river at the same site in 1992 was about 20 percent of normal (Hess and others, 1993, p. 192) when total precipitation for the year at Elko was about 70 percent of normal (fig. 3).

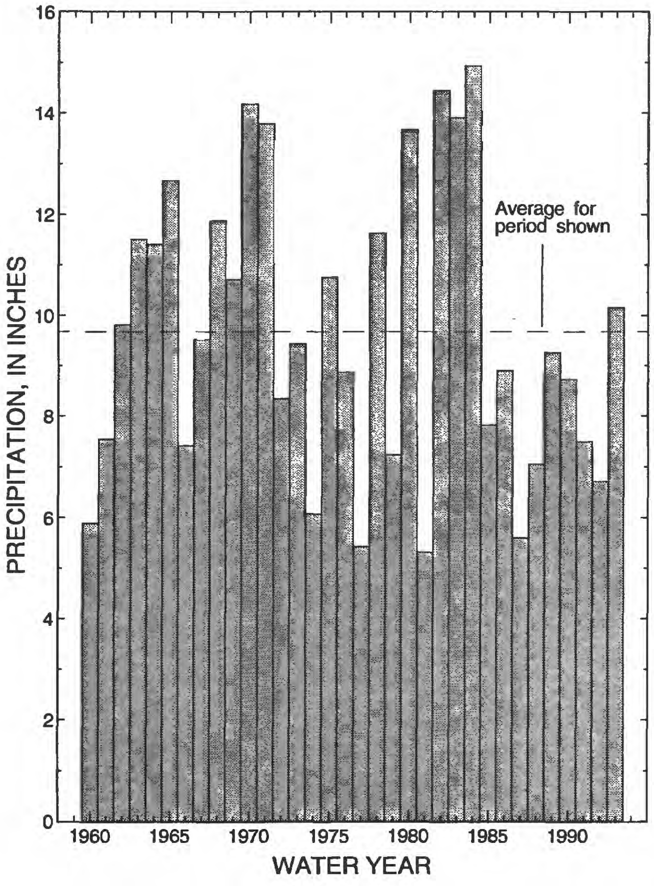


Figure 3. Annual precipitation at Elko, Nev., water years 1960-93 (data from National Climatic Center, 1959-93).

Several approaches have been used to define the distribution of precipitation in Nevada. An early approach was to subdivide the basin into precipitation zones (Maxey and Jameson, 1948, p. 107-109; Eakin and others, 1951) on the basis of the State precipitation map (Hardman, 1965). More recently, attempts have been made in southern and central Nevada to define statistical relations between precipitation and altitude on the basis of data from widely scattered weather stations (Quiring, 1965). These approaches are area specific because of the effect of latitude on winter storm tracks (see Houghton and others, 1975, p. 8-19, for a discussion of storm tracks).

Precipitation data for 14 stations at various altitudes were analyzed as a part of the Maggie Creek study (Plume, 1995, p. 9-11) to develop a statistical relation between precipitation and altitude for northeastern Nevada. The equation for this relation is

$$P = (A \times 0.00356) - 8.56, \qquad (1)$$

where P is mean annual precipitation, in inches, and
A is altitude, in feet above sea level.

The relation is useful for estimating annual precipitation in altitude zones ranging from 4,000 to 8,000 ft in northeastern Nevada.

The relation was used to make estimates of total annual precipitation for the hydrographic areas of the study area. This was done by using a digital-elevation model (DEM) consisting of a digital grid of land-surface altitudes. Each cell in the grid represents an area of 2 acres. The relation was applied to the mean altitude of each cell to compute annual precipitation for the cell. Total annual precipitation for each hydrographic area is the sum of estimated annual precipitation for all cells in the area (table 1). The average annual volume of precipitation for the study area is about 1,300,000 acre-ft.

HYDROGEOLOGIC SETTING

Properties of Water-Bearing Rocks

For purposes of this study, rocks and basin-fill deposits have been grouped into six hydrogeologic units on the basis of lithologic and hydrologic similarities. Four of the units are collectively referred to as bedrock. They are (1) carbonate rocks of Cambrian to Permian age, (2) siltstones of Ordovician to Devonian age, (3) granitic rocks of Jurassic and Tertiary age, and (4) volcanic rocks of Jurassic and Tertiary age. Bedrock units form mountain ranges and structural basins in which thousands of feet of unconsolidated to semiconsolidated basin-fill deposits have accumulated. Basin-fill deposits consist of two units, referred to as older basin-fill deposits (Cretaceous to Tertiary age) and younger basin-fill deposits (Tertiary and Quaternary age). The hydrogeologic characteristics and occurrence of the six units in the Carlin trend study area are summarized in table 2 and are described in the following sections.

Bedrock

Carbonate Rocks and Siltstones

Carbonate rocks and siltstones are the two oldest hydrogeologic units in the study area. The two units are discussed together in this report because they have been closely associated since they were deposited along the ancient continental margin of western North America several hundred million years ago. Carbonate rocks were deposited in relatively shallow water on the continental shelf and siltstones were deposited at about the same time in deeper water on the continental slope and rise. In Late Devonian to Early Mississippian time, the siltstones were emplaced by thrust faulting as much as 90 mi eastward (in modern coordinates) over the carbonate rocks (Stewart, 1980, p. 36). The low-angle fault along which thrusting took place is called the Roberts Mountains thrust (pls. 1 and 2).

Carbonate rocks consist of the eastern and transitional assemblages of Stewart and Carlson (1976) and Stewart (1980, p. 16-35), and the overlap assemblage of Stewart (1980, p. 57). Although this unit consists mostly of carbonate rocks, it also includes subordinate thicknesses of other rock types. In the study area, carbonate rocks are exposed in the southern Adobe Range, Independence and Tuscarora Mountains, and at Schroeder and Marys Mountains (pl. 1). Thickness and lithology of the unit are: (1) more than 5,000 ft of sandy limestone, dolomite, and siltstone of Late Pennsylvanian and Permian age in the southern Adobe Range, (2) at least 5,150 ft of silty and sandy limestone of Silurian, Devonian, and Mississippian age in the Independence Mountains (Evans and Ketner, 1971), and (3) 5,500-6,400 ft of limestone, dolomite, sandstone, quartzite, and chert of Ordovician to Devonian age in the Tuscarora Mountains (Radtke, 1985, p. 9). The cumulative thickness of all stratigraphic units that make up this hydrogeologic unit may exceed

45,000 ft (table 2). However, the entire thickness is rarely present at a single place because thicknesses of individual units differ areally and parts have been removed by faulting and erosion.

Though not exposed west of the Tuscarora Mountains (pl. 1), the unit of carbonate rocks is inferred to underlie siltstones at increasing depths in this part of the study area (pl. 2, sections *A-A'* and *B-B'*). The proportion of clastic material in the unit undoubtedly increases and becomes the dominant lithology to the west. If carbonate rocks are present in this part of the study area, their depths probably exceed 2,000 to 3,000 ft (Bruce Harvey, Newmont Gold Co., oral commun., 1994)

The siltstone unit consists of rocks of the siliceous (western) assemblage and the carbonate-detrital belt, both defined by Stewart and Carlson (1976). Although this unit consists of a variety of rocks including clastic sedimentary rocks (siltstones, mudstones, sandstone, and shale), chert, subordinate carbonate rocks, and volcanic rocks (table 2), it is referred to in this report as the siltstone unit. Siltstones are exposed extensively in the Adobe Range, Independence Mountains, Tuscarora Mountains, at Marys and Schroeder Mountains, and along the western sides of the Sheep Creek Range and the Argenta Rim (pl. 1). The unit underlies much of the western part of the study area, but is concealed beneath volcanic rocks or basin-fill deposits (pls. 1 and 2, sections *A-A'* and *B-B'*). Thickness and lithology of siltstones are: (1) about 4,700 ft of mostly chert and shale of Ordovician age in the Independence Mountains (Evans and Ketner, 1971); (2) more than 7,800 ft of chert, shale, sandstone, quartzite, limestone, and dolomite of Ordovician and Silurian age in the Tuscarora Mountains (Radtke, 1985, p. 22-25); and (3) 10,000-20,000 ft of chert, shale, quartzite, sandstone, and greenstone of Ordovician, Silurian, and Devonian age west and southwest of the Argenta Rim (thickness based on measured stratigraphic sections 10-20 mi to the south; Gilluly and Gates, 1965, p. 23-38).

The permeability of carbonate rocks and siltstones depends on the degree to which the rocks have been fractured. These rocks can be extremely permeable along fault zones where fracturing is extensive. In addition, secondary permeability of carbonate rocks can be further improved by solution widening of fractures. However, carbonate rocks and siltstones can be poorly permeable where they are less fractured in areas away from faults. Stone and others (1991, p. 14) note that alteration and mineralization can reduce fracture permeability. The mining companies and their consultants have made many aquifer tests at and near the Gold Quarry and Post-Betze mines to quantify transmissivity, hydraulic conductivity, and storage coefficient of the carbonate rocks and siltstones. Over large parts of the study area, however, the hydraulic properties of these two units have not been measured.

At Gold Quarry mine, aquifer tests near faults indicate that transmissivity and storage coefficient of carbonate rocks range from 8,600 to 110,000 ft^2/d and from 0.00063 to 0.014, respectively (Pettit, 1992, p. 17). Test results also indicate that fractured rock may be twice as permeable along the fault zone as it is across the fault zone (Pettit, 1992, p. 18). Hydraulic conductivity near Gold Quarry mine was found to range from 15 to 150 ft/d for the carbonate rocks and from 20 to 100 ft/d for the siltstones (Hydrologic Consultants, Inc., 1992, p. 23 and 25). Rocks of both hydrogeologic units are less fractured and, as a result, less permeable in areas away from faults (Hydrologic Consultants, Inc., 1992, p. 24 and 26).

Aquifer tests of carbonate rocks and siltstones have also been done on the west side of the Tuscarora Mountains at the Post-Betze mine and nearby mines. Ranges of transmissivity and hydraulic conductivity of fractured limestones of the Popovich Formation (carbonate rocks; table 2) are 4.3 to 6,000 ft^2/d and 0.10 to 10 ft/d (Hydro-Geo Consultants, Inc., 1990, table 3-2, and 1992, table 2-1). Storage coefficient ranges from 0.0002 to 0.01. A transmissivity of 360,000 ft^2/d and storage coefficients ranging from 0.0008 to 0.45 were obtained from numerical modeling in the area (Anton Mayer, Barrick Goldstrike Mines Inc., written commun., 1995).

Measured ranges of transmissivity and hydraulic conductivity for the Vinini Formation (siltstones; table 2) are 40 to 420 ft^2/d and 0.0014 to 100 ft/d, respectively (Hydro-Geo Consultants, Inc., 1992, table 2-1). Storage coefficient ranges from 0.00001 to 0.0001. A transmissivity of 6,200 ft^2/d and storage coefficient ranging from 0.0008 to 0.03 were obtained from numerical modeling in the area (Anton Mayer, Barrick Goldstrike Mines Inc., written commun., 1995). As at Gold Quarry Mine, the transmissivity of carbonate rocks can be low where the rocks have not been affected by fault or fracture zones.

Table 2. Summary of hydrogeologic units, Carlin trend area, north-central Nevada

[Sources of lithologic data: Regnier, 1960; Roberts and others, 1967, p. 15, 27, 28; Smith and Ketner, 1975, p. A12, 16, 18, 25, 27, 35, 39, 46, 52, 61; Smith and Ketner, 1976, p. B6, 10, 14, 19, 32, 35, 40-41; Stewart and McKee, 1977, p. 20-22; Stewart, 1980, p. 35; Radtke, 1985, p. 12-13, 15, 19, table 1; Coats, 1987, p. 29, 38-39, 46-47, 56, 61-62, 65; Ettner, 1989, p. 60. Sources of water-bearing characteristics: Bredehoeft, 1963, table 4; Bredehoeft and Farvolden, 1963, p. 210; p. 6; Hydro-Geo Consultants, Inc., 1990, p. 9, 321, 1992, p. 2, table 2-1; Hydrologic Consultants, Inc., 1992, p. 21-26; Leggette, Brashears, and Graham, Inc., 1990, p. 5, table 2; Stone and others, 1991, p. 25, 28-30, 33; Pettit, 1992, p. 17, 20. Abbreviations and symbols: ft/d, feet per day; gal/min, gallon per minute; <, less than; >, greater than]

Hydrogeologic unit	Geologic age	Rock or stratigraphic unit	Lithology	Thickness[1] (feet)	Water-bearing characteristics
			Basin-fill deposits		
Younger basin-fill deposits	Quaternary and Tertiary	Includes unnamed deposits and Hay Ranch formation of Regnier (1960).	Deposits of alluvial fans, basin lowlands, and stream flood plains. Deposits of alluvial fans and lowlands consist of boulders, gravel, sand, silt, clay, and, in places, beds of limestone and rhyolitic ash. Flood-plain deposits consist of sorted to poorly sorted boulders, gravel, sand, silt, and clay. Flood-plain deposits are tens of feet thick along smaller streams and hundreds of feet thick along Humboldt River in Boulder Flat.	1,600	Hydraulic conductivity ranges from 0.5 to 2,000 ft/d; many values between 2.8 and 74 ft/d. Hydraulic conductivity for very productive well in Boulder Flat is 2,000 ft/d. Hydraulic conductivity of flood-plain deposits measured at 22 wells in north-central Nevada ranged from 16 to 1,100 ft/d and mean was 130 ft/d. Flood-plain deposits contain shallow water-table aquifer. Lower parts of alluvial-fan deposits may be saturated, with permeability ranging through several orders of magnitude.
Older basin-fill deposits	Tertiary and Cretaceous	Upper part of Raine Ranch formation of Regnier (1960), Carlin formation of Regnier (1960), Humboldt Formation (restricted) of Smith and Ketner, (1976), Elko Formation, limestone, conglomerate, and cherty limestone of Smith and Ketner (1976), Rand Ranch formation of Regnier (1960), Newark Canyon Formation	Siltstone, claystone, shale, limestone, conglomerate, and sandstone, with some tuff, flows, and diatomite. Locally tuffaceous.	7,600	Hydraulic conductivity ranges from about 1 to 7 ft/d. Permeability is dominantly primary. Carlin formation yields water to wells from <100 to 1,000 gal/min.

Bedrock					
Volcanic rocks	Tertiary and Jurassic	Big Island Formation, Banbury Formation, Palisade Canyon Rhyolite of Regnier (1960), Rhyolitic welded tuff of Smith and Ketner (1976), Safford Canyon formation and lower part of Raine Ranch formation of Regnier (1960), Indian Well Formation, mafic to intermediate units of Smith and Ketner (1976), and Frenchie Creek Rhyolite.	Felsic flows, domes, and ash-flow tuffs; intermediate lava flows, pyroclastic rocks, and air-fall tuffs; mafic volcanic rocks; and ash.	13,000	Horizontal hydraulic conductivity ranges from 0.01 to 10 ft/d with average of about 2 ft/d. Permeability is dominantly primary as result of depositional environment. Irrigation wells finished partly in volcanic rocks near lower Maggie Creek yield as much as 2,000 gal/min.
Granitic rocks	Tertiary and Jurassic	Quartz monzonite plutons of Swales and Lone Mountains. Also includes large plutons inferred, from aeromagnetic data, to underlie Marys Mountain and west part of Sheep Creek Range.	Felsic to intermediate, plutons, dikes, and minor plugs.	--	Hydraulic conductivity ranges from 0.001 ft/d in unfractured rock to 26 ft/d in fractured rocks. Generally poorly permeable to impermeable. May yield small quantities of water near fault zones.
Siltstones	Devonian to Ordovician	Valmy Formation, Vinini Formation, Silurian rocks of Marys Mountain, Elder Sandstone, Woodruff Formation, and Slaven Chert.	Quartzite, chert, shale, mudstone, siltstone, intermediate and mafic volcanic rocks, and sandstone.	23,000	Hydraulic conductivity ranges from 0.0014 to 100 ft/d with most values between 0.01 and 0.5 ft/d for unfractured rock. Permeability is secondary, as result of faulting, fracturing, and solution widening.
Carbonate rocks	Permian to Mississippian	Tripon Pass Limestone, Webb Formation, argillite of Lee Canyon, Chainman Shale, Diamond Peak Formation, Moleen Formation, Tomera Formation, Strathearn Formation, Carlin Sequence (amended), sandstone and siltstone of Horse Mountain, and Edna Mountain Formation.	Mudstone, siltstone, quartzite, limestone, shale, and sandstone.	26,000	Hydraulic conductivity ranges from 0.1 to >150 ft/d, with most values from 0.2 to 10 ft/d. Some thermal water occurs in these rocks. Permeability is dominantly secondary as result of faulting, fracturing, and solution widening.
	Devonian to Cambrian	Hamburg Dolomite, Pogonip Group, Eureka Quartzite, Hansen Creek Formation, Ordovician rocks of Marys Mountain, Roberts Mountains Formation, Lone Mountain Dolomite, Popovich Formation, Rodeo Creek unit of Ettner (1989), Nevada Formation, Devils Gate Limestone, and Wenban Limestone.	Limestone, dolomite, limy siltstone, sandy dolomite, claystone, chert, and quartzite.	19,000	

[1] Combined thickness of all stratigraphic units. Listed total thickness probably not present at any single locality.

The areas around both the Gold Quarry and Post Betze mines are composed of what Stone and others (1991, p. 22) call hydrogeologic domains. Each domain is bounded by faults, intrusive contacts, mineralized zones, changes in bedrock lithology, or changes in fracture permeability. Water levels and the response to pumping can vary from one domain to another.

Granitic Rocks

Intrusion of granitic bodies along a regional northwesterly trend during Early Jurassic through early Tertiary time (Radtke, 1985, p. 27; and Coats, 1987, p. 76) caused doming and uplift of overlying rocks (Roberts, 1986, p. 77). Subsequent erosion of the upper plate of the Roberts Mountains thrust has exposed carbonate rocks in the lower plate of the thrust in the vicinity of these domes (pl. 1). The deeper intrusions are generally exposed in association with carbonate rocks in the Tuscarora and Independence Mountains. The lateral extent of the intrusive rocks is unknown but can be inferred from geophysical data.

Granitic rocks in the study area mostly consist of quartz monzonite, granodiorite, and diorite. These rocks are exposed at the south end of the Adobe Range and in the Independence and Tuscarora Mountains (pl. 1). Aeromagnetic data, discussed in a subsequent section, suggest that large bodies of granitic rocks underlie Marys Mountain and the southern Tuscarora Mountains and the western part of the Sheep Creek Range northeast of Battle Mountain.

Granitic rocks near the Post-Betze mine are poorly permeable except along high-angle faults (Hydro-Geo Consultants, Inc., 1990, table 3-2; and 1992, table 2-1). Results of aquifer tests indicate that the hydraulic conductivity of the granodiorite is 3-5 ft/d where the rock is highly fractured (Hydro-Geo Consultants, Inc., 1990, table 3-2). Where the rock is less fractured, measured hydraulic conductivity ranges from 0.1 to 0.5 ft/d (Hydro-Geo Consultants, Inc., 1990, table 3-2; and 1992, table 2-1). The rock is probably even less permeable in areas where fracturing is minimal.

Volcanic Rocks

Volcanic rocks of two different ages are found in the study area, and are grouped together as one unit for this report. The Frenchie Creek Rhyolite (volcanic rocks; table 2), which consists mostly of rhyolite flows, is of Jurassic age. These rocks are exposed in the southern Tuscarora Mountains (pl. 1). Thick sequences of volcanic rocks also accumulated during Tertiary time. These rocks consist of lava flows, flow domes, ash-fall and water-lain tuffs, and interbedded deposits of lacustrine and fluvial origin. Compositions include basalt, andesite, and rhyolite. Volcanic rocks are exposed in parts of the Adobe Range, Independence and Tuscarora Mountains, and at Marys Mountain. In addition, these rocks make up large parts of mountain ranges in the western part of the study area, including the Sheep Creek Range and the Argenta Rim (pl. 1). The total cumulative thickness of volcanic rocks exceeds 13,000 ft in and near the study area (table 2). However, this thickness may not be present at any single place.

The permeability of volcanic rocks has been measured only in the vicinity of the reservoir used to store water pumped from the Post-Betze mine. Water infiltrates through fractured volcanic rocks in the reservoir floor. Movement of the water from the reservoir to springs several miles to the south and southeast is in volcanic rocks and indicates that the rocks can be very permeable. In this area, hydraulic conductivity of volcanic rocks ranges from 0.01 to 10 ft/d (Stone and others, 1991, p. 29). Results of numerical modelling suggest that the transmissivity of the volcanic rocks is 120,000 ft^2/d (Anton Mayer, Barrick Goldstrike Mines Inc., written commun., 1995).

Volcanic rocks exposed along lower Maggie Creek and in the subsurface to the south also are permeable (Plume, 1995, p. 39). These rocks probably function as a drain between the shallow aquifer near Maggie Creek and Carlin spring several miles to the south in the Marys Creek Area.

Basin-Fill Deposits

Older Basin-Fill Deposits

Older basin-fill deposits in the study area are of Cretaceous and Tertiary age (table 2). These deposits accumulated in basins that predated, or that were precursors of, the basins that began to develop in the earliest stages of extensional faulting of what is now the Great Basin. As a result, older basin-fill deposits not only constitute much of the basin fill in present-day basins, but also are exposed in mountainous areas such as the hills northeast of Maggie Creek Canyon and in the unnamed mountains that bound Willow Creek Valley (pl. 1). These deposits were uplifted with parts of mountain ranges as the present distribution of structural basins developed during the last 15-20 million years.

Older basin-fill deposits consist of poorly consolidated shale, claystone, siltstone, sandstone, conglomerate, and subordinate beds of limestone, diatomite, and volcanic flows and tuff. Their permeability probably ranges through several orders of magnitude because of the different lithologies present. In the Maggie Creek Area, the hydraulic conductivity of older basin-fill deposits ranges from about 1 to 7 ft/d (table 2) and transmissivity from 780 to 9,800 ft^2/d. These ranges of values are based on five aquifer tests that were done at two wells northeast of Schroeder Mountain and at one well southeast of the mountain (Plume, 1995, p. 18-24), and at a test well near the reservoir used to store water from Gold Quarry mine (Pettit and others, 1992, p. 5-6).

The transmissivity of older basin-fill deposits in northern parts of Boulder Flat is 70-300 ft^2/d (Stone and others, 1991, p. 28). However, the thickness of aquifer that represents these values is not known, so the hydraulic conductivity cannot be estimated.

Younger Basin-Fill Deposits

Younger basin-fill deposits consist of deposits of alluvial fans, basin lowlands, and stream flood plains. They are the erosion products of bedrock in the adjacent mountain ranges and older basin-fill deposits. Alluvial fans are found along the bases of mountain ranges. These deposits are unsorted to poorly sorted clay, silt, sand, gravel, and boulders. Deposits of basin lowlands are somewhat better sorted than alluvial fans and consist mostly of clay, silt, sand, and gravel. These deposits are most extensive in Boulder Flat, Rock Creek Valley, and Willow Creek Valley (pl. 1).

Deposits of stream flood plains consist of sorted to well sorted fine-grained material (clay and silt) and interbedded coarse-grained material (sand and gravel). These types of deposits are restricted to present stream flood plains and adjacent areas where stream channels have been abandoned. The ratio of coarse-grained to fine-grained material is relatively high in flood-plain deposits in the south part of Boulder Flat along the Humboldt River and Rock Creek flood plains (Bredehoeft, 1963, p. 39-43). In this area, the thickness of predominantly coarse-grained deposits ranges from less than 100 ft near Battle Mountain to 200-300 ft 10-20 mi farther east in Boulder Flat (Bredehoeft, 1963, p. 44).

Hydraulic conductivity of younger basin-fill deposits ranges widely (table 2). Hydraulic conductivity in Whirlwind Valley was estimated to range from 26 to 35 ft/d (Bredehoeft, 1963, p. 46). Near Battle Mountain, the transmissivity of flood-plain deposits is an estimated 4,500 ft^2/d, the storage coefficient is an estimated 0.0025 (Loeltz, 1953, p. 5-8), and the hydraulic conductivity is an estimated 20 ft/d.

Structural Features of Hydrographic Areas

Each of the hydrographic areas in the Carlin trend study area is made up of one or more structural basins that underlie the topographic basin. Structural basins generally are bounded by bedrock of adjacent mountain ranges and contain basin-fill deposits that are several thousand feet thick or more. The movement of ground water in the study area is influenced by the geometry and hydrologic properties of these units.

The geometry of hydrogeologic units in each of the hydrographic areas was estimated along five hydrogeologic sections (pl. 2) that were developed as cross-sectional models using gravity and magnetic data (Saltus, 1988, and T.G. Hildenbrand, U.S. Geological Survey, written commun., 1990).

The models consist of several bodies, each representing one or more hydrogeologic units. The measured gravity and aeromagnetic fields along each section (pl. 2) were used with a computer program (Webring, 1985) to develop each model. The program calculates the gravity and magnetic profiles that result from the hypothetical configuration of bodies that constitute the cross section. The geometry and values of density and magnetic susceptibility for each body were repeatedly adjusted until calculated profiles matched measured profiles as closely as possible.

The geologic models are constrained by surficial geology, limited borehole data, reported thicknesses of hydrogeologic units, and reported density and magnetic susceptibility of similar rock types. Simultaneous use of gravity and magnetic data provided an additional constraint because the two provide contrasting information. However, the models shown are not unique; similar fits of calculated and observed profiles could be achieved by changing model geometries and physical properties. In spite of these limitations, the models are considered reasonable conceptualizations of the subsurface distribution of bedrock and basin-fill deposits along each section.

Values of magnetic susceptibility and density used for developing the sections in plate 2 are listed below. These are estimated values; they have never been systematically measured in the field in the study area. However, the values are within accepted ranges for similar rock types (Carmichael, 1989, p. 333-349; Olhoeft and Johnson, 1989, p. 161-173; and H. R. Blank, U.S. Geological Survey, oral commun., 1993).

Hydrogeologic unit	Density (g/cm^3)	Magnetic susceptibility[1]
Basin-fill deposits..........	2.12-2.17	0.0001
Granitic rocks.............	2.57-2.71	.0012-.0017
Volcanic rocks	2.60-2.72	.0010-.0025
Siltstones and carbonate rocks	2.57-2.62	.000001

[1] Magnetic susceptibility is a dimensionless property. Values shown above are for the cgs (centimeter-gram-second) system.

Comparison of calculated and measured gravity and magnetic profiles for the five sections (pl. 2) indicate that volcanic rocks greatly complicate efforts to achieve fits of calculated and measured profiles. The simple, tabular bodies of volcanic rocks in sections *A-A'*, *B-B'*, and *C-C'* may be much more complex, especially if the rocks were deposited on a surface of significant relief. In addition, the magnetic susceptibility of bodies of volcanic rocks may change over short distances. More detailed measurements of the gravity and magnetic fields in the area would make it possible to improve the fits of calculated and measured profiles, and thus improve the sections. In addition, field and laboratory measurements of the density and magnetic susceptibility of hydrogeologic units would reduce the uncertainty of the models.

Upper Maggie Creek Area

The upper reach of the Maggie Creek Area is underlain by the deepest structural basin known in the study area. Basin-fill deposits are estimated to be 7,000-8,000 ft thick where section *D-D'* crosses the basin (pl. 2). A similar thickness was estimated by Stone and others (1991, pl. 4). The structural basin is formed by down-faulted carbonate rocks and siltstones. Granitic rocks underlie the basin at depths greater than those shown on the section (see Plume, 1995, fig. 14). Older basin-fill deposits are overlain by younger basin-fill deposits along stream flood plains and alluvial fans.

Lower Maggie Creek, Marys Creek, and Susie Creek Areas

A broad structural basin underlies the combined area of the lower reach of the Maggie Creek Area, the southern part of the Susie Creek Area, and the Marys Creek Area (pls. 1 and 2). This structural basin is formed by down-faulted siltstones that overlie carbonate rocks along the Roberts Mountains thrust fault. The structural basin is bounded by uplifted bedrock along range-front faults to the northwest at the hills northeast of Maggie Creek Canyon, at Schroeder Mountain, and to the west at Marys Mountain. The structural basin is an estimated 3,000-4,000 ft deep near Maggie Creek and about 2,000 ft deep near Susie Creek (pl. 2, sections *D-D'* and *E-E'*). Stone and others (1991, pl. 4) estimate a similar depth for the basin beneath Susie Creek, but only about 1,000-2,000 ft beneath lower Maggie Creek. The depth of the basin decreases to less than 1,000 ft near the Humboldt River (pl. 2, section *D-D'*).

Willow Creek Valley

The structural basin in Willow Creek Valley is relatively narrow and oriented northeast-southwest (pl. 1). The basin is formed by down-faulted volcanic rocks and underlying siltstones (pls. 1 and 2, section *B-B'*). The western part of the structural basin consists of an estimated 700-800 ft of volcanic rocks overlying the siltstones. Carbonate rocks may be present at depth as the lower plate of the Roberts Mountains thrust fault.

The western part of the structural basin is relatively shallow where basin-fill deposits are estimated to be less than 500 ft thick (pl. 2, section *B-B'*). Exposures of bedrock farther east (pl. 1) suggest that the basin-fill deposits also are thin in this part of the area.

Rock Creek Valley

The structural basin that underlies Rock Creek Valley is a relatively shallow, bowl-shaped depression. Bedrock offsets along basin-bounding, high-angle faults appear to have formed the basin, although warping or bending of volcanic rocks and siltstones also may have been important (pl. 2, sections *A-A'* and *B-B'*). The structural basin consists of an estimated 1,000 to perhaps as much as 2,000 ft of volcanic rocks that overlie siltstones (pls. 1 and 2, sections *A-A'* and *B-B'*). Positions of the Roberts Mountains thrust fault and underlying carbonate rocks are very uncertain.

A large body of granitic rocks underlies the Sheep Creek Range at estimated depths of 2,500-3,500 ft (pl. 2, section *A-A'*). The depth of the body has been inferred to be much shallower in gravity and magnetic models developed by Gott and Zablocki (1968, p. 16). This discrepancy could be resolved by drill holes and field measurements of magnetic susceptibility and density.

The magnetic anomaly associated with the body of intrusive rocks and volcanic rocks in the Sheep Creek Range (pls. 1 and 2, section *A-A'*) is part of a linear magnetic anomaly that extends southeastward from southern Oregon to central Nevada. Sources for this magnetic anomaly have been postulated to be late Miocene age volcanic flows and flow domes and associated granitic bodies (Stewart and others, 1975, p. 267).

Sections *A-A'* and *B-B'* (pl. 2) indicate that older basin-fill deposits and the overlying younger basin-fill deposits could range in thickness from 800 to almost 2,000 ft in the Rock Creek Valley. The deposits thin toward the basin margins, and in places lap over topographic divides to the east and north (pl. 1). The deepest parts of the structural basin may be in the eastern part of the hydrographic area (pl. 2, section *A-A'*).

Boulder Flat

The principal structural basin in Boulder Flat underlies the area between the Sheep Creek Range on the northwest, the Argenta Rim on the south, and Tuscarora Mountains on the east (pls. 1 and 2, sections *B-B'* and *C-C'*). The north and east parts of the structural basin are underlain by granitic rocks and volcanic rocks overlying siltstones (pl. 2, section *B-B'*). Volcanic rocks beneath the northwest side are an estimated 1,500 ft thick. The structural basin is bounded by range-front faults along the west side of the Tuscarora Mountains and east side of the Sheep Creek Range. The basin is estimated to be as deep as 2,500 ft. The prism of basin fill is inferred to consist of no more than a few hundred feet of younger basin-fill deposits overlying older basin-fill deposits.

Farther west, the structural basin is bounded by high-angle faults along the Sheep Creek Range to the north and the Argenta Rim to the south (pl. 2, section *C-C'*). The structural basin is underlain by an estimated 500 ft of volcanic rocks, which overlie siltstones. The combined thickness of younger and older basin-fill deposits is estimated to be about 3,500 ft in the deepest parts of the basin (pl. 2, section *C-C'*). A similar thickness was previously estimated (Stone and others, 1991, pl. 4) near section *B-B'* (pl. 2). However, they estimate a depth of about 5,000 ft near section *C-C'*.

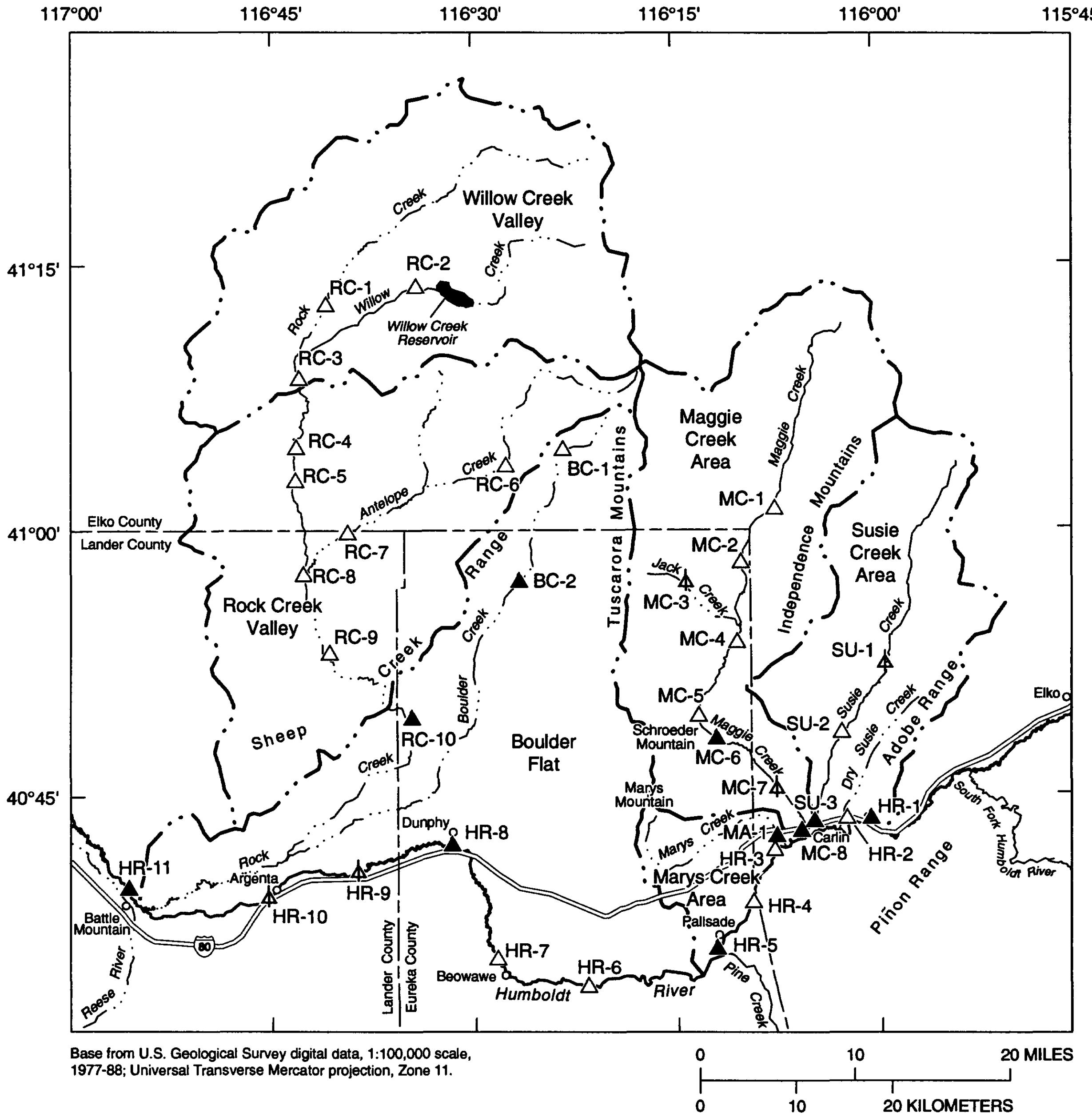
SURFACE WATER

The study area is drained by several tributaries of the Humboldt River (fig. 4). These tributaries are Susie Creek, Maggie Creek, and Marys Creek on the east side of the Tuscarora Mountains, and Rock Creek and its tributaries on the west side of the mountains. Except for Pine Creek, tributary basins of the Humboldt River south of the study area are usually dry and do not produce much runoff.

High flows of the Humboldt River and its tributaries in the study area generally result from the snowmelt runoff in late winter, spring, and early summer. Warm winter storms, especially rain on snowpack, less frequently result in high flows. After the snowmelt runoff, streamflow subsides to a low-flow condition in middle to late summer and fall. Some reaches of these streams have a baseflow that is sustained by ground-water discharge to the stream channel. Along such reaches, the water table is above the river channel. Other reaches lose flow as a result of irrigation diversions, infiltration through the channel to the underlying aquifer, and evaporation, and may go dry in late summer and early fall.

Streamflow in the study area was characterized using flow records from stream-gaging stations and measurements that were made intermittently during periods of low flow in the summer and late fall. Records from the stream-gaging stations were used for describing annual runoff characteristics of the Humboldt River and its tributaries.

Streamflow was continuously measured at nine gaging stations during the study. In addition, streamflow had been measured in the past at six other stream-gaging stations that are currently inactive. Locations of these gaging stations and periods of record for each are shown in figure 4 and listed in table 3, respectively. Comparative analysis of the streamflow data for these gaging stations is difficult because no two stations have identical periods of record. To simplify the analysis, several periods of record were selected. These periods are described in the following sections for each stream.



EXPLANATION

Hydrographic-area boundary—Modified from Rush (1968); not shown where coincident with Humboldt River

HR-1 **Active stream-gaging station**—Label refers to site name in appendix 1. Abbreviations: **HR**, Humboldt River; **SU**, Susie Creek; **MC**, Maggie Creek; **MA**, Marys Creek; **BC**, Boulder Creek; and **RC**, Rock Creek

HR-9 **Inactive stream-gaging station**—Label refers to site name in appendix 1. Abbreviations: **HR**, Humboldt River; **SU**, Susie Creek; and **MC**, Maggie Creek and its tributary, Jack Creek

RC-9 **Streamflow measurement site**—Label refers to site name in appendix 1. Abbreviations: **HR**, Humboldt River; **SU**, Susie Creek; **MC**, Maggie Creek; **BC**, Boulder Creek; and **RC**, Rock Creek and its tributaries

Figure 4. Stream-gaging stations and sites where streamflow was measured intermittently in the Carlin trend area, north-central Nevada.

Table 3. Periods of record for stream-gaging stations, Carlin trend area, north-central Nevada

Site name [1]	Site number [2]	Period of record
	Humboldt River	
Near Carlin	HR-1	Oct. 1944-present.
At Palisade	HR-5	Oct. 1902-Oct. 1906, July 1911-present.
At Hwy 40 at Dunphy	HR-8	Feb. 1991-present.
Near Argenta	HR-9 [3]	Feb. 1946-Sept. 1982.
Below Slaven Ditch near Argenta	HR-10 [3]	Oct. 1980-Sept. 1983.
At Battle Mountain	HR-11	May 1896-Dec. 1897, Mar. 1921-Apr. 1924, Oct. 1945-Sept. 1981, Feb. 1991-present.
	Susie Creek	
Near Carlin	SU-1 [3]	Oct. 1955-Sept. 1958.
At Carlin	SU-3	Apr. 1992-present.
	Jack Creek	
Below Indian Creek near Carlin	MC-3 [3]	Apr. 1991-Apr. 1993.
	Maggie Creek	
At Maggie Creek Canyon near Carlin	MC-6	Sept. 1989-present.
Near Carlin	MC-7 [3]	Dec. 1989-May 1992.
At Carlin	MC-8	July 1913-Dec. 1921, Apr.–May 1922, Apr. 1923-Sept. 1924, Apr. 1992-present.
	Marys Creek	
At Carlin	MA-1	Nov. 1989-present.
	Boulder Creek	
Near Dunphy	BC-2	Feb. 1991-present.
	Rock Creek	
Near Battle Mountain	RC-10	Mar.-July 1896, Mar. 1918-Sept. 1925, Mar. 1927-May 1929, Oct. 1945-present.

[1] General geographic location of site. For example, site HR-1 is Humboldt River near Carlin and MC-3 is Jack Creek below Indian Creek near Carlin.

[2] See figure 4 for locations and appendix 1 for additional site information.

[3] Inactive gaging station as of 1993.

Locations of sites where streamflow measurements were made intermittently during the present study are shown in figure 4 and the measurements are listed in appendix 1. These measurements were used for estimating gains and losses over relatively short reaches of stream channel, for estimating baseflow rates and for understanding relations between streams and aquifers. This information and that gained from analysis of gaging-station records was used for estimating components of ground-water budgets in the study area. Intermittent measurements made during the study period represent conditions during an extended period of drought, and may not represent long-term average conditions.

The 12-month period from October 1 to September 30 is referred to as the water year. The water year is used in this report for discussing annual or long-term flow characteristics of a stream. References to the calendar year are accompanied either by the month or time of year (September 1990 or fall of 1990, for example).

Susie Creek

The Susie Creek Area consists of the Dry Susie Creek and Susie Creek drainage basins. Dry Susie Creek probably flows for short periods only during the snowmelt runoff or during intense storms. Flow in this stream was never observed during the study.

Streamflow of Susie Creek was recorded continuously at a gaging station about 15 mi upstream from its mouth during water years 1956 through 1958 (fig. 4, site SU-1). As a part of the present study, streamflow of Susie Creek has been recorded continuously at a gaging station near its mouth (SU-3) since May 1992. In addition, streamflow of Susie Creek has been measured intermittently at sites SU-2 and SU-3 since October 1991.

The flow of Susie Creek at site SU-1 near the center of the hydrographic area during water years 1956-58 ranged from no flow during short periods in the summer to about 60 to 90 ft^3/s during the snowmelt runoff of each year (fig. 5*A*). Total annual flows were about 4,600 acre-ft in water year 1956, 4,400 acre-ft in 1957, and 4,300 acre-ft in 1958 (U.S. Geological Survey, 1963, p. 250). These annual flows may be average to slightly above average because annual flows of the Humboldt River near Carlin (site HR-1, fig. 4) in water years 1956-58 ranged from 100 to 120 percent of the long-term average (U.S. Geological Survey, 1963, p. 249).

Measurements made on Susie Creek at sites SU-1 and SU-2 during low flows (fig. 4) indicate that this 5-mi reach gains flow, either as a result of small tributary streams or ground-water discharge to the stream channel (Newmont Gold Co., 1993d, table 3). Measured gains were about 1 ft^3/s in September 1993.

The reach of Susie Creek between sites SU-2 and SU-3 loses flow as infiltration to the underlying aquifer. Flow losses along this reach were 1.6 ft^3/s in April 1992, 3 ft^3/s in October 1992, and 3.1 ft^3/s in September 1993 (app. 1, and Newmont Gold Co., 1993d, table 3).

The flow of Susie Creek at the gaging station near its mouth (fig. 4, site SU-3) ranged from none during the summers of 1992 and 1993 to more than 200 ft^3/s during the snowmelt runoff of spring 1993 (fig. 5*B*). The periods of no flow during the two summers extended from May through part of October in 1992 and from July through September in 1993.

The total flow of Susie Creek in water year 1993 was about 9,500 acre-ft (Emett and others, 1994, p. 231). The flow of the Humboldt River near Carlin during the same year was slightly above the long-term average annual flow (Emett and others, 1994, p. 228). Thus, the flow of Susie Creek near its mouth may have been nearly normal in 1993.

Intermittent flow measurements and the record for the gaging station near its mouth indicate that Susie Creek has no baseflow during the summer and early fall (app. 1; fig. 5*B*). After evapotranspiration decreases to minimum rates in late fall, the baseflow of the stream increases to about 0.2-1 ft^3/s.

Maggie Creek

Streamflow was measured at eight sites in the Maggie Creek Area. Four of the sites are on the mainstem of upper Maggie Creek (sites MC-1, MC-2, MC-4, and MC-5, fig. 4). Streamflow of Jack Creek (site MC-3, fig. 4), a tributary of Maggie Creek, also was measured.

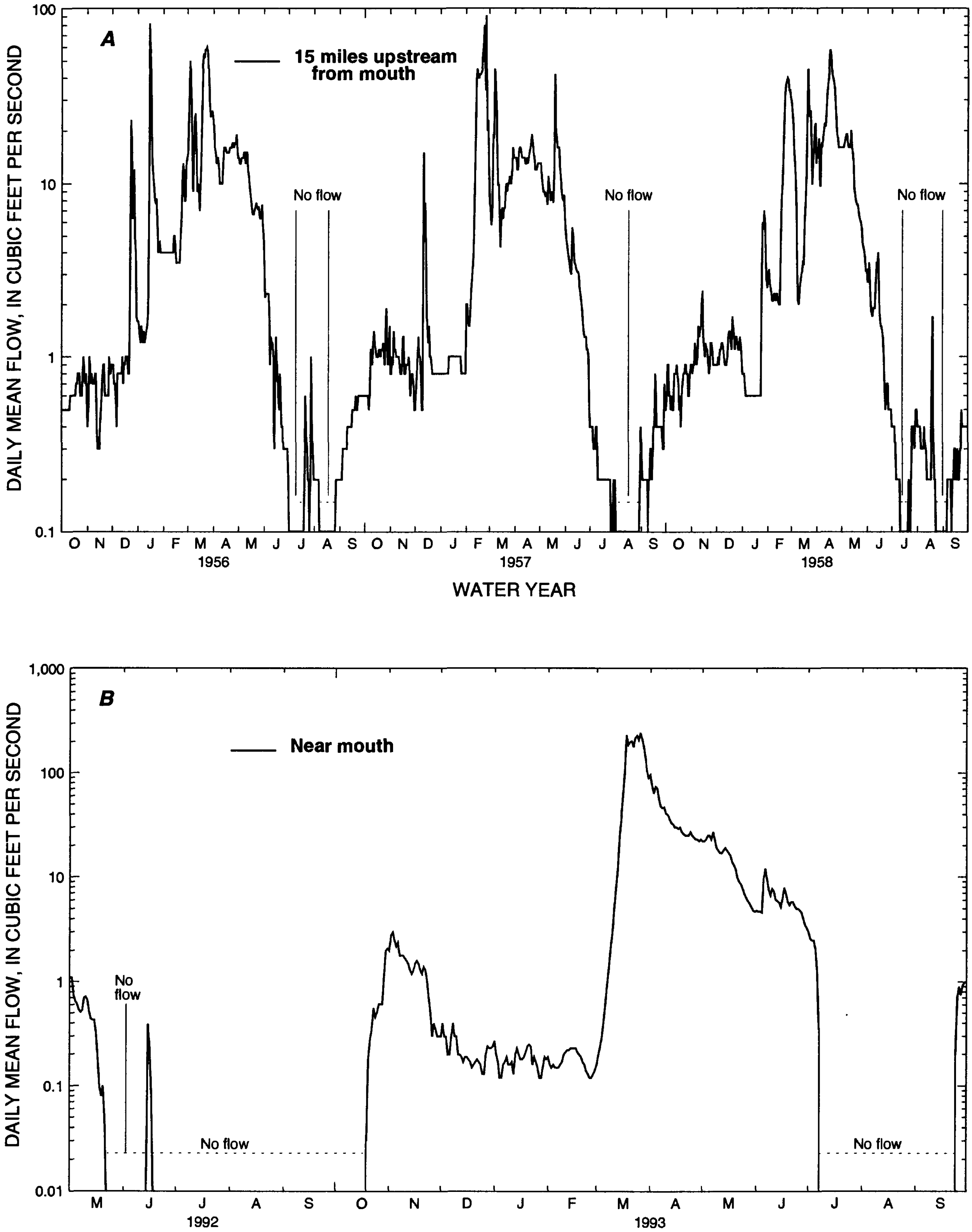


Figure 5. Daily mean flow of Susie Creek in Carlin trend area, north-central Nevada. (***A***) Above Adobe Creek near Carlin (fig. 4, site SU-1), October 1955 through September 1958; and (***B***) at Carlin (fig. 4, site SU-3), May 1992 through September 1993.

Flows of Jack Creek ranged from about 0.01 ft^3/s early in water year 1993 to nearly 200 ft^3/s during the snowmelt runoff in March 1993 (fig. 6; Emett and others, 1994, p. 232). During the snowmelt runoffs of water years 1991 and 1992, flows barely exceeded 2 ft^3/s. Total flow of the stream during 1992, which is the only complete water year of streamflow records, was about 280 acre-ft (Hess and others, 1993, p. 196).

Streamflow measurements made in September 1993 show that the gaging station was on a gaining reach of Jack Creek and that the stream consisted of several gaining and losing reaches (Newmont Gold Co., 1993d, fig. 7). Except for periods during the snowmelt runoff, the flow of Jack Creek is lost to infiltration and irrigation diversions before reaching Maggie Creek.

Upper Maggie Creek consists of a losing reach between sites MC-1 and MC-2 and a gaining reach between sites MC-2 and MC-5 (app. 1). Measured flow losses between MC-1 and MC-2 in June 1991 and August 1992 were 0.5 ft^3/s and 1.2 ft^3/s, respectively along the 4-mi reach (app. 1). These losses were the result of irrigation diversions and infiltration to the underlying aquifer.

Flow losses between MC-1 and MC-2 in October 1991 were about 0.3 ft^3/s. One year later, measurements showed no losses along the reach. The losses in October 1991 were mostly the result of infiltration of streamflow to the underlying aquifer because little or no water was being diverted and evapotranspiration probably was at minimum rates. The baseflow of Maggie Creek at the upper end of this reach is about 1 ft^3/s (app. 1).

The reach of upper Maggie Creek between sites MC-2 and MC-5 consistently gains flow from groundwater discharge to the stream channel, even during the summer when flows are diverted for irrigation and evapotranspiration is at maximum rates (app. 1). The average baseflow of Maggie Creek at the lower end of this reach was previously estimated to be about 5 ft^3/s (Plume, 1995, p. 32). Measurements made during the present study indicate that this is a reasonable estimate for baseflow.

In the Maggie Creek Canyon, the 2-mi reach between sites MC-5 and MC-6 (fig. 4), loses flow as infiltration through the stream channel. Measured flow losses along this reach ranged from 1.6 to 1.7 ft^3/s during summer and fall of 1991 and 1992 (app. 1).

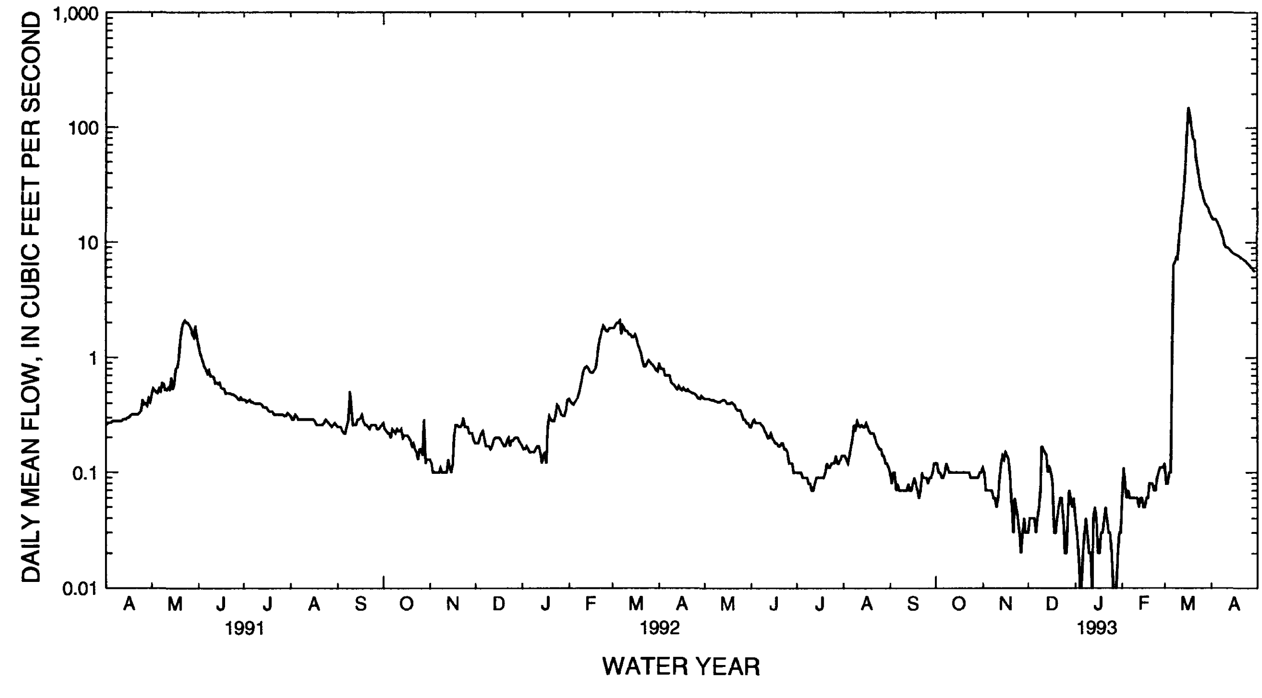


Figure 6. Daily mean flow of Jack Creek in Carlin trend area, north-central Nevada, April 1991 through April 1993 (fig. 4, site MC-3).

Seasonal and total annual flows of Maggie Creek at the stream-gaging station downstream from Maggie Creek Canyon (site MC-6, fig. 4) differed during water years 1990-93 because of variations in winter precipitation. The tabulation below lists high, low and average mean daily flows and total annual flows during the four water years. High flows during the snowmelt runoff ranged from 15 ft^3/s to 520 ft^3/s during the four water years, and total volumes of flow ranged from 2,300 acre-ft to 29,000 acre-ft. Periods of no flow late in water years 1991 and 1992 both were during years of extended drought. In water year 1993, when flows may have been above normal, the late summer baseflow at site MC-6 (app. 1, fig. 7*A*) was comparable to late summer flows measured from 1988 to 1990 (Plume, 1995, p. 33). These data and comparisons with measurements made earlier suggest that, as of October 1993, pumping at Gold Quarry mine had not affected the baseflow of Maggie Creek at site MC-6.

Flow of Maggie Creek at Maggie Creek Canyon (fig. 4, site MC-6)

Water Year	Flows [1]			
	High (ft^3/s)	Low (ft^3/s)	Average (ft^3/s)	Total (acre-ft)
1990	50	1.6	11	8,100
1991	24	0	7.4	5,400
1992	15	0	3.2	2,300
1993	520	0	40	29,000

[1] Bostic, and others, 1991, p. 166; Garcia and others, 1992, p. 185; Hess and others, 1993, p. 198; and Emett and others, 1994, p. 233.

Maggie Creek has no baseflow in late summer and early fall at the gaging station near its mouth (site MC-8, fig. 7*A* and Plume, 1995, p. 32). During water years 1913-24, peak flows were as high as 800 ft^3/s in May 1922, and the average annual flow for the period was about 17,000 acre-ft/yr (U.S. Geological Survey, 1960, p. 374). Peak flows at site MC-8 were 640 ft^3/s in March 1993 (fig. 7*A*), and total flow in that water year was about 29,000 acre-ft (Emett and others, 1994, p. 234). On the basis of the two periods of record, the average flow of Maggie Creek at its mouth is about 18,000 acre-ft/yr (Emett and others, 1994, p. 234).

The reach of Maggie Creek between sites MC-6 and MC-8 consistently loses flow, except during some water years when low-altitude snowmelt in the basin between the two stations results in flow gains. This type of gain has been measured in February 1990 (Plume, 1995, p. 33) and in March-May 1993 (fig. 7*B*).

Total flow losses along the reach of Maggie Creek between sites MC-6 and MC-8 depend on the capacity of the stream channel to transmit losses to the underlying aquifer and on the availability of flow at the upper site. The infiltration capacity of the stream channel in the reach has been estimated to range from 10 to 20 ft^3/s (Plume, 1995, p. 33). In water year 1993, streamflow losses along this 9-mi reach were as much as 26 ft^3/s in April and decreased to less than 10 ft^3/s in the summer (fig. 7*B*). When daily mean flow at the upper gaging station is less than about 20 ft^3/s, most or all of this flow enters the aquifer as recharge. When the mean daily flow exceeds about 20 ft^3/s, the excess leaves the basin as runoff.

The total volume of streamflow infiltration to the underlying aquifer between sites MC-6 and MC-8 in water year 1993 was an estimated 3,500 acre-ft. This value was determined by comparing daily mean flows for the water year at the two gaging stations. For those days during which a loss was recorded, the daily volume of infiltration was computed as the loss between the gaging stations. For those days in March, April, and May when a gain was recorded, the daily volume of infiltration was computed using a rate of 20 ft^3/s.

Marys Creek

Over most of its length, Marys Creek is a dry wash that flows only during the snowmelt runoff and during periods of heavy precipitation. The reach of Marys Creek from Carlin spring to the Humboldt River has a baseflow that is sustained throughout the year by discharge of the spring. Part of the spring discharge is diverted upstream from the gaging station at site MA-1 for municipal use at Carlin. The volume of flow diverted is recorded by the City of Carlin.

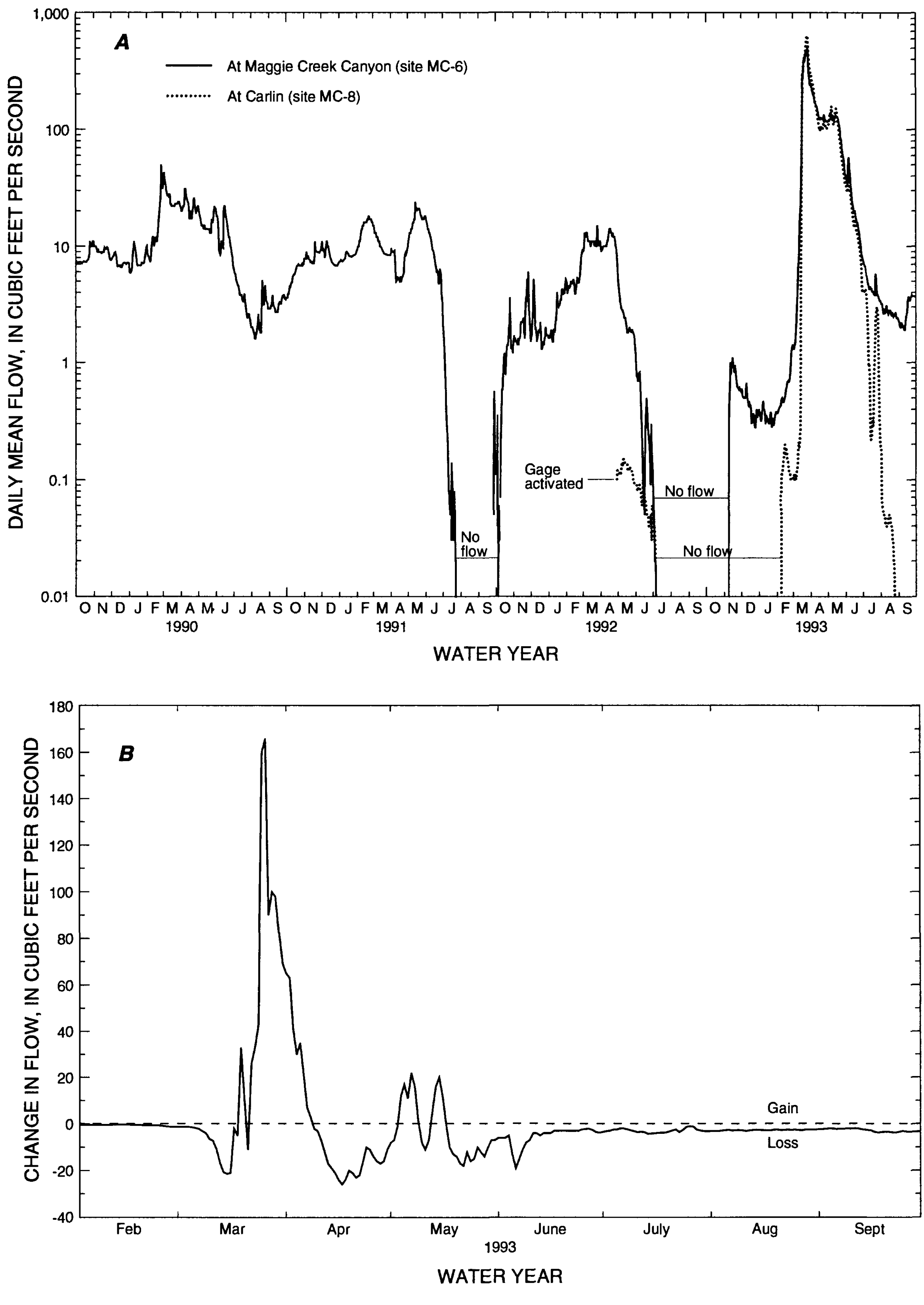


Figure 7. Flow characteristics of Maggie Creek in Carlin trend area, north-central Nevada. (***A***) Daily mean flow at Maggie Creek Canyon, October 1989 through September 1993, and at Carlin, May 1992 through September 1993 (fig. 4, sites MC-6 and MC-8); and (***B***) difference in flow between the two sites, February through September 1993.

The daily flow of Marys Creek below Carlin spring at site MA-1 has ranged from as little as about 0.6 ft^3/s during municipal diversion in the summer of 1991 to about 400 ft^3/s during snowmelt runoff in the spring of 1993 (fig. 8). The baseflow during periods without municipal diversion or upstream runoff is about 4 ft^3/s. Daily mean flows during the snowmelt runoff were about 20 ft^3/s in water year 1990, 10 ft^3/s in 1991, and 400 ft^3/s in 1993 (fig. 8). Annual volumes of flow recorded at the Marys Creek gaging station were about 2,200 acre-ft in water year 1991, 2,000 acre-ft in water year 1992, and 4,700 acre-ft in water year 1993 (Garcia and others, 1992, p. 188; Hess and others, 1993, p. 202; and Emett and others, 1994, p. 235).

The total volume of discharge from Carlin spring each water year can be computed as the total flow of Marys Creek measured at the gaging station plus the amount of water diverted for the town of Carlin minus the volume of the upstream runoff. The volume of the upstream runoff can be approximated for short periods of time as total flow measured at the gaging station during the runoff minus discharge from Carlin spring that is assumed to be a constant 4 ft^3/s. Using this approach, total volumes of discharge at Carlin spring in water years 1990 and 1991 were estimated to be 2,800 acre-ft and 2,700 acre-ft, respectively (Plume, 1995, p. 34-35). The resulting average discharge of the spring during the 2 years was 3.9 ft^3/s and 3.7 ft^3/s, respectively. The assumption of constant springflow makes these values approximate.

A better estimate of average springflow was obtained in water year 1992, when there was no upstream runoff from the Marys Creek Area (fig. 8). Total flow measured at the Marys Creek gaging station was about 2,000 acre-ft (Hess and others, 1993, p. 202), and the amount of water diverted for Carlin was 590 acre-ft (C.L. Aiazi, City of Carlin, written commun., 1993). Thus, the total volume of discharge from Carlin spring that year was about 2,600 acre-ft, and average discharge was about 3.6 ft^3/s.

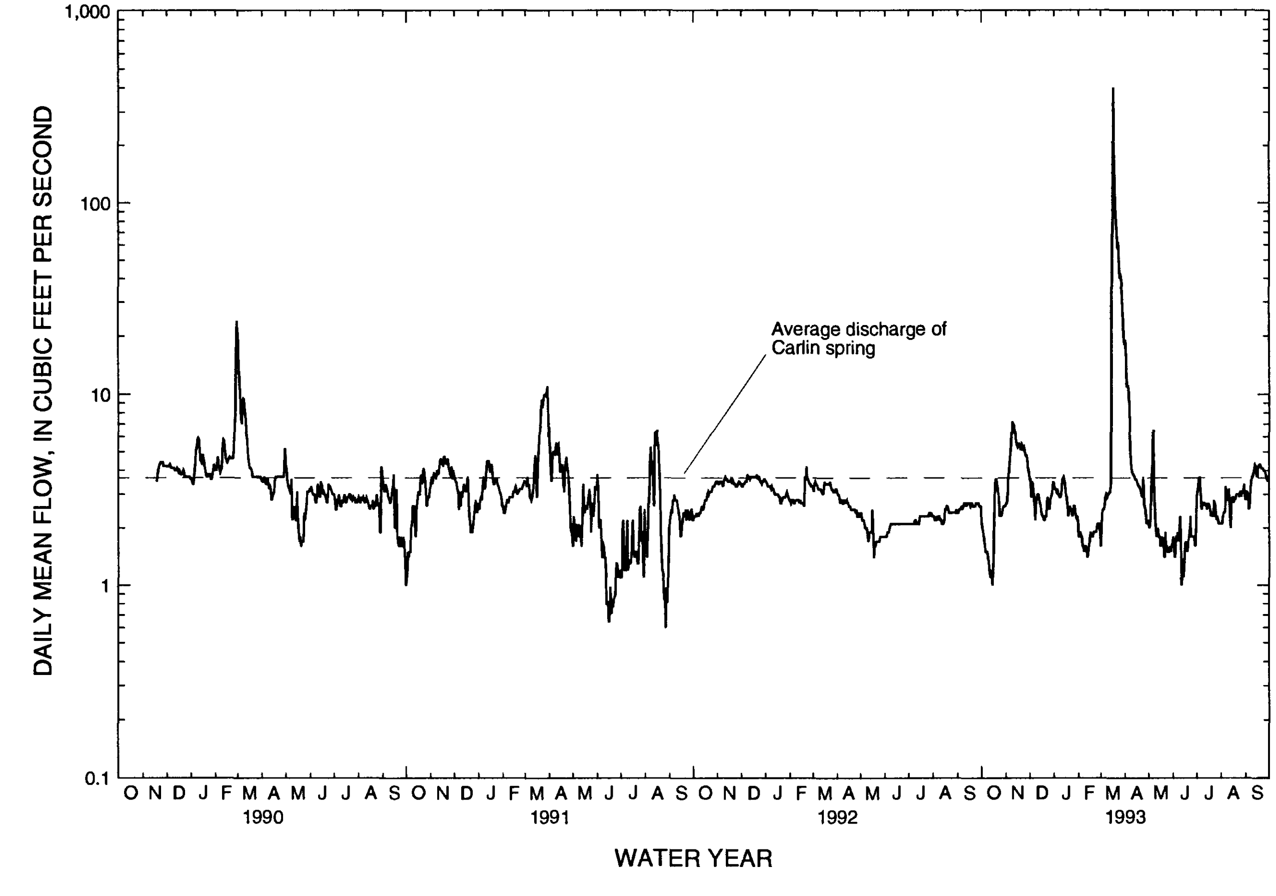


Figure 8. Daily mean flow of Marys Creek in Carlin trend area, north-central Nevada, October 1989 through September 1993 (fig. 4, site MA-1).

In water year 1993, the total volume of flow at the Marys Creek gaging station was about 4,700 acre-ft. Upstream runoff was recorded in November and from mid-March to early April (Emett and others, 1994, p. 235). The total volume of flow at the gaging station during these two periods was about 3,100 acre-ft. If the average discharge of Carlin spring during runoff is assumed to have been 4 ft^3/s, then the volume of upstream runoff is an estimated 2,700 acre-ft. The amount of water diverted for the town of Carlin during the year was about 630 acre-ft (L.F. Greenwood, City of Carlin, oral commun., 1994). Thus, the total volume of discharge from Carlin spring in water year 1993 was about 2,600 acre-ft, and the average discharge was about 3.6 ft^3/s.

To summarize, the average discharge of Carlin spring in water years 1990-93 ranged from 3.6 to 3.9 ft^3/s. The most accurate estimate is 3.6 ft^3/s, in 1992. Given the approximate nature of estimates for other years, the decrease in estimated average flow from 3.9 ft^3/s in 1990 to 3.6 ft^3/s in 1993 is probably not meaningful. The general agreement of estimates suggests that springflow had not been measurably affected by pumping at Gold Quarry mine as of 1993.

Rock Creek and Its Tributaries

Rock Creek and its tributary, Willow Creek, are the principal streams in Willow Creek Valley. Flows of each stream are influenced by irrigation diversions and releases from Willow Creek Reservoir (fig. 4). Measurements made on October 23, 1991 at sites RC-1, RC-2, and RC-3 show a loss of about 5.4 ft^3/s (app. 1). In contrast, measurements made a year later at the three sites show a gain of about 3 ft^3/s (app. 1). The latter situation is probably more realistic because wet meadows and marshes indicate that the southern part of the hydrographic area near Rock Creek is an area of ground-water discharge.

The reach of Rock Creek between sites RC-3 and RC-4 is in a canyon incised in the unnamed mountain range between Willow Creek Valley and Rock Creek Valley (fig. 4). Flows measured at the two sites indicate that this reach was not gaining or losing appreciable flow in the fall of 1992 (app. 1).

Rock Creek Valley is drained by Rock Creek and its main tributary, Antelope Creek, which drains the eastern part of the area. Rock Creek consistently loses streamflow as infiltration through the stream channel between sites RC-4, RC-5, and RC-8 (fig. 4). Total losses over the 9-mi reach ranged from 1.4 ft^3/s to 3.5 ft^3/s in summer and fall of 1991 and 1992 (app. 1). Infiltration rates through the stream channel undoubtedly differ depending on the amount of flow.

Antelope Creek is an ephemeral stream except for two short reaches where baseflow is sustained by ground-water discharge. Flows of appreciable volume probably occur only during the snowmelt runoff in years of at least average precipitation. Otherwise much of the stream channel is dry during the year. Baseflows of 0.01-0.16 ft^3/s were measured at sites RC-6 and RC-7 in 1991 and 1992 during drought conditions (app. 1).

The 5-mi reach of Rock Creek between sites RC-8 and RC-9 (fig. 4) gains flow as a result of ground-water discharge to the stream channel. Gains ranged from about 0.08 ft^3/s to 0.88 ft^3/s from June 1991 to October 1992 (app. 1). Flows measured at site RC-9 in October 1991 and 1992 were 1.4 ft^3/s and 0.64 ft^3/s, respectively (app. 1).

The reach of Rock Creek between sites RC-9 and RC-10 is in a canyon in the Sheep Creek Range (fig. 4). This reach of the stream was not gaining or losing appreciable flow when measurements were made in the summer and fall of 1991 and 1992 (app. 1).

Two periods of record are used for describing flow characteristics of Rock Creek at the stream-gaging station at site RC-10 (fig. 4). The period consisting of water years 1947-81 was used to analyze long-term flow characteristics and for comparisons with flows of the Humboldt River. Flows in water years 1991-92 also are compared because the two years were so different with regard to streamflow.

Streamflow characteristics of Rock Creek for water years 1947-81 at the gaging station are summarized by the graph in figure 9. The curves in this graph, referred to as flow-duration curves, show the frequency that a given flow was equaled or exceeded. These types of curves are useful for analyzing streamflow characteristics of a basin. For a stream with high flows coming mainly from snowmelt, the flow-duration curve will tend to have a relatively flat slope at the upper end (Searcy, 1959, p. 22). Flow-duration curves also are useful for analyzing baseflow characteristics of a stream. The slope of the curve will tend to be relatively flat at the lower end for a stream with baseflow, and steep at the lower end for a stream with no baseflow (Searcy, 1959, p. 22).

The flow-duration curve for Rock Creek shows that streamflow equaled or exceeded 150 ft^3/s about 5 percent of the time, 3 ft^3/s about 50 percent of the time, and 0.1 ft^3/s about 88 percent of the time. The curve also indicates that Rock Creek has no baseflow at site RC-10.

The flow of Rock Creek at site RC-10 differed by large amounts between water years 1992 and 1993. Water year 1992 was the eighth year of drought, and daily mean flows at the gaging station during the snowmelt runoff were 44 ft^3/s in late February (fig. 10*A*; Hess and others, 1993, p. 208). The total volume of streamflow for water year 1992 was about 2,500 acre-ft, compared to an annual average of about 29,000 acre-ft for the period 1918-92 (Hess and others, 1993, p. 208-209). The stream was dry from early July through the rest of the water year.

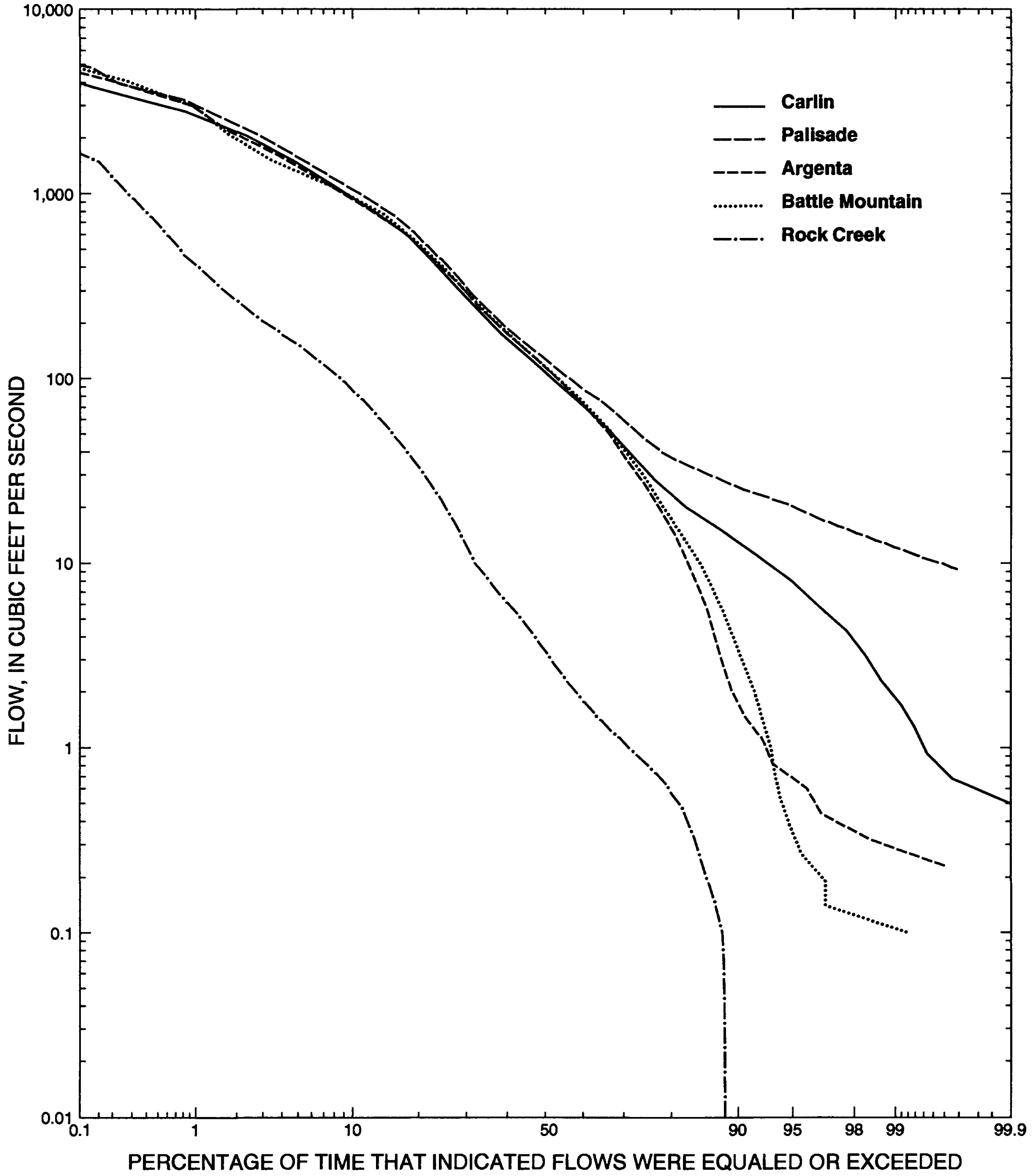


Figure 9. Frequency distribution of daily mean flow of Rock Creek and of Humboldt River near Carlin, at Palisade, near Argenta, and at Battle Mountain (fig. 4, sites RC-10, HR-1, HR-5, HR-9, and HR-11, respectively) in Carlin trend area, north-central Nevada, October 1946 through September 1981.

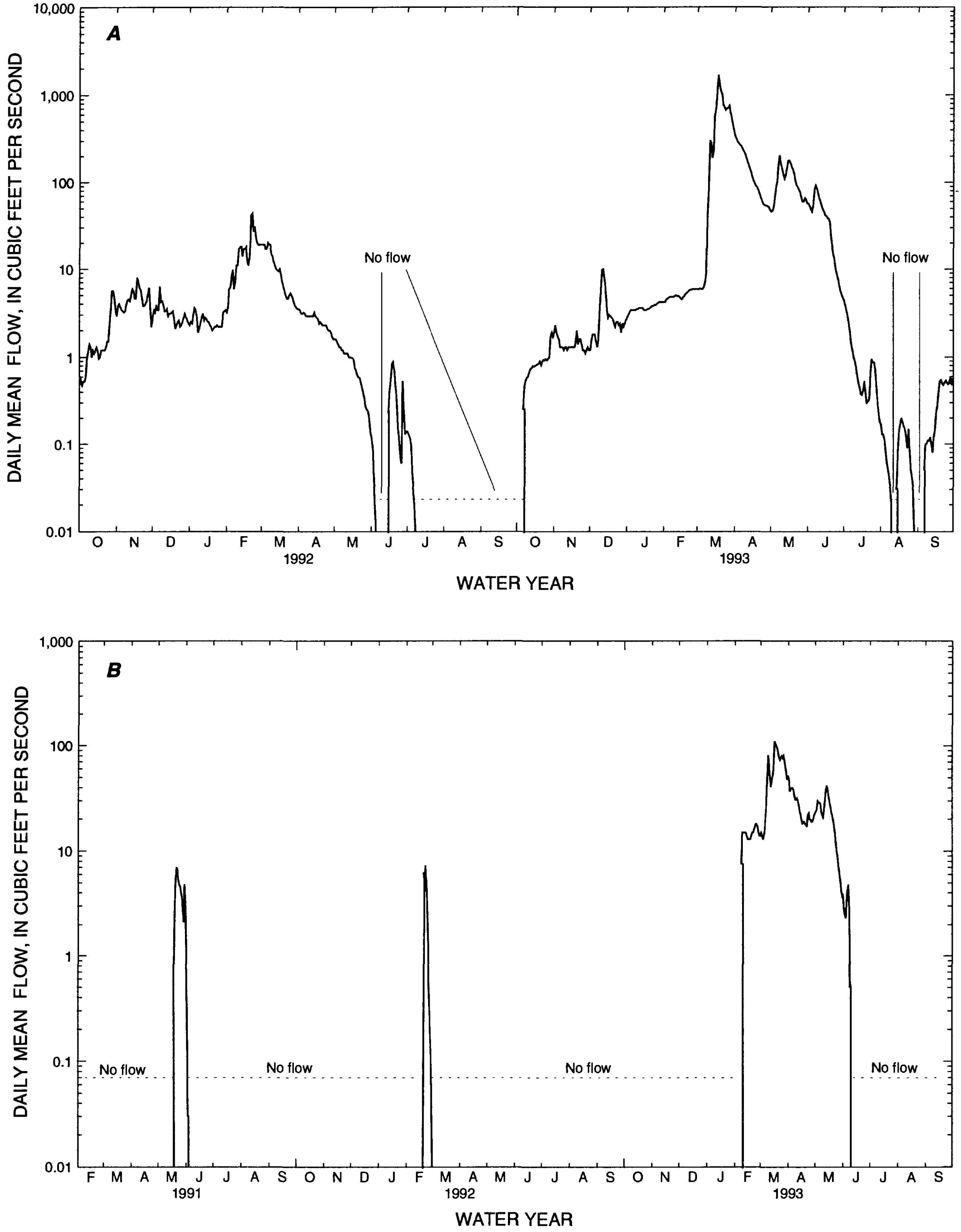


Figure 10. Daily mean flow of (*A*) Rock Creek, October 1991 through September 1993, and (*B*) Boulder Creek, February 1991 through September 1993 in Carlin trend area, north-central Nevada (fig. 4, sites RC-10 and BC-2).

The flow of Rock Creek in water year 1993 was about 170 percent of the long-term average. The daily mean flow was as much as 1,680 ft^3/s in the middle of March, and the stream was dry for short periods in August and September (fig. 10*A*; Emett and others, 1994, p. 239). The total volume of streamflow for the water year was about 49,000 acre-ft (Emett and others, 1994, p. 239).

Boulder Creek, the main tributary of Rock Creek in Boulder Flat, is an ephemeral stream over most of its length. The only exception is a short reach near the headwaters where streamflow is sustained by discharge from springs and seeps (fig. 4, site BC-1). Measured flows at site BC-1 in 1991 and 1992 ranged from 0 to 0.42 ft^3/s (app. 1). The flow of this reach of Boulder Creek probably never exceeds about 1 ft^3/s, except during the snowmelt runoff or during intense storms.

The flow of Boulder Creek at the gaging station at site BC-2 (fig. 4) was completely dominated by the snowmelt runoff in water years 1991-93 (fig 10*B*). In water year 1991, daily mean flows were as much as 7 ft^3/s, and the flow period extended from May 18 to June 3. The total volume of flow for the water year was about 120 acre-ft (Garcia and others, 1992, p. 196). In water year 1992, daily mean flows again were as much as 7 ft^3/s, and the flow period extended from February 20 to March 8. The total flow volume in 1992 was about 62 acre-ft (Hess and others, 1993, p. 211). In water year 1993, daily mean flows were as much as 110 ft^3/s, and the flow period extended from February 8 to June 9. The total flow volume in 1993 was about 7,200 acre-ft (Emett and others, 1994, p. 240).

Flow of Rock and Boulder Creeks is lost to infiltration through the stream channels and irrigation diversions and probably does not reach the Humboldt River in years of below-normal runoff. In water year 1993, the river gained a total of about 40,000 acre-ft between the gaging stations at Dunphy (site HR-10) and Battle Mountain (HR-11). Most of this gain was probably from Rock and Boulder Creeks, which had a combined total flow of about 56,000 acre-ft at the gaging stations at sites RC-10 and BC-2 (fig. 4).

Humboldt River

Between the stream-gaging stations near Carlin and at Battle Mountain, the Humboldt River is a regional sink for ground-water flow from the north and south, and forms the southern boundary of the study area (fig. 1). Two periods of record were selected for comparison of Humboldt River streamflow. Water years 1947 through 1981 were selected because this is the longest period that includes records for four gaging stations. Gaging stations being operated during this period were near Carlin, at Palisade, near Argenta, and at Battle Mountain (sites HR-1, HR-5, HR-9, and HR-11, fig. 4, table 3). Flow conditions for water years 1992 and 1993 also were compared. These two years were selected because 1992 was the eighth consecutive year of drought, and 1993 was a year of near normal flows. Gaging stations operated during this period are near Carlin (HR-1), at Palisade (HR-5), at Dunphy (HR-8), and at Battle Mountain (HR-11).

During the period 1947-81, streamflow characteristics of the Humboldt River at the Carlin, Palisade, Argenta, and Battle Mountain gaging stations were similar during high flows. Flow-duration curves for the river at the four gaging stations indicate that flows equaled or exceeded 100 to 140 ft^3/s about 50 percent of the time (fig. 9). Flows of this magnitude or greater typify the snowmelt runoff in late winter and spring and, to a lesser extent, winter storms.

Flow characteristics of the river at the four gaging stations differed when flows were less than about 100 ft^3/s during water years 1947-81 (fig. 9). The reach of the river between the Carlin and Palisade gaging stations gained flow as a result of runoff and ground-water discharge into the river channel, mostly from the Maggie Creek, Marys Creek, and Susie Creek Areas. The reaches between the Palisade, Argenta, and Battle Mountain gaging stations lost flow as a result of irrigation diversions and infiltration of streamflow through the river channel.

Flow-duration curves for the Carlin and Palisade gaging stations indicate that streamflow at Palisade consistently exceeds that at the upstream Carlin station (fig. 9). Baseflows of the river ranged from less than 1 ft^3/s to about 10 ft^3/s at the Carlin gaging station and from 10 to 30 ft^3/s at the Palisade station (fig. 9). The average annual gain in flow of this reach of the river previously was estimated to be about 38,000 acre-ft/yr (Plume, 1995, p. 36). Ground-water discharge directly into the river channel and from springflow was estimated to account for about 7,000 acre-ft of the annual gain (Plume, 1995, p. 37).

The value for ground-water discharge estimated by Plume (1995) is revised herein on the basis of further analysis of the flow data for the Carlin and Palisade gaging stations. The solid curve shown in figure 11 is similar to the flow-duration curves in figure 9. The difference is that the curve in figure 11 shows the frequency distribution of flow gains of the Humboldt River between the Carlin and Palisade gaging stations. Flow gains along this reach of the river equaled or exceeded 120 ft^3/s about 5 percent of the time and 12 ft^3/s about 95 percent of the time during water years 1947-81 (fig. 11).

Flow gains between the Carlin and Palisade gaging stations due to ground-water discharge are represented in figure 11 by the straight-line part of the solid curve at its low end and its extension as the dashed line. This part of the graph indicates that the baseflow gain of this reach of the river is generally less than about 20 ft^3/s. The smallest gains usually are in late summer when evapotranspiration is at maximum rates and ground-water levels are lowest. Higher rates of baseflow gain, indicated by the dashed curve, are sustained by ground-water discharge when evapotranspiration is minimal, and possibly by water discharging from temporary bank storage. That part of the solid curve above the dashed curve represents snowmelt runoff from Maggie, Marys, and Susie Creeks. This curve indicates that the snowmelt runoff affected the flow between the Carlin and Palisade gaging stations, resulting in gains that exceeded baseflow about 40-50 percent of the time.

The volumes of total and baseflow gains were computed as areas beneath each of the curves (fig. 11). On the basis of the computations, which were made for 5-percent intervals of time, the total volume of annual gain is an estimated 38,000 acre-ft/yr, and the total volume resulting from ground-water discharge is an estimated 12,000 acre-ft/yr. The difference, 26,000 acre-ft/yr, is the estimated average annual volume of the snowmelt runoff, mostly from the Maggie Creek, Marys Creek, and Susie Creek Areas. The value for total gain in flow agrees with an estimate made previously (Plume, 1995, p. 36). In contrast, the value for annual ground-water discharge (12,000 acre-ft/yr) exceeds the previous estimate of 7,000 acre-ft/yr, which was recognized as possibly being low (Plume, 1995, p. 59).

During water years 1947-81, the Humboldt River lost flow as a result of irrigation diversions and infiltration of streamflow to the underlying aquifer between the Palisade, Argenta, and Battle Mountain gaging stations (fig. 9). These losses occurred even with additional inflow from Pine Creek, which joins the river about 0.8 mi downstream from the Palisade gaging station and Rock Creek which joins the river several miles upstream from the Battle Mountain station, respectively (fig. 4).

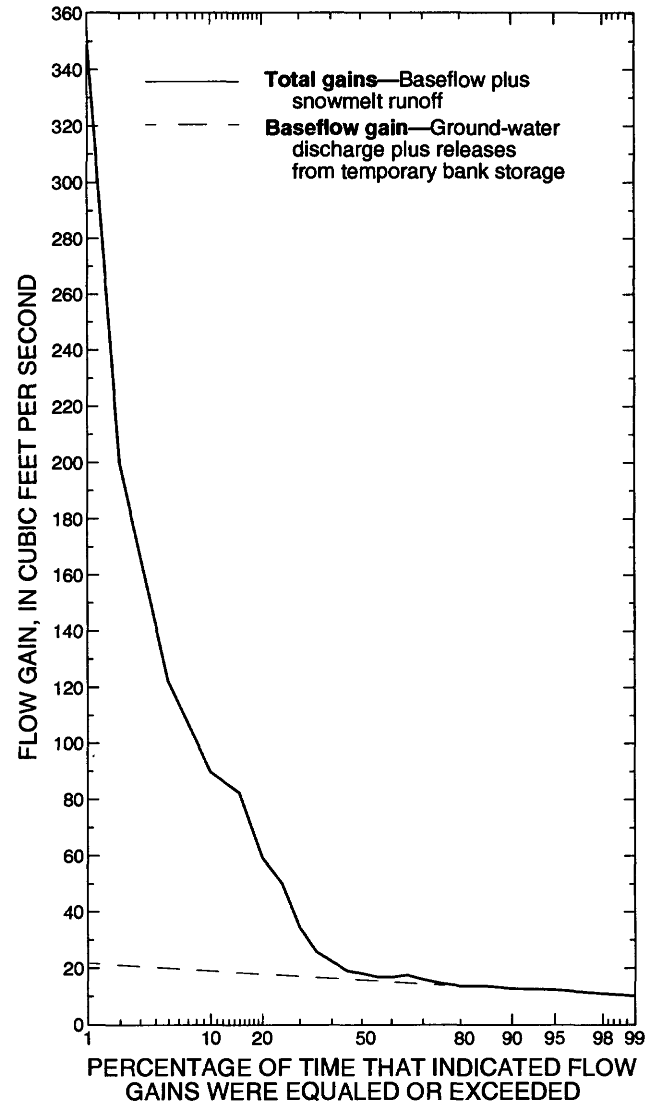


Figure 11. Frequency distribution of streamflow gains of Humboldt River between Carlin and Palisade gaging stations (fig. 4, sites HR-1 and HR-5) in Carlin trend area, north-central Nevada, October 1946 through September 1981.

Flow characteristics of the river at the Argenta and Battle Mountain gaging stations were similar during water years 1947-81 when flows equaled or exceeded about 20 ft^3/s (fig. 9). The reach gained when flows at the two gaging stations ranged from about 1 to 20 ft^3/s and lost when flows were less than 1 ft^3/s (fig. 9).

Near the Argenta gaging station, flow of the Humboldt River equaled or exceeded 0.6 ft^3/s 95 percent of the time during water years 1947-81, and the baseflow was probably less than 1 ft^3/s (fig. 9). The river was dry when the site was visited in late July and mid-October 1992.

Flows at the Battle Mountain gaging station equaled or exceeded about 0.3 ft^3/s 95 percent of the time during water years 1947-81 (fig. 9). The shape of the flow-duration curve for this gaging station suggests that the river had little or no baseflow during part of each year. No flow was recorded in late summer and early fall 1948, 1949, and 1959 (U.S. Geological Survey, 1960, p. 64).

Streamflow losses between the Palisade and Battle Mountain gaging stations are an estimated 40,000 acre-ft/yr, assuming that Rock Creek does not normally contribute flow to the river. This value was computed as the sum of average annual flow of the Humboldt River at Palisade (270,000 acre-ft/yr from 1947-81) and of Pine Creek (9,600 acre-ft/yr) minus the average annual flow at Battle Mountain (240,000 acre-ft/yr from 1947-81). The losses are the result of irrigation diversions and infiltration of streamflow between the two stations.

Two short reaches of the river between the Palisade and Battle Mountain gaging stations gain flow as a result of ground-water discharge to the river channel. The reach of about 8 mi between sites HR-6 and HR-7 was gaining at a rate of about 7 ft^3/s on October 19, 1992 (app. 1). The reach of about 7 mi between sites HR-9 and HR-10 was gaining about 1.5-2 ft^3/s in 1991 and 1992 (app. 1). Both of these short reaches coincide with bedrock narrows that reduce the cross-sectional area of the basin-fill aquifer beneath the river flood plain (pl. 1 and fig. 4). As a result, the water table at the restrictions is above the river channel and ground water discharges into the channel. However, the flow gains reinfiltrate the river channel below the restrictions where the cross-sectional area of the aquifer increases.

The flow of the Humboldt River differed by large amounts between water years 1992 and 1993 (fig. 12). Water year 1992 was the eighth year of drought and, as a result, flows of the river were well below normal. Total volumes of flow during water year 1992 were about 55,000 acre-ft near Carlin, 64,000 acre-ft at Palisade, 58,000 acre-ft at Dunphy, and 46,000 acre-ft at Battle Mountain (Hess and others, 1993, p. 192, 204, 206, and 212). These volumes of flow were about 20 percent of normal.

Water year 1993 was characterized by flows in the river that were above normal because of the substantial late winter snowpack in the upper Humboldt River Basin. Total volumes of flow during the water year were about 290,000 acre-ft near Carlin, 330,000 acre-ft at Palisade, 310,000 acre-ft at Dunphy, and 350,000 acre-ft at Battle Mountain (Emett and others, 1994, p. 228, 236, 237, and 242). These volumes of flow ranged from 107 percent of normal near Carlin to 142 percent of normal at Battle Mountain.

GROUND WATER

This section describes ground-water flow and ground-water conditions in the Carlin trend study area. The descriptions only approximate the hydrologic setting prior to mining activities because water-level data are sparse east of the Tuscarora Mountains prior to about 1988 and west of the Tuscarora Mountains prior to 1990. Although some ground water was being pumped from 1988 through 1990, the volume was small compared to that pumped from 1991 through 1993 (fig. 2). For these reasons, water levels from the Maggie Creek Area in 1988 and from the Boulder Flat in 1990 are assumed to approximate conditions prior to large-scale mining activity. Water levels measured in 1993, and changes in ground-water conditions and water-level gradients from 1990 through 1993, are used to describe the effects of mining activities in a later section.

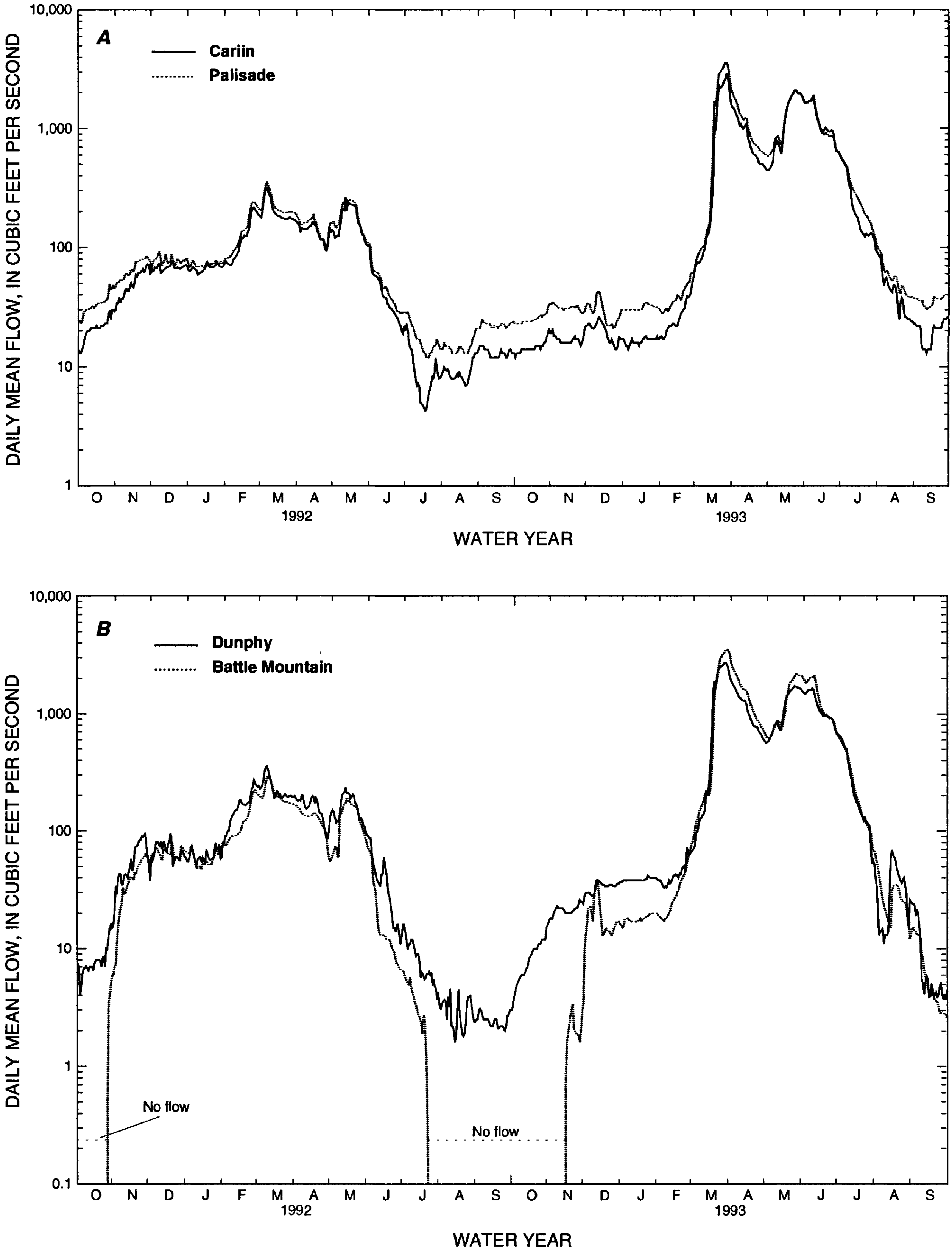


Figure 12. Daily mean flow of Humboldt River in Carlin trend area, north-central Nevada, October 1991 through September 1993. (***A***) Near Carlin and at Palisade (fig. 4, sites HR-1 and HR-5); and (***B***) at Dunphy and at Battle Mountain (fig. 4, sites HR-8 and HR-11).

Descriptions of ground-water flow and conditions in the study area are based on water-level measurements made mostly from 1989 through 1993, on lithologic logs, and on well-construction data. The lithologic and well-construction data include a description of materials penetrated during drilling, well depth, depth of perforated intervals or gravel-packed zones surrounding well perforations, and altitude of the well (app. 3 and 4). Lithologic and well-construction data were obtained from drillers' logs submitted to the Nevada Division of Water Resources and descriptions supplied by mining companies. Well altitudes were obtained from 1:24,000-scale USGS topographic maps or from surveys made by the mining companies. Water-level data from 1989 through 1993 were obtained from measurements made by USGS at about 140 wells and measurements made by the mining companies at about 70 wells. Water-level data prior to 1989 for about 30 wells were obtained from records in the USGS National Water Information System data base. Water-level data are summarized in appendix 4.

In any hydrologic system, ground water can be found under unconfined, confined, or perched conditions. The upper surface of saturated materials in an unconfined aquifer is known as the water table. The pressure in the aquifer at the water table is equal to atmospheric pressure. Thus, water levels in wells that barely penetrate the top of an unconfined aquifer will stand at the water table.

The pressure in a confined aquifer is greater than atmospheric pressure, generally because upward flow is impeded by a zone of low permeability. The zone of low permeability can be an overlying hydrogeologic unit that is less permeable than the confined aquifer, or zones of low permeability within the confined aquifer. The second example represents an anisotropic aquifer (vertical hydraulic conductivity is less than horizontal hydraulic conductivity).

Water levels in wells that penetrate a confined aquifer will stand above the material in which the confined aquifer is found (Lohman and others, 1972, p. 14). This condition also can be found where no confining zone is present, but a strong upward component of ground-water flow is present.

Perched ground water is usually unconfined, but is separated from deeper aquifers by an unsaturated zone. Perched ground water is found where the downward flux of recharge is impeded. The same geologic features that produce confined conditions in areas of upward flow can cause perched conditions in areas of downward flow.

The presence of an unsaturated zone beneath perched ground water is difficult to confirm (Stone and others, 1991, p. 35). However, vertical hydraulic gradients measured between wells of different depths provide a means of inferring the presence of perched ground water. A vertical hydraulic gradient that is downward and greater than 1.0 (the change in water level is greater than the change in depth) indicates that ground water in the shallower well is separated from ground water in the deeper well by an unsaturated zone (David E. Prudic, U.S. Geological Survey, oral communication, 1993). Downward gradients that exceed 1.0 most likely represent perched conditions.

Vertical gradients also provide evidence of the potential for flow between hydrogeologic units. Vertical hydraulic gradients in the study area were determined from measured or estimated water levels at pairs of sites (app. 3). The pairs consisted of two wells with different perforated intervals that are either nested within the same drill hole or located reasonably close to each other. Individual wells and nearby gaining reaches of streams also were used as pairs of sites because the altitude of the stream channel along the gaining reach indicates the minimum altitude of the water table.

The distribution and movement of ground water in the study area are controlled by the heterogeneity and anisotropy of hydrogeologic units, faults, and geologic structures, and by water-level changes caused by mining activities. Stone and others (1991, p. 23) used the three types of ground-water conditions to define three ground-water systems in the study area. However, boundaries between the three systems are indistinct, ground water flows between all three, and ground-water conditions can change in response to increased ground-water pumping. In this report, water-level altitudes, ground-water conditions, and vertical gradients are used to describe the general direction of ground-water flow through the study area.

The descriptions represent a conceptualization of regional ground-water flow within the study area. Detailed studies near mines indicate that ground-water flow is very complex in mineralized bedrock units. The conceptualization presented in this report does not include a detailed description of these complexities. Water-level data from the carbonate rocks and siltstones are sparse except near mining activities and in the Susie Creek Area, Marys Creek Area, Rock Creek Valley, and Willow Creek Valley, water-level data are sparse in basin-fill deposits and very sparse in underlying volcanic rocks. For these reasons, the conceptualization is considered a working hypothesis to be revised as more data are collected.

Description of Ground-Water Flow

Ground-water flow within the study area is driven by recharge from precipitation mainly in the Independence and Tuscarora Mountains and the unnamed mountains north of Willow Creek Valley. Precipitation along the crests of these mountain blocks moves downward through fractures or weathered zones to recharge ground water within the bedrock or it runs off as streamflow. Ground water in bedrock moves generally downward and away from the crests of the mountain blocks to recharge basin-fill deposits.

Detailed studies near mines have shown that, on a small scale, ground-water flow in bedrock can be divided into individual, hydrologic domains (Stone and others, 1991, p. 22). The hydrologic domains or compartments are separated by zones of low permeability along faults, intrusions, and mineralized zones. Water levels and movement of ground water can differ greatly between adjacent compartments. Thus, ground-water flow in the mountain blocks is complex and poorly understood.

The discharge of springs in the mountain blocks is thought to represent perched ground water that is not connected to the water table. (U.S. Bureau of Land Management, 1991, p. 3-36; Stone and others, 1991, p. 35). Such springs are found where rocks with differing permeability are in fault or intrusive contact (Stone and others, 1991, p. 34). Impermeable or unfractured zones within the bedrock or faults may restrict ground-water flow resulting in perched zones of ground water. Ground water discharges as springflow where such zones intersect land surface. Water levels measured in wells in the mountain blocks also may represent perched ground water where the altitude of ground water is far above water levels in adjacent basins (Stone and others, 1991, pl. 9).

The presence of an unsaturated zone beneath springs in the mountain blocks has not been confirmed. However, dissolved-solids concentrations and the isotopic composition of water at springs in the mountain blocks differ from deeper ground water near the mines (Stone and others, 1991, p. 35). Water at high-altitude springs is more dilute than deeper ground water. This shows that deep ground water near the mines is not the source for springflow in the mountain blocks.

Downstream from the bedrock contact, as streams enter the basins, streamflow infiltrates the channels to recharge the basin-fill deposits. Infiltration of precipitation that falls on basin-fill deposits is also a source of ground-water recharge. Ground water in basin-fill deposits moves downward toward low-lying parts of the basins where ground-water is discharged by evapotranspiration, inflow to stream channels, or subsurface flow out of the hydrographic area.

Measured vertical gradients generally confirm that ground-water flow is downward near mountain fronts and upward where ground water discharges in basin lowlands and along the Humboldt River. Within the mountain blocks, vertical directions of ground-water flow can be upward or downward depending on the structural and lithologic complexity of hydrogeologic units.

The depth to saturated materials differs greatly within the study area. In bedrock forming the mountain blocks, the depth to water ranges from more than 900 ft below land surface in the Sheep Creek Range (app. 4 and fig. 20, site R-9) to land surface at springs and gaining reaches of streams. The distribution of depth to water in bedrock of the mountain blocks is poorly understood because relatively few wells are located in the higher parts of the mountain blocks. In basin-fill deposits, the depth to water is more than 400 ft below land surface beneath upland areas in the Sheep Creek Range (app. 4, sites R-3 and R-5), more than 200 ft near the contact between basin fill and bedrock along basin margins (app. 4, sites M-2 and M-19), and less than 10 ft at sites near the Humboldt River.

The direction and rate of unconfined ground-water flow is determined by the altitude and configuration of the water table (pl. 3). Unconfined water-level contours on plate 3 were constructed using water levels measured mostly in the fall of 1990 or spring of 1991 (app. 4). In some cases, in areas not affected by mining activities, water levels from 1992 and 1993 were also used for plate 3. To minimize the effects of vertical hydraulic gradients and confined conditions, only measurements made at wells perforated in the upper 500 ft of unconfined, saturated materials were used to construct the contours. The main exception is that water levels at deeply perforated wells or at wells tapping confined ground water were used if they provide the only available estimate of water-level altitude.

Gaining and losing reaches of streams identified from streamflow measurements were used to guide the construction of water-level contours where wells were not available. The altitude of the water table was presumed to be at or above the altitude of the stream channel along gaining reaches of streams. Conversely, the altitude of the water table was presumed to be below the stream channel along losing reaches.

Unconfined water levels in the study area indicate that the Tuscarora Mountains function as a ground-water divide (pl. 3) and form two separate flow systems in the study area—one east and one west of the Tuscarora Mountains. To the east, ground water in the Maggie Creek, Marys Creek, and Susie Creek Areas ultimately flows southward, crossing hydrographic area boundaries, to the Humboldt River. To the west, ground water in Willow Creek Valley, Rock Creek Valley, and Boulder Flat flows southwest and west, also crossing hydrographic area boundaries, to the Humboldt River and the Clovers Area.

As described above, unconfined water levels determine flow directions in the uppermost part of the ground-water system. Water-level data from deep parts of the flow system (from 500 to greater than 1,000 ft below the water table) are available only near the mines. Where available (see confined sites, pl. 3), these water levels suggest that the Tuscarora Mountains also function as a divide for confined, deeper ground-water flow. Deep ground-water flow within and near the study area is described in a following section.

Flow System East of Tuscarora Mountains

Ground-water flow east of the Tuscarora Mountains is schematically illustrated in figure 13*A*. In the upper reach of the Maggie Creek Area, ground water moves through siltstones and carbonate rocks that form the Independence and Tuscarora Mountains and into a thick lens of basin-fill deposits (pl. 3, flow lines H and I). Near the basin margins, vertical gradients in basin-fill deposits are downward at two pairs of sites (fig. 14, app. 3, sites M-6 and M-7, and sites M-14 and M-18). Thus, ground water moves both downward and laterally toward Maggie Creek and southward along the basin axis toward Maggie Creek Canyon.

Flowing wells (sites M-21 and M-22, app. 4), upward vertical gradients (fig. 14 and app. 3, site M-23), and streamflow gains of Maggie Creek (fig. 4 and app. 1 sites MC-4 and MC-5) indicate that ground-water flow is upward in basin-fill deposits immediately north of Maggie Creek Canyon. In part, this condition could be caused by zones of low permeability, which result in anisotropy within the basin-fill deposits. Also, siltstones with low permeability northeast of the canyon could impede subsurface flow to the lower reach of the hydrographic area. Carbonate rocks of Schroeder Mountain are more permeable than the siltstones and could allow small amounts of ground-water flow between the two reaches of the hydrographic area (pl. 3, flow line G). Plume (1995, p. 41) estimated this flow to be no more than 1,000 acre-ft/yr. Faults between older basin-fill deposits and carbonate rocks and in the carbonate rocks may impede this flow and make ground-water flow paths more complex than implied by flow line G (pl. 3).

In the upper Maggie Creek reach, siltstones and carbonate rocks are confined by overlying, older basin-fill deposits (app. 4, sites M-4, M-27, M-28, and M-32). The siltstones are anisotropic as a result of unfractured zones and other differences in permeability. Carbonate rocks are unconfined where exposed at land surface (app. 4, site M-30). Vertical gradients indicate that in 1991 and 1992 the potential for flow was downward from basin-fill deposits to carbonate rocks and within carbonate rocks at sites M-27 and M-28 (fig. 14, app. 3).

In the lower Maggie Creek reach, ground water moves southward and eastward through siltstones and carbonate rocks of the Independence and Tuscarora Mountains and through basin-fill deposits and interbedded volcanic rocks in the Susie Creek, Maggie Creek, and Marys Creek Areas (pl. 3, fig. 13*A*). The ground water in basin-fill deposits crosses hydrographic area boundaries and discharges at Carlin spring and the Humboldt River channel (flow lines F, G, J, and K). In addition, streamflow losses from Maggie Creek move southward through volcanic rocks interbedded with basin-fill deposits to Carlin spring (Plume, 1995. p. 39). Ground water that does not discharge at Carlin spring or the Humboldt River channel is consumed by evapotranspiration along the flood plains of Susie and Maggie Creeks and the Humboldt River.

Ground water is confined in the siltstones and carbonate rocks near Gold Quarry mine, either by overlying, older basin-fill deposits or by relatively unfractured zones in the siltstones. Water-level data from the period 1989-91, prior to large-scale dewatering, show that confined water-level altitudes in the siltstones and carbonate rocks ranged from about 5,040 to 5,090 ft (app. 4, sites M-28, M-33, M-36, M-40, and M-45).

Ground water in the siltstones can be unconfined where these rocks are exposed at land surface or at shallow depths (app. 4, site M-37; Stone and others, 1991, p. 31).

Vertical gradients near Gold Quarry mine indicate a potential for upward flow in siltstones or from carbonate rocks to siltstones early in 1989 (app. 3 and fig. 14, sites M-36 and M-37). However, this upward gradient had reversed several months later, probably as a result of pumping. Elsewhere near the mine, vertical gradients indicated a potential for downward flow from basin-fill deposits to carbonate rocks at site M-33 and M-34 in 1990, and at site M-46 in 1992 (app. 3).

In the Marys Creek Area, both the siltstones and carbonate rocks are confined at the base of Marys Mountain (app. 4, site MR-2). Stone and others (1991, p. 31) suggest that unfractured zones within the siltstones are the confining unit and that faulting on the eastern side of the Tuscarora Mountains restricts the downgradient flow of ground water. Thus, ground-water flow near site MR-2 is hypothesized to be restricted within a compartmentalized cell, probably localized on the eastern slope of Marys Mountain.

In the Susie Creek Area and the lower parts of the Maggie Creek and Marys Creek Areas, ground water in volcanic rocks is confined by overlying basin-fill deposits (app. 4, sites S-3, S-5, M-56, and MR-4). The potential for vertical flow between younger basin-fill deposits and volcanic rocks is downward along lower Maggie Creek, (app. 3 and fig. 14, sites M-51 and M-52). Farther south near the Humboldt River, the potential for ground-water flow is upward from volcanic rocks to younger basin-fill deposits (app. 3 and fig. 14, sites M-56, and MR-3 and MR-4). This upward potential, which may result from thinning of the basin-fill aquifer, drives ground-water discharge at Carlin spring.

Flow System West of Tuscarora Mountains

Ground water moves through siltstones and carbonate rocks on the western slope of the Tuscarora Mountains into volcanic rocks and basin-fill deposits in Willow Creek Valley, Rock Creek Valley, and Boulder Flat (fig. 13*B* and *C*). Ground-water in volcanic rocks moves southward from the northern side of Willow Creek Valley into basin-fill deposits. In addition, flow of Boulder, Antelope, Rock, and Willow Creeks infiltrates into stream channels and recharges basin-fill deposits.

Assuming that the volcanic rocks west of the Tuscarora Mountains are permeable, the sparse water-level data suggest that ground water in volcanic rocks and basin-fill deposits may flow southward and westward across hydrographic area boundaries between Boulder Flat, Willow Creek Valley, and Rock Creek Valley (pl. 3, flow lines A through E; fig. 13*B* and *C*). In a later section of this report, ground-water flow along flow lines B, C, and E is evaluated using chemical and isotopic data collected at wells and springs.

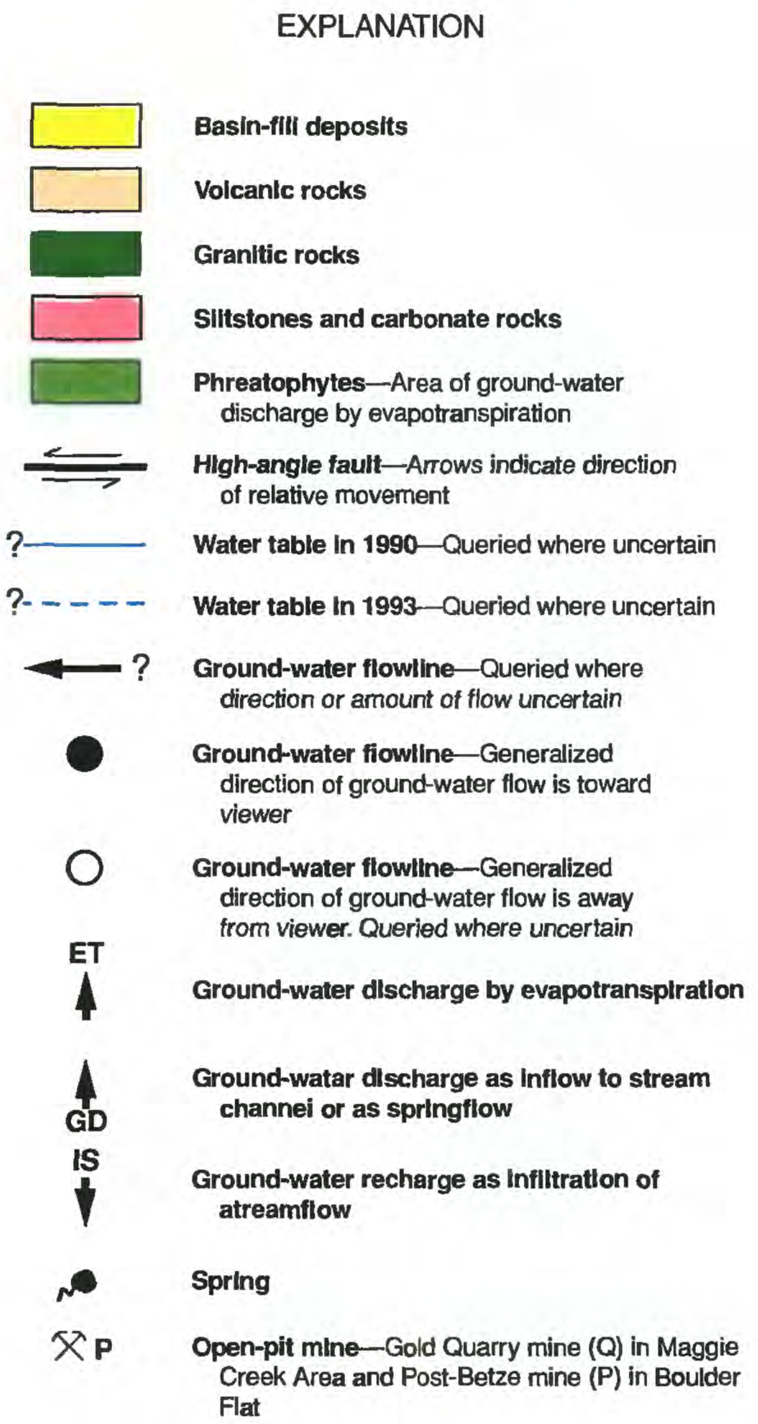
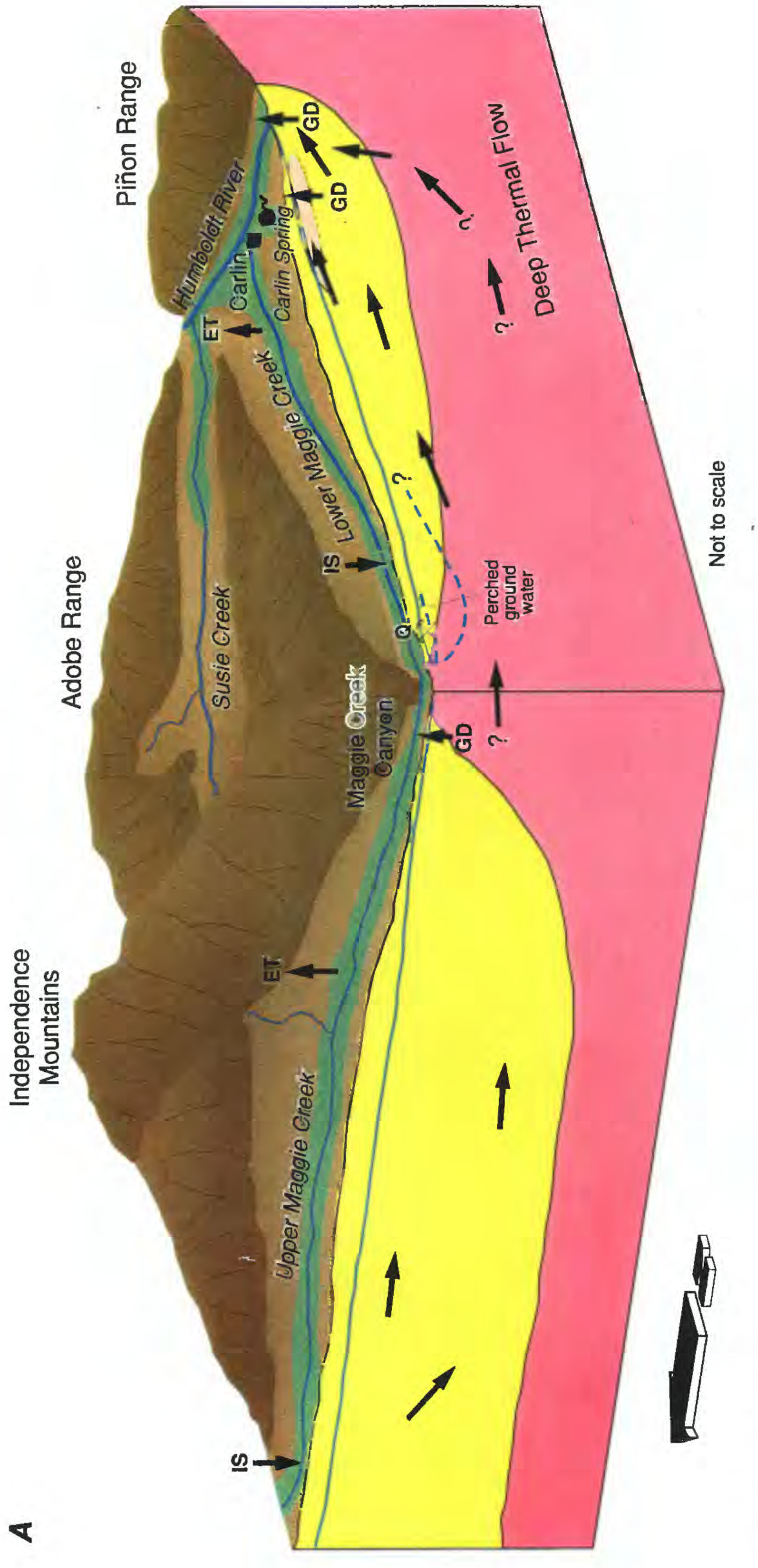


Figure 13. Schematic block diagrams of Carlin trend area, north-central Nevada. (***A***) Maggie Creek Area, looking east; (***B***) Rock Creek Valley, looking northwest; and (***C***) Boulder Flat, looking northwest.



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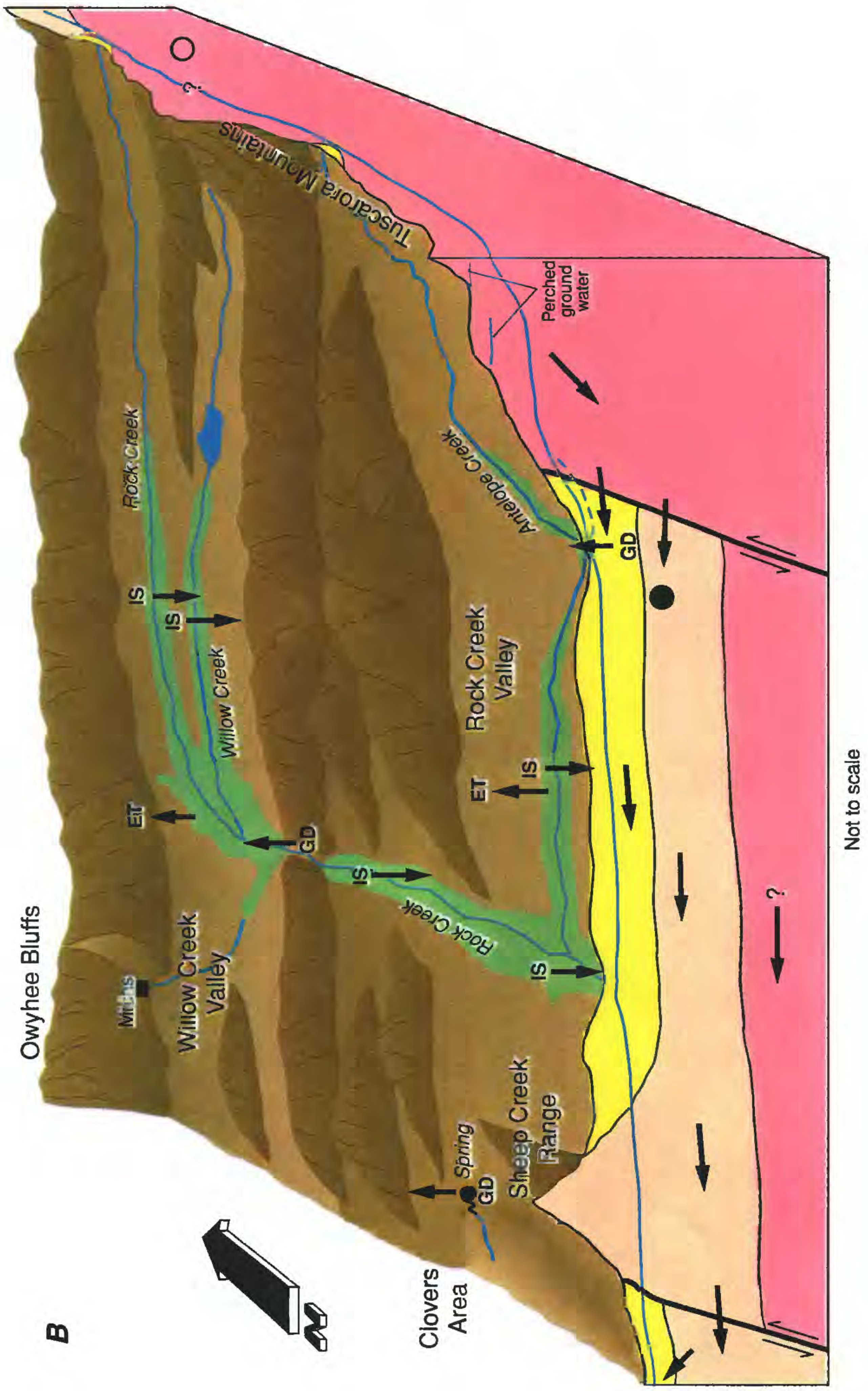

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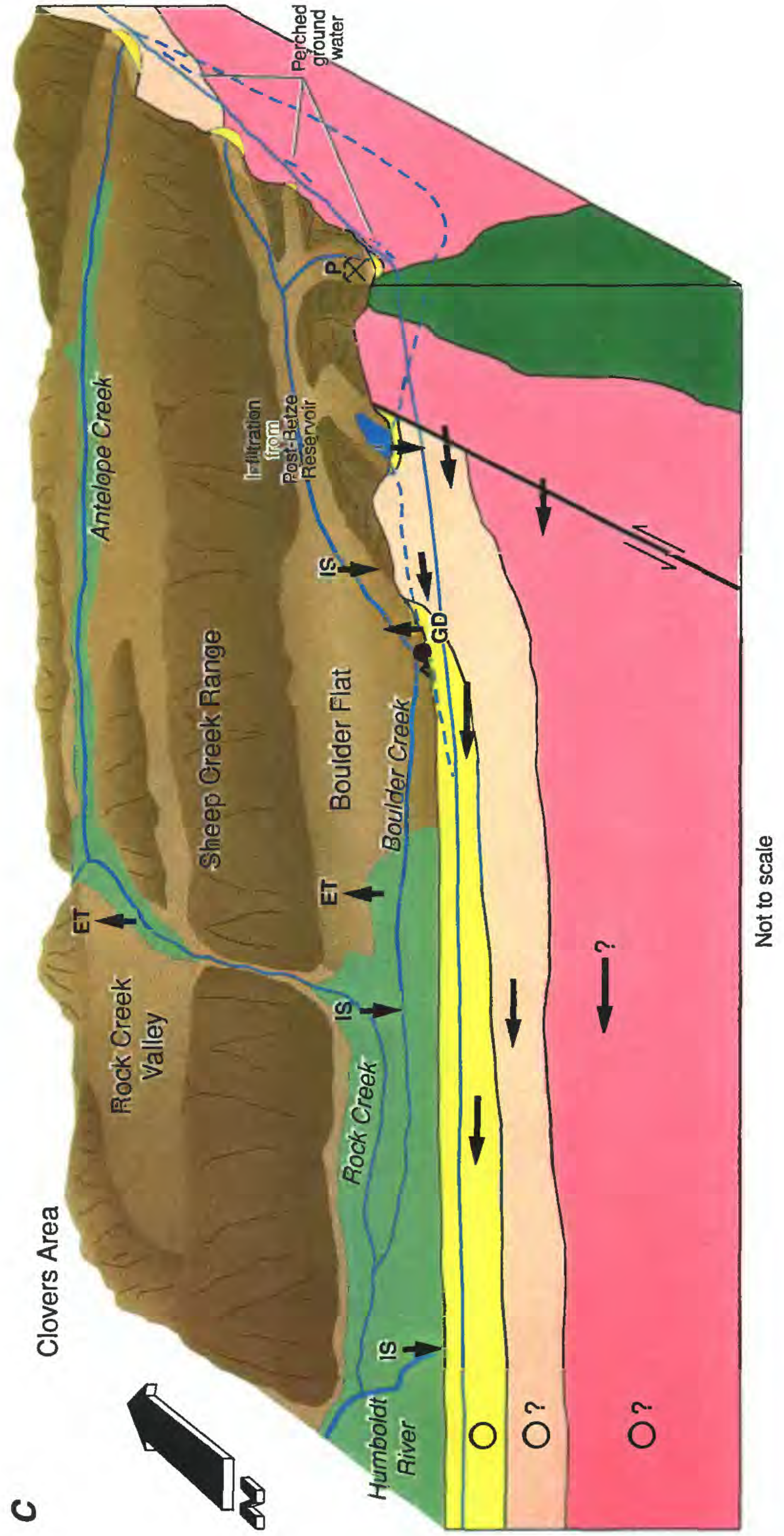

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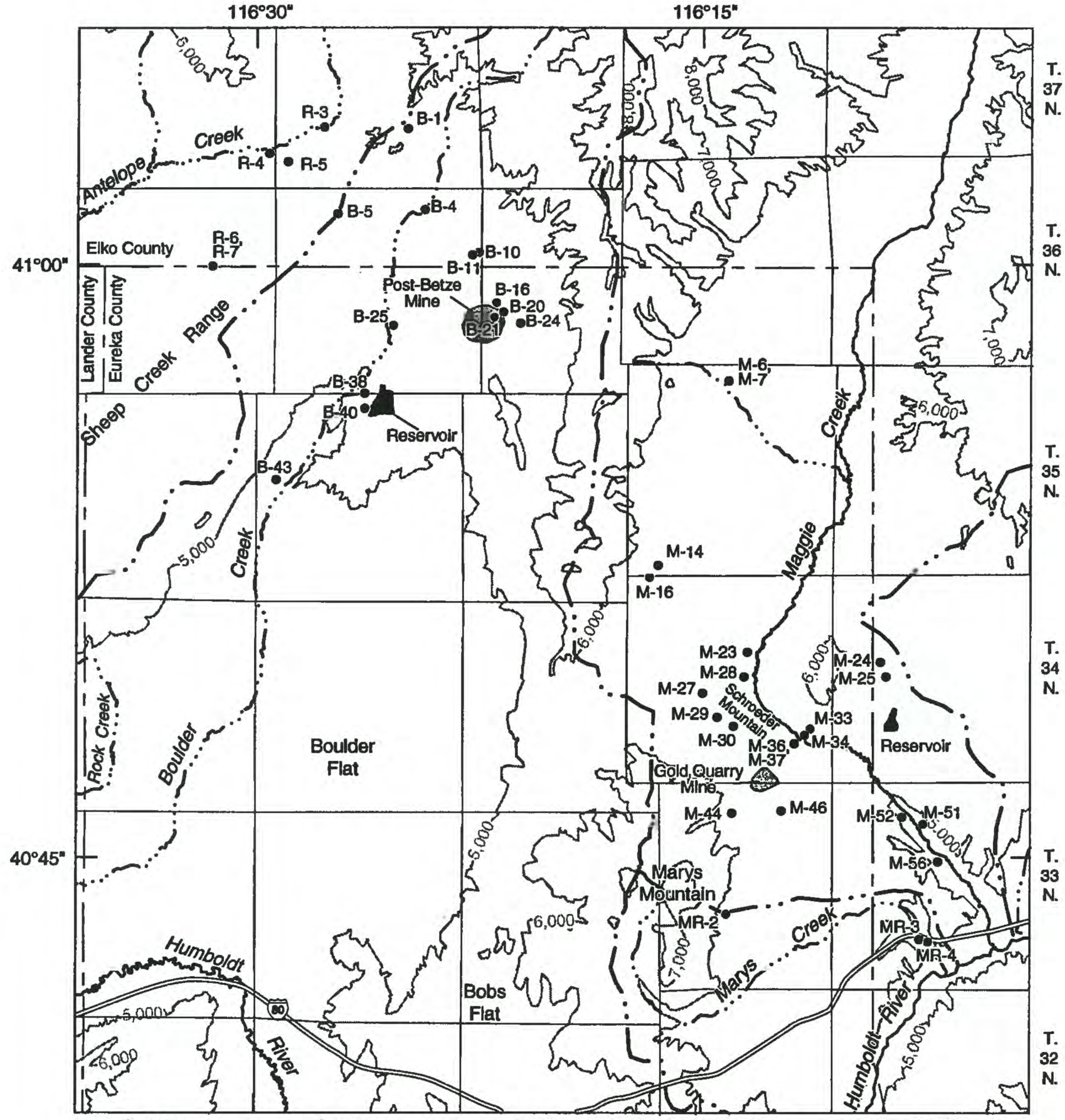


Base from U.S. Geological Survey digital data, 1:100,000 scale, 1977-88; Universal Transverse Mercator projection, Zone 11. Contour interval: 1,000 feet. Altitude: National Geodetic Vertical Datum of 1929

0 5 10 MILES

0 5 10 KILOMETERS

EXPLANATION

—·· — **Hydrographic-area boundary**—Modified from Rush (1968); not shown where coincident with Humboldt River

M-46 ● **Well**—Label refers to site name in appendixes 3 and 4. Abbreviations: **M**, Maggie Creek Area; **MR**, Marys Creek Area; **R**, Rock Creek Valley; and **B**, Boulder Flat

Figure 14. Sites where vertical hydraulic gradients were determined in central part of Carlin trend area, north-central Nevada

Water-level data are not available for siltstones and carbonate rocks, which may deeply underlie western parts of the study area. However, the direction of ground-water flow in these rocks also may be to the southwest.

In 1990-91, a ground-water divide, trending northeast-southwest, extended southwestward across Rock Creek Valley through the center of the Sheep Creek Range (flow line D, pl. 3). Ground water flows to the Clovers Area northwest of this divide and to Boulder Flat southeast of the divide. In the Clovers Area, springflow (site SP-2, pl. 3) most likely represents ground-water flow from Rock Creek Valley. This ground-water divide is not a physical barrier to ground-water flow. Its location depends on the distribution of recharge and water levels in the eastern parts of Willow Creek Valley and Rock Creek Valley. Changes in water levels in the eastern parts of Willow Creek Valley and Rock Creek Valley could change the location of the divide.

In 1990-91, ground water in the northernmost part of Boulder Flat moved to the southwest through siltstones, volcanic rocks, carbonate rocks, and basin-fill deposits under a steep hydraulic gradient (pl. 3). The steep gradient was likely caused by a combination of the low permeability of some of the hydrogeologic units, and a fault or geologic structure with low permeability that impeded ground-water flow. This feature will be discussed further in a subsequent section.

Farther south in Boulder Flat, ground water from Rock Creek Valley (pl. 3, flow line E) and from the northernmost part of Boulder Flat moved to the south and west through basin-fill deposits and underlying volcanic rocks and was discharged mostly as evapotranspiration in the lowlands of Boulder Flat. The remaining ground water left the area as subsurface flow to the southwest though basin-fill and volcanic rocks between the Sheep Creek Range and the Argenta Rim (pls. 2 and 3, fig. 13*C*). In 1990, near the east-central part of Boulder Flat, the 4,625-ft and 4,650-ft contours bent sharply to the east where an elongate cone of depression had developed from pumping for irrigation. Beneath the southeastern part of the area at Bobs Flat, ground water flowed south and west to the Humboldt River (pl. 3).

Contours of unconfined ground water are shown on plate 3 for the northern parts of Crescent Valley, Whirlwind Valley, and Lower Reese River Valley south of the study area. These contours indicate that unconfined ground-water flow also is toward the river. Thus, the Humboldt River also is a sink for unconfined ground-water flow from the south.

In the northern part of Boulder Flat, ground water in volcanic rocks, siltstones, and carbonate rocks is confined by older basin-fill deposits. In addition, unfractured zones and variations in permeability in the siltstones also could result in confined conditions in these rocks and underlying carbonate rocks. Prior to dewatering, confined water-level altitudes near the Post-Betze mine were about 5,300 ft west of a major fault zone and from 5,400 to 5,600 ft east of the fault zone on the western flank of the Tuscarora Mountains (Hydro-Geo Consultants, 1990, p. 6; Anton Mayer, Barrick Goldstrike Mines Inc., oral commun., 1995). These values are consistent with water levels measured in or before 1990 (app. 4, sites B-7, B-14, B-16, and B-30).

In Rock Creek Valley, ground water in volcanic rocks is confined by overlying older basin-fill deposits in the eastern part of the basin (app. 4, sites R-1 and R-7). Because water-level data from volcanic rocks in the remainder of the basin and in Willow Creek Valley are very sparse, the extent of confined ground water in the volcanic rocks is not known.

Volcanic rocks in Willow Creek Valley and Rock Creek Valley could be as much as 2,000 ft thick and are underlain by siltstones that are more than 4,000 ft thick (pl. 2). Ground-water conditions in the siltstones and in the carbonate rocks, which may deeply underlie the siltstones, are unknown.

In the northern part of Boulder Flat, the earliest available water-level data show that in 1990-91 potential directions of ground-water flow were downward in basin-fill deposits and downward from older basin-fill deposits to volcanic rocks and siltstones (fig. 14, app. 3, sites B-4, B-16, B-25, B-43). Potential flow in 1991-92 also was downward in volcanic rocks (app. 3, sites B-38 and B-40), from siltstones to carbonate rocks (sites B-10 and B-11), and in carbonate rocks (site B-21). Gradients measured in 1992 could have been affected by pumping for dewatering. In 1991, a zone of perched ground water existed in basin-fill deposits overlying volcanic rocks along Boulder Creek (app. 3, site B-25).

Upward gradients at site B-1 and between sites B-20 and B-16 in 1992 and 1993 (app. 3) indicate that ground-water levels had probably not been affected by pumping and that the potential for ground-water flow was upward within siltstones and volcanic rocks. This ground-water flow could be from siltstones exposed at higher altitudes in the Tuscarora Mountains. Data are not available to determine vertical gradients in southern parts of Boulder Flat, which is an area of ground-water discharge; however, the vertical gradient in this part of the hydrographic area is assumed to be upward in basin-fill deposits.

In Rock Creek Valley, at sites where water levels have not been greatly affected by pumping, vertical gradients indicate that the potential for ground-water flow is downward from basin-fill deposits to underlying volcanic rocks (Antelope Creek stream channel and R-3, R-4 and R-5, and R-6 and R-7, app. 3) and downward within the volcanic rocks (R-5). At site R-7, a water level difference of about 0.5 ft, indicates a slight upward gradient and potential for upward flow at depths of about 1,000 ft in the volcanic rocks. Elsewhere in Rock Creek Valley and Willow Creek Valley, vertical gradients are not known; however, there is potential for zones of perched ground water along Antelope and Rock Creeks, where infiltration of streamflow recharges basin-fill deposits. Additional water-level data are needed from volcanic rocks underlying basin-fill deposits to further define the potential for ground water flow between the two units and the possible presence of perched ground water.

Deep Ground-Water Flow

The carbonate rocks in the study area are part of a deep, regional ground-water flow system that includes several basins north and south of the Humboldt River (Prudic and others, 1993, p. 87-91). Stone and others (1991, p. 32) note that carbonate rocks penetrated by wells in the study area represent only the uppermost part of the regional geologic section of carbonate rocks (table 2). However, they also suggest that the Eureka Quartzite, which underlies the uppermost part of the carbonate rocks, acts as a barrier to vertical ground-water flow. Water levels in wells that penetrate deep carbonate rocks suggest that ground-water flow is downward in carbonate rocks near Gold Quarry mine (app. 3, sites M-27 and M-28). Prudic and others (1993, p. 88) show that the direction of deep ground-water flow could be to the southwest from the study area.

Several wells tapping confined ground water in carbonate rocks near the mines have thermal water with temperatures exceeding 20°C. Wells tapping deep confined ground water in basin-fill sediments in the upper reach of the Maggie Creek Area also have thermal water with similar temperatures. Heads measured at these wells before dewatering began ranged from 5,040 ft to more than 5,100 ft.

Deep ground-water flow may discharge at hot springs along the channel of the Humboldt River downstream from Carlin (app. 2, SP-9) where the temperature of the spring discharge is 79°C (Trexler and others, 1983), and the altitude of the spring orifice is about 4,880 ft. These temperatures and altitudes of heads are consistent with southern and southwestern directions of deep ground-water flow suggested by Prudic and others (1993). Water in carbonate rocks at the mines and at the thermal spring is isotopically heavier than confined ground water in basin-fill deposits in the upper Maggie Creek reach (Plume, 1995, p. 50-51). The isotopic data do not support deep ground-water flow from the upper Maggie Creek reach to the springs, but the flow could originate from confined ground water near Gold Quarry mine.

The Beowawe geysers in Whirlwind Valley south of Boulder Flat also lie in the general direction of deep ground-water flow from the study area, as suggested by Prudic and others (1993, p. 88). Downward flow of confined ground water near the mines could be the recharge source for spring discharge at Beowawe.

Day (1987, p. 71 and 72) suggests that the source of thermal water at Beowawe could be ground water of Pleistocene age from deep carbonate-rock aquifers. However, the results of a hydrologic reconnaissance in Whirlwind Valley indicate that recharge in the basin can account for both thermal and nonthermal ground-water discharge and that circulation depths of thermal fluids exceed 16,000 ft (Olmsted and Rush, 1987, p. 35 and p. 39). Thus, deep ground-water flow in the Beowawe area could be within a small isolated system restricted to the approximate area underlain by Whirlwind Valley.

At the present time, data do not conclusively indicate the presence of a large regional flow system in carbonate rocks near the study area. Instead, deep ground-water flow could be restricted to several isolated systems where the horizontal distance from recharge area to discharge area is relatively short.

Seasonal and Annual Water-Level Fluctuations

Changes in water levels indicate that ground water is moving into, or out of, storage. Water levels rise in response to recharge, decline in response to discharge, and fluctuate in response to natural changes in the hydrologic system. Water levels fluctuate from spring to fall in response to seasonal changes in precipitation, streamflow, and evapotranspiration. Variations in annual precipitation produce water-level fluctuations of a longer frequency. Changes in ground-water storage caused by pumping for irrigation or mine dewatering and by infiltration from holding reservoirs produce water-level changes that are superimposed on these natural fluctuations.

Seasonal water-level fluctuations from spring to fall are greatest in unconfined ground water of basin-fill deposits near reaches of losing streams. Variations in streamflow result in variations in recharge to underlying aquifers. Seasonal water-level fluctuations ranging from less than 10 ft to as much as 30 ft were measured near losing reaches of Jack, Maggie, and Rock Creeks and the Humboldt River (app. 4, sites M-7, M-34, M-52, B-83, B-90). Water levels at these sites are generally highest in spring and early summer after snowmelt runoff and decline in late summer and fall after streamflow decreases.

Seasonal fluctuations are generally only 1–2 ft in unconfined basin-fill deposits near gaining reaches of streams, distant from streams, near areas of phreatophyte discharge, and where ground water is deep (app. 4, sites S-8, M-17, M-38, M-63, B-57, B-63, B-87, R-6, and C-3). Seasonal fluctuations are also small in confined basin-fill deposits (sites M-22 and M-23), but are 3 to 4 ft in confined volcanic rocks near a losing reach of Maggie Creek (sites M-51 and M-56). Seasonal fluctuations in siltstones and carbonate rocks are less than 3 ft where the effects of mining activities are minimal (app. 4, sites M-4 and MR-2).

Annual water-level fluctuations caused by variations in the amount of annual precipitation and snowmelt runoff can be large. In unconfined basin-fill deposits near a losing reach of Maggie Creek, water levels rose about 50 ft from the fall of 1988 to the spring of 1993 at site M-52 (app. 4). In confined volcanic rocks at site S-5, water levels declined about 50 ft from 1983 when runoff was above normal to 1989 during the drought (app. 4). Elsewhere, annual fluctuations are generally smaller. Water levels in 1993 rose from 1 to about 7 ft above those in 1991 and 1992 at sites M-7, M-34, MR-4, B-83, B-90, and SO-8.

Where depth to water is large or confined conditions exist, the response to variations in annual precipitation can be delayed. Water levels continued to decline in 1993 at site M-10 where depth to water is more than 180 ft in basin-fill deposits, declined in 1993 at site M-4 in confined siltstones, and remained nearly constant at site MR-2 in confined siltstones (app. 4). As far as is known, water levels at these sites have not been affected by pumping.

The fluctuations suggest that the response of water levels in bedrock to seasonal and annual variations in recharge differs from place to place. Because few wells exist in bedrock units except near the mines, water-level data not affected by mining activities are sparse. Additional water-level data from bedrock units in areas distant from mining activities would provide insight into the range of natural fluctuations, and a means to distinguish natural fluctuations from those caused by mining activities.

Budgets

Ground-water budgets for each of the hydrographic areas in the study area are complex and poorly understood because subsurface flow between the areas cannot be accurately quantified. For this reason, only budgets for the ground-water flow systems east and west of the Tuscarora Mountains are presented.

Infiltrating precipitation and runoff are the principal sources of recharge to each hydrographic area, although infiltration of streamflow from through-flowing streams and subsurface flow between areas also are recharge sources. Ground water discharges as evapotranspiration, as inflow to stream channels, and as subsurface flow. Methods used to quantify elements of recharge and discharge are described below.

Ground-water recharge from infiltrating precipitation and runoff is estimated using the Maxey-Eakin method, which was first developed and applied in southern and eastern Nevada (Maxey and Jameson, 1948, p. 107-109; Eakin and others, 1951). Recharge generally is considered to be negligible where annual precipitation is less than 8 in/yr, and to range from 3 percent to 25 percent of total annual precipitation where annual precipitation exceeds 8 in/yr. According to Stone (1992, p. 4 and 5), chloride profiles in the unsaturated zone indicate that about 2 percent of annual precipitation becomes recharge in the Marys Creek Area near Carlin. This percentage generally agrees with the lower range of percentages used for the Maxey-Eakin method.

A DEM (digital elevation model) was used to make estimates of recharge from infiltrating precipitation and runoff for each hydrographic area. Annual precipitation in each cell of the DEM was computed from the average altitude of the cell and equation 1 (see section titled "Climate"). Recharge to the cell was computed on the basis of the following percentages:

- 25 percent of precipitation exceeding 20 in/yr;
- 15 percent of precipitation ranging from more than 15 to 20 in/yr;
- 7 percent of precipitation ranging from more than 12 to 15 in/yr;
- 3 percent of precipitation ranging from more than 8 to 12 in/yr; and
- 0 percent of precipitation of 8 in/yr or less (Eakin, 1961, p. 20).

Total recharge in each hydrographic area is the sum of recharge to all cells in the DEM.

The Maxey-Eakin method originally was developed and applied in closed basins that produce little or no surface-water outflow. Thus, the method may result in over-estimates of recharge for basins with measurable surface-water outflow, such as those of the study area. However, comparisons with discharge estimates, presented in the following section, suggest that the recharge estimates made for the study area are reasonably accurate.

Rock Creek and the Humboldt River are through-flowing streams that provide recharge, as infiltration of streamflow, to Rock Creek Valley and Boulder Flat. However, to date, intermittent measurements of the flow of Rock Creek do not provide reliable estimates of infiltration because the available measurements represent low flows affected by a severe drought. Long-term records for stream-gaging stations provide a means of estimating streamflow losses from Rock Creek and the Humboldt River in Boulder Flat, although the losses result from irrigation diversions in addition to infiltration.

Estimates of evapotranspiration are based on areas of phreatophytes mapped during the study (pl. 3) and on field measurements of evapotranspiration rates also made during the study. Evapotranspiration of ground water is limited to areas where water levels are sufficiently shallow that ground water either is transpired by phreatophytes or is evaporated from bare soil. The most common phreatophytes in the study area are big sage (*Artemesia tridentata*), rabbit-brush (*Chrysothamnus sp.*), greasewood (*Sarcobatus vermiculatus*), willow (*Salix*), salt grass (*Distichlis stricta*), and various grasses in meadows. These plants occupy low-lying areas where water levels are no deeper than 40-60 ft below land surface (pl. 3). Evaporation from bare soil is generally limited to areas where water levels are less than 10 ft below land surface.

Differing evapotranspiration rates have been used for estimating ground-water discharge by phreatophytes in the Great Basin. These rates generally depend on plant type and density and on depth to ground water. In previous studies in Pine and Huntington Valleys, south and southeast of the study area, rates of 0.1-0.5 ft/yr were used for greasewood, rabbitbrush, saltgrass, and willow where depths to water range from a few feet to 20 ft below land surface. Where water is near land surface in meadows and pastures, rates used were 0.75-1.25 ft/yr (Eakin, 1961, p. 22, and Rush and Everett, 1966, p. 22). In Whirlwind Valley, Olmsted and Rush (1987, p. 38) used 4 ft/yr for wet meadows; 1 ft/yr for saltgrass and meadow grass; 0.5 ft/yr for saltgrass, rabbitbrush, and greasewood; and 0.2 ft/yr for areas of mostly greasewood.

Micrometeorological methods for quantifying the components of the energy budget at the surface of the Earth recently have been used to measure ground-water evapotranspiration rates at several sites in the study area. Maximum evapotranspiration rates are measured during the summer months. However, the length of the growing season and its timing are not well understood (W.D. Nichols, U.S. Geological Survey, oral commun., 1994). Nichols (1993, p. 2775) concluded that (1) the annual growing season for greasewood in northern Nevada ranges from 140 to 165 days, and (2) phreatophytes rely on soil moisture for the first 40-65 days of the season and on ground water for the remaining 100 days. Robinson (1970, p. D25) reports that rabbitbrush and willow stop growing in the fall when overnight temperatures drop below 28°F. The growing season was assumed to be 100 days for rates measured in this study.

Measured rates at three sites in the Maggie Creek Area (pl. 3, sites 3, 4, and 5) were 0.9 ft/yr in meadows where ground water is near land surface and 0.5 ft/yr in areas of rabbitbrush and grass (Plume, 1995, p. 42).

Ground-water evapotranspiration rates were measured at two sites in Boulder Flat as part of the present study (pl. 3). At site 1, the depth to water is about 20 ft, and phreatophytes consist almost entirely of greasewood. At site 2, the depth to water is about 15 ft, and phreatophytes consist of a mixed stand of greasewood, rabbitbrush, and grass. Measurements were made in July and August 1991 at both sites and continually at site 1 from May 1992 to August 1993.

Average ground-water evapotranspiration rates at site 1 were 0.0046 ft/d in July and August 1991, 0.0020 ft/d in summer 1992, and 0.0030 ft/d in summer 1993. The average rate at site 2 was 0.0039 ft/d in July and August 1991 (Johnson, 1995, p. 7-8, and W.D. Nichols, U.S. Geological Survey, written and oral commun., 1994).

Evapotranspiration rates measured at the two sites during the three growing seasons varied because of differences in the availability of soil moisture. Soil moisture at Boulder Flat probably was low in the spring of 1992 because of 8 consecutive years of below-normal winter precipitation. As a result, phreatophytes were in poor condition that summer and measured ground-water evapotranspiration rates at site 1 were comparatively low.

Phreatophytes at site 1 were in much better condition in the summer of 1993, apparently because soil moisture was available early in the growing season. Rates of ground-water evapotranspiration measured during this period may be more representative of a long-term average. The annual rate would be 0.3 ft/yr on the basis of a 100-day growing season during which the plants relied on ground water.

The following rates for plant types were used to estimate ground-water discharge by evapotranspiration in the study area. A rate of 0.3 ft/yr was used for areas where greasewood is the principal phreatophyte. A rate of 0.5 ft/yr was used where a mixture of shrubs (big sage, rabbitbrush, and greasewood) is present. A rate of 0.6 ft/yr was used where a mixture of shrubs and grasses is present. A rate of 1 ft/yr was used where grasses and willow are present in wet meadows and in areas of irrigated agriculture.

Ground-water discharge as inflow to stream channels is common in the study area. This inflow generally sustains the baseflow of short reaches of streams, but also reinfiltrates the stream channel farther downstream and does not represent significant ground-water discharge. The principal exception to this is the ground-water discharge, as inflow and spring discharge, to the Humboldt River channel adjacent to the Susie Creek, Maggie Creek, and Marys Creek Areas.

Subsurface flow is common in the study area. Water-level contours (pl. 3) indicate that ground water flows beneath hydrographic-area divides between the Susie Creek and Maggie Creek Areas and between the Maggie Creek and Marys Creek Areas on the east side of the Tuscarora Mountains. On the west side of the mountains, ground water flows beneath basin divides from Willow Creek Valley to Rock Creek Valley and the Clovers Area, from Rock Creek Valley to the Clovers Area and Boulder Flat, and from Boulder Flat to the Clovers Area.

Subsurface flow between hydrographic areas is difficult to accurately quantify because water-level data are sparse over parts of the study area and because estimates of hydraulic conductivity and aquifer thickness are uncertain and can change over short distances. For these reasons, preliminary estimates are made only for subsurface flow from the flow system west of the Tuscarora Mountains to the Clovers Area. These estimates may be uncertain by as much as an order of magnitude, but they do provide insights regarding the order of magnitude of such flow and the types of data needed to improve the estimates.

Estimates of subsurface flow between hydrographic areas were made using water-table contours and ground-water flow lines to define cross-sectional areas of flow (pl. 3). The flow of ground water (Q), in acre-feet per year, through each cross-sectional area was computed using the following form of Darcy's law:

$$Q = 0.0084 \times K \times i \times A \qquad (2)$$

where K is the hydraulic conductivity of the aquifer, in feet per day,

i is the horizontal hydraulic gradient of ground-water flow, in feet per foot (dimensionless);

A is the area, in square feet, of the aquifer cross section through which ground water flows; and

the factor 0.0084 produces a value of Q, in acre-feet per year.

The average hydraulic gradient (i) for each aquifer cross section was calculated from the equation

$$i = \frac{c}{A'/L} \qquad (3)$$

where c is the interval, in feet, of the water-table contours;

A' is the planimetric area, in square feet, bounded by contours and flow lines; and

L is the average width, in feet, of the aquifer cross section (Walton, 1970, eq. 3.183, p. 189).

This approach for estimating subsurface flow is based on the assumption that no recharge enters the aquifer cross section between its bounding contour lines and flow lines.

Volcanic rocks provide the primary hydraulic connection between the flow system west of the Tuscarora Mountains and the Clovers Area. Because data on water levels in the volcanic rocks are sparse, they are assumed to be approximated by water levels measured in the overlying basin-fill deposits. The average hydraulic conductivity of volcanic rocks in this part of the study area is assumed to be about 2 ft/d (Stone and others, 1991, p. 29). The average saturated thickness of volcanic rocks is estimated to be 500 ft. This value was multiplied by the width of each cross section (L) to obtain the cross-sectional area of flow (A).

Flow System East of Tuscarora Mountains

Recharge

Infiltration of precipitation and runoff is the only source of ground-water recharge to the flow system on the east side of the Tuscarora Mountains. Total recharge to the flow system is an estimated 35,000 acre-ft/yr (table 4). The Susie Creek Area receives 9,700 acre-ft/yr, the Maggie Creek Area 23,000 acre-ft/yr, and the Marys Creek Area 2,100 acre-ft/yr (table 4).

Discharge

Ground water discharges from the flow system on the east side of the Tuscarora Mountains as evapotranspiration, as inflow to the Humboldt River channel, and as springflow near the river. Total discharge from the flow system is an estimated 27,000 acre-ft/yr (table 5).

Total evapotranspiration from the flow system is an estimated 15,000 acre-ft/yr. Evapotranspiration is an estimated 1,700 acre-ft/yr in the Susie Creek Area, 11,000 acre-ft/yr in the Maggie Creek Area, and 2,000 acre-ft/yr in the Marys Creek Area (see table 5 for areas and types of phreatophytes).

Ground-water discharge as inflow to the Humboldt River channel and as nearby springflow was previously estimated to be about 7,000 acre-ft/yr (Plume, 1995, p. 45). However, further analysis of the streamflow records, in a previous section of this report indicates that ground-water discharge to the Humboldt River channel is about 12,000 acre-ft/yr. This volume of discharge consists of about 3,400 acre-ft/yr of springflow in the Marys Creek Area (table 5). The balance, 8,600 acre-ft/yr, is ground-water inflow directly to the river channel from the three areas (table 5).

Budget Imbalances

Estimates of recharge and discharge for the flow system east of the Tuscarora Mountains exceed those made by Plume (1995, p. 57-59) because the previous study used drainage-basin boundaries rather than hydrographic area boundaries for budget calculations. In addition, the estimate of ground-water discharge to the Humboldt River channel was revised as part of the present study.

The difference between recharge and discharge, 8,000 acre-ft/yr, represents an imbalance of 23 percent (recharge minus discharge, divided by recharge). Part of the reason for this imbalance may be that the Maxey-Eakin method for estimating infiltration of precipitation and runoff produced an overestimate of recharge. Also, the value for discharge is considered more reliable because it is based on measured evapotranspiration rates and on long-term streamflow records for the Humboldt River. However, increasing the rates used for evapotranspiration by only 0.1 ft/yr increases the total discharge estimate by more than 10 percent. Given this, and the approximate nature of the Maxey-Eakin method, the imbalance of 23 percent is considered minimal. This further suggests that the Maxey-Eakin method produces reasonable estimates of recharge for basins where streamflow leaves the basin.

Flow System West of Tuscarora Mountains

Recharge

Total ground-water recharge to the flow system west of the Tuscarora Mountains is an estimated 88,000 acre-ft/yr. The flow system receives recharge from infiltration of precipitation and runoff in each of the three hydrographic areas, infiltration of streamflow from the Humboldt River in Boulder Flat, and subsurface inflow from Crescent Valley and Whirlwind Valley to the south.

For the entire flow system, recharge as infiltration of precipitation and runoff is an estimated 47,000 acre-ft/yr. Willow Creek Valley receives an estimated 20,000 acre-ft/yr, the Rock Creek Valley 13,000 acre-ft/yr, and Boulder Flat 14,000 acre-ft/yr (table 4).

Table 4. Potential recharge from infiltration of precipitation to ground-water flow systems on east and west sides of Tuscarora Mountains, Carlin trend area, north-central, Nevada

[Abbreviations and symbols: in/yr; inches per year; acre-ft/yr, acre-feet per year; --, highest parts of basin are below 8,000 ft or lowest parts are above 4,700 ft; >, greater then; <, less than]

Altitude zone (feet above sea level)	Precipitation		Flow system east of Tuscarora Mountains[1]							
			Susie Creek Area		Maggie Creek Area		Marys Creek Area		Flow-system totals	
	Average[2] (in/yr)	Percent as recharge[3]	Area (acres)	Potential recharge (acre-ft/yr)	Area (acres)	Potential recharge (acre-ft/yr)	Area (acres)	Potential recharge (acre-ft/yr)	Area (acres)	Potential recharge (acre-ft/yr)
Above 8,000	>20	25	40	17	1,400	590	--	--	1,400	610
6,600-8,000	>15-20	15	9,900	2,200	52,000	11,000	2,200	480	64,000	14,000
5,800-6,600	>12-15	7	79,000	6,200	110,000	8,700	13,000	1,000	200,000	16,000
4,700-5,800	>8-12	3	53,000	1,300	94,000	2,400	23,000	580	170,000	4,300
Below 4,700	[4]8	0	--	--	--	--	--	--	--	--
Totals[1]			140,000	9,700	260,000	23,000	38,000	2,100	440,000	35,000

Altitude zone (feet above sea level)	Precipitation		Flow system west of Tuscarora Mountains[1]							
			Willow Creek Valley		Rock Creek Valley		Boulder Flat		Flow-system totals	
	Average[2] (in/yr)	Percent as recharge[3]	Area (acres)	Potential recharge (acre-ft/yr)	Area (acres)	Potential recharge (acre-ft/yr)	Area (acres)	Potential recharge (acre-ft/yr)	Area (acres)	Potential recharge (acre-ft/yr)
Above 8,000	>20	25	2,100	880	--	--	470	200	2,600	1,100
6,600-8,000	15-20	15	35,000	7,700	4,800	1,100	15,000	3,300	55,000	12,000
5,800-6,600	12-15	7	110,000	8,700	85,000	6,700	54,000	4,300	250,000	20,000
4,700-5,800	8-12	3	120,000	3,000	200,000	5,000	250,000	6,200	570,000	14,000
Below 4,700	[4]8	0	--	--	--	--	36,000	0	36,000	0
Totals[1]			270,000	20,000	290,000	13,000	360,000	14,000	910,000	47,000

[1] Values rounded to two significant figures.
[2] Computed from precipitation-altitude relation (see section titled "Climate").
[3] Percentages from Eakin, 1961, p. 20.
[4] 8 in/yr or less.

Table 5. Estimated discharge from ground-water flow systems on east and west sides of Tuscarora Mountains, Carlin trend area, north-central Nevada

[Individual components of discharge are rounded to two significant figures. Abbreviations: ft/yr, foot per year; ft^3/s, cubic feet per second; acre-ft/yr, acre-foot per year]

Hydrographic area [1] (figure 1)	Evapotranspiration: Area of phreatophytes[2] (acres)	Evapotranspiration: Rates (ft/yr)	Evapotranspiration: Annual volume [3] (acre-ft/yr)	Inflow to Humboldt River channel (acre-ft/yr)	Subsurface outflow from study area (acre-ft/yr)	Springflow (acre-ft/yr)	Total (acre-ft/yr)
			Flow system east of Tuscarora Mountains				
Susie Creek Area..	[4]3,400	0.5	1,700		0	0	
Maggie Creek Area	[5]16,400	[5]0.6, 1.0	11,000	[7]8,600	0	0	[9]27,000
Marys Creek Area.	[6]2,240	[6]0.6, 1.0	2,000		0	[8]3,400	
Totals..........	22,000		15,000	8,600	0	3,400	27,000
			Flow system west of Tuscarora Mountains				
Willow Creek Valley	[10]11,900	[10]0.6, 1.0	9,000	0	[12]4,300	0	13,000
Rock Creek Valley	[4]9,200	0.5	4,600	0	[12]2,800	0	7,400
Boulder Flat	[11]99,000	[11]0.3, 0.6	51,000	0	[13]12,000	0	63,000
Totals..........	120,000		65,000	0	19,000	0	83,000

[1] Defined by Rush (1968).
[2] See plate 3.
[3] Equal to areas of phreatophytes, multiplied by evapotranspiration rates.
[4] Mostly rabbitbrush, big sage, and greasewood.
[5] Rates used are 1.0 ft/yr for 1,800 acres of meadow grass and willows, 1.0 ft/yr for 400 acres of irrigated agriculture, and 0.6 ft/yr for 14,200 acres of mostly big sage, rabbitbrush, and grass.
[6] Rates used are 1.0 ft/yr for 1,720 acres of meadow grass and willows, and 0.6 ft/yr for 520 acres of rabbitbrush, big sage, and grass.
[7] Value represents total for all three hydrographic areas. Computed as difference between total gain of Humboldt River between Carlin and Palisade gaging stations and estimated springflow.
[8] Value from combined average discharge of 3.7 ft^3/s at Carlin spring and about 1 ft^3/s at nearby unnamed spring.
[9] Rounded total for all three hydrographic areas.
[10] Rates used are 1.0 ft/yr for 4,640 acres of willows, meadow grass, and irrigated pastures, and 0.6 ft/yr for 7,260 acres of rabbitbrush, big sage, and grass.
[11] Rates used are 0.6 ft/yr for 72,000 acres of rabbitbrush, big sage, greasewood, and meadow grass where depth to ground water is 5-15 ft, and 0.3 ft/yr for 27,000 acres of mostly greasewood where depth to ground water is 15-30 ft.
[12] Estimated subsurface outflow to Clovers Area.
[13] Estimates of subsurface outflow in basin-fill aquifer at section *C-C'* (plates 1 and 2) are 9,700 acre-ft/yr, and 15,000 acre-ft/yr, depending on thickness used for basin-fill deposits. Value shown is rounded average.

In Boulder Flat, streamflow losses from the Humboldt River are an estimated 40,000 acre-ft/yr. This value was computed as the combined average annual flow of the river at the Palisade and Pine Creek gaging stations, minus the average annual flow of the river at the Battle Mountain gaging station (see section titled "Surface Water"). These flow losses include irrigation diversions in addition to infiltration of streamflow. However, water diverted for irrigation eventually is lost to evapotranspiration or reenters the river as irrigation return flows. Therefore, net streamflow losses are treated as recharge.

Subsurface ground-water inflow to Boulder Flat from Crescent Valley and Whirlwind Valley has been estimated to be no more than a few hundred acre-ft/yr (Zones, 1961, p. 23) and 400 acre-ft/yr (Olmsted and Rush, 1987, p. 38), respectively. Thus, total subsurface inflow to Boulder Flat from these two areas could be about 600 acre-ft/yr.

Discharge

Total ground-water discharge from the flow system west of the Tuscarora Mountains is an estimated 83,000 acre-ft/yr. The discharge occurs as evapotranspiration and as subsurface outflow.

Total evapotranspiration from the three hydrographic areas west of the Tuscarora Mountains is an estimated 65,000 acre-ft/yr. Evapotranspiration is an estimated 9,000 acre-ft/yr in Willow Creek Valley, 4,600 acre-ft/yr in Rock Creek Valley, and 51,000 acre-ft/yr in Boulder Flat (see table 5 for areas and types of phreatophytes).

Subsurface outflow from the flow system west of the Tuscarora Mountains is an estimated 19,000 acre-ft/yr. This total includes flow from Willow Creek Valley, Rock Creek Valley, and Boulder Flat to the Clovers Area (pl. 3). As discussed earlier, estimates of subsurface flow are uncertain because estimates of aquifer properties and hydraulic gradient are uncertain. In spite of the uncertainties, preliminary estimates of subsurface outflow are made to complete estimates of ground-water discharge from this part of the study area.

Subsurface outflow from Willow Creek Valley to the Clovers Area, computed using equations 2 and 3, is an estimated 4,300 acre-ft/yr (table 5). This flow is through an aquifer cross section between the 4,700- and 4,800-ft contours and flow lines A and B (pl. 3). The width of the cross section is about 12 mi and the gradient an estimated 0.0081.

Subsurface outflow from Rock Creek Valley to the Clovers Area is an estimated 2,800 acre-ft/yr (table 5). This flow is through an aquifer cross section between the 4,700- and 4,800-ft contours and flow lines B and D (pl. 3). The width of this cross section is about 13 mi, and the gradient an estimated 0.0048.

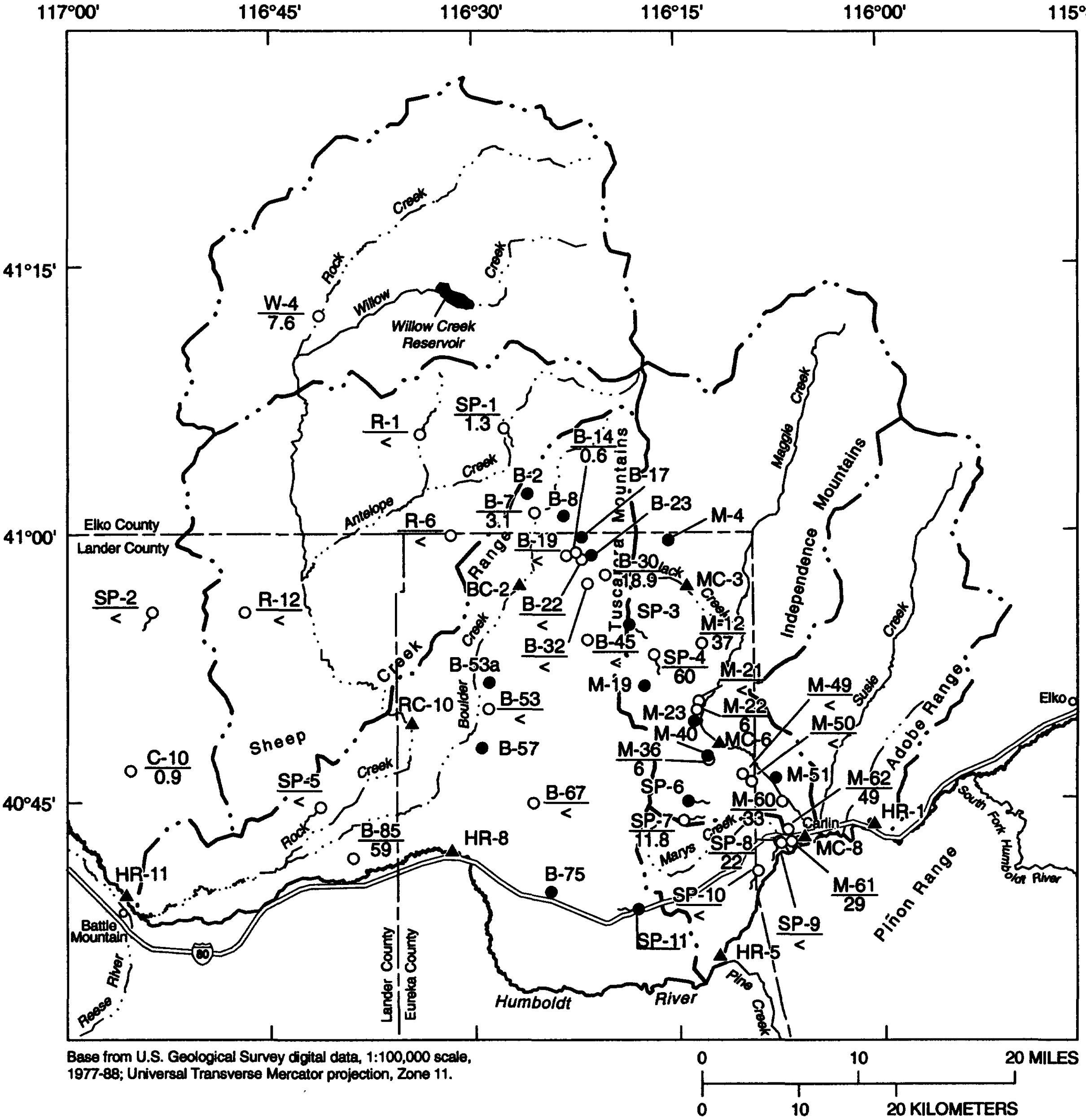
Subsurface outflow from Boulder Flat to the Clovers Area is through basin-fill deposits that underlie the Humboldt River flood plain and adjacent lowlands between the Sheep Creek Range and Argenta Rim. Most of this flow is in a triangular-shaped prism of basin-fill deposits, although some flow also may be in underlying volcanic rocks and siltstones (pls. 1 and 2, section *C-C'*). The area of the triangular prism of basin-fill deposits at section *C-C'* (pl. 2) is about 4.8×10^7 ft^2 (estimated triangular width of 30,000 ft and depth of 3,200 ft). The hydraulic conductivity of the basin-fill deposits is an estimated 20 ft/d (Loeltz, 1953, p. 5 and 8). The hydraulic gradient, determined from water levels measured near section *C-C'* (pls. 1 and 3), is an estimated 0.0012. Using these values in equation 2, subsurface flow is an estimated 9,700 acre-ft/yr. If a cross-sectional area of flow 5,000 ft thick is used (Stone and others, 1991, pl. 4), the value for subsurface flow is an estimated 15,000 acre-ft/yr. For purposes of water budgets in this report, the average of the two values, 12,000 acre-ft/yr, is used as the estimate of subsurface outflow (table 5).

Budget Imbalances

The difference between recharge and discharge west of the Tuscarora Mountains, 5,000 acre-ft/yr, represents an imbalance of about 6 percent, with discharge exceeding recharge. This close agreement could be largely fortuitous because estimates of subsurface outflow to the Clovers Area are approximate. However, the same methods of estimating infiltration of precipitation and runoff, and evapotranspiration were used with acceptable results east of the Tuscarora Mountains. This similarity suggests that estimates of infiltration of streamflow from the Humboldt River and of subsurface outflow are reasonable.

CHEMICAL CHARACTER OF SURFACE WATER AND GROUND WATER

Defining the chemical character of surface water and ground water in the study area is important for two reasons. First, such data can be used as a basis for evaluating future changes in water quality. Second, inferred ground-water flow paths, recharge sources, and ground-water ages could be evaluated using these data. Surface water and ground water were sampled at 56 sites as part of the study (fig. 15). Samples were collected for determination of major dissolved constituents, dissolved trace elements, dissolved nutrients, dissolved organic carbon, total and dissolved cyanide, tritium, deuterium, oxygen-18, carbon-13, and carbon-14. Water temperature, pH, specific conductance, alkalinity, and dissolved oxygen were measured in the field using instruments calibrated on-site. Alkalinity was determined by incremental titration with 0.16-Normal sulfuric acid.



EXPLANATION

— · · —	**Hydrographic-area boundary**—Modified from Rush (1968); not shown where coincident with Humboldt River	C-10 / 0.9 ○	**Well**—Top number is site name in appendix 4; bottom number or symbol indicates tritium concentration, in picocuries per liter (pCi/L), or if <, tritium value is below analytical detection limit of 0.3 pCi/L
HR-6 ▲	**Active stream-gaging station**—No tritium analysis available. Label refers to site name in appendix 1	SP-3 ●	**Spring**—No tritium analysis available. Label refers to site name in appendix 2
B-57 ●	**Well**—No tritium analysis available. Label refers to site name in appendix 4	SP-2 / < ○	**Spring**—Top number is site name in appendix 2; bottom number or symbol indicates tritium concentration, in picocuries per liter (pCi/L), or if <, tritium value is below analytical detection limit of 0.3 pCi/L

Figure 15. Sites where water-quality data and tritium analyses are available for streamflow and ground water in Carlin trend area, north-central Nevada

Samples for laboratory analysis were collected as follows. Water for major- and trace-element analyses was filtered through a 0.45-µm membrane filter and collected in polyethylene bottles. The filter and bottles were pre-rinsed with sample water. Samples for cation and trace-element analyses were acidified to a pH of less than 2.0 with pure nitric acid (Timme, 1994, p. 17). Samples for nutrient analyses were collected in opaque, pre-rinsed (sample water) polyethylene bottles, preserved with mercuric chloride, and kept at 4°C until the analyses were made (Timme, 1994, p. 17). Water samples for dissolved organic carbon were filtered through a 0.45-µm silver filter placed in a stainless steel cylinder. The filtrate was collected in a glass bottle that had been baked at 350°C overnight. These samples were kept at 4°C from the time of collection to analysis (Wershaw and others, 1987, p. 7-8). Water samples for dissolved cyanide were filtered through a pre-rinsed (sample water) 0.45-µm membrane filter and collected in pre-rinsed polyethylene bottles. Samples for total cyanide were whole water and also collected in pre-rinsed (sample water) polyethylene bottles. Samples for both total and dissolved cyanide were preserved with sodium hydroxide to a pH of at least 12 and kept at 4°C until the analyses were made (Timme, 1994, p. 17).

Samples for the isotopes tritium, deuterium, and oxygen-18 were whole water collected in glass bottles. Samples for the isotopes ^{14}C and ^{13}C were collected by chemically precipitating dissolved carbonate from a water sample. Samples for ^{14}C analysis were collected in a 2-L linear polyethylene bottle that was attached to the bottom of a 200-L, stainless-steel precipitation tank. The tank was flushed with nitrogen gas and then filled with the water sample. Next, the pH of the water sample was raised to above 10 by adding a carbonate-free sodium hydroxide solution to convert all dissolved inorganic carbon to carbonate. Strontium carbonate was then precipitated by adding a carbonate-free strontium chloride solution. The precipitate was allowed to settle into the sample bottle for about 1 hour. Samples for ^{13}C analysis were collected in a 1-L glass bottle that had been flushed with several volumes of sample water. Strontium carbonate was precipitated by adding carbonate-free ammoniacal strontium chloride solution to the sample. For both carbon-isotope samples, suspended particles were filtered out of the water before precipitation of carbonate.

All of the samples described above were analyzed using standard methods (Timme, 1994) at the USGS National Water-Quality Laboratory in Arvada, Colo., or at one of its contract laboratories.

The variability in the major-chemical composition, dissolved-solids concentrations, and pH of water can be graphically displayed on what is referred to as a Durov plot (fig. 16). The graph consists of five fields—two triangular and three rectangular (Zaporozec, 1972, p. 38). Each chemical analysis is plotted as five points on the graph. The relative proportions of major cations (calcium, magnesium, and sodium plus potassium) and anions (sulfate, chloride, and carbonate plus bicarbonate) are shown on the left and upper triangles, respectively. The pH and dissolved-solids concentrations are plotted in the bottom and right rectangles, respectively. The central rectangle functions as a transitional area to connect the four outside triangular and rectangular fields. The arrows in figure 16 show how the cation and anion points for a single analysis are projected from the cation and anion triangles to the central rectangle and then to the pH and dissolved-solids rectangles.

The advantage of a Durov plot is that it provides a visual characterization, on a single illustration, of eight major chemical constituents, pH, and dissolved-solids concentration of the water. The principal application of this type of diagram is to examine where the data points tend to group in each of the fields. Durov plots are used in this report to summarize chemical characteristics of the Humboldt River and some of its tributaries and of ground water.

Surface Water

Inorganic Composition

Samples of streamflow were collected at eight stream-gaging stations on the Humboldt River and its tributaries during the study. Four of the gaging stations are on the river near Carlin, at Palisade, at Dunphy, and at Battle Mountain (fig. 15, sites HR-1, HR-5, HR-8, and HR-11, respectively). Streamflow at the gaging station near Carlin was sampled five to six times per year as part of the U.S. Geological Survey National Stream-Quality Accounting Network. Sampling at the other three gaging stations was done as part of the Carlin trend study. Water samples at Battle Mountain were collected concurrently with sampling at the Carlin gaging station. Samples were collected at Palisade and Dunphy after the snowmelt runoff and during low-flow periods of summer and fall.

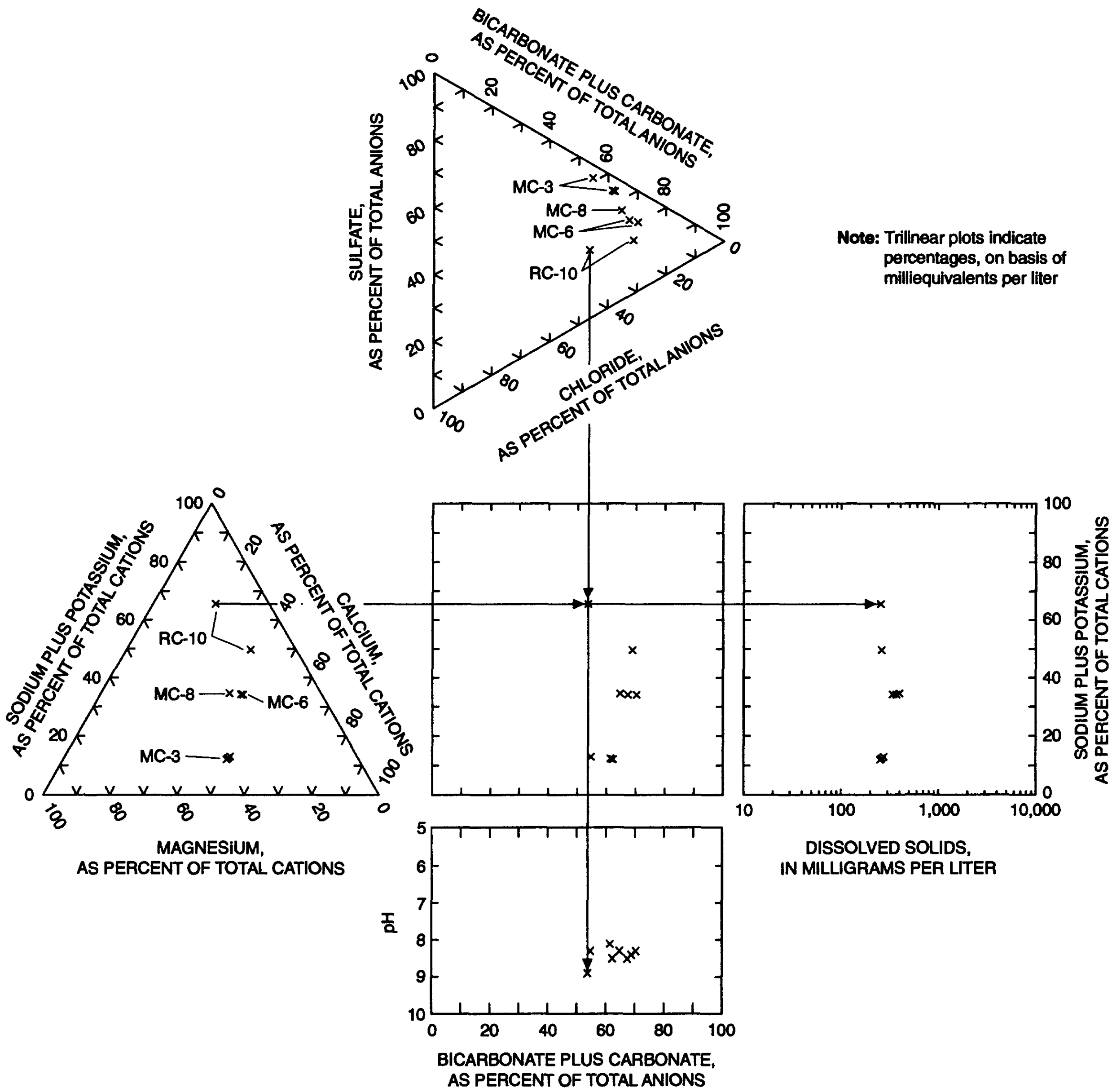


Figure 16. Chemical quality of Jack Creek (site MC-3), Maggie Creek (sites MC-6 and MC-8), and Rock Creek (site RC-10) during low flow, 1990-94, Carlin trend area, north-central Nevada. See figure 15 for site locations. Arrows indicate projection of single sample at site RC-10 from triangles to rectangles.

Water samples also were collected as part of the study at four stream-gaging stations on tributaries of the Humboldt River. These gaging stations are on Jack Creek, Maggie Creek at Maggie Creek Canyon, Maggie Creek at Carlin, and Rock Creek (fig. 15, sites MC-3, MC-6, MC-8, and RC-10, respectively). Samples also were collected at these sites after the snowmelt runoff in early summer and during low-flow periods of late summer and fall.

The chemical quality, in terms of major ions, of water in Jack, Maggie, and Rock Creeks differs over a wide range (fig. 16). The principal cations in water at

Jack Creek are calcium and magnesium and the principal anions are bicarbonate plus carbonate[2] and sulfate (fig. 16, site MC-3). Water from Maggie Creek is a mixed-cation type, and bicarbonate and carbonate are the principal anions. The principal cations in water at Rock Creek are sodium plus potassium. The principal anions are bicarbonate plus carbonate, although the proportion of chloride in water of Rock Creek is greater than at the other sites. At all of the tributaries, pH ranged from 8.1 to 8.9. Dissolved-solids concentrations (as residue-on-evaporation at 180°C) ranged from 252 to 276 mg/L in water of Jack Creek and Rock Creek, and from 339 to 465 mg/L in Maggie Creek (fig. 16).

When flows of the Humboldt River were less than 100 ft^3/s, the chemical composition of water at the Carlin gaging station differed from that of water at the Palisade, Dunphy, and Battle Mountain gaging stations farther downstream (fig. 17). Chemical analyses for water from the river sampled under these flow conditions in water years 1989-94 are represented by areas in figure 17 that are labeled with a "C" (Carlin gaging station) and with a "P" (Palisade, Dunphy, and Battle Mountain gaging stations).

Water from the Humboldt River at the Carlin gaging station is a mixed-cation, bicarbonate plus carbonate water. Proportions of cations, in milliequivalents per liter, are 38-47 percent calcium, 34-42 percent sodium plus potassium[2], and 17-23 percent magnesium. Proportions of anions, in milliequivalents per liter, are 63-80 percent bicarbonate plus carbonate, 11-24 percent sulfate, and 8-13 percent chloride. The pH of the water ranges from 7.8 to 8.7. Dissolved-solids concentrations range from 270 mg/L to 377 mg/L.

Water in the Humboldt River at the Palisade, Dunphy, and Battle Mountain gaging stations also is a mixed-cation, bicarbonate plus carbonate water. Proportions of cations are 37-50 percent sodium plus potassium, 33-43 percent calcium, and 16-22 percent magnesium. Proportions of anions are 51-74 percent bicarbonate plus carbonate, 15-27 percent sulfate, and 10-27 percent chloride. The pH of the water ranges from 8.2 to 8.7, and dissolved-solids concentrations range from 301 mg/L to 516 mg/L.

The chemical quality of the Humboldt River at the four stream-gaging stations during the snowmelt runoff (flows exceeding 100 ft^3/s) is generally similar to the chemical quality of the river at the Carlin gaging station during low-flow periods. The main differences are that dissolved-solids concentrations are less and the proportions of calcium, sodium plus potassium, and bicarbonate plus carbonate increase slightly. The chemical quality of the river at high flows is not shown because the differences are not large.

Differing proportions of sodium plus potassium at sites along the Humboldt River river and its tributaries (figs. 16 and 17) are probably related to the presence of volcanic rocks[3] in basins upstream from sampling sites. The Jack Creek watershed is underlain by siltstones; no volcanic rocks are present in the watershed. As a result, water in the stream is low in sodium and potassium. The proportion of sodium and potassium in other parts of the Maggie Creek Area is higher probably because of the presence of volcanic rocks (pl. 1). Sodium and potassium are the dominant cations in water of Rock Creek because large parts of Willow Creek Valley and Rock Creek Valley are underlain by volcanic rocks.

The slight increase in proportions of sodium plus potassium along the Humboldt River can also be attributed to volcanic rocks. Large parts of the Humboldt River Basin upstream from the Carlin gaging station are underlain by a variety of rock types, including carbonate and volcanic rocks. However, proportions of carbonate rocks decrease and proportions of volcanic rocks increase in areas downstream from the Carlin gaging station (pl. 1). Increases in the proportions of sodium plus potassium and chloride may also be due to salts that are flushed from soils and that enter the river as irrigation return flows or as runoff from low-altitude snowmelt. Dissolved-solids concentrations in the Humboldt River between the Carlin and Battle Mountain gaging stations increase downstream, probably as a result of evaporation.

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[2]Where percent anions are shown as bicarbonate plus carbonate and percent cations as sodium plus potassium, the predominant anion generally is, by far, bicarbonate and the predominant cation is sodium. For sampled ground water (see subsequent section), no carbonate was detected and sodium is generally, by far, the predominant cation.

[3]Much of the volcanic rock in the study area consists of rhyolite and andesite (see previous section of this report). These types of volcanic rocks are sodium-rich, which may account for differences in the sodium content of streamflow and ground water.

Ground-water discharge to the river channel near Carlin has no discernible effect on the chemical quality of water in the Humboldt River. The chemical quality of springflow near Carlin and of streamflow in Marys Creek, which is fed by Carlin spring, are similar to the chemical quality of water sampled at the Carlin gaging station (fig. 17).

Ground Water

Inorganic Composition

Ground water was sampled at 48 wells and springs in the study area (fig. 15). Chemical data for ground-water sites are listed in appendix 5. At most of the sites, sampled ground water is chemically similar,

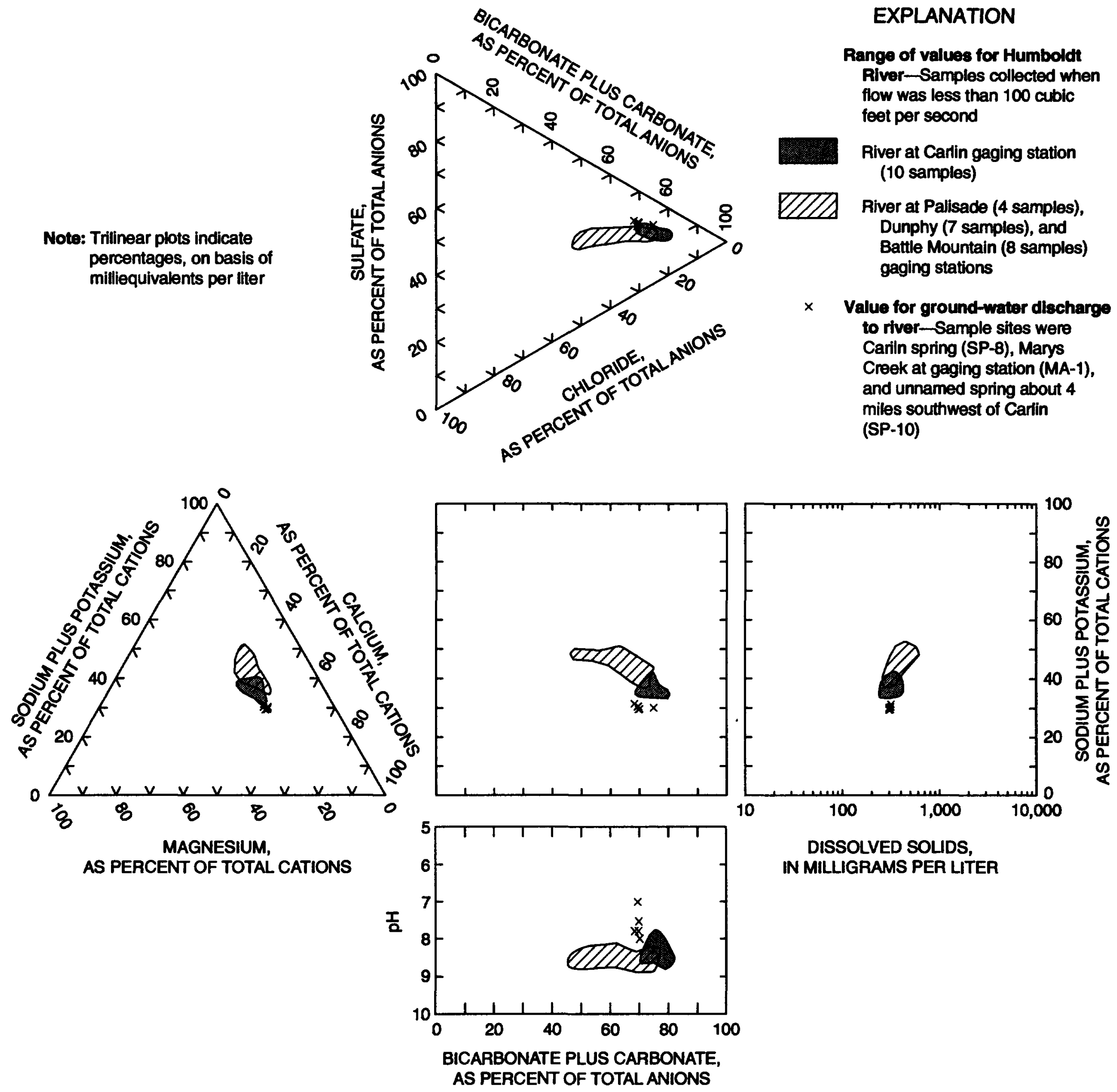


Figure 17. Chemical quality of Humboldt River at Carlin, Palisade, Dunphy, and Battle Mountain gaging stations during low flow, 1989-94, and of ground-water discharge to the river channel near Carlin, Carlin trend area, north-central Nevada. Site locations shown on figures 4 and 15.

and consists of a mixed-cation, bicarbonate type. Most samples contain less than 50 percent of any individual cation and more than 50 percent bicarbonate, on a milliequivalent basis (fig. 18). Calcium and sodium are generally the most abundant cations and most samples contain between 30 and 50 percent of each (fig. 18 and app. 5). Ground water in all six hydrographic areas is near neutral, and pH ranges from slightly more than 6 to almost 8 (fig. 18). The concentration of dissolved solids, calculated from the major-ion chemistry, ranged from 83 to 1,500 mg/L, but most samples contained 200-600 mg/L. Dissolved-solids concentrations were calculated by multiplying the bicarbonate concentration by 0.4916 to make the result comparable to a "residue-upon-evaporation" value and summing all the major-element concentrations. A calculated rather than measured dissolved-solids concentration was used in the Durov plot because not all of the samples analyzed

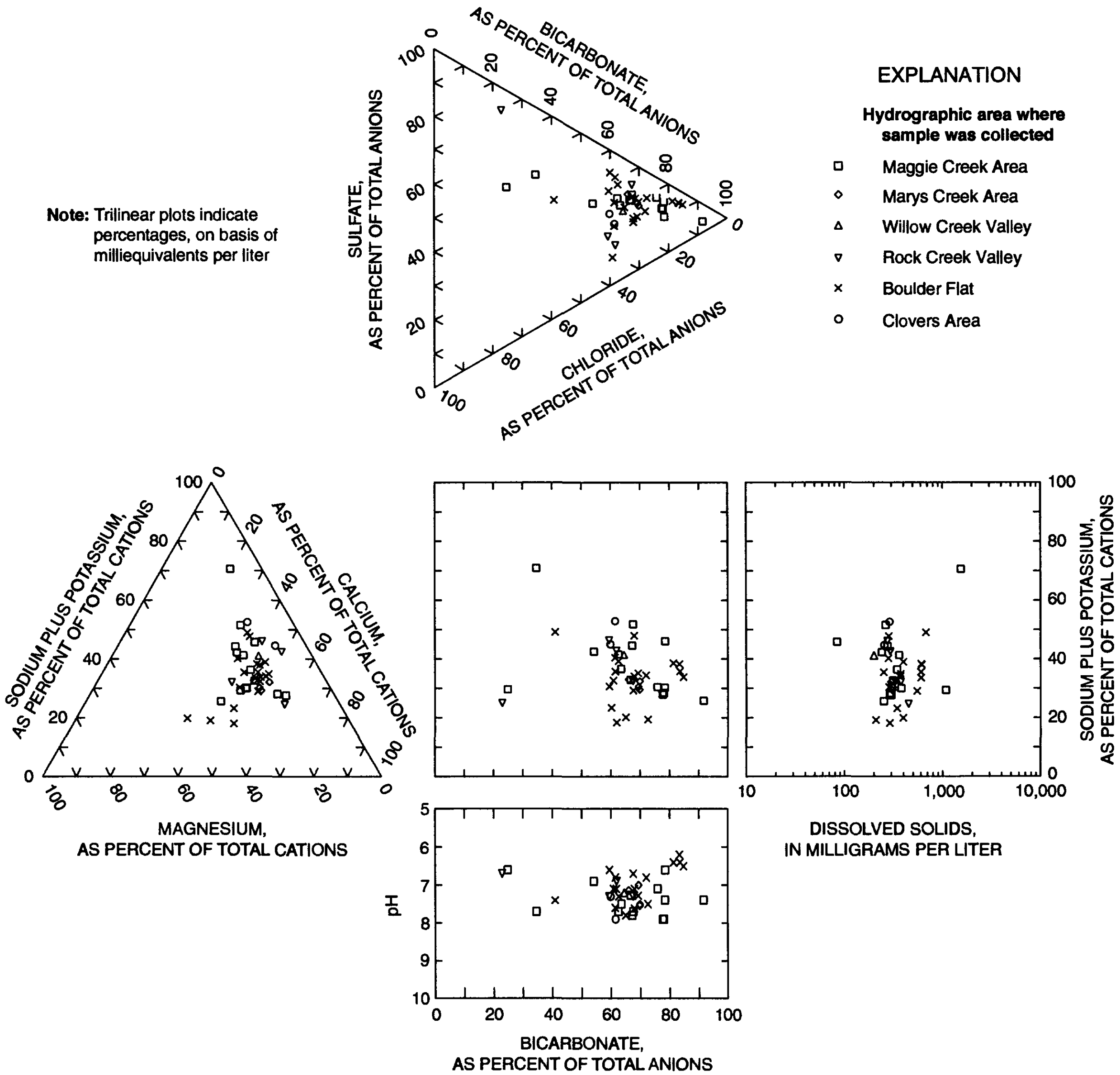


Figure 18. Chemical quality of ground water in Carlin trend area, north-central Nevada. See figure 15 for site locations.

for major ions were also analyzed for dissolved-solids residues. Ground-water samples with the lowest and highest measured dissolved-solids concentrations are from the Maggie Creek Area.

Ground water that differed from the general composition described above came from three sites in the Maggie Creek Area, one in Rock Creek Valley, and three in Boulder Flat (fig. 18). Two of the sites in the Maggie Creek Area are a spring and well, each with high proportions of sulfate (app. 5, sites SP-3 and M-61). Water discharging at the spring is a calcium sulfate type and the dissolved-solids concentration is 1,240 mg/L (app. 5). The chemical quality of this water may have been affected by sulfide mineralization nearby (Plume, 1995, p. 46). The well with a high proportion of sulfate in its water is adjacent to the Humboldt River flood plain. Water at this well is a sodium sulfate type. Possible sources of the sodium and sulfate are evaporite beds in the basin-fill deposits penetrated by the well or contamination from an unidentified source (Plume, 1995, p. 46). The third site is a spring near the base of the Tuscarora Mountains (fig. 15, site SP-4). The dissolved-solids concentration of water from this spring was the lowest measured in ground water in the study area (96 mg/L). This low concentration reflects the close proximity of the spring to high-altitude recharge areas in the nearby mountains.

Ground water from a well in Rock Creek Valley is a calcium sulfate type (app. 5, site R-1). Water from this well had the highest proportion of sulfate (70 percent) in ground water sampled in the study area. The source of high sulfate most likely is nearby sulfide mineralization.

Ground water from three wells in Boulder Flat had some of the highest proportions of magnesium and the lowest proportions of sodium plus potassium of ground water in the study area (app. 5, wells B-14, B-30, and B-45). Ground water at these wells is a magnesium bicarbonate type. The wells are near exposures of carbonate rocks in the Tuscarora Mountains (fig. 15 and pl. 1). Thus, the chemical composition of water from these wells probably reflects dissolution of dolomite.

Isotopic Composition

The most common isotopes in water are hydrogen-1 (^{1}H) and oxygen-16 (^{16}O). However, the isotopes hydrogen-2 (^{2}H), called deuterium, and oxygen-18 (^{18}O) also can be present in small proportions. The deuterium composition of water is expressed as a ratio to hydrogen-1 ($^{2}H/^{1}H$) and is reported as delta deuterium (δD), which is the difference between the ratio measured in a water sample compared to a standard. The oxygen-18 composition of water is expressed as a ratio to oxygen-16 ($^{18}O/^{16}O$) and is reported as delta oxygen-18 ($\delta^{18}O$), which is the difference between the ratio measured in a water sample as compared to a standard. Both δD and $\delta^{18}O$ are reported in permil, relative to Vienna Standard Mean Ocean Water (VSMOW; Fritz and Fontes, 1980, p. 11-14).

Deuterium and oxygen-18 are stable isotopes, which means that they do not undergo radioactive decay. The two isotopes are part of the water molecule and can be used as an aid in determining sources of ground water. After recharge occurs, concentrations of deuterium and oxygen-18 in nonthermal ground water generally are affected only by evaporation. Evaporation results in preferential removal of hydrogen-1 and oxygen-16 from water relative to deuterium and oxygen-18. This is because hydrogen-1 and oxygen-16 are lighter than deuterium and oxygen-18 and have lower bond energies. Thus, water that has undergone evaporation becomes isotopically heavier (delta values are less negative) than the original water.

Carbon-14 (^{14}C) and carbon-13 (^{13}C) are part of carbon dissolved in the ground water and can be used to calculate a ground-water age for water that is several thousand to about 40,000 years old. Carbon-14 is radioactive and has a half-life of 5,730 years (Friedlander and others, 1981). Carbon-13 is a stable isotope and is expressed as a ratio to carbon-12 ($^{13}C/^{12}C$) and reported as delta carbon-13 ($\delta^{13}C$), which is the difference between the ratio measured in a water sample as compared to a standard. Delta carbon-13 is reported in permil relative to a standard referred to as Peedee Belemnite (PDB; Craig, 1957). Together, carbon-13 and carbon-14 analyses are used to estimate the age of ground water. The age indicated by carbon-14 generally must be adjusted by accounting for mass transfer of carbon using the carbon-13 analysis.

Tritium (^3H), like deuterium and oxygen-18, is also part of some water molecules. However, tritium is radioactive and decays. The half-life of tritium is 12.33 years (Friedlander and others, 1981). Thus, tritium can be used to identify ground water that has recently—within about the last 60 years—been exposed to the atmosphere (time since recharge).

Deuterium and Oxygen-18

Deep ground water sampled in the upper reach of the Maggie Creek Area is isotopically lighter than ground water from other parts of the study area. This isotopically lighter ground water is from three flowing wells (figs. 15 and 19, M-21, M-22, and M-23) that tap deep parts of the basin-fill aquifer. The lower proportions of deuterium and oxygen-18 in this ground water originally were thought to have resulted from the effects of altitude on isotopic compositions of precipitation in the northern part of the Maggie Creek Area (Plume, 1995, p. 50). Generally, precipitation at high altitudes is isotopically lighter than precipitation at low altitudes because temperatures are cooler at high altitudes and proportions of deuterium and oxygen-18 increase with decreasing temperature. However, this isotopically light ground water also may have been recharged during a cooler climate. On the basis of the ^{14}C analysis, water from well M-23 contains only 4.3 percent modern carbon; whereas water from five other sites in the study area contains 29 to 61 percent modern carbon. The low level of ^{14}C in water from well M-23 indicates that the water may be thousands of years old. The lack of isotopically light ground water in the lower part of the Maggie Creek Area indicates that ground-water flow through Schroeder Mountain from the upper part of the area to the lower part is minimal (Plume, 1995, p. 50).

A sample from well B-57 in Boulder Flat plots to the right of the rest of the samples (fig. 19). Water at this site appears to have undergone more evaporation than other ground water sampled in the study area. The depth to water in well B-57 was about 22 ft during the study period. This depth would preclude evaporation from the water table near this well, unless the evaporation occurred upgradient from the well or at a time when the depth to water was shallower. However, the well is adjacent to a stock pond that stores water from the well and collects runoff. Downward percolation of evaporated water from the pond is a possible source of the isotopically heavier ground water at the well.

With the exceptions just described, deuterium and oxygen-18 compositions of sampled ground water do not differ much in the study area (fig. 19). The similarity of compositions in ground water suggests that isotopic compositions of precipitation—the main source of ground-water recharge—have not differed much. All ground-water samples, except one from the Maggie Creek Area, plot to the right of the global meteoric line, as shown in figure 19. The distribution indicates that the ground water had undergone evaporation before infiltrating downward to become recharge. The similarities of isotopic compositions of ground water preclude estimation of amounts of possible interbasin flow.

Tritium

Ground water at about half the sites sampled in the study area has no measurable tritium (fig. 15). The absence of tritium indicates that this water was recharged more than 60 years ago, because it has not been exposed to the atmosphere for at least that long. This is reasonable for water from wells and springs that are several miles or more from recharge areas in mountain blocks and from losing reaches of streams. In contrast, ground water with measurable tritium is found at springs near recharge areas in mountains (sites SP-1, SP-4, and SP-7), and at some wells near mines (fig. 15, sites B-7, B-14, B-30, and M-36), which also are near recharge areas in mountains. Water in wells adjacent to Willow Creek (W-4), Maggie Creek (M-60), and the Humboldt River (B-85) also contain tritium, indicating that recharge from the streams has occurred in the last 60 years.

Deep production wells for mining operations that pump from bedrock have water with differing tritium concentrations. Ground water from some sites has tritium concentrations of as much as 19 pCi/L. However, water in other nearby wells has no measurable tritium even though these wells are also near the same recharge areas. These differences in tritium concentration probably result from complex flow paths in fractured bedrock and support the concept of compartmentalized ground-water domains in bedrock.

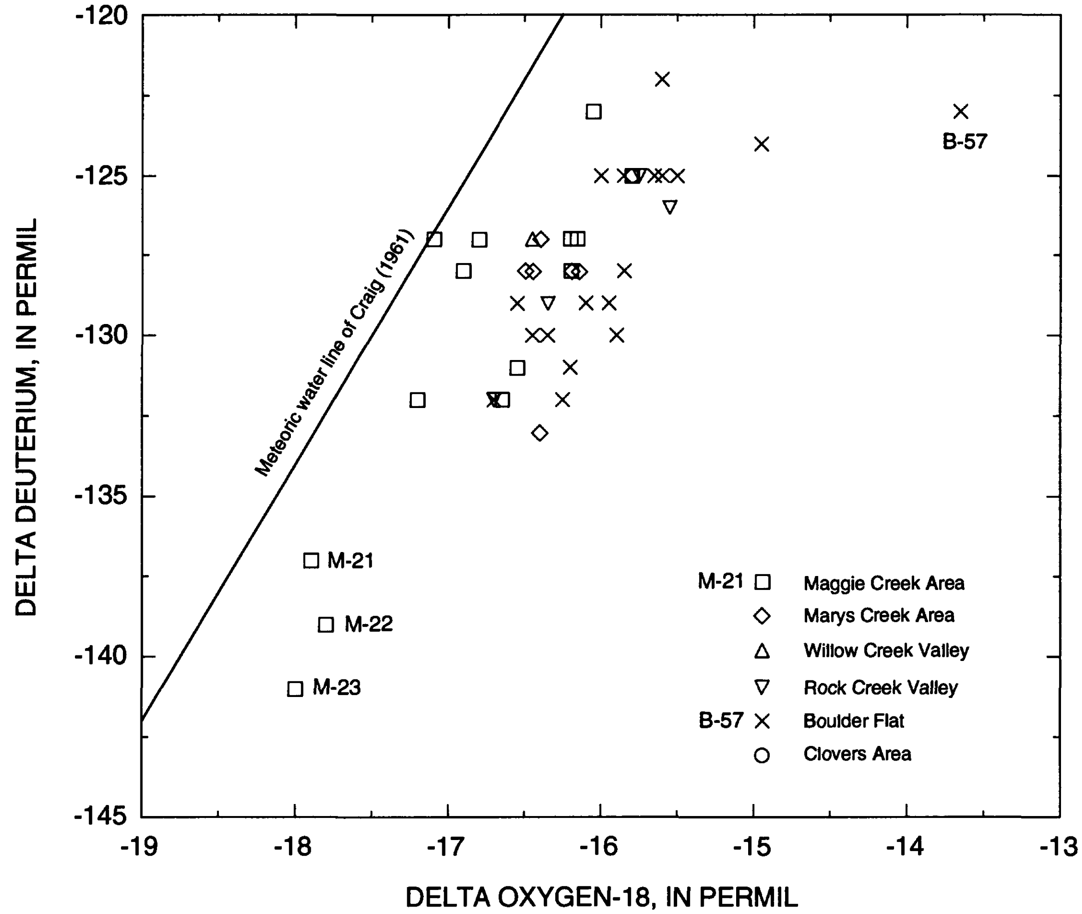


Figure 19. Relation between deuterium and oxygen-18 for ground-water in Carlin trend area, north-central Nevada. Equation for meteroric water line is $\delta D = (8 \times \delta^{18}O) + 10$ (Craig, 1961). See figure 15 for site locations.

Ground water at other sites also has measurable tritium. The tritium concentration from an irrigation well in the Clovers Area (C-10, fig. 15) is 0.9 pCi/L, which is barely above the detection level. Infiltration of irrigation water could be the source of the tritium.

The tritium concentration of water from well M-22 is 6.0 pCi/L. A source of water containing measurable tritium is not obvious, because this well is 755 ft deep (app. 4), and water from an adjacent shallower well (M-21) contains no measurable tritium. Furthermore, a 1,000-ft well nearby (M-23) contains only 4.3 percent modern carbon, which indicates that the water is several thousand years old.

Water from well M-62 and from Carlin spring (SP-8) contains 49 and 22 pCi/L of tritium, respectively. Plume (1995, p. 50) cites Maggie Creek as the source of this young water. Infiltration of streamflow through the Maggie Creek channel enters fractured volcanic rocks, and the ground water flows southward to Carlin spring.

Geochemical Modeling of Hypothetical Ground-Water Flow Paths

Water chemistry was used to investigate possible ground-water flow between Willow Creek Valley, Rock Creek Valley, the Clovers Area, and Boulder Flat. Mass transfers of major dissolved ions between the water and aquifer material along proposed flow paths were calculated using minerals identified in the aquifers (Coats, 1987) as sources and sinks of the ions. Equilibrium calculations were made for the minerals used in the mass-transfer calculations to determine if the proposed flow paths are geochemically feasible. Mass-transfer calculations do not yield unique

Table 7. Saturation indices [1] for minerals in water at sites along two proposed ground-water flow paths, Carlin trend area, north-central Nevada (see table 6).

[Computations made using the computer program NETPATH (Plummer and others, 1991)]

Site [2]	Albite[3]	Anorthite[3]	Biotite[3]	Calcite[3]	Chalcedony[3]	Dolomite[3]	Potassium feldspar[3]	Kaolinite[3]
W-4	-1.0	-5.0	-13	-1.1	0.6	-2.6	0.8	2.8
R-12	-1.2	-4.9	-9.2	-.5	.5	-1.5	.4	1.6
SP-2	-.3	-2.1	-6.8	-.4	.4	-1.4	1.2	3.9
R-6	.2	-2.5	-11	-.8	.7	-2.4	2.1	4.8
BC-2	.7	0	-7.5	-.7	.3	-1.8	2.7	6.7
B-53a	-1.1	-5.0	-11	-.4	.6	-1.2	-1.3	2.2

[1] SI (saturation index) = IAP/K_T, where *IAP* is ion-activity product and K_T is equilibrium constant at temperature *T* of water, for mineral of interest (Drever, 1988, p. 22-23). Positive value of SI indicates mineral can precipitate from solution; negative value indicates mineral can dissolve if present. If reported aluminum concentration was less than 10 micrograms per liter, 10 micrograms per liter was used for calculations.

[2] Letters and numbers are site names used in this report in figure 15 and appendixes 1, 2, 4, and 5.

[3] Chemical formulas are: albite, $NaAlSi_3O_8$; anorthite, $CaAl_2Si_2O_8$; biotite, $KMg_3AlSi_3O_{10}(OH)_2$; calcite, $CaCO_3$; chalcedony, SiO_2; dolomite, $CaMg(CO_3)_2$; potassium feldspar, $KAlSi_3O_8$; kaolinite, $Al_2Si_2O_5(OH)_4$.

thermodynamic calculations indicate that the waters are at saturation with respect to the potassium-feldspar mineral adularia. In addition, the 0.01 mmol/kg of biotite indicated to be precipitating is not thermodynamically feasible. However, the extremely small mass transfers of potassium feldspar and biotite do not invalidate the model. The amounts of mass transfer involved are very small, and could indicate lesser reactions that have not been accounted for, variations in ground-water chemistry, or the analytical uncertainty of potassium and magnesium analyses.

For the second flow path (flow line E, pl. 3), water from a well in the eastern part of Rock Creek Valley (pl. 3 and fig. 15, R-6) was chosen to represent the chemical quality of ground water near the beginning of the flow path. At an intermediate point along this flow path, infiltration of streamflow from Boulder Creek (fig. 15, site BC-2) is mixed with the ground water from the beginning of the flow path. Ground water in Boulder Flat at site B-53a, (fig. 15) is thought to be a mixture of water from the two sources. The same phases used for the first model also were used for this mass-transfer model. In addition, the mineral dolomite was included as a phase because erosion of carbonate rocks nearby in the Tuscarora Mountains is a source of carbonate minerals in basin-fill deposits in Boulder Flat (pl. 1).

The mass-transfer model for ground-water flow from the eastern part of Rock Creek Valley to Boulder Flat (table 6) is thermodynamically feasible (table 7). On the basis of water chemistry, the model calculates that a mixture of 60 percent ground water from Rock Creek Valley and 40 percent water from infiltration of streamflow from Boulder Creek, along with the geochemical reactions, is needed to produce the water of the chemical quality in Boulder Flat at well B-53a. The model indicates that plagioclase, calcite, pyrite, dolomite, biotite, and carbon dioxide gas would dissolve and silica and kaolinite would precipitate or form. Dissolution of large amounts of carbon dioxide gas for this model (table 6) is not inconsistent with the dissolution of much smaller amounts for the first model. For the first model, water at the beginning and intermediate points is ground water with little dissolved carbon dioxide. Water from Boulder Creek, however, must move through an unsaturated zone before recharging the underlying aquifer. The unsaturated zone should contain an elevated carbon-dioxide partial pressure compared to the atmospheric partial pressure of the gas. Thus, carbon dioxide gas should dissolve as water from Boulder Creek recharges the aquifer.

Ground-water flow paths in the Maggie Creek and Marys Creek Areas were evaluated using geochemical models as part of a previous study solutions, but, if based on known mineralogy, can provide reasonable estimates of the kinds and amounts of reactions, or mixing of waters, within an aquifer. Calculated mass transfers have to be thermodynamically feasible for the mass-transfer models to be acceptable and for the proposed flow path and mixing to be possible.

Two proposed ground-water flow paths that involve mixing of water from different sources and hydrographic areas were investigated. The first flow path extends from Willow Creek Valley through Rock Creek Valley to the Clovers Area and is generally defined by flow lines B and C (pl. 3). The second flow path extends from the eastern part of Rock Creek Valley through the Sheep Creek Range to the northern part of Boulder Flat and is generally defined by flow line E (pl. 3). A mass-transfer model was constructed for each of the proposed flow paths using ground-water chemistry (app. 5) and surface-water chemistry and the mineralogy of the aquifers (Coats, 1987). Bedrock within the hydrographic areas is primarily volcanic rock that is composed of plagioclase, with an average chemical composition of $Na_{0.7}\,Ca_{0.3}\,Al_{1.3}\,Si_{2.7}\,O_8$, potassium feldspar ($K\,Al\,Si_3\,O_8$), and biotite ($K\,Mg_3\,Al\,Si_3\,O_{10}$) (Coats, 1987). In addition, pyrite ($Fe\,S_2$) is present in mineralized areas. Physical and chemical weathering of these rocks should result in basin-fill deposits that consist of these minerals along with clay minerals, silica, and calcite. Thus, plagioclase, potassium feldspar, biotite, pyrite, kaolinite, silica, and calcite were chosen as phases for the geochemical modeling. In addition, carbon dioxide gas was chosen as a phase because it is present in the soil zone.

For the first flow path (pl. 3, flow lines B and C), water from a well in Willow Creek Valley (fig. 15, W-4) was used to represent the chemical quality of ground water at the beginning of the flow path. This well is near Willow and Rock Creeks, and thus, is near a recharge source. At an intermediate point along the flow path, water from a well in Rock Creek Valley (fig. 15 and pl. 3, R-12) is mixed with the water from Willow Creek Valley. The mixture of ground water from these two sources is thought to be chemically representative of water discharging from a large spring near the end of the flow path (pl. 3 and fig. 15, SP-2).

The mass-transfer model for ground water along this flow path (table 6) is thermodynamically feasible and consistent with saturation indices in table 7. On the basis of water chemistry, the model indicates that a mixture of about 60 percent ground water from Willow Creek Valley (W-1) and 40 percent ground water from Rock Creek Valley (R-12), along with the geochemical reactions, is needed to produce water of the chemical quality at spring SP-2. The model indicates that plagioclase, calcite, pyrite, potassium feldspar, and carbon dioxide gas would dissolve and silica, kaolinite, and biotite would precipitate or form. The 0.02 mmol/kg of potassium feldspar that is indicated to be dissolving may instead be from the exchange of calcium or magnesium ions dissolved in the water with potassium ions on clays, or dissolution of some other mineral that contains potassium, because

Table 6. Mass transfer of mineral and gas phases along two proposed ground-water flow paths, Carlin trend area, north-central Nevada

[Computations made using computer program NETPATH (Plummer and others, 1991). Values in millimoles per kilogram. Negative value indicates phase is leaving solution as mineral precipitation, mineral formation, or outgassing, and positive value indicates phase is dissolving. Symbol: --, constituent not used for mass-transfer calculation.]

Flow path [1]	Carbonate minerals		Aluminosilicate minerals				Other phases		
	Calcite	Dolomite	An_{30} [2]	Biotite	Kaolinite	K-feldspar	Pyrite	SiO_2	CO_2 gas
W-4 + R-12 = SP-2	0.07	--	0.44	-0.01	-0.29	0.02	0.05	-0.71	0.01
R-6 + BC-2 = B-53a	.26	.09	1.02	.07	-.70	--	.12	-1.44	2.92

[1] Letters and numbers are site names in figure 15 and appendixes 1, 2, 4, and 5. For first flow path, mass-balance calculation involves mixing 60 percent water at well W-4 with 40 percent water at well R- 12 to obtain composition of water at spring SP-2. For second flow path, mass-balance calculation involves mixing 60 percent water at well R-6 with 40 percent water from Boulder Creek at site BC-2 to obtain composition of water at well B-53a.

[2] Signifies plagioclase that is 30 percent anorthite and 70 percent albite.

(Plume, 1995, p. 52-54). Model results indicate that water discharging from Carlin spring could be a mixture of about 80 percent recharge from infiltration of Maggie Creek streamflow and 20 percent high-altitude recharge from the south end of the Tuscarora Mountains and the Schroeder Mountain uplift (Plume, 1995, p. 54). The results of the models show that ground-water flow along flow lines C, E, G, and J (pl. 3) is reasonable given the chemical composition of ground water near the paths.

WATER-LEVEL CHANGES RELATED TO MINING ACTIVITIES

Mining at Gold Quarry is expected to be complete by the year 2001 (U.S. Bureau of Land Management, 1993, section 2, p. 22). At that time, the altitude of the pit floor is expected to be 4,075 ft (U.S. Bureau of Land Management, 1993, section 2, p. 29). In comparison, the altitude of the Humboldt River channel about 7 mi to the south is about 4,900 ft. Mining at Post-Betze is expected to be complete by the year 2004 (D.A. Moody, Barrick Goldstrike Mines Inc., oral commun., 1994). At that time, the altitude of the pit floor is expected to be 4,160 ft (U.S. Bureau of Land Management, 1991, section 2, p. 25 and 29). In comparison, the altitude of the Humboldt River about 20 mi to the south is about 4,600 ft.

Water in excess of that needed for mining and milling is temporarily stored in reservoirs near the Gold Quarry and Post-Betze mines (fig. 1). Part of the water in the reservoir near the Gold Quarry mine is used to irrigate crops a few miles north of Carlin and part is released to the channel of Maggie Creek. Part of the water in the reservoir near the Post-Betze mine is used to irrigate crops and part infiltrates beneath the reservoir through fractured volcanic rocks.

The potential hydrologic effects of mining activities include flow changes in ground-water and surface-water systems and changes in ground-water and surface-water quality. These changes can result from pumping for ore processing and pit dewatering, infiltration from holding reservoirs, application of mine water for irrigation, and releases from holding reservoirs to stream channels.

During the study period, extended drought conditions made evaluation of the effects of mining activities on the surface-water system difficult. However, the flow of both Maggie Creek and Carlin spring did not appear to decrease as a result of pumping during 1990-93 at Gold Quarry mine (see "Surface Water" section). Near the Post-Betze mine, baseflows of Antelope Creek and Boulder Creek (app. 1, sites RC-6 and BC-1) increased slightly from 1991 to 1992, and flows of Boulder Creek (site BC-2) during the snowmelt runoff increased from 1991 and 1992 to 1993. However, these flow increases are believed to be natural fluctuations and not related to activities at Post Betze mine. As will be discussed later, ground-water flow and hydrologic responses to pumping are controlled by geologic structures. These structures also limit the areal effect of pumping on streamflow.

Water-quality data collected throughout the study area also show no appreciable changes that can be attributed to mining activities. These data, listed in appendix 5, provide baseline information from which an evaluation of the effects of mining on the water quality can be made with continued data collection.

The largest hydrologic response from mining activities observed from 1990 through 1993 was in the ground-water system. Pit dewatering and infiltration from holding reservoirs resulted in large changes in ground-water levels. These water-level changes have been documented by measurements made by USGS, by Newmont Gold Company (1992a and b, 1993a-d, 1994a), and by Barrick Goldstrike Mines Inc. (1991a and b, 1992a-d, 1993a-c, 1994a and b). Measurements made by the USGS and selected measurements made by the mining companies are listed in appendix 4.

Water-level declines resulting from pit dewatering have caused ground-water conditions to change from confined to unconfined, mainly in the siltstones and carbonate rocks. Water levels in overlying, less permeable basin-fill deposits and siltstones have not declined at the same rate or have remained relatively constant. This has increased the downward vertical gradient and created zones of perched ground water over the areas with greatest declines. To show the amount of water-level decline, contours were constructed using unconfined water levels from siltstones and carbonate rocks in the areas with largest declines. Perched water levels in basin-fill deposits and siltstones were not used. The resulting configuration of the water table in the fall of 1993 is shown in figure 20 for the central and eastern parts of the study area. Water-level changes from 1990 through 1993 in other parts of the study area were minimal.

Figure 21 shows the approximate distribution of water-level changes in unconfined water levels from 1990-91 through 1993. The network of wells where water levels could be measured changed from 1990 through 1993. Some wells measured in 1990-91 were dry three years later because of water-level declines, and many wells measured in 1993 were installed after 1990. Lines of equal water-level rise or decline on figure 21 were developed by subtracting gridded values for water-level contours for 1993 (fig. 20) from gridded values for water-level contours for 1990-91 (pl. 3). Wells where water levels were available in both 1990-91 and 1993 were used to constrain the lines of equal water-level change. However, the distribution of water-level change is considered approximate because identical networks of wells could not be measured. In addition, water levels in overlying perched zones have shown little decline.

Near Gold Quarry, water is pumped from both siltstones and carbonate rocks at about 15 wells as deep as 1,600 ft. The total volume of water pumped for dewatering from 1988 through 1993 is estimated to have been about 34,000 acre-ft (C.J. Zimmerman, Newmont Gold Company, 1993, written commun.). The volume of water lost to infiltration from the holding reservoir used to store water from the mine is estimated to have been about 750 acre-ft from January 1993 to January 1994 (Newmont Gold Company, 1993b-d, 1994a, p. 6).

Near the Gold Quarry mine, water levels in the siltstones declined nearly 100 ft at site M-37 from 1989 through 1993 (app. 4), and 200 ft at site M-45 from 1991 through 1993 (fig. 22). Water levels declined over 100 ft from 1992 through 1993 in the carbonate rocks at site M-46 (app. 4). About 2-3 mi northwest of Gold Quarry mine, confined water levels declined from 50 to about 70 ft in carbonate rocks from 1990 through 1993 (app. 4, site M-27, M-28, and M-33). Hydrogeologic units penetrated by the well at site M-31 where water levels declined about 100 ft from 1989 through 1993 are probably siltstone or carbonate rocks (app. 4). Water levels in basin-fill deposits and volcanic rocks southeast of Gold Quarry mine showed little change (app. 4, sites M-51, M-55, M-58, and MR-1).

As a result of water-level declines, ground-water conditions changed from confined to unconfined in late summer 1991 at site M-45, and in fall 1992 at site M-46. Downward vertical gradients from basin-fill deposits to underlying carbonate rocks and within carbonate rocks increased during 1990-93 at sites M-27, M-28, M-33 and M-34 (app. 3). A zone of perched ground water was present in older basin-fill deposits at site M-29 in 1993 (app. 3). This zone could remain perched in the future if vertical hydraulic conductivities are sufficiently low. If vertical hydraulic conductivity is high, however, the zone could drain rapidly.

From 1990 to 1993, water levels declined as much as 200 ft near the Gold Quarry mine (fig. 21). The extent of water-level declines in siltstones and carbonate rocks cannot be defined south of the mine because the present (1993) network of monitoring wells does not extend into that area. Water-level declines exceeding 50 ft extended about 3 mi north of the mine.

As of 1993, water-levels in basin-fill deposits and volcanic rocks had not declined in response to pumping from siltstones and carbonate rocks. This implies that a poor hydraulic connection exists between the hydrogeologic units. If continued pumping produces water-level declines in basin-fill deposits and volcanic rocks, the baseflows of Maggie Creek, Carlin spring, and the Humboldt River could be decreased.

EXPLANATION

P — **Open-pit mine**—Label is abbreviation for Post-Betze mine (P) and Gold Quarry mine (Q)

P — **Reservoir**—Used to store water from Post-Betze mine (P) and Gold Quarry mine (Q)

Hydrographic-area boundary—Modified from Rush (1968); not shown where coincident with Humboldt River

– –4,800— **Water-table contour**—Shows altitude of water table. Dashed where uncertain. Contour interval, in feet, is variable. Datum is sea level

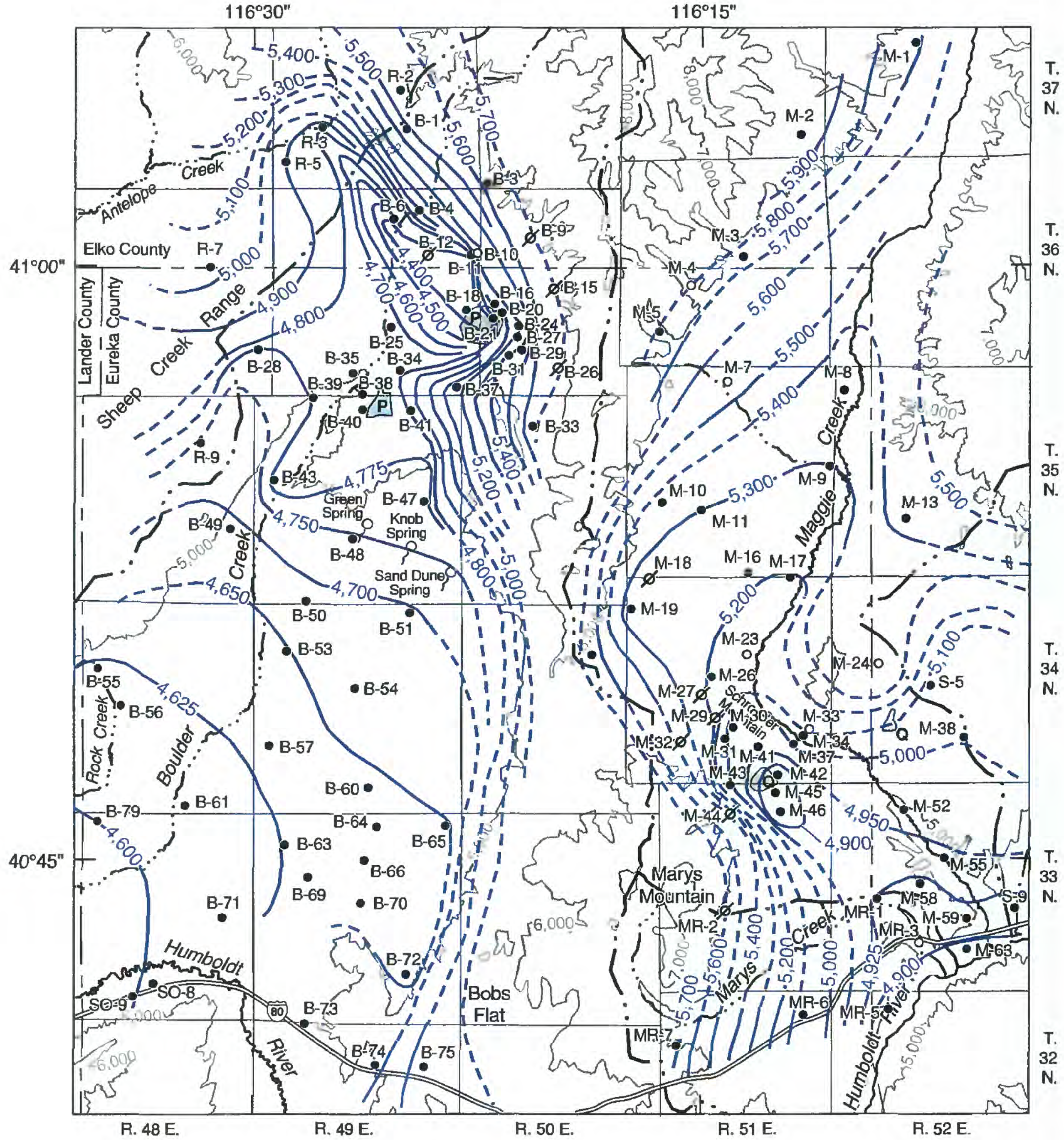
B-54 ● **Well**—Penetrates unconfined (water-table) aquifer. Label refers to site name in appendix 4. Water level at well in 1993 used to construct water-table contours

M-4 ○ **Well**—Penetrates confined or perched aquifer. Label refers to site name in appendix 4. Water level at well in 1993 used to construct water-table contours

B-25 ø **Well**—Penetrates confined or perched aquifer. Label refers to site name in appendix 4. Not used to construct water-table contours

Green Spring — **Spring**—Informal name referred to in text. Flow originated as water that infiltrated floor of reservoir used to store water from Post-Betze mine. Altitude of spring orifice is minimum altitude of unconfined ground water at site

Figure 20. Altitude of unconfined ground-water levels, 1993, in central part of Carlin trend area, north-central Nevada.



Base from U.S. Geological Survey digital data, 1:100,000 scale, 1977-88; Universal Transverse Mercator projection, Zone 11. Contour interval: 1,000 feet. Altitude: National Geodetic Vertical Datum of 1929

Hydrology by D.K. Maurer, 1994

0 5 10 MILES

0 5 10 KILOMETERS

Figure 20. Continued.

Faults and a basin-bounding structure to the southwest between Marys Mountain and the Maggie Creek Area control complex water-level changes measured near the Gold Quarry mine (Newmont Gold Co. 1994a, p. 7). The orientation of water-level declines at the mine is northwest-southeast, which is parallel to the Carlin trend and similar to the orientation of water-level declines at the Post-Betze mine.

Near the holding reservoir at Gold Quarry mine, water levels at site M-24 have risen about 3 ft in the siltstones and about 24 ft in the carbonate rocks (app. 4). The water-level rise in the carbonate rocks is thought to be the result of the water level slowly reaching equilibrium through a partly clogged screen rather than a response to leakage from the reservoir (Paul Pettit, Newmont Gold Co., oral commun., 1994). Wells near the reservoir installed after the study period showed water-level rises of 5-7 ft in basin-fill deposits by December 1993 (Newmont Gold Co. 1994a, p. 8). In following years, releases from the holding reservoir will be discharged to Maggie Creek. These releases will increase baseflows of Maggie Creek and possibility of the Humboldt River.

In Boulder Flat, water-level changes related to mining activities include declines near the Post-Betze mine, rises near the reservoir used to store water from the mine, and rises where pumping for agriculture ceased. Near the Post-Betze mine, water is pumped from carbonate rocks and siltstones at about 23 wells as deep as 1,700 ft (Anton Mayer, Barrick Goldstrike Mine Inc., 1993, oral commun.). The total volume pumped from 1988 through 1993 is estimated to be about 235,000 acre-ft (D.A. Moody, Barrick Goldstrike Mine Inc., 1993, written commun.). The volume of water that infiltrated beneath the reservoir from May 1990 to September 1993 is estimated to be about 167,000 acre-ft (D.A. Moody, Barrick Goldstrike Mine Inc., 1993, written commun.). Balleau (1990, p. 5) estimates that about 11,000 acre-ft/yr had been pumped in Boulder Flat for irrigation of about 2,800 acres of alfalfa and pastures. By 1993, this pumping had ceased.

From 1990-91 to 1993, water levels near the Post-Betze mine declined more than 850 ft at site B-18 (fig. 23*A*). As a result, ground-water conditions changed from confined to unconfined at sites B-7, B-13, and B-16 (app. 4). Shallow water levels at some wells declined as little as 10 ft in older basin-fill deposits (fig. 23*A*, site B-12; app. 4, sites B-5 and B-16). In addition, deeper water levels in volcanic rocks, siltstones, and carbonate rocks at these sites declined more rapidly than shallow water levels in siltstones and basin-fill deposits. Because of these differences in rates of water-level declines, zones of perched ground water developed in basin-fill deposits and siltstones at sites B-5, B-10, B-24, and possibly at site R-4 in Rock Creek Valley (app. 3). Zones of perched ground water could eventually drain; however, this ground water could remain perched indefinitely if vertical hydraulic conductivities are sufficiently low.

Pumping at the Post-Betze mine has created a northwest-trending cone of depression about 8 mi long (fig. 20). The area of maximum drawdown (fig. 21) is bounded on the northeast by a range-front fault along the Tuscarora Mountains. Permeable carbonate rocks are southwest of the fault and less permeable carbonate rocks and siltstones are northeast of the fault (Anton Mayer, Barrick Goldstrike Mines Inc., oral commun., 1995). Granodiorite southeast of the mine and two other faults along the southwest side of the cone of depression also bound the area of greatest drawdown (pl. 1). Carbonate rocks appear to have lower permeability southwest of these faults (Anton Mayer, Barrick Goldstrike Mines Inc., oral commun., 1995). Thus, the cone of depression is bounded by faults, an igneous intrusive, and changes in the fracture permeability of the carbonate rocks and siltstones.

EXPLANATION

P **Open-pit mine**—Label is abbreviation for Post-Betze mine (P) and Gold Quarry mine (Q)

P **Reservoir**—Used to store water from Post-Betze mine (P) and Gold Quarry mine (Q)

Hydrographic-area boundery—Modified from Rush (1968); not shown where coincident with Humboldt River

-20 – –? **Line of equal water-level change**—Dashed where uncertain. Queried where southern extent near Gold Quarry unknown. Shows approximate net change, in feet, of altitude of water table, 1990-93. Positive value indicates water-level decline; negative value indicates rise. Interval is variable

B-60 ● **Well**—Penetrates unconfined (water-table) aquifer. Label refers to site name in appendix 4

M-27 ○ **Well**—Penetrates confined or perched aquifer. Water-level change not used to construct lines of equal change. Label refers to site name in appendix 4

Figure 21. Net change in unconfined ground-water levels, 1990-91 to 1993, in central part of Carlin trend area, north-central Nevada. Lines of equal change were contoured from a grid of water-level changes that is the difference between gridded water levels for 1990-91 (pl. 3) and 1993 (fig. 20).

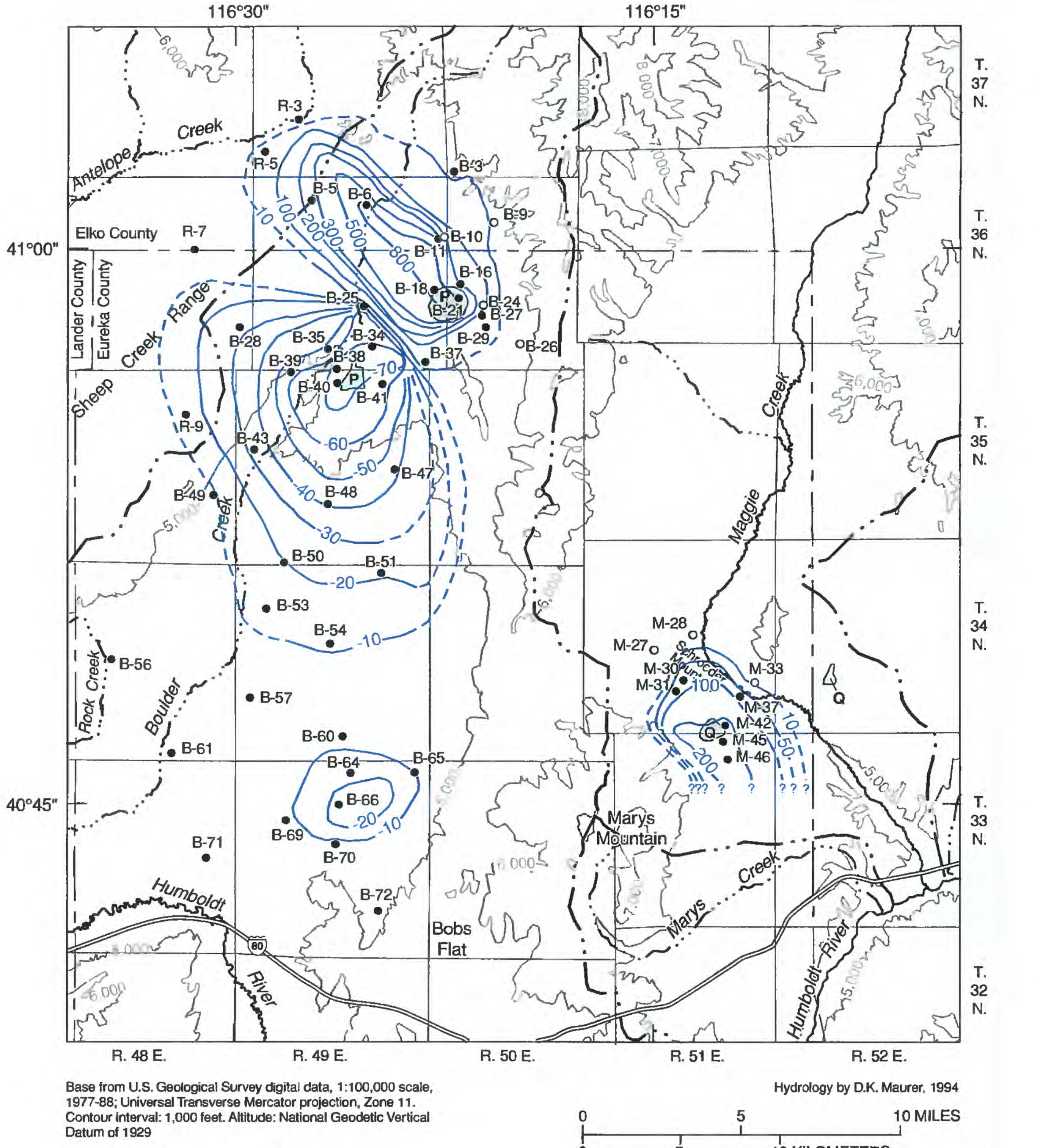


Figure 21. Continued.

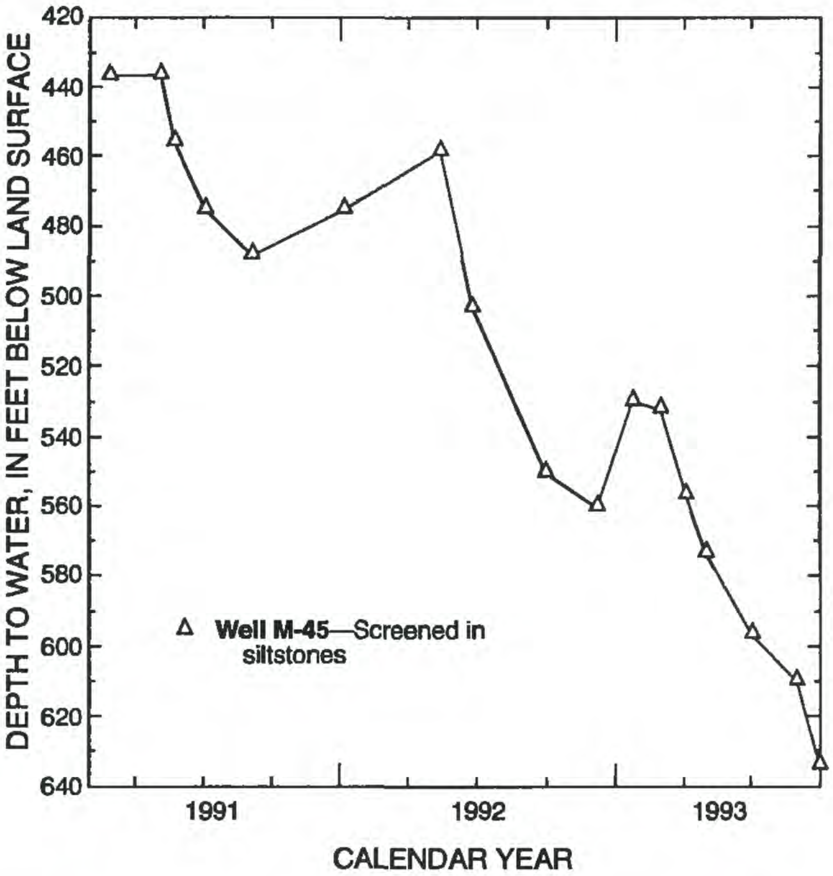


Figure 22. Depth to water in well M-45, 1990-93, near Gold Quarry mine in Maggie Creek Area, north-central Nevada (see fig. 20 and appendix 4).

Northeast and southwest of the cone of depression, water levels in carbonate rocks fluctuated several feet at sites B-3 and B-15 and declined about 50 ft at site B-27 and 8 ft at site B-31 (app. 4). Water levels in volcanic rocks and siltstones rose less than 2 ft at site B-1 and declined about 3 ft at sites B-9 and B-26 and about 50 ft at site B-27 (app. 4, fig. 21).

From 1990-91 through 1993, water levels declined more than 800 ft beneath an area of about 3 mi^2, more than 100 ft beneath about 24 mi^2, and more than 10 ft beneath about 40 mi^2 (fig. 21). As a result, downward vertical gradients from basin-fill deposits to underlying bedrock increased, which also increased the potential for downward ground-water flow.

The cone of depression at the Post Betze mine has intercepted ground-water flow that, prior to dewatering, would have moved from the western flank of the Tuscarora Mountains to the southwest, across Boulder Flat and Rock Creek Valley. Although data points are sparse in the northeastern parts of Rock Creek Valley, the cone of depression also appears to have intercepted ground water that would have moved from the northeastern part of Rock Creek Valley into the southern part of Boulder Flat. By 1993, the cone of depression had affected part of the flow system east of flow line D (fig. 21 and pl. 3), but probably had not induced additional subsurface flow from Rock Creek Valley to Boulder Flat.

The amount of ground-water flow intercepted by the cone of depression could be relatively small compared to the volume removed from storage.The steep water-table gradient in northernmost Boulder Flat in 1990 (pl. 3) suggests that a zone of low permeability impeded ground-water flow. The presence of faults and changes in fracture permeability that bound the cone of depression indicates that permeability to the southwest is low. Intercepted flow and water removed from storage returns to the ground-water system as infiltration from the holding reservoir.

From 1990-91 through 1993, infiltration of water from the reservoir caused water levels to rise, as much as 70 ft beneath about 3 mi^2, and as much as 10 ft beneath about 90 mi^2 (fig. 21). In volcanic rocks at sites B-47 and B-48, ground-water conditions changed from unconfined to confined (app. 4). Water levels in volcanic rocks rose at similar rates in wells screened at different depths, distances, and directions from the reservoir (fig. 23*B*). In addition, water-level rises have extended westward through basin-fill deposits and volcanic rocks across the hydrographic-area boundary into Rock Creek Valley (figs. 21 and 23*B*). Water levels in wells screened in basin-fill deposits did not rise until 1993 (fig. 23, sites B-43 and B-54). The water-level rises increased the horizontal hydraulic gradient in northern Boulder Flat from about 10-30 ft/mi in 1990 (pl. 3) to 30-50 ft/mi in 1993 (fig. 20).

Vertical gradients in northern Boulder Flat also were affected by water-level rises. In volcanic rocks, downward vertical gradients increased at sites B-38 and B-40 (app. 3). The gradient between basin-fill deposits and underlying volcanic rocks decreased (site B-25) or reversed (site B-43) as water levels rose more rapidly in the volcanic rocks than in the basin-fill deposits (app. 3).

In 1992, water infiltrating from the reservoir began to resurface as springs several miles to the southwest in the northern part of Boulder Flat. The springs—all near outcrops of volcanic rocks—have been informally named Sand Dune, Knob, and Green springs (fig. 20). Sand Dune spring began to flow at a rate of about 6 ft^3/s in May 1992 (Barrick Goldstrike Mines Inc., 1992d, app. 5). Knob spring began to flow in October 1992 and Green spring began to flow in April or May of 1993. Total springflow in October 1993 was about 24 ft^3/s (Barrick Goldstrike Mines Inc., 1994a, app. 5).

In the eastern part of Rock Creek Valley, water-level declines resulting from pumping and water-level rises resulting from reservoir infiltration show that volcanic rocks hydraulically connect Boulder Flat and the Rock Creek Valley. These water-level changes support the conclusion that ground water flows between Willow Creek Valley, Rock Creek Valley, the Clovers Area, and Boulder Flat.

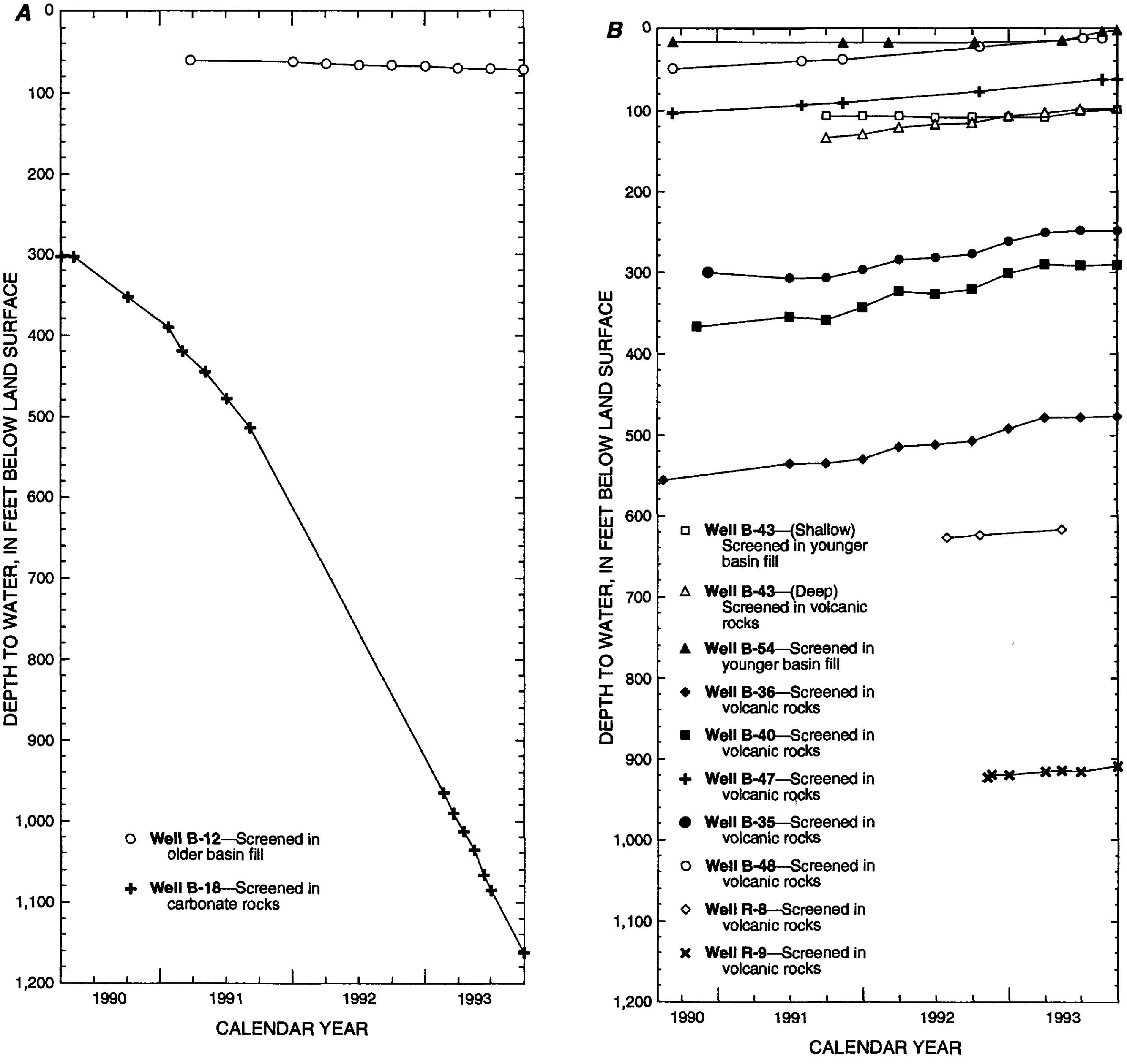


Figure 23. Depth to water in selected wells, 1990-93, in northern part of Boulder Flat and adjacent parts of Rock Creek Valley, north-central Nevada (see fig. 20 and appendix 4). (*A*) Wells B-12 and B-18 near Post Betze mine; and (*B*) Wells B-35, B-36, B-40, B-43, B-47, B-48, and B-54 near reservoir used to store water from Post-Betze mine, and wells R-8 and R-9 in Rock Creek Valley.

Water levels in Boulder Flat also changed in 1993 because pumping for irrigation ceased in that year. In southeastern Boulder Flat, the water-level rise of more than 20 ft (fig. 21) represents a maximum value because water levels in 1990 were measured in the fall after the maximum seasonal drawdown from irrigation pumping. In northern Boulder Flat, water-level rises in 1993 were from 10 to 20 ft. However, these rises probably resulted from a combination of cessation of irrigation pumping, infiltration from the holding reservoir to the north, and application of water from the reservoir for irrigation.

Water-level rises in northern Boulder Flat from 1990-91 through 1993 may have approximately doubled the rate of ground-water flow to the south because this rate changes in direct proportion to changes in the horizontal hydraulic gradient (equation 2), which also approximately doubled. If water-level rises continue to extend southward across Boulder Flat, reaches of the Humboldt River that presently lose flow could become gaining reaches and increase the baseflow of the river.

The largest effect of mining activities on the water resources of the study area has been removal of ground water from storage. In 1993, about 3,700 acre-ft of mine water was used for irrigation in Boulder Flat (Barrick Goldstrike Mines Inc., 1994a, p. 1), and about 600 acre-ft was used for irrigation of crops near Maggie Creek (Newmont Gold Company, 1993d, p. 6). Much of this water was consumed by crops. In addition, relatively small amounts of water were lost by evaporation from the surface of holding reservoirs. Water lost to consumptive use and evaporation represents a net loss from ground-water storage.

In 1993, infiltration from the holding reservoir replaced much of the water pumped from the Post Betze mine back into ground-water storage beneath large areas downgradient from the cone of depression. However, the rate of evapotranspiration has been shown to be a function of depth to water (Nichols, 1994, p. 3270), and water-level rises have probably increased ground-water discharge by evapotranspiration from plants and from bare soil where depth to water is now (1993) less than 10 ft (app. 4, sites B-51 and B-54). This increase in evapotranspiration represents an additional net loss from ground-water storage.

In 1993 near the Gold Quarry mine, infiltration from the holding reservoir had not greatly increased ground-water storage. Part of planned releases from the holding reservoir to Maggie Creek will infiltrate through the stream channel to increase ground-water storage, but most may be lost from the ground-water system.

To summarize, water-level changes resulting from mining activities show that faults, mineralized zones, and differences in fracture permeability and bedrock lithology control the distribution and magnitude of water-level change. These features also control ground-water flow in the mountain blocks and result in complex ground-water flow paths. Prior to mining activities, water levels were in long-term equilibrium. The effects of geologic features on ground-water flow generally are not apparent until large stresses are placed on the ground-water system. Water-level changes have produced cones of depression that are parallel to the orientation of the Carlin trend zone of mineralization. Thus, the same structures and zones of permeability that controlled the location of mineralization appear to control ground-water flow and the response of the ground-water system to large-scale withdrawals.

SUMMARY AND CONCLUSIONS

Gold-mining activities along the Carlin trend have resulted in pumping of large amounts of ground water for mining use and for dewatering open-pit mines. Total annual pumpage at the Gold Quarry and Post-Betze mines, the two largest mines along the Carlin trend, increased from about 5,000 acre-ft/yr in 1988 to more than 100,000 acre-ft/yr in 1993. Pumpage could be in excess of 135,000 acre-ft/yr by the year 2000, but is expected to decrease in subsequent years.

The purpose of this report is to describe the hydrogeologic setting and ground-water and surface-water resources of the area surrounding the gold-mining activities. The study area is north of the Humboldt River and includes the Susie Creek, Maggie Creek, and Marys Creek Areas east of the Tuscarora Mountains and Boulder Flat, Rock Creek Valley, and Willow Creek Valley west of the mountains. Each of these hydrographic areas is underlain by bedrock that forms a structural basin. Bedrock consists of carbonate rocks, siltstones, volcanic rocks, and granitic rocks. Each structural basin contains basin-fill deposits that are thousands of feet thick in the deepest parts. Basin-fill deposits consist of older, semiconsolidated sediments and younger, unconsolidated sediments.

Carbonate rocks and siltstones underlie the entire study area, but are exposed mainly in and east of the Tuscarora Mountains. These rocks have been intruded by granitic rocks. Volcanic rocks ranging in thickness from 500 to 2,000 ft overlie the siltstones and carbonate rocks over most of the western part of the study area.

Carbonate and volcanic rocks can be permeable and form the principal bedrock aquifers in the area. The siltstones and granitic rocks can be permeable where fractured, but otherwise are poorly permeable. Faulting of these bedrock units has had several hydrologic effects. Faults can juxtapose permeable and impermeable rocks, forming barriers to ground-water flow. Relatively impermeable siltstones structurally overlie more permeable carbonate rocks along the Roberts Mountains thrust fault and can confine ground water in the carbonate rocks. Bedrock units are generally more permeable where fractured along fault zones, although mineralization and alteration along fault zones can reduce rather than enhance permeability. Finally, high-angle faulting of bedrock formed structural basins in each of the hydrographic areas.

Basin-fill deposits are some of the principal aquifers in the study area. They are as much as 7,000-8,000 ft thick in the upper part of the Maggie Creek Area. Elsewhere, they are as much as 1,000-4,000 ft thick in the lower Maggie Creek Area, less than 500 ft thick in Willow Creek Valley, 800-2,000 ft thick in Rock Creek Valley, and 2,500-5,000 ft thick in Boulder Flat. Younger basin-fill deposits typically are no more than a few hundred feet thick and generally are more permeable than the older basin-fill deposits.

The principal tributaries of the Humboldt River within the study area are Susie, Maggie, and Marys Creeks east of the Tuscarora Mountains, and Rock Creek and its tributaries, Willow, Antelope, and Boulder Creeks, west of the mountains. Peak flows of the Humboldt River and its tributaries during the snowmelt runoff represent the part of annual precipitation that does not evaporate or contribute to ground-water recharge. Infiltrating streamflow and runoff provides recharge to the ground-water system, and gaining reaches of streams are areas of ground-water discharge.

Susie Creek gains flow about 10-15 mi upstream from its mouth and loses flow downstream from this point. Total flow of Susie Creek near its mouth was about 9,500 acre-ft in water year 1993.

Upper Maggie Creek is a gaining reach with a baseflow of about 5 ft^3/s (3,600 acre-ft/yr). The lower reach of Maggie Creek loses flow as infiltration through the stream channel. The infiltration capacity of this reach of channel may be as much as 20 ft^3/s. Infiltration losses along lower Maggie Creek in water year 1993 were about 3,500 acre-ft. Average annual flow of Maggie Creek at its mouth is about 18,000 acre-ft/yr.

Marys Creek is a perennial stream from Carlin spring to the Humboldt River. Annual flows of Marys Creek below the spring have ranged from about 2,000 acre-ft in water year 1992 to about 4,700 acre-ft in 1993. Average discharge of Carlin spring is estimated to be about 3.6 ft^3/s. Flow in excess of this comes mostly from spring snowmelt or intense storms.

Upper reaches of Rock and Willow Creeks lose flow in Willow Creek Valley. In the southwest part of the area, Rock Creek gains about 3 ft^3/s. In Rock Creek Valley, the upper reach of Rock Creek loses flow, and the lower reach gains, and has baseflow of about 1 ft^3/s. The long-term average flow of Rock Creek at the gaging station where it enters Boulder Flat is about 29,000 acre-ft/yr. Most of this flow infiltrates the stream channel or is diverted for irrigation of crops and pasture. Flow of the stream probably enters the Humboldt River only in years of above-normal runoff.

The Humboldt River gains about 38,000 acre-ft/yr between the Carlin and Palisade gaging stations. Most of this gain comes from the Susie Creek, Maggie Creek, and Marys Creek Areas. Runoff accounts for about 26,000 acre-ft/yr of the total gain. The remaining 12,000 acre-ft/yr comes from ground-water discharge as inflow to the channel and nearby springflow. Between the Palisade and Battle Mountain gaging stations, the Humboldt River loses flow as irrigation diversions and as infiltration through the stream channel. Long-term average losses along this reach of the river are an estimated 40,000 acre-ft/yr.

Ground-water flow in the study area is driven by recharge, which originates as precipitation mainly in the Independence and Tuscarora Mountains and the unnamed mountains north of Willow Creek Valley. A small part of this precipitation moves downward through fractures or weathered zones and enters carbonate-rock and volcanic-rock aquifers or enters basin-fill aquifers as infiltrating streamflow along basin margins. Ground water in bedrock generally moves downward and away from mountain blocks and enters basin-fill aquifers. However, faulting or variations in the fracture permeability of bedrock can result in zones of perched ground water that probably are not connected to the regional water table. Water levels near mines indicate that ground-water flow in bedrock is complex and separated into hydrologic domains or compartments by faults, differences in bedrock lithology and fracture permeability, and mineralized zones. Water levels and directions of ground-water flow can differ greatly between adjacent compartments.

Along basin margins, streams lose flow that infiltrates basin-fill deposits and becomes ground-water recharge. This ground water moves laterally and downward toward low-lying parts of the basins and then upward beneath areas where ground water is discharged as evapotranspiration, inflow to stream channels, and springflow.

Two separate ground-water flow systems, one on each side of the Tuscarora Mountains, have been identified in the study area. Ground water east of the Tuscarora Mountains moves through the Maggie Creek, Susie Creek, and Marys Creek Areas to the Humboldt River. Ground water west of the Tuscarora Mountains moves through Willow Creek Valley, Rock Creek Valley, and Boulder Flat to the Humboldt River and to the Clovers Area, which is west of the study area.

In the upper part of the Maggie Creek Area, basin-fill deposits are recharged by infiltration of streamflow and by ground water from siltstones and carbonate rocks of the Independence and Tuscarora Mountains. North of Maggie Creek Canyon, the basin-fill aquifer may be anisotropic. In addition, poorly permeable siltstones northeast of the canyon impede ground-water flow to the lower part of the Maggie Creek Area, and cause upward ground-water flow that discharges to the Maggie Creek channel. Ground-water flow through carbonate rocks of Schroeder Mountain is minimal and probably does not exceed 1,000 acre-ft/yr.

In the lower part of the Maggie Creek Area, ground water moves through siltstones and carbonate rocks of the Tuscarora and Independence Mountains and through basin-fill deposits and interbedded volcanic rocks beneath divides of the Maggie Creek, Susie Creek, and Marys Creek Areas. Ground-water flow from much of the lower part of the Maggie Creek Area and the northwestern part of the Susie Creek Area discharges at Carlin spring. Also, volcanic rocks function as a permeable drain along which streamflow losses from Maggie Creek move southward and discharge at Carlin spring. In addition to springflow, ground water also discharges as evapotranspiration and inflow to the Humboldt River channel. Deep ground-water flow through carbonate rocks may discharge at thermal springs near the river.

Ground water from siltstones and carbonate rocks beneath the western slope of the Tuscarora Mountains flows into volcanic rocks and basin-fill deposits in Willow Creek Valley, Rock Creek Valley, and Boulder Flat. Infiltration of streamflow from Boulder, Antelope, Rock, and Willow Creeks also recharges basin-fill deposits. Water-level changes from mining activities near the northern end of Boulder Flat indicate that volcanic rocks in that area are permeable. Volcanic rocks elsewhere west of the Tuscarora Mountains are assumed to be similarly permeable.

In 1990-91, a ground-water divide extended southwest across Rock Creek Valley and the central Sheep Creek Range. Northwest of this divide, ground water in Willow Creek Valley and Rock Creek Valley moves west and southwest into the Clovers Area through basin-fill deposits and underlying volcanic rocks. Southeast of the divide, ground water in Rock Creek Valley moves south and southwest into Boulder

Flat through volcanic rocks of the Sheep Creek Range. The divide is not a physical barrier to ground-water flow. Its location is controlled by the distribution of recharge and water levels in the eastern parts of Willow Creek and Rock Creek Valleys. Changes in water levels in that area could affect the location of the divide.

In Boulder Flat, ground water moves to the south and west through basin-fill deposits and underlying volcanic rocks. This ground water discharges as evapotranspiration in the basin lowlands and as subsurface flow though basin fill and volcanic rocks between the Sheep Creek Range and Argenta Rim.

In the western part of the study area, ground water also may move southwestward through siltstones and carbonate rocks as it does in the overlying basin-fill deposits and volcanic rocks. However, water-level data are not sufficient to confirm this assumption. Isotopic data and water budget estimates suggest that deep flow of confined ground water beneath the study area is in isolated flow systems of limited areal extent.

Water-level fluctuations resulting from seasonal and annual variations in precipitation and streamflow are as much as 50 ft near losing reaches of streams in basin-fill deposits and volcanic rocks, and are generally less than 10 ft elsewhere. Water level fluctuations in siltstones and carbonate rocks differ from place to place and are poorly understood.

Ground-water budgets were developed for the two ground-water flow systems identified, on the east and west sides of the Tuscarora Mountains. Ground-water recharge to the flow system in the Susie Creek, Maggie Creek, and Marys Creek Areas, east of the Tuscarora Mountains, is an estimated 35,000 acre-ft/yr and discharge is an estimated 27,000 acre-ft/yr. Ground-water recharge to the flow system in Willow Creek Valley, Rock Creek Valley, and Boulder Flat, west of the Tuscarora Mountains, is an estimated 88,000 acre-ft/yr, and discharge is an estimated 83,000 acre-ft/yr. Imbalances for both water budgets result mostly from uncertainties in the methods used to compute the different budget components.

Water in the Humboldt River between the Carlin and Battle Mountain gaging stations is a mixed-cation bicarbonate type when flows are less than 100 ft^3/s. However, proportions of sodium increase downstream from Palisade. Water in tributaries of the river also is a mixed-cation bicarbonate type, except for Rock Creek, which is a sodium bicarbonate type. The higher proportions of sodium in Rock Creek and in the river downstream from Palisade are related to the relative proportions of volcanic rocks in upstream areas.

Ground water in the study area is generally a mixed-cation (calcium and sodium) bicarbonate type, with pH near neutral and dissolved-solids concentrations of about 200-600 mg/L. However, certain rock types seem to affect ground-water compositions that differ from these. Ground water from mineralized areas contains increased proportions of sulfate because the water has been in contact with sulfide minerals. Some ground water from northern Boulder Flat has high proportions of magnesium, which probably reflects dissolution of dolomite in the Tuscarora Mountains.

Deuterium and oxygen-18 compositions of ground water in the study area are consistent with the conclusion that the main source of recharge is precipitation. Proportions of these two isotopes do not differ much over the study area except in the upper part of the Maggie Creek Area where deep ground water is isotopically lighter. In addition, this deep water contains only 4 percent modern carbon. These isotopic compositions suggest that the ground water was recharged thousands of years ago when the climate was cooler than at present.

Tritium concentrations indicate that ground water at about half the sites sampled in the study area is older than 60 years. Relatively young ground water is found near recharge sources in mountain blocks and along stream flood plains. Tritium concentrations in water from production wells tapping fractured bedrock at the Post-Betze mine range from below the detection limit to as much as 19 pCi/L. These differences show that ground-water flow paths are complex in fractured bedrock and support the concept of compartmentalized ground-water domains in bedrock.

Geochemical mass-transfer models support the conclusion that ground water moves as subsurface flow between hydrographic areas in the western part of the study area. Model results indicate that water discharging from a large spring in the Clovers Area could be a mixture of about 60 percent water from Willow Creek Valley and 40 percent water from Rock Creek Valley and that ground water in Boulder Flat could be a mixture of about 60 percent water from Rock Creek Valley and 40 percent water from Boulder Creek.

As of 1993, streamflow and water quality in the study area had not been measurably affected by mining activities. From 1990 through 1993, mine dewatering resulted in water-level declines in siltstones and carbonate rocks of 800 ft beneath about 3 mi^2, more than 100 ft beneath about 24 mi^2, and more than 10 ft beneath about 40 mi^2 at the Post Betze mine. At the Gold Quarry mine, water-level declines in siltstones and carbonate rocks were about 200 ft, and declines exceeding 50 ft extended about 3 mi north of the mine. Water-level declines in siltstones and carbonate rocks south of the Gold Quarry mine can not be defined because the network of monitoring wells did not extend into that area. Elongate cones of depression oriented northwestward, parallel to the Carlin trend, have formed at both mines. Large amounts of ground water have been removed from storage, and water-level declines have changed confined conditions to unconfined, reversed upward vertical gradients, increased downward vertical gradients, and caused zones of perched ground water to develop in poorly permeable siltstones and basin-fill deposits overlying the cones of depression. The lateral extent of water-level declines is controlled by granitic rocks, faults which juxtapose permeable and impermeable rocks, and variations in lithology and fracture permeability. Near the Gold Quarry mine, water levels in basin-fill deposits and volcanic rocks had not declined as of 1993, suggesting a poor hydraulic connection between these rocks and adjacent siltstones and carbonate rocks.

From 1990 through 1993, infiltration from the reservoir used to store water from the Post-Betze mine resulted in water-level rises in volcanic rocks of more than 70 ft beneath about 3 mi^2, and more than 10 ft in volcanic rocks and basin-fill deposits beneath about 90 mi^2. The area of water-level rise forms an elliptical mound oriented northwestward that extends into Rock Creek Valley. Movement of ground water in permeable volcanic rocks has produced springflow and upward gradients from volcanic rocks to basin-fill deposits in northern Boulder Flat.

The cone of depression near the Post Betze mine intercepts ground-water flow from the crest of the Tuscarora Mountains that, prior to dewatering, would have moved downgradient into Boulder Flat and Rock Creek Valley. The volume of ground water intercepted is probably small compared to the volume removed from storage. Both the intercepted ground water and that removed from storage re-enter the ground-water system as infiltration beneath the holding reservoir. This infiltration may have doubled the volume of ground water moving to the southwest beneath northern Boulder Flat and increased the rate of discharge by evapotranspiration. If water-level rises extend southward across Boulder Flat, formerly losing reaches of the Humboldt River could become gaining reaches, increasing the baseflow of the river.

The greatest effect of mining activities on water budgets in the study area has been removal of ground water from storage. Although water that infiltrates beneath holding reservoirs is returned to ground-water storage, large quantities also are lost from storage. These losses result from mining and irrigation use and from increased evapotranspiration rates in saturated parts of Boulder Flat.

The effects of geologic structures on ground-water flow are not apparent until large stresses are placed on the system. The structures and zones of permeability that controlled emplacement of the ore deposits appear to control ground-water flow and the response of the ground-water system to large-scale withdrawals.

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APPENDIXES

This section of the report lists only part of the data collected during the study. Only those data specific to discussions in the text are included. The data collected during the study are available from the U.S.Geological Survey National Water Information System data bases. Requests for data can be made to the U.S. Geological Survey in Carson City, Nev. Appendix 1 lists streamflow measurements and other information for surface-water sites. Appendix 2 lists descriptive information and flow measurements for selected springs in the study area. Springflow for additional springs is monitored and reported by Newmont Gold Co. (Gilbert and others, 1992, Gilbert and Jordan, 1993, and Newmont Gold Company, 1994b) and Barrick Goldstrike Mines, Inc. (1992c and d, 1993a-c, and 1994a and b). Appendix 3 lists vertical hydraulic gradients determined at pairs of sites. Appendix 4 lists water levels and other data for wells. Appendix 5 lists chemical and isotopic data for ground water.

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Appendix 1. Streamflow measurements and other data for surface-water sites, Carlin trend area, north-central Nevada

[Downstream-order number: --, number not assigned to this station. Type of station: R, continuously recording stream-gaging station; I, inactive gaging station (see table 3 for period of record); M, site at which streamflow measurements made intermittently. Availability of water-quality data: A, data in USGS data bases include analyses for major cations and anions, trace elements, nutrients, and, at some sites, oxygen-18 and deuterium; N, as far as is known, site has not been sampled. Other abbreviations and symbols: ft^3/s, cubic feet per second; --, not available or not applicable]

Site name[1]	Downstream-order number[2]	Land-net location[3]		Land-surface altitude (feet above sea level)	Type of station	Miscellaneous flow measurements			Availability of water-quality data
						Date	Time	Discharge (ft^3/s)	
				Humboldt River					
HR-1	10321000	SESE	S21 T33N R53E	4,932	R	10-19-92	1320	16	A
HR-2	10321100	SESW	S20 T33N R53E	4,940	M	8-29-91		19	N
						10-22-91	0930	23	
						7-29-92	1020	12	
HR-3 (HR-7)	10322200	NESE	S33 T33N R52E	4,880	M	8-29-91	--	22	N
						10-22-91	1100	27	
HR-4 (HR-9)	10322425	SWNW	S20 T32N R52E	4,860	M	8-29-91	--	26	N
						10-22-91	0950	32	
HR-5 (HR-10)	10322500	SESE	S35 T32N R51E	4,826	R	10-22-91	--	32	A
						7-29-92	1715	18	
						7-30-92	0915	17	
						10-19-92	1640	27	
HR-6	10323080	SESW	S 8 T31N R50E	4,740	M	8-29-91	--	23	N
						10-22-91	1300	32	
						7-30-92	1135	12	
						10-19-92	1835	24	
HR-7	--	SESW	S32 T32N R49E	4,685	M	10-19-92	--	[4]31	N
HR-8	10323425	SESE	S26 T33N R48E	4,630	R	10-22-91	1345	7.4	A
						7-30-92	1355	2.7	
						10-19-92	--	11	
HR-9	10323500	SENW	S 2 T32N R47E	4,580	M,I	8-30-91	--	.81	N
						10-22-91	1715	1.6	
						7-30-92	1410	0	
						10-19-92	--	0	

Appendix 1. Streamflow measurements and other data for surface-water sites in Carlin trend area, north-central Nevada—Continued

Site name[1]	Downstream-order number[2]	Land-net location[3]		Land-surface altitude (feet above sea level)	Type of station	Miscellaneous flow measurements			Availability of water-quality data
						Date	Time	Discharge (ft^3/s)	
				Humboldt River—Continued					
HR-10	10323600	NWSE	S11 T32N R46E	4,540	M,I	8-30-91		2.6	N
						10-22-91	1800	3.1	
						7-30-92	1510	2.4	
						10-19-92	--	2.4	
HR-11	10325000	NENW	S 8 T32N R45E	4,500	R	8-30-91	--	0	A
						10-22-91	1630	0	
						7-30-92	1550	0	
						10-19-92	--	0	
				Maggie Creek					
MC-1	--	SWSW	S 9 T36N R52E	5,515	M	6-18-91	--	3.2	N
						10-24-91	--	.85	
						8- 1-92	1135	1.5	
						10-20-92	1010	.62	
MC-2	10321790	SWNE	S31 T36N R52E	5,385	M	6-18-91	--	2.7	A
						10-24-91	1030	.58	
						8- 1-92	1040	.30	
						10-20-92	1010	.62	
MC-3	10321860	NWSE	S 4 T35N R51E	5,640	R	--	--	--	
MC-4	--	SWNW	S30 T35N R52E	5,250	M	6-18-91	--	4.6	N
						10-22-91	--	3.2	
						8- 1-92	1005	.31	
						10-20-92	1230	1.7	
MC-5 (MC-1)	10321940	SENE	S22 T34N R51E	5,130	M	6-18-91	--	7.1	N
						6-19-91	--	6.7	
						10-24-91	1245	5.8	
						8- 1-92	1440	.56	
						10-20-92	1335	3.3	
MC-6 (MC-3)	10321945	SWNE	S26 T34N R51E	5,100	R	6-19-91	--	5.4	N
						10-24-91	1345	4.2	

Appendix 1. Streamflow measurements and other data for surface-water sites in Carlin trend area, north-central Nevada—Continued

Site name[1]	Downstream-order number[2]	Land-net location[3]		Land-surface altitude (feet above sea level)	Type of station	Miscellaneous flow measurements			Availability of water-quality data
						Date	Time	Discharge (ft^3/s)	
Maggie Creek—Continued									
MC-7 (MC-6)	10321950	SENESE	S26 T34N R51E	5,100	I	6-19-91	--	1.0	A
						10-24-91	1400	2.1	
						8- 1-92	0810	0	
						10-20-92	1430	0	
MC-8	10322000	NESENW	S26 T33N R52E	4,910	R	6-19-91	--	0.13	A
						10-24-91	--	0	
						8- 1-92	0750	0	
						10-20-92	--	0	
Marys Creek									
MA-1	10322150	SESESE	S28 T33N R52E	4,920	R	--	--	--	A
Susie Creek									
SU-1	10321500	SW	S12 T35N R53E	5,550	I	--	--	--	N
SU-2	--	NENE	S30 T34N R53E	5,050	M	4-16-92	--	3.0	N
						10-19-92	1025	3.0	
SU-3 (SU-1)	10321590	NWNENW	S25 T33N R52E	4,910	M	10-24-91	1445	.36	N
						4-16-92	--	1.4	
						4-29-92	--	.97	
						7-29-92	--	0	
						10-19-92	0900	0	
						10-20-92	0925	.18	
						10-21-92	1110	.21	
Boulder Creek									
BC-1	--	SESW	S13 T37N R49E	5,720	M	9-19-91	--	.05	N
						8- 2-92	--	0	
						11-17-92	1130	.42	
BC-2	10324700	NESE	S33 T36N R49E	5,010	R	--	--	--	A

Appendix 1. Streamflow measurements and other data for surface-water sites in Carlin trend area, north-central Nevada—Continued

Site name[1]	Downstream-order number[2]	Land-net location[3]		Land-surface altitude (feet above sea level)	Type of station	Miscellaneous flow measurements			Availability of water-quality data
						Date	Time	Discharge (ft^3/s)	
Rock Creek and its tributaries									
RC-1	--	NESE	S32 T39N R47E	5,165	M	7-31-92	--	0	N
						10-23-91	--	0	
						10-20-92	--	0	
RC-2	--	SENE	S29 T39N R48E	5,295	M	10-23-91	--	5.4	N
						7-31-92	1415	.53	
						10-20-92	1000	.36	
RC-3	--	SWNW	S30 T38N R47E	5,090	M	10-23-91	--	0	N
						10-20-92	0910	3.3	
RC-4	10324000	SWSW	S18 T37N R47E	4,990	M	6-19-91	--	[5]5.8	N
						8- 2-92	--	[4]3.5	
						10-20-92	1550	[4]3.5	
RC-5	--	NENE	S36 T37N R46E	4,960	M	10-23-91	0945	3.6	N
						8- 2-92	--	3.5	
						10-20-92	1650	.55	
RC-6	--	SESE	S25 T37N R48E	5,280	M	10-23-91	--	.01	N
						8- 2-92	1550	0	
						10-20-92	1120	.03	
RC-7	--	SWNW	S15 T36N R47E	4,950	M	10-23-91	--	.10	N
						8- 2-92	1135	0	
						10-20-92	1235	.16	
RC-8	--	NWNE	S31 T36N R47E	4,870	M	6-19-91	--	0	N
						10-23-91	1300	.80	
						8- 2-92	--	0	
						10-20-92	--	0	
RC-9	--	NWNE	S29 T35N R47E	4,810	M	6-19-91	--	0.88	N
						10-23-91	1115	1.4	
						8- 2-92	1058	.08	
						10-20-92	1340	.64	

Appendix 1. Streamflow measurements and other data for surface-water sites in Carlin trend area, north-central Nevada—Continued

Site name[1]	Downstream-order number[2]	Land-net location[3]		Land-surface altitude (feet above sea level)	Type of station	Miscellaneous flow measurements			Availability of water-quality data
						Date	Time	Discharge (ft^3/s)	
Rock Creek and its tributaries—Continued									
RC-10	10324500	SWSE	S17 T34N R48E	4,680	R	6-19-91	--	1.0	A
						10-23-91	1600	1.3	
						8- 2-92	1810	0	
						10-21-92	--	.58	

[1] Site names are informal designations used only in this report (fig. 4). Site names in parentheses are designations used in previous report (Plume, 1995, p. 31).

[2] In this table, each site is identified by a short site name and standard identification called the downstream-order number. Except for this table, only site name is used in report. The downstream-order number is the most convenient means of identifying and retrieving information for specific site from computer data bases operated by U.S. Geological Survey. Number consists of eight digits, first two identifying regional location of site and following digits identify downstream-order part of number. First site in this table (downstream-order number 10321000) is in Great Basin (first two digits are 10) and next six digits identify site as Humboldt River near Carlin, Nev. Downstream-order number is assigned according to geographic location of station in the drainage network; larger number stations are downstream from smaller number stations.

[3] The land-net designation is based on the official rectangular subdivision of the public lands, referenced to the Mount Diablo base line and meridian. Each designation consists of four units. For example, the designation for site HR-1 is SESE S21 T33N R53E. This site is in the southeast quarter of the southeast quarter of section 21, Township 33 north, Range 53 east, Mount Diablo base line and meridian.

[4] Includes combined flow in four nearby irrigation diversions on same date of 13 ft^3/s. All of the diversions are upstream from site HR-7.

[5] Includes flow in irrigation diversion 500 ft upstream from site: 4.4 ft^3/s on 6-19-91, 0.02 ft^3/s on 8-2-92, and 2.3 ft^3/s on 10-20-92.

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Appendix 2. Data for springs, Carlin trend area, north-central Nevada

[Water use: P, public supply; S, stock; U, unused. Availability of water-quality data: A, data in USGS data base include analyses for major cations and anions, trace elements, nutrients, tritium, oxygen-18, and deuterium; L, data in USGS data base limited to analyses for chloride, iodide, bromide, oxygen-18, and deuterium]

Site name[1]	U.S. Geological Survey site designations		Name[2]	Land-surface altitude (feet above sea level	Water use	Availability of water-quality data
	Local identification	Standard identification[2]				
SP-1	62 N37 E49 08ACC 1	410557116274501	Unnamed	5,420	S	A
SP-2	64 N35 E45 10BACD1	405543116534101	Unnamed[3]	4,720	S	A
SP-3	51 N35 E50 13BBAC1	405456116183201	Unnamed	6,120	S	A
SP-4	51 N35 E51 30DDCB1	405314116164601	Unnamed	5,560	S	A
SP-5	61 N33 E47 09CBDC1	404445116411901	Whitehouse Spring	4,600	S	A
SP-6	52 N33 E51 15BCC 1	404449116141301	Unnamed	5,880	S	L
SP-7	52 N33 E51 21DCAA1	404342116143801	Cherry Spring	6,030	S	L
SP-8	52 N33 E52 28DC 1	404242116074001	Unnamed[4]	4,930	P	A
SP-9	52 N33 E52 33DBDC1	404200116074801	Unnamed	4,980	U	L
SP-10	52 N32 E52 05CDBA1	404104116091401	Unnamed[5]	5,000	S	A
SP-11	61 N32 E50 14AABC1	403859116175501	Unnamed	5,760	S	A

[1] In this table, each site is identified by site name, and by U.S. Geological Survey site designations that consist of local (Nevada) site-identification system and standard identification number. Except for this table, only site name is used in report. Two designations are usually most convenient means of identifying and retrieving information for specific site from computer data bases operated by U.S. Geological Survey. Local site-identification system based on index of hydrographic areas in Nevada (Rush, 1968) and on rectangular subdivision of public lands referenced to Mount Diablo base line and meridian. Each number consists of four units separated by spaces: First unit is hydrographic area number. Second unit is township, preceded by an N to indicate location north of base line. Third unit is range, preceded by an E to indicate location east of meridian. Fourth unit consists of section number and letters designating quarter section, quarter-quarter section, and so on (A, B, C, and D indicate northeast, northwest, southwest, and southeast quarters, respectively), followed by number indicating sequence in which well was recorded. For example, local identification for site SP-3 in this table is 51 N35 E50 13BBAC1. Site is in the Maggie Creek Area (hydrographic area 51) and is first site recorded in southwest quarter (C), of northeast quarter (A), of northwest quarter (B), of northwest quarter (B) of section 13, Township 35 North, Range 50 East, Mount Diablo base line and meridian.

Standard identification for each site is based on grid system of latitude and longitude. Number consists of 15 digits. First six digits denote degrees, minutes, and seconds of latitude; next seven digits denote degrees, minutes, and seconds of longitude; and last two digits (assigned sequentially) identify sites within a 1-second grid. For example, standard identification for site SP-3 in this table is 405456116183201. This number refers to 40°54'56" latitude and 116°18'32" longitude, and is first site recorded in that 1-second grid. This 15-digit number is retained as permanent identifier even if more precise latitude and longitude are determined later.

[2] Except for Whitehouse and Cherry Springs (SP-5 and SP-7), other springs have not been named. Flows are distributed as seeps and could not be measured, with exceptions listed below.

[3] Unnamed spring in east part of Clovers Area. Flows measured during study have ranged from 2.3 cubic feet per second on Oct., 23, 1991 to 4.4 cubic feet per second on July 30, 1992 (Hess and others, 1993, p. 498, and Emett and others, 1994, p. 474). Average of 16 flow measurements made in water years 1992-93 is 3.7 cubic feet per second.

[4] Unnamed spring along Marys Creek near Carlin. Informally referred to as Carlin spring in this report and by Plume (1995). Municipal water supply for Carlin. Flows summarized in section of report titled "Surface Water".

[5] Spring orifice is at base of bluffs above Humboldt River about 5 miles southwest of Carlin (SP-10). Discharge difficult to measure, but estimated to be about 0.8 cubic foot per second.

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Appendix 3. Vertical hydraulic gradients measured at wells, Carlin trend area, north-central Nevada

[Positive hydraulic gradient indicates potential for upward ground-water flow; negative gradient indicates potential for downward flow. Mid-point and water-level altitudes in feet above sea level. Differences in mid-point altitudes and water-level altitudes in feet. Differences in mid-point altitudes: >, probable value exceeds that indicated because upper mid-point altitude is minimum value. Ground-water conditions: C, confined; P, perched; U, unconfined; and ?, indicated condition uncertain. Hydrogeologic unit: Y, younger basin-fill deposits; O, older basin-fill deposits; V, volcanic rocks; S, siltstones; C, carbonate rocks; and ?, indicated unit uncertain]

Site name[1]	Mid-point altitude[2]	Difference in mid-point altitudes	Ground-water conditions, 1990	Hydro-geologic unit[3]	Water Levels[4] Date	Water Levels[4] Altitude	Difference in water-level altitude[5]	Vertical hydraulic gradient[6]	Remarks
M-7 (JKC-2 M-6 (JKC-1)	5,486 5,231	255	U U	Y Y,O	8-21-91 8-21-91	5,522.26 5,508.22	-14.04	-0.06	Potential flow downward from younger to older basin fill.
M-7 (JKC-2 M-6 (JKC-1)	5,486 5,231	255	U U	Y Y,O	8-30-93 9-02-93	5,525.5 5,507.33	-18.17	-0.07	Downward gradient increased from 8/91 to 9/93.
M-14 M-18 (CV-10)	5,155 4,032	1,123	U U	Y,O? Y,O?	10-05-92 10-24-92	5,322.38 5,234.70	-87.68	-0.08	Potential flow downward in younger or older basin fill.
M-14 M-18 (CV-10)	5,155 4,032	1,123	U U	Y,O? Y,O?	8-25-93 9-23-93	5,323.17 5,235.80	-87.37	-0.08	Little or no change in gradient with pumping or precipitation.
Maggie Creek M-23 (NMC-2)	5,140 4,579	561	U C	Y Y,O	-- 3/14/89	5,140 5,156.1	+16.1	+0.03	Altitude of stream bed used for mid point and water level. Potential flow upward in younger basin fill.
Maggie Creek M-23 (NMC-2)	5,140 4,579	561	U C	Y Y,O	-- 8-25-93	5,140 5,155.06	+15.06	+0.03	Small change in gradient.
M-24 (HW-1S) M-24 (HW-1D)	4,353 3,726	627	C C	S C	8-21-92 8-21-92	5,269.75 5,248.25	-21.5	-0.03	Potential flow downward from siltstones to carbonate rocks.
M-24 (HW-1S) M-24 (HW-1D)	4,353 3,726	627	C C	S C	9-23-93 9-23-93	5,272.54 5,271.79	-0.75	-0.00	Gradient decreasing with pumping, precipitation, or reservoir leakage.
M-25 M-24 (HW-1S)	5,360 4,353	1,007	U C	O S	4-28-92 8-21-92	5,369.62 5,269.75	-99.87	-0.10	Potential flow downward from older basin fill to siltstones.
M-28 (CBN-3D) M-27 (CV-5)	4,584 2,533	2,051	C C	C C	6-24-92 5-27-92	5,038.03 5,001.37	-36.66	-0.02	Potential flow downward in carbonate rocks.
M-28 (CBN-3D) M-27 (CV-5)	4,584 2,533	2,051	C C	C C	9-30-93 9-30-93	4,990.12 4,950.89	-39.23	-0.02	Head differences indicate gradient increasing with pumping.
M-28 (CBN-3S) M-28 (CBN-3D)	Above 4,783 4,584	>199	U? C	C,O? C	4-15-91 4-15-91	5,087.85 5,056.73	-31.12	-?	Bad seal on shallow well, gradient not computed. Head differences indicate downward gradient.

Appendix 3. Vertical hydraulic gradients measured at wells in Carlin trend area, north-central Nevada—Continued

Site name[1]	Mid-point altitude[2]	Difference in mid-point altitudes	Ground-water conditions, 1990	Hydro-geologic unit[3]	Water Levels[4] Date	Water Levels[4] Altitude	Difference in water-level altitude[5]	Vertical hydraulic gradient[6]	Remarks
M-28 (CBN-3S) M-28 (CBN-3D)	Above 4,783 4,584	>199	U? C	C,O? C	8-04-93 8-04-93	5,046.70 5,003.18	-43.52	-?	Head differences indicate downward gradient increasing with pumping.
M-29 (MK-2) M-29 (MK-1)	5,178 4,876	302	U U	O O	9-30-93 9-30-93	5,211.43 5,206.35	-5.08	-0.02	Potential flow downward in older basin fill.
M-29 (MK-1) M-30 (T-2)	4,876 4,681	195	P U	O C	9-30-93 9-30-93	5,206.35 4,986.08	-220.27	-1.1	Perched ground water? Potential flow downward from older basin fill to carbonate rocks.
M-34 (G-51) M-33 (JI-2)	5,095 4,627	468	U C	Y C	9-13-90 9-12-90	5,090.16 5,074.20	-15.96	-0.03	Potential flow downward from younger basin fill to carbonate rocks.
M-34 (G-51) M-33 (JI-2)	5,095 4,627	468	U C	Y C	8-25-93 9-30-93	5,089.97 5,010.94	-79.03	-0.17	Gradient increasing with pumping.
M-37 (MC-1) M-36 (MC-2)	4,854 4,402	452	U C?	S S,C	3-14-89 3-14-89	5,079.50 5,091.30	11.8	+0.03	Potential flow upward from carbonate rocks to siltstones or upward in siltstones.
M-37 (MC-1) M-36 (MC-2)	4,854 4,402	452	U C?	S S,C	10-16-89 10-16-89	5,065.40 5,059.70	-5.7	-0.01	Gradient reversed with pumping.
M-44 (J2-S) M-44 (J2-D)	5,241 4,961	280	C C	S S	9-09-92 9-09-92	5,638.64 5,638.79	+0.15	+0.00	Very slight upward gradient in siltstones.
M-44 (J2-S) M-44 (J2-D)	5,241 4,961	280	C C	S S	9-23-93 9-23-93	5,638.49 5,638.49	0	0.0	No gradient.
M-46 (GQP-34S) M-46 (GQP-34D)	Above 4,721 4,102	>619	U? C	C,O C	8-26-92 8-26-92	5,259.00 4,974.70	-284.3	-?	Bad seal on shallow well, gradient not computed. Head differences indicate downward gradient.
M-52 M-51 (USGS-5)	4,935 4,833	102	U U	Y V	9-13-90 11-05-90	4,961.40 4,928.0	-33.4	-0.33	Potential flow downward from younger basin fill to volcanic rocks.
M-52 M-51 (USGS-5)	4,935 4,833	102	U U	Y V	8-25-93 9-23-93	4,975.87 4,929.76	-46.11	-0.45	Gradient increasing with reservoir leakage or precipitation.

Appendix 3. Vertical hydraulic gradients measured at wells in Carlin trend area, north-central Nevada—Continued

Site name[1]	Mid-point altitude[2]	Difference in mid-point altitudes	Ground-water conditions, 1990	Hydro-geologic unit[3]	Water Levels[4] Date	Water Levels[4] Altitude	Difference in water-level altitude[5]	Vertical hydraulic gradient[6]	Remarks
M-56 (USGS-1B) M-56 (USGS-1A)	4,917 4,885	32	C C	Y,V? V?	9-11-90 9-11-90	4,932.01 4,932.06	0.05	+0.00	Very slight upward gradient from volcanic rocks to younger basin fill.
M-56 (USGS-1B) M-56 (USGS-1A)	4,917 4,885	32	C C	Y,V? V?	5-16-93 5-16-93	4,931.15 4,931.22	0.07	+0.00	Small change in gradient.
MR-3 MR-4 (MYC-2)	4,915 4,879	36	U C	Y V	8-25-93 8-04-93	4,919.37 4,929.70	10.33	+0.28	Potential flow upward from volcanic rocks to younger basin fill.
MR-2 (CS-1) MR-2 (CS-2)	5,658 5,435	223	C C	S C	7-23-91 7-23-91	5,987.21 6,007.97	20.76	+0.09	Potential flow upward from carbonate rocks to siltstones.
MR-2 (CS-1) MR-2 (CS-2)	5,658 5,435	223	C C	S C	9-03-93 9-03-93	5,986.98 5,996.6	9.62	+0.04	Gradient decreasing pumping or precipitation.
B-1(NA-2U) B-1 (NA-2L)	5,334 5,084	250	U U	V V	1-01-92 1-01-92	5,469.10 5,498.10	29.0	+0.12	Potential flow upward in volcanic rocks.
B-1(NA-2U) B-1 (NA-2L)	5,334 5,084	250	U U	V V	10-01-93 10-01-93	5,461.52 5,499.67	38.15	+0.15	Gradient increasing with pumping or precipitation.
B-4 (COW-3U) B-4 (COW-3L)	5,135 4,850	285	U U	Y,O? O,C or S	11-29-90 11-29-90	5,284.17 5,242.17	-42.0	-0.15	Potential flow downward from younger to older basin fill, in older basin fill, or from older basin fill to siltstones or carbonate rocks.
B-4 (COW-3U) B-4 (COW-3L)	5,135 4,850	285	U U	Y,O? O,C or S	10-01-93 10-01-93	5,185.87 5,081.95	-103.92	-0.37	Gradient increasing with pumping.
B-5 (NA-25S) B-5 (NA-25D)	5,667 5,027	640	P U	O V	5-05-92 5-05-92	5,627.00 5,022.13	-604.87	-0.95	Potential flow downward from older basin fill to volcanic rocks.
B-5 (NA-25S) B-5 (NA-25D)	5,667 5,027	640	P U	O V	7-01-93 7-01-93	5,619.50 4,886.88	-732.62	-1.1	Perched ground-water conditions developed as a result of pumping?
B-10 (PZM-92-3S) B-10 (PZM-92-3D)	4,827 3,857	970	U C	O S	10-22-92 10-22-92	5,281.35 5,230.22	-51.13	-0.05	Potential flow downward from older basin fill to siltstones.
B-10 (PZM-92-3S) B-10 (PZM-92-3D)	4,827 3,857	970	U C	O S	10-01-93 10-01-93	5,253.39 5,127.14	-126.25	-0.13	Gradient increasing with pumping.

Appendix 3. Vertical hydraulic gradients measured at wells in Carlin trend area, north-central Nevada—Continued

Site name[1]	Mid-point altitude[2]	Difference in mid-point altitudes	Ground-water conditions, 1990	Hydro-geologic unit[3]	Water Levels[4] Date	Water Levels[4] Altitude	Difference in water-level altitude[5]	Vertical hydraulic gradient[6]	Remarks
B-10 (PZM-92-3D) B-11 (PZM-92-5D)	3,857 3,541	316	C C	S C	10-22-92 9-23-92	5,230.22 5,175.91	-54.31	-0.17	Potential flow downward from siltstones to carbonate rocks
B-10 (PZM-92-3D) B-11 (PZM-92-5D)	3,857 3,541	316	C C	S C	10-01-93 10-01-93	5,127.14 4,388.61	-738.53	-2.3	Perched ground-water conditions developed as a result of pumping.
B-16 (POW-10U) B-16 (POW-10L)	5,154 4,569	585	U C	O S	10-02-90 10-02-90	5,326.44 5,279.44	-47.0	-0.08	Potential flow downward from older basin fill to siltstones.
B-16 (POW-10U) B-16 (POW-10L)	5,154 4,569	585	U C	O S	10-01-93 10-01-93	5,314.92 5,101.15	-213.77	-0.37	Gradient increasing with pumping.
B-20 (POW-11) B-16 (POW-10L)	4,765 4,569	196	U C	S S	10-01-93 10-01-93	5,040.13 5,101.15	61.02	+0.31	Potential flow upward in siltstones.
B-21 (PZ-92-11S) B-21 (PZ-92-11D)	4,742 4,445	297	U U	C C	8-19-92 8-19-92	4,771.37 4,768.25	-3.12	-0.01	Potential flow downward in carbonate rocks.
B-24 (PZ-92-16S) B-24 (PZ-92-16D)	5,211 5,114	97	P C	O O,S	1-03-93 1-03-93	5,402.21 5,286.21	-116.0	-1.2	Perched water table. Potential flow downward from younger basin fill to siltstones.
B-24 (PZ-92-16S) B-24 (PZ-92-16D)	5,211 5,114	97	P C	O O,S	10-01-93 10-01-93	5,367.34 5,192.67	-174.67	-1.8	Gradient increasing with pumping.
B-25 (NA-7S) B-25 (NA-7D)	4,728 4,678	50	P U	O,V V	10-01-91 10-01-91	4,948.29 4,732.42	-215.87	-4.3	Perched water table. Potential flow downward from older basin fill to volcanic rocks.
B-25 (NA-7S) B-25 (NA-7D)	4,728 4,678	50	P U	O,V V	10-01-93 10-01-93	4,931.28 4,792.49	-138.79	-2.8	Still perched ground-water conditions, but gradient decreasing as a result of reservoir leakage.
B-40 (NA-14) B-38 (NA-23)	4,691 4,465	226	U U	V V	11-10-90 9-01-90	4,722.67 4,717.71	-4.96	-0.02	Potential flow downward in volcanic rocks.
B-40 (NA-14) B-38 (NA-23)	4,691 4,465	226	U U	V V	10-01-93 10-01-93	4,798.72 4,789.30	-9.42	-0.04	Gradient increasing with reservoir leakage.
B-43 (NA-9S) B-43 (NA-9D)	4,664 4,357	307	U C	Y V	10-01-91 10-01-91	4,748.32 4,721.08	-27.24	-0.09	Potential flow downward from younger basin fill to volcanic rocks.

Appendix 3. Vertical hydraulic gradients measured at wells in Carlin trend area, north-central Nevada—Continued

Site name[1]	Mid-point altitude[2]	Difference in mid-point altitudes	Ground-water conditions, 1990	Hydro-geologic unit[3]	Water Levels[4] Date	Water Levels[4] Altitude	Difference in water-level altitude[5]	Vertical hydraulic gradient[6]	Remarks
B-43 (NA-9S) B-43 (NA-9D)	4,664 4,357	307	U C	Y V	7-01-93 7-01-93	4,752.96 4,756.16	3.2	+0.01	Potential flow upward from volcanic rocks to younger basin fill. Gradient reversed with reservoir leakage.
B-43 (NA-9S) B-43 (NA-9D)	4,664 4,357	307	U C	Y V	10-01-93 10-01-93	4,755.73 4,757.80	2.07	+0.01	Potential flow upward from volcanic rocks to younger basin fill. Head differences indicate gradient decreasing.
Antelope Creek R-3 (NA-28S)	5,300 4,528	772	U U	Y V	-- 10-01-93	5,300 4,797.45	502.55	-0.65	Altitude of stream bed used for mid point and water level. Potential flow downward from younger basin fill to volcanic rocks.
R-4 R-5 (NA-33-S)	5,195 4,971	224	P U	Y? V	8-24-93 10-01-93	5,192.76 4,948.63	-244.13	-1.1	Perched water table. Potential flow downward from younger basin fill to volcanic rocks.
R-5 (NA-33-S) R-5 (NA-33-D)	4,971 4,803	168	U U	V V	10-01-93 10-01-93	4,948.63 4,900.33	-48.30	-0.29	Potential flow downward in volcanic rocks.
R-6 R-7 (NA-30-S)	5,035 4,900	135	U C	O V	8-25-93 10-01-93	5,054.80 5,048.21	-6.59	-0.05	Potential flow down from older basin fill to volcanic rocks.
R-7 (NA-30S) R-7 (NA-30D)	4,900 4,480	420	C C	V V	10-01-93 10-01-93	5,048.21 5,048.72	0.51	+0.00	Very slight upward gradient in volcanic rocks.

[1] Site locations in figure 14. Site information in appendix 4. Supplemental site designations used in other reports (Barrick Goldstrike Mines Inc., 1991a, b, 1992a-d, 1993 a-c, 1994a, b; Newmont Gold Co., 1992a, b, 1993a-d, 1994a, b; and Plume, 1995) are in parentheses.

[2] Altitude, in feet above sea level, of mid point of gravel-packed interval, mid point of perforated interval if gravel pack is not reported, or mid point of well depth if neither gravel pack nor perforated interval is reported.

[3] See plates 1 and 2 and table 2.

[4] See appendix 4.

[5] Computed by subtracting water level of shallower (higher-altitude) mid point from water level for deeper (lower-altitude) mid point. Positive value indicates that water level in shallower well is at lower altitude than water level in deeper well; negative value indicates that water level in shallower well is at higher altitude than water level in deeper well.

[6] Computed by dividing difference in water-level altitudes by difference in mid-point altitudes. Values rounded to two significant figures but never reported to precision exceeding hundredths. Value is approximate for wells where measuring-point altitude was estimated or for wells with large perforated interval or gravel-packed zone.

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Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada

[Land-surface altitude in feet above sea level. All depths in feet below land surface. Abbreviations: --, not recorded;. ?, designation uncertain. Hydrogeologic unit type: Y, younger basin-fill deposits; O, older basin-fill deposits; V, volcanic rocks; S, siltstones; C, carbonate rocks; and PZ, undifferentiated siltstones and carbonate rocks. Depth to top: LS, top of indicated unit at land surface. Aquifer type: U, unconfined; C, confined; P, perched.]

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
				Susie Creek Area						
S-1	N35 E53 14BCCA1 405520115591001	5,815	--	--	--	04-29-82	*0.00	O?	LS?	U?
S-2	N35 E53 22ACCB1 405427115594401	5,710	--	--	--	04-29-82	*91.90	O?	LS?	U?
S-3[6] (SC-1)	N34 E53 03ACCD1 405145115594601	5,215	140	120	140	08-05-93 08-10-93 09-23-93	*9.49 9.39 8.49	V	35	C
S-4	N34 E52 15AADA1 405020116061301	5,210	400	180	400	05-11-49 03-15-89 10-18-89 09-13-90 11-10-91	180 159 166.23 *162.0 158.8	Y	LS	U
S-5	N34 E52 21ADA 1 404923116073301	5,350	395	--	--	09-09-83 03-15-89 10-18-89 09-13-90 05-16-93 08-25-93	220 274.0 273.93 *274.6 277.18 **277.65	V	380	C
S-6	N34 E53 30AACD1 404833116025201	5,080	28.0	--	--	04-29-82	*28.0	Y?	LS	U
S-7[6] (SC-2)	N34 E52 36DAA 1 404725116035701	5,026	100	80	100	08-10-93 09-23-93	*15.13 14.63	O	15	U

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals: Depth to top	Open intervals: Depth to bottom	Water levels: Date[4]	Water levels: Depth[5]	Hydrogeologic unit: Type	Hydrogeologic unit: Depth to top	Aquifer type
S-8 (G67)	N33 E52 13BD 1 404452116043701	4,960	--	--	--	10-25-88 03-14-89 10-18-89 04-12-90 09-11-90 11-10-91 04-28-92 07-29-92 05-16-93 08-25-93	17.09 16.36 17.26 16.97 *17.51 17.52 17.40 17.92 17.26 18.40	Y?	LS?	U?
S-9	N33 E52 24CAC 1 404345116044401	4,950	300	200	300	10-27-88 03-16-89 10-18-89 04-13-90 09-13-90 05-16-93	34.17 32.5 34.31 33.72 *35.97 35.53	Y	LS	U
S-10	N33 E52 24CC 1 404333116045201	4,947	53	37	47	02-19-88 10-27-88 03-16-89 10-16-89 04-13-90 09-13-90	37 39.22 37.4 38.16 36.88 *38.07	Y	LS	U
				Maggie Creek Area						
M-1	N37 E52 16DCBC1 410536116080101	5,765	321	84	315	07-11-50 06-18-91 08-01-92 05-16-93	84 *75.0 73.6 **59.5	O	LS	U
M-2 (G77)	N37 E51 36BDCC1 410318116115301	6,230	840	640	840	06-18-91 05-16-93 08-25-93	*242.2 246.9 **246.64	O	LS	U
M-3[6] (COY-2)	N35 E51 15CAC 1 410023116135601	5,753	50	45	50	08-30-93 09-23-93	5.67 *,**4.77	Y	LS	U

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
M-4[6] (LJCK-1)	N36 E51 20DDBA1 405929116153201	5,774	170	135	170	06-16-92	*-13.32	S	85	C
						07-28-92	-13.32			
						09-08-92	-12.17			
						10-29-92	-12.17			
						12-22.92	-13.32			
						06-21-93	-7.75			
						08-05-93	-6.37			
						09-10-93	**-6.83			
M-5[6] (JCK-4)	N36 E51 32BBBC1 405818116163501	5,810	50	45	50	08-30-93	17.73	Y	LS	U
						09-23-93	*,**19.53			
M-6[6] (JCK-1)	N35 E51 04DABB1 405704116141801	5,540	318	308	318	08-21-91	31.78	Y/O?	LS	U
						11-11-91	32.00			
						01-08-92	31.47			
						07-28-92	*32.37			
						10-29-92	32.67			
						01-28-93	32.27			
						09-02-93	32.67			
M-7[6] (JCK-2)	N35 E51 04DABB2 405703116142001	5,540	58	48	58	08-21-91	17.74	Y	LS	U
						11-11-91	20.0			
						12-10-91	20.45			
						01-08-92	20.40			
						03-17-92	18.80			
						04-20-92	17.30			
						09-08-92	*19.80			
						10-29-92	23.90			
						04-26-93	11.20			
						05-26-93	11.35			
						07-07-93	12.30			
						07-19-93	12.50			
						08-04-93	13.10			
						08-30-93	**14.50			
M-8[6] (COY-1)	N35 E52 6C 1 405651116102301	5,378	110	105	110	08-30-93	36.66	Y	LS	U
						09-23-93	*,**36.26			
M-9[6] (JCK-3)	N35 E51 13DDBD1 405457116105301	5,307	40	35	40	09-23-93	*,**15.45	Y	LS	U

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
M-10 (G21)	N35 E51 30AAAA1 405400116163001	5,519	--	--	--	04-11-90	179.50	O?	LS	U?
						09-12-90	*180.1			
						11-11-91	187.3			
						04-28-92	187.1			
						08-03-92	189.89			
						10-05-92	188.8			
						05-16-93	189.1			
						08-25-93	*191.28			
M-11 (SIC-1)	N35 E51 28BCBA1 405348116151001	5,353	180	170	180	08-14-91	34	Y/O?	LS	U
						12-10-91*	52.65			
						07-28-92	56.10			
						12-07-92	55.45			
						05-16-93	55.10			
						09-03-93	**56.05			
M-12 (REB1)	N35 E51 27AACC1 405352116131601	5,340	--	--	--	04-14-90*	58.50	O?	LS	U?
M-13 (G30, PETROCHEM)	N35 E52 28BCC 1 405336116082101	5,482	187	75	95	06-20-80	50	O	LS	U
				135	175	10-16-89	43.0			
						04-13-90	44.85			
						09-12-90*	46.14			
						11-11-91	46.5			
						04-28-92	45.39			
						08-01-92	46.56			
						08-25-93	**45.72			
M-14 (G23)	N35 E51 31DDD 2 405217116163402	5,380	300	--	--	11-11-91	*56.08	Y/O?	LS	U
						04-28-92	56.12			
						08-03-92	58.73			
						10-05-92	57.62			
						05-16-93	60.20			
						08-25-93	56.83			
M-15	N35 E51 31DDD 1 405217116163401	5,380	152	115	139	01-02-80	40	Y/O?	LS	U
						10-17-89	99.6			
						04-11-90	76.45			
						09-12-90	*106.8			
						11-11-91	PLUGGED			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
M-16 (G26)	N34 E51 03ABBB1	5,235	69	--	--	04-29-82	3.93	O	LS	U
	405215116133701					03-14-89	7.12			
						10-17-89	9.09			
						04-14-90	8.67			
						09-12-90	*12.91			
						11-11-91	14.7			
						10-05-92	15.7			
						05-16-93	6.85			
						08-25-93	**11.83			
M-17 (G27)	N35 E51 35DCD 1	5,215	--	--	--	03-14-89	14.09	Y	LS	U
	405216116121301					10-16-89	15.43			
						04-11-90	14.66			
						09-12-90	*15.73			
						11-11-91	15.66			
						04-28-92	15.22			
						08-11-92	15.45			
						05-16-93	15.56			
						08-25-93	**15.78			
M-18[6] (CV-10)	N34 E51 06ABDB1	5,457	1,435	1,395	1,435	10-24-92	222.30	Y	LS	U
	405206116165401					03-09-93	221.80			
						05-27-93	221.30			
						07-19-93	221.40			
						09-23-93	**221.20			
M-19 (G24)	N34 E51 07BBB 1	5,510	301	246	262	12-14-79	220	O	LS	U
	405120116173301			276	292	10-17-89	212.5			
						06-11-90	215.1			
						09-12-90	*219.8			
						11-11-91	214.1			
						04-28-92	213.5			
						08-03-92	215.77			
						10-05-92	212.65			
						05-16-93	213.7			
						08-25-93	**214.5			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
M-20 (G25)	N34 E50 10DAB 1 405010116185001	5,710	250	217	238	06-29-56	180	Y/O	LS	U
						10-17-89	160.8			
						09-12-90	*162.54			
						11-11-91	163.0			
						10-05-92	173.85			
						05-16-93	163.7			
						08-25-93	**165.1			
M-21	N34 E51 10DC 2 405036116133002	5,167	163	43	163	03-14-89	-5.1	Y	LS	C
M-22	N34 E51 10DC 1 405036116133001	5,167	755	160	735	03-14-89	-5.7	Y/O	LS	C
						10-16-89	-5.3			
						06-11-90	-4.9			
						09-13-90	*-4.3			
						11-11-91	-3.7			
M-23 (NMC-2, G19)	N34 E51 15BDD 1 405010116134101	5,147	1,000	178	958	03-14-89	-9.1	Y/O	200	C
						10-16-89	-8.1			
						06-11-90	-8.4			
						09-13-90	*-7.7			
						11-11-91	-8.6			
						04-28-92	-9.4			
						09-03-92	-8.2			
						08-25-93	**-8.06			
M-24[6] (HW-1D)	N34 E52 17CABC2 404957116091702	5,471	1,754	1,734	1,754	08-21-92	222.75	C	1,665	C
						09-08-92	220.25			
						10-28-92	217.35			
						01-28-93	215.80			
						05-26-93	215.25			
						07-15-93	200.35			
						09-23-93	198.90			
M-24[6] (HW-1S)	N34 E52 17CABC1 404957116091701	5,471	1,140	1,120	1,140	08-21-92	201.25	S	960	C
						09-08-92	200.25			
						10-28-92	199.51			
						01-28-93	199.95			
						05-26-93	201.20			
						07-15-93	198.35			
						09-23-93	**198.15			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
M-25 (G53)	N34 E52 20BAA 1 404937116091001	5,420	92	30	90	05-29-59	54	O	LS	U
						03-16-89	46.23			
						10-16-89	47.19			
						04-15-90	44.95			
						09-12-90	*45.94			
						11-11-91	48.13			
						04-28-92	50.38			
M-26 (G46)	N34 E51 21BAA 1 40493611614500	5,240	--	--	--	03-14-89	43.98	O?	LS?	U?
						10-16-89	45.81			
						04-14-90	45.67			
						09-13-90	*46.0			
						06-18-91	46. 2			
						11-11-91	46.4			
						04-28-92	45.7			
						08-03-92	44.38			
						10-05-92	46.4			
						05-16-93	44.62			
						08-25-93	**43.2			
M-27[6] (CV-5)	N34 E51 21CBA 1 404909116151001	5,273	2,750	2,730	2,750	05-27-92	271.63	C	1,730	C
						07-27-92	277.98			
						09-26-92	287.83			
						12-07-92	291.53			
						05-24-93	300.13			
						07-20-93	306.83			
						09-30-93	**322.11			
M-28[6] (CBN-3D)	N34 E51 22ABB 2 404931116133402	5,161	580	575	580	04-15-91	104.27	C	265	C
						05-21-91	104.62			
						06-26-91	107.32			
						07-31-91	113.02			
						08-30-91	116.67			
						10-18-91	119.82			
						12-09-91	120.22			
						06-24-92	122.97			
						08-21-92	131.92			
						09-26-92	136.02			
						12-07-92	140.52			
						03-31-93	146.62			
						06-23-93	151.62			
						08-04-93	157.82			
						09-30-93	170.88			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
M-28[6] (CBN-3S)	N34 E51 22ABB 1 404931116133401	5,161	378	373	378	04-15-91	*73.15	O?/C	LS?/265	C
						05-21-91	69.50			
						06-26-91	63.45			
						08-30-91	61.10			
						10-18-91	65.90			
						12-09-91	69.60			
						06-24-92	77.70			
						08-21-92	74.90			
						09-26-92	78.50			
						12-07-92	82.00			
						03-31-93	89.10			
						06-23-93	92.30			
						08-04-93	114.30			
M-29[6] (MK-1)	N34 E51 28ABDC2 404834116144201	5,363	505	470	505	08-03-93	156.65	O	15	P
						09-30-93	156.65			
M-29[6] (MK-2)	N34 E51 28ABDC1 404833116144201	5,363	200	180	200	09-30-93	**151.57	O	LS	U
M-30[6] (T-2)	N34 E51 27CBBA1 404819116140601	5,461	800	778	800	07-31-91	417.40	C	LS	U
						08-30-91	421.75			
						10-23-91	423.80			
						01-08-92	424.25			
						05-28-92	425.00			
						08-26-92	441.20			
						03-31-93	448.40			
						05-28-93	453.27			
						07-31-93	461.21			
						09-30-93	**474.92			
M-31 (G-48)	N34 E51 28DD 1 404802116142201	5,600	--	--	--	03-14-89	432.0	O/PZ?	?	U?
						10-16-89	458.3			
						09-13-90	*473.4			
						06-18-91	486.7			
						11-11-91	498.2			
						04-28-92	488.3			
						09-03-92	510.7			
						10-05-92	515.2			
						05-16-93	492.0			
						08-24-93	**531.8			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals: Depth to top	Open intervals: Depth to bottom	Water levels: Date[4]	Water levels: Depth[5]	Hydrogeologic unit: Type	Hydrogeologic unit: Depth to top	Aquifer type
M-32[6] (MK-3)	N34 E51 29DCC 1	5,519	203	183	203	09-17-93	-34.65	S	130	C
	404757116155101					09-30-93	**-34.88			
M-33[6,7] (JI-2)	N34 E51 25CAB 1	5,214	655	585	605	09-12-90	139.8	C	550	C
	404816116113501					12-11-90	144.12			
						04-08-91	148.12			
						06-21-91	150.50			
						09-02-91	155.50			
						01-09-92	162.00			
						05-28-92	165.60			
						09-26-92	173.50			
						01-28-93	183.00			
						05-27-93	190.40			
						09-30-93	**203.06			
M-34 (G51)	N34 E51 25BCAB1	5,100	14	13	14	06-14-89	9.22	Y	LS	U
	404806116114601					10-16-89	9.28			
						04-11-90	9.05			
						09-13-90	*9.84			
						06-18-91	9.33			
						09-17-91	12.56			
						11-11-91	9.4			
						04-28-92	9.44			
						10-05-92	14.0			
						05-16-93	7.99			
						08-25-93	**10.03			
M-35	N34 E51 25DAA 2	5,075	13	12	13	10-16-89	11.86	Y	LS	U
	404805116105302					04-15-90	11.64			
						09-12-90	*12.06			
						06-18-91	11.82			
M-36 (MC-2)	N34 E51 35AABA1	5,205	1,208	398	`1,208	03-14-89	113.7	S/C	490	C?
	404751116120801					10-16-89	145.3			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
M-47 (JC-2)	N33 E51 12CBA 1	5,247	1,040	--	--	09-23-88	114.79	O?	LS?	U?
	404535116114101					03-13-89	119.7			
						10-18-89	*130.20			
M-48 (WW2)	N33 E52 06ABC 1	5,153	880	--	--	03-14-89	241.0	O/S?	?	U?
	404649116100401					10-17-89	196.1			
						04-12-90	218.9			
						09-10-90	*161.8			
M-49 (PW-4)	N33 E52 06DBA 1	5,140	540	140	380	09-09-84	111	O	15	U
	404630116102301			400	520					
M-50 (PW-2)	N33 E52 06DDD 1	5,105	79	196	456	07-10-84	102	O	10	U
	404605116094101			476	776	--	--			
M-51 (USGS-5)	N33 E52 04DCCD1	4,995	175	152	172	11-05-90	*67	V	LS	U
	404605116074901					03-24-91	65.1			
						06-18-91	67.37			
						08-20-91	68.7			
						11-10-91	66.6			
						04-28-92	67.94			
						08-01-92	68.99			
						05-16-93	67.59			
						08-05-93	66.14			
						09-23-93	65.24			
M-52 (G57)	N33 E52 04CCB 1	5,000	100	30	100	10-25-88	61.00	Y	LS	U
	404613116082601					03-16-89	28.21			
						10-19-89	26.25			
						11-17-89	26.30			
						04-14-90	24.14			
						09-13-90	*38.6			
						06-18-91	20.1			
						11-11-91	47.6			
						04-28-92	19.65			
						10-05-92	39.9			
						05-16-93	10.83			
						08-25-93	**24.13			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
M-53 (G58)	N33 E52 09BBB 2 404600116083301	5,030	--	--	--	03-16-89	*67.58	Y?	LS?	U?
						10-19-89	66.30			
						04-14-90	76.39			
						06-18-91	76.14			
						11-11-91	66.62			
						04-28-92	67.95			
						10-05-92	67.1			
						05-16-93	67.37			
						08-25-93	67.34			
M-54[6,7] (JC-3)	N33 E52 07DCD 1 404518116095901	5,130	1,220	698	740	09-23-88	74.42	O	LS	U
				758	1,220	10-27-88	74.86			
						03-13-89	77.0			
						10-18-89	80.16			
						04-12-90	82.9			
						09-11-90	*85.02			
						11-11-91	95.5			
M-55 (USGS-4)	N33 E52 10CCAD1 404522116070501	4,972	97	77	97	11-02-90	*39	V	LS	U
						03-24-91	39.0			
						06-18-91	41.3			
						11-10-91	40.00			
						04-28-92	41.22			
						10-05-92	41.7			
						05-16-93	40.92			
						08-05-93	41.03			
						09-23-93	**40.63			
M-56 (G62, (USGS-1B)	N33 E52 16ADD 2 404457116072602	4,970	63	43	63	09-13-89	38	Y/V?	LS/50	U
						09-22-89	37.81			
						10-18-89	37.2			
						04-12-90	35.88			
						09-11-90	*37.99			
						06-18-91	39.03			
						11-11-91	37.8			
						04-28-92	39.04			
						05-16-93	38.85			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
M-56 (G63, USGS-1A)	N33 E52 16ADD 1 404457116072601	4,970	100	75	95	09-13-89	38	V?	50	C
						09-22-89	37.77			
						10-18-89	37.19			
						04-12-90	35.88			
						09-11-90	37.94			
						06-18-91	39.05			
						11-11-91	37.8			
						04-28-92	39.04			
						10-05-92	39.5			
						05-16-93	38.78			
M-57	N33 E52 15CBD 1 404430116070001	4,955	--	--	--	03-16-89	23.98	Y?	LS	U
						03-23-89	24.08			
						10-19-89	24.36			
						09-13-90	*25.23			
M-58 (G65, USGS-2)	N33 E52 16DCCC1 404421116075301	5,020	160	127	147	09-12-89	100	Y	LS	U
						09-22-89	101.20			
						10-18-89	100.96			
						04-12-90	99.90			
						09-11-90	*101.30			
						06-18-91	101.40			
						11-11-91	101.7			
						04-28-92	101.68			
						08-01-92	103.25			
						10-05-92	103.2			
						05-16-93	102.41			
						08-25-93	**101.39			
M-59	N33 E52 22DDC 1 404329116062001	4,990	--	--	--	03-17-89	67.5	Y?	LS	U?
						10-18-89	64.0			
						04-15-90	66.10			
						09-13-90	*67.56			
						08-25-93	**67.3			
M-60	N33 E52 15BCBA1 404459116071601	4,970	130	48	115	09-11-90	38.50	Y/V	LS/75	C
M-61	N33 E52 27DCBC1 404244116064501	4,989	--	--	--	--	--	Y?	LS?	U?
M-62	N33 E52 27BAB 1 404325116065801	5,080	654	207	649	04-12-90	158.38	Y/O	LS/250	C

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
M-63 (CITY SHOPS)	N33 E52 27DDBA1	4,895	500	--	--	04-09-38	6.25	Y	LS	U
	404240116025001					04-16-75	6.21			
						03-19-76	6.87			
						03-08-77	7.36			
						04-10-78	6.50			
						03-23-79	6.48			
						03-19-80	6.16			
						03-18-81	7.44			
						10-27-88	8.42			
						03-15-89	7.12			
						10-19-89	8.20			
						04-12-90	7.80			
						09-13-90	*8.39			
						05-18-93	7.00			
						08-25-93	*7.81			
				Marys Creek Area						
MR-1	N33 E52 20ACC 1	5,020	--	--	--	03-13-89	93.1	Y?	LS	U
	404359116092001					10-18-89	90.9			
						04-12-90	91.61			
						09-11-90	*93.8			
						05-18-93	93.0			
						08-25-93	91.90			
MR-2[6] (CS-2)	N33 E51 21DACD2	5,957	419	419	625	06-26-91	-42.17	C	350	C/P?
	404347116142502					07-23-91	-50.97			
						01-07-92	-60.85			
						06-17-92	-66.47			
						08-17-92	-41.06			
						01-01-93	-42.22			
						09-03-93	-39.60			
MR-2[6] (CS-1)	N33 E51 21DACD1	5,958	300	280	300	07-23-91	*-29.21	S	225	C/P?
	404347116142501					06-15-92	-26.90			
						08-17-92	-26.90			
						10-28-92	-26.90			
						07-02-93	-29.21			
						08-26-93	-28.52			
						09-03-93	**-28.98			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
MR-3	N33 E52 28DBD 1 404250116074101	4,925	--	--	--	04-13-89	5.78	Y	LS	U?
						05-12-89	5.59			
						10-18-89	6.23			
						04-12-90	5.84			
						09-11-90	*6.55			
						05-18-93	5.94			
						08-25-93	**5.63			
MR-4[6,7] (MYC-2)	N33 E52 28CD 1 404253116075701	4,951	84	74	84	08-29-91	*24.20	V	50	C
						12-09-91	23.40			
						06-25-92	24.45			
						07-28-92	25.0			
						09-07-92	23.90			
						09-28-92	24.0			
						10-29-92	23.8			
						12-04-92	24.1			
						03-11-93	23.5			
						04-27-93	22.3			
						05-24-93	23.8			
						06-21-93	22.7			
						07-19-93	21.7			
						08-04-93	21.3			
						09-04-93	22.9			
MR-5[6] (PAL-1)	N32 E52 05DB 1 404111116085801	4,906	300	280	300	09-28-92	*33.70	S	20	U
						12-08-92	35.20			
						03-19-93	35.50			
						04-27-93	35.10			
						05-27-93	35.00			
						06-22-93	34.50			
						07-13-93	34.61			
						08-30-93	35.40			
						09-23-93	**34.85			
MR-6 (G78)	N32 E51 01CBB 1 404103116114901	5,220	--	--	--	03-17-89	149.6	Y	LS	U
						10-20-89	149.6			
						04-12-90	*149.27			
						11-11-91	149.0			
						04-30-92	149.1			
						05-18-93	152.0			
						08-25-93	**148.7			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
MR-7[6] (MYC-3)	N32 E51 07CA 1 404014116160101	6,015	1,033	1,013	1,033	09-25-92 11-06-92 03-10-93 05-27-93 07-17-93 09-23-93	*276.65 272.55 269.80 268.25 268.05 **266.95	S	?	?
				Willow Creek Valley						
W-1	N39 E46 20ABAA1 411446116474801	5,760	--	--	--	03-25-91*	54.9	S	LS	U?
W-2 (G112)	N39 E47 20DBAA1 411433116410701	5,225	85	25	85	01-22-91 06-19-91 11-13-91 03-04-92 07-31-92	25 *16.22 16.96 17.26 17.01	Y	LS	U
W-3 (G114)	N39 E46 34DACD1 411238116453801	5,262	345			03-27-91 11-13-91 03-04-92 07-31-92 10-08-92 05-17-93 08-24-93	*21.7 25.1 27.3 28.05 29.2 31.60 25.2	O	LS	U
W-4	N38 E47 05ABBC1 411217116412201	5,162	--	--	--	--	--	Y	LS	U
W-5 (G113)	N38 E46 02BCDD1 411157116451001	5,195	500	85	500	03-04-92 10-08-92 05-17-93 08-24-93	*85.69 87.6 91.25 85.49	Y/0	LS	U
W-6 (G115)	N38 E46 10BABB1 411128116461701	5,214	180	125	180	01-28-60 06-19-91 11-13-91 03-04-92 07-31-92 10-08-92 05-17-93 08-24-93	120 *106.38 108.2 107.4 108.39 128.2 107.8 102.5	Y	LS	U

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
W-7 (G116)	N38 E46 15BCBA1 411021116462901	5,151	100	55	100	03-01-51	55	Y/O	LS	U
						06-19-91	*60.3			
						03-04-92	60.5			
						07-31-92	61.62			
						10-08-92	61.8			
						05-17-93	60.9			
						08-24-93	60.9			
W-8 (G117)	N38 E46 21DB 1 410912116470401	5,120	93	45	93	01-31-60	40	Y	LS	U
						06-19-91	*33.27			
						03-04-92	33.3			
						07-31-92	34.35			
						10-08-92	34.6			
						08-24-93	33.8			
W-9 (G118)	N38 E46 33BBDC1 410755116473601	5,158	105	69	102	10-20-54	65	Y	LS	U
						06-19-91	*60.00			
						03-04-92	60.42			
						08-24-93	61.98			
W-10	N38 E47 09BACD1 401118116402801	5,160	20	--	--	07-31-91	*13.67	Y	LS	U
						05-17-93	3.35			
						08-24-93	10.3			
				Rock Creek Valley						
R-1 (IV-5)	N37 E48 09CCBD1 410536116335601	5,349	340	100	340	05-24-90	*13	V	40	C
R-2 (G89)	N37 E49 22AB 1 410425116251601	5,732	398	378	398	08-22-91	*194.75	S	10	U
						11-12-91	196.7			
						08-02-92	212.55			
						10-07-92	206.92			
						05-18-93	**179.4			
R-3[8] (NA-28D)	N37 E49 29BDBA2 410329116275302	5,291.67	1099	899	1099	06-03-93	492	V	10	U
						07-01-93	495.72			
						10-01-93	**494.41			
R-3[8] (NA-28S)	N37 E49 29BDBA1 410329116275301	5,291.67	799	739	799	06-03-93	492	V	10	U
						07-01-93	495.70			
						10-01-93	494.22			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open Intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
R-4 (G111)	N37 E48 25DDCA1	5,225	60	--	--	10-23-91	34.99	Y	LS	P
	410254116293901					03-04-92	*31.46			
						05-20-92	31.15			
						08-02-92	33.10			
						10-20-92	36.05			
						05-14-93	31.11			
						08-24-93	32.24			
R-5[8] (NA-33D)	N37 E49 31BDBA2	5,404.67	660	500	660	05-28-93	472	V	220	U
	410236116290302					07-01-93	493.27			
						10-01-93	**504.34			
R-5[8] (NA-33S)	N37 E49 31BDBA1	5,404.67	460	400	460	07-01-93	455.66	V	220	U
	410236116290301					10-01-93	456.04			
R-6 (G110)	N36 E48 14BCCB1	5,455	490	390	480	03-27-68	410	O	LS	U
	405956116314101					09-19-91	*399.7			
						05-20-92	399.4			
						07-29-92	399.7			
						05-14-93	399.3			
						08-25-93	400.2			
R-7[7,8] (NA-30D)	N36 E48 14BCDB2	5,452.01	995	955	995	10-01-92	403.31	V	460	C
	405957116313302					01-01-93	404.57			
						04-01-93	403.16			
						07-01-93	403.22			
						10-01-93	**403.29			
R-7[7,8] (NA-30S)	N36 E48 14BCDB1	5,452.01	560	540	560	10-01-92	403.84	V	460	C
	405957116313301					01-01-93	404.95			
						04-01-93	403.70			
						07-01-93	403.70			
						10-01-93	403.80			
R-8 (G109)	N36 E48 27ABCD1	5,417	698	653	695	05-14-59	645	V	230	U
	405822116320901					07-29-92	*626.8			
						10-20-92	624.4			
						05-14-93	617.4			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
B-10[8] (PZ-92-3S)	N36 E49 12DDDC2	5,481.59	700	620	700	10-22-92	200.24	O	LS	U
	410018116224002					11-05-92	202.20			
						12-03-92	205.61			
						01-02-93	211.25			
						02-01-93	213.35			
						03-04-93	216.02			
						04-01-93	217.89			
						05-06-93	220.00			
						06-03-93	222.23			
						07-07-93	223.86			
						10-01-93	**228.20			
B-11[8] (PZ-92-5D)	N36 E49 13ABAA1	5,475.91	1,995	1,895	1,995	09-23-92	300	C	945	C
	410015116225301					07-01-93	800.37			U
						10-01-93	**187.30			
B-12[8] (MW-4)	N36 E49 14BAAA1	5,300.57	140	130	140	03-20-91	*60	O	20	U
	410013116242001					01-01-92	62.39			
						04-01-92	63.55			
						07-01-92	65.00			
						10-01-92	66.30			
						01-01-93	67.08			
						04-01-93	69.17			
						07-01-93	70.19			
						10-01-93	**71.38			
B-13[7,8] (NA12)	N36 E49 16AADD1	5,294.60	600	560	600	08-01-91	*234	V	540	C
	410005116260301					09-18-91	255.7			
						11-12-91	284.6			
						05-20-92	415.9			
						10-19-92	511.5			
						01-01-93	570.76			U
						04-01-93	DRY			
B-14 (PPW3)	N36 E50 18DCB 1	5,400	1,210	538	1,048	05-06-89	*43	O/S	1,095	C
	405936116215901			1,085	1,205	--	--			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
B-15[8] (NA-24)	N36 E50 21BBBB1	5,715.44	436	394	436	08-20-91	*22	C	130	C
	405924116200801					10-01-91	15.82			
						01-01-92	14.68			
						04-01-92	12.50			
						07-01-92	14.61			
						10-01-92	16.71			
						01-01-93	15.83			
						04-01-93	12.25			
						07-01-93	12.12			
						10-01-93	**15.18			
B-16[8] (POW-10L)	N36 E50 19BDDC2	5,344.44	797	757	797	10-02-90	65	S	240	C
	405901116220202					07-01-93	153.00			
						10-01-93	**243.29			U
B-16[8] (POW-10U)	N36 E50 19BDDC1	5,344.44	210	170	210	10-02-90	*18	O	LS	U
	405901116220201					07-01-93	26.72			
						10-01-93	29.52			
B-17[8] (BW2)	N36 E50 19BCC 1	5,538	1,320	410	450	04-26-90	*300	C	100	U
	405859116222601			470	710	--	--			
				730	810	--	--			
				830	870	--	--			
				890	1,310	--	--			
B-18[8] (SJ-233)	N36 E49 24DBCA1	5,547.70	1,533	41	1,491	03-29-90	302.78	C	265	U
	405852116230201					05-04-90	302.67			
						09-30-90	*352.62			
						01-21-91	391.35			
						03-01-91	419.40			
						05-02-91	443.98			
						07-01-91	477.37			
						09-03-91	513.91			
						02-20-93	966.57			
						03-20-93	990.02			
						04-17-93	1,013.76			
						05-15-93	1,037.00			
						06-12-93	1,067.80			
						07-02-93	1,087.33			
						10-01-93	**1,162.81			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
B-19 (BW3)	N36 E49 24CAD 1 405847116231101	5,321	1,282	122 742	682 1,262	-- --	-- --	PZ/C?	125	?
B-20[8] (POW-11)	N36 E50 19DCBA1 405844116215101	5,264.55	520	480	520	07-01-93 10-01-93	141.00 **224.42	S	LS	U
B-21[8] (PZ92-11D)	N36 E50 19CDBC1 405839116220901	4,861.67	440	400	440	08-19-92 07-01-93 10-01-93	93.42 350.40 **DRY	C	35	U
B-21[8] (PZ92-11S)	N36 E50 19CDBC2 405839116220902	4,861.67	140	100	140	08-19-92	90.30	C	35	U
B-22 (PPW10)	N36 E50 19CDD 1 405836116220301	5,102.6	341	129 270	230 310	03-05-90 --	FLOWING --	PZ	LS	C
B-23 (AA)	N36 E50 20CCC 1 405836116211901	5,497	720	160	700	--	--	O/PZ	578	?
B-24[8] (PZ92-16D)	N36 E50 29BBCA2 405827116211702	5,510.87	420	380	420	01-03-93 07-01-93 10-01-93	224.66 292.40 **318.20	S	375	C
B-24[8] (PZ92-16S)	N36 E50 29BBCA1 405827116211701	5,510.87	320	280	320	01-03-93 07-01-93 10-01-93	108.66 134.79 143.53	O	LS	P
B-25[8] (NA-7D)	N36 E49 27BADB1 405826116253202	5,109.27	457	417	457	10-01-91 01-01-92 04-01-92 07-01-92 08-14-92 01-01-93 04-01-93 07-01-93 10-01-93	376.85 366.43 352.96 351.33 350.33 330.11 319.43 318.06 **316.78	V	300	U

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
B-25[8] (NA-7S)	N36 E49 27BADB2	5,108.47	203	143	183	10-01-91	160.18	Y	LS	P
	405826116253201					01-01-92	160.62			
						04-01-92	165.82			
						07-01-92	165.42			
						10-01-92	168.49			
						01-01-93	169.38			
						04-01-93	171.74			
						07-01-93	172.28			
						10-01-93	177.19			
B-26[8] (NA-16)	N36 E50 28BCAC1	5,728.77	290	250	290	08-27-91	*64	S	80	C
	405816116200201					10-01-91	85.49			U
						01-01-92	65.54			C
						04-01-92	65.30			
						07-01-92	91.84			U
						10-01-92	117.01			
						01-01-93	91.84			
						04-01-93	78.96			C
						07-01-93	70.82			
						10-01-93	**67.35			
B-27[7,8] (AA-88-5)	N36 E50 29BCCC1	5,506.85	2,470	0	2,000	07-01-91	181.90	Y/O	LS/100/	C?
	405811116211901					10-01-91	201.94	S/C	525/1,270	
						01-01-92	238.26			
						04-01-92	225.14			
						07-01-92	218.73			
						10-01-92	214.61			
						01-01-93	180.14			
						04-01-93	220.92			
						07-01-93	215.04			
						10-01-93	**229.22			
B-28[8] (NA-27)	N36 E48 25DCBB1	5,479.27	900	800	860	04-26-92	741	V	55	U
	405752116295801					05-05-92	742.57			
						07-01-92	749.96			
						10-01-92	736.17			
						01-01-93	731.43			
						04-01-93	723.42			
						07-01-93	718.95			
						10-01-93	**715.10			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
B-29[8] (NA-13)	N36 E50 29CCAC1 405752116211101	5,534.84	101	61	101	08-22-91	*45	O	LS	U
						10-01-91	46.14			
						01-01-92	47.18			
						04-01-92	49.50			
						07-01-92	51.18			
						10-01-92	54.16			
						01-01-93	54.70			
						04-01-93	51.76			
						07-01-93	52.82			
						10-01-93	**57.38			
B-30 (GEN 6)	N36 E50 29DDC 1 405744116201901	5,670	968	0	968	05-14-88	44	PZ	230	C
B-31[8] (GS-1706)	N36 E50 30DDCC1 405743116213701	5,689.81	1,685	150	1,600	07-01-93	277.35	C	150	U
						10-01-93	**285.76			
B-32 (GNTW3)	N36 E50 31DDB 1 415702116213001	--	--	--	--	--	--	S	LS	U
B-33[8] (NA-3)	N36 E50 33BCAC1 405724116195801	5,812.84	783	743	783	10-01-91	*133.32	C	407	C
						01-01-92	134.27			
						04-01-92	104.50			
						07-01-92	112.79			
						10-01-92	127.60			
						01-01-93	133.80			
						04-01-93	126.26			
						07-01-93	117.75			
						10-01-93	**115.43			
B-34[8] (NA-10)	N36 E49 34ACDB1 405721116251401	5,180.77	568	469	569	08-11-90	458	V	265	U
						07-01-91	446.53			
						10-01-91	447.44			
						01-01-92	436.02			
						04-01-92	421.26			
						07-01-92	419.13			
						10-01-92	414.96			
						01-01-93	397.46			
						04-01-93	385.82			
						07-01-93	384.90			
						10-01-93	**384.05			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
B-35[8] (NA-8)	N36 E49 33BDCC1 405717116264901	5,040.57	356	316	356	12-07-90	*300	V	145	U
						07-01-91	307.98			
						10-01-91	306.91			
						01-01-92	298.48			
						04-01-92	285.00			
						07-01-92	282.46			
						10-01-92	278.15			
						01-01-93	262.73			
						04-01-93	251.30			
						07-01-93	249.83			
						10-01-93	**248.57			
B-36[8] (NA-17)	N36 E49 35DBAA1 405714116240201	5,272.27	648	538	638	08-17-90	556	V	180	U
						07-01-91	535.65			
						10-01-91	535.90			
						01-01-92	529.18			
						04-01-92	514.43			
						07-01-92	511.72			
						10-01-92	508.03			
						01-01-93	491.89			
						04-01-93	478.53			
						07-01-93	478.20			
						10-01-93	**477.31			
B-37[8] (NA-11)	N36 E49 36CDCB1 405655116232101	5,392.67	356	292	356	12-03-91	*233	PZ	LS	U
						01-01-92	194.78			
						04-01-92	195.72			
						07-01-92	196.98			
						10-01-92	198.50			
						01-01-93	200.65			
						04-01-93	203.00			
						07-01-93	204.86			
						10-01-93	**209.91			
B-38[8] (NA-23)	N35 E49 03BBBD1 405644116262901	5,127.71	710	648	708	09-01-90	410	V	LS	U
						04-01-93	340.07			
						07-01-93	336.25			
						10-01-93	**338.41			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
B-39[8] (NA-22)	N35 E49 05ABDA1	4,991.67	348	248	348	09-19-90	*275	O/V	LS/345	U
	405640116280801					07-01-91	263.60			
						10-01-91	260.03			
						01-01-92	255.50			
						04-01-92	249.07			
						07-01-92	244.24			
						10-01-92	240.54			
						01-01-93	231.54			
						04-01-93	222.88			
						07-01-93	218.86			
						10-01-93	**216.12			
B-40[8] (NA-14)	N35 E49 03CBBA1	5,089.67	427	387	427	11-10-90	*367	V	100	U
	405621116262801					07-01-91	354.96			
						10-01-91	358.56			
						01-01-92	344.25			
						04-01-92	324.06			
						07-01-92	327.44			
						10-01-92	322.14			
						01-01-93	301.55			
						04-01-93	290.97			
						07-01-93	291.95			
						10-01-93	**290.75			
B-41[8] (NA-18)	N35 E49 02CAAA1	5,164.59	528	468	528	12-05-90	*435	V	75	U
	405620116245301					07-01-91	433.13			
						10-01-91	432.65			
						01-01-92	421.76			
						04-01-92	408.74			
						07-01-92	405.62			
						10-01-92	402.00			
						01-01-93	385.58			
						04-01-93	372.95			
						07-01-93	372.80			
						10-01-93	**372.10			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
B-42[8] (NA-1)	N35 E50 03CCDD1 405558116204901	5,790.32	220	177	217	08-20-91	*95	Y	LS	U
						10-01-91	95.20			
						01-01-92	94.78			
						04-01-92	94.50			
						07-01-92	94.99			
						10-01-92	94.79			
						01-01-93	94.64			
						04-01-93	94.63			
						07-01-93	94.60			
						10-01-93	**110.69			
B-43[8] (NA-9S)	N35 E49 18DBBB2 405433116292702	4,855.26	211	171	211	10-01-91	106.94	Y	LS	U
						01-01-92	108.08			
						04-01-92	107.20			
						07-01-92	109.04			
						10-01-92	109.19			
						01-01-93	109.64			
						04-01-93	109.10			
						07-01-93	102.30			
						10-01-93	**99.53			
B-43[8] (NA-9D)	N35 E49 18DBBB1 405433116292701	4,855.16	518	478	518	10-01-91	134.08	V	355	C
						01-01-92	129.54			
						04-01-92	122.12			
						07-01-92	117.89			
						10-01-92	115.89			
						01-01-93	108.29			
						04-01-93	102.76			
						07-01-93	99.00			
						10-01-93	97.36			
B-44 (G20)	N35 E50 21ABAB1 405406116213702	5,280	715	580	700	09-10-90	*39.0	O/PZ?	620	C
						11-12-91	35.7			
B-45 (MIDDLE)	N35 E50 21ABB 1 405406116213701	5,240	--	--	--	09-30-85	--	Y/PZ?	?	?
B-46 (LOWER MID)	N35 E50 20BBCB1 405402116230601	4,952	337	217	337	09-04-64	248	O/V	250	C
						04-27-82	246.90			
						09-10-90	*238.4			
						11-12-91	231.5			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
B-47 (G18, TS#2)	N35 E49 23AACA1 405403116242701	4,814	154	90	150	06-01-48	115	V	89	U
						04-27-82	110.12			
						09-10-90	*103.6			
						08-01-91	93.88			
						11-12-91	91.7			
						10-19-92	77.00			C
						08-24-93	61.2			
						10-01-93	**60.36[8]			
B-48 (G16,TS#1)	N35 E49 28AAC 1 405306116264801	4,750	233	154	233	08-29-73	72	V	45	U
						09-10-90	*49.2			
						08-01-91	40.11			C
						11-12-91	37.9			
						10-19-92	22.36			
						07-08-93	12.1			
						08-24-93	11.16			
						10-01-93	**10.21[8]			
B-49[6] (NA-26)	N35 E48 24CDCB1 405320116305201	4,786.88	377	277	377	10-01-92	121.03	Y	LS	U
						01-01-93	119.33			
						04-01-93	118.21			
						07-01-93	119.40			
						10-01-93	**117.97			
B-50	N34 E49 05BAA 1 405131116282101	4,728	390	0	369	12-31-55	70	Y	LS	U
						09-10-90	*85.7			
						11-12-91	82.20			
						05-18-93	**67.6			
B-51 (SAND DUNE, G17, TS#3)	N34 E49 02BCAD1 405114116245401	4,694	134	50	130	05-12-48	28	Y	LS	U
						04-27-82	25.05			
						09-10-90	*26.0			
						08-01-91	25.76			
						11-12-91	25.76			
						03-05-92	25.19			
						05-18-93	4.33			
						10-01-93	**5.60[8]			
B-52	N34 E48 01CAAA1 405105116303701	4,710	145	92	140	06-08-48	90	Y	LS	U
						09-10-90	*74.7			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
B-53	N34 E49 07ADD 1 405016116290101	4,685	480	80	480	01-23-75 09-10-90 11-12-91 05-18-93 08-24-93	36 *52.9 49.68 39.28 **36.76	Y	LS	U
B-53a	N34 E49 06AAA 1 405131116290001	4,730	636	108	636	08-24-93	77.47	Y/O	LS/215	U/C
B-54 (ALKALI, G38, TS#8)	N34 E49 16DABA1 404919116264401	4,668	130	64	127	05-09-48 04-27-82 09-10-90 11-12-91 03-05-92 10-07-92 05-15-93 08-24-93 10-01-93	16 14.29 *16.7 17.49 17.29 17.90 15.17 3.64 **2.43[8]	Y	LS	U
B-55 (BVN-4, G88)	N34 E48 08CDDB1 404949116351801	4,690	293	280	290	08-22-91 11-12-91 10-07-92 07-08-93 08-24-93 10-01-93	*68.30 68.8 70.1 68.9 68.67 **71.31[8]	V	LS	U
B-56 (G34)	N34 E48 21BBBB1 404853116343201	4,655	137	71	134	06-10-48 09-11-90 11-12-91 03-05-92 10-07-92 07-08-93 08-24-93	48 *41.7 43.1 42.80 43.9 41.8 **42.10	Y	LS	U
B-57 (GRAVEL PIT, G37, TS#5)	N34 E49 30BADB1 404752116293401	4,652	83	15	77	05-06-48 04-27-82 08-01-91 11-12-91 03-05-92 10-07-92 05-15-93 07-08-93 08-24-93 10-01-93	20 20.21 *22.00 22.4 22.40 21.97 22.15 21.6 21.45 **21.31[8]	Y	LS	U

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
B-58[8] (I-3)	N34 E50 19DD 1 404808116220801	4,900	325	--	--	11-07-90	*210	Y	LS	U
B-59[8] (I-5)	N34 E50 29CA 1 404727116213401	5,010	225	--	--	11-07-90	*110	Y	LS	U
B-60 (G39)	N34 E49 34BDBC1 404649116261501	4,679	166	120	165	06-19-48	40	Y	LS	U
						09-10-90	*36.8			
						07-30-91	37.6			
						05-15-93	37.85			
						08-24-93	**37.37			
B-61 (G35)	N34 E48 34DDDB1 404621116322201	4,626	83	36	80	06-16-48	17	Y	LS	U
						09-11-90	*17.2			
						11-12-91	19.29			
						10-07-92	18.05			
						05-15-93	16.25			
						07-07-93	16.21			
						08-24-93	**17.00			
B-62 (G 36)	N33 E48 01ACBA1 404559116302701	4,645	580	200	580	09-10-90	*25.0	Y	LS	U
B-63 (G87)	N33 E49 07AABA1 404522116290301	4,644	29	24	29	03-03-92	18	Y	LS	U
						03-05-92	*17.88			
						05-20-92	18.09			
						06-04-92	18.50			
						06-20-92	18.30			
						08-18-92	18.20			
						09-03-92	18.30			
						09-16-92	18.40			
						10-07-92	18.40			
						05-14-93	18.75			
						05-15-93	18.75			
						05-18-93	18.75			
						07-08-93	18.77			
						08-25-93	**18.78			
B-64	N33 E49 03DBBB1 404549116255801	4,686	486	198	486	04-06-76	28.0	Y	LS	U
						09-10-90	*73.3			
						08-24-93	**58.71			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
B-65 (G45)	N33 E49 01BDDD1 404550116234301	4,755	--	--	--	09-10-90	*126.2	Y	LS	U
						11-12-91	120.7			
						03-05-92	117.50			
						10-07-92	118.3			
						05-15-93	113.21			
						08-24-93	**111.76			
B-66 (G42)	N33 E49 10BCDC1 404458116262401	4,685	--	--	--	09-10-90	*67.8	Y	LS	U
						11-12-91	53.6			
						03-05-92	50.19			
						07-28-92	53.62			
						05-15-93	47.15			
						08-24-93	**45.91			
B-67	N33 E49 10ACDD1 404458116254201	4,705	565	205	565	--	--	Y	LS	U
B-68	N33 E49 11BCCC1 404458116252301	4,718	160	120	160	05-13-77	56.	Y	LS	U
B-69 (G41)	N33 E49 08DCCC1 404432116281601	4,662	--	--	--	09-10-90	*36.6	Y	LS	U
						11-12-91	29.5			
						07-28-92	30.05			
						05-15-93	30.61			
						08-24-93	**30.35			
B-70 (G68)	N33 E49 15CBCC1 404354116263001	4,696	130	56	128	06-21-48	40	Y	LS	U
						04-27-82	46.29			
						09-10-90	*57.1			
						03-05-92	57.49			
						07-28-92	57.06			
						05-15-93	55.95			
						08-24-93	**55.02			
B-71 (G86)	N33 E48 24BBCB1 404331116310601	4,628	400	200	400	08-12-57	36	Y	LS	U
						08-22-91	*13.83			
						11-12-91	14.81			
						03-05-92	16.53			
						07-28-92	15.67			
						05-15-93	15.60			
						08-24-93	**13.69			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
B-72 (G69)	N33 E49 26CDBA1	4,873	376.	230	250	09-10-90	*218.3	V	LS	U
	404205116250001			336	376	11-12-91	218.4			
						10-07-92	223.84			
						08-24-93	**223.12			
B-73 (G83)	N32 E49 05BADB1	4,770	187	--	--	09-18-91	*115.8	Y	LS	U
	404049116282301					11-12-91	115.7			
						10-05-92	116.5			
						05-18-93	116.1			
						08-24-93	**116.0			
B-74 (G82)	N32 E49 10BDDA1	5,040	40	--	--	09-17-91	377.62	PZ	LS	U
	403947116260101					11-10-91	*366.69			
						10-05-92	366.8			
						05-15-93	374.32			
						08-24-93	**367.8			
B-75 (G81)	N32 E49 11ADAC1	5,074	350	246	318	06-18-56	225	Y	LS	U
	403945116242101					04-30-82	225.01			
						07-19-91	*216.43			
						11-10-91	215.85			
						04-30-92	215.86			
						10-05-92	215.9			
						05-15-93	216.10			
						08-24-93	**216.00			
B-76 (G80)	N32 E49 22ADDB1	4,902	203	120	200	04-23-58	115	Y	LS	U
	403802116253401					04-26-82	113.15			
						07-30-91	*110.81			
						11-12-91	110.82			
						10-05-92	114.74			
						05-15-93	113.93			
						08-24-93	110.65			
B-77 (G79)	N32 E50 19CBAC1	5,100	402	280	320	04-11-58	275	Y	LS	U
	403740116230301			360	400	04-26-82	271.51			
						07-30-91	*269.0			
						11-12-91	267.9			
						04-30-92	267.8			
						10-05-92	269.8			
						05-15-93	268.10			
						08-24-93	267.53			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
B-78	N32 E49 28CBBB1 403703116273801	4,700	387	67	387	04-26-82	*13.87	Y	LS	U
B-79 (G33)	N33 E48 05BBD 1 404557116351701	4,612	--	--	--	09-11-90 03-05-92 07-07-93 08-24-93	*11.7 15.17 11.21 **12.74	Y	LS	U
B-80 (G32)	N33 E47 01CBCC1 404540116375601	4,598	72	--	--	09-11-90 03-05-92 07-07-93 08-25-93	*12.4 13.32 7.8 11.2	Y	LS	U
B-81 (G91)	N33 E47 10DCAC1 404438116393001	4,589	66	18	63	12-10-48 07-29-91 03-05-92 07-07-93 08-25-93	13 *11.79 11.29 9.1 11.1	Y	LS	U
B-82 (G92)	N33 E47 14ADAB1 404416116380201	4,591	13	--	--	07-29-91 11-13-91 03-05-92 10-21-92 07-07-93 08-25-93	*9.52 9.75 9.20 10.51 7.5 **9.0	Y	LS	U
B-83 (G93)	N33 E47 24DBBA1 404311116371601	4,589	--	--	--	07-29-91 11-13-91 03-05-92 10-21-92 07-07-93 08-24-93	*5.35 6.89 6.27 7.81 1.7 4.1	Y	LS	U

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
B-84	N33 E48 19CDBD1	4,595	--	--	--	06-16-60	6.99	Y	LS	U
						09-18-63	6.26			
						09-18-64	6.50			
						09-17-65	4.99			
						09-27-66	6.74			
						03-18-68	6.34			
						03-23-70	5.10			
						04-07-71	5.40			
						04-05-72	4.49			
						04-11-73	4.48			
						04-16-75	5.11			
						03-19-76	*4.33			
B-85	N33 E47 26CCDC1 404157116390001	4,581	--	--	--	08-21-91	--	Y	LS	U
B-86 (G95)	N33 E47 26BADB1 404239116384101	4,581	11	--	--	06-20-91	*4.08	Y	LS	U
						07-29-91	5.60			
						11-13-91	5.64			
						03-05-92	4.70			
						07-07-93	3.24			
						08-25-93	4.9			
B-87 (G96)	N33 E47 27CBBA1 404221116394701	4,575	33	--	--	07-29-91	*5.42	Y	LS	U
						11-13-91	4.98			
						03-05-92	4.26			
						07-07-93	3.36			
						08-25-93	5.1			
B-88 (G97)	N33 E47 29CBAA1 404221116422101	4,563	27	--	--	07-29-91	*6.38	Y	LS	U
						03-05-92	5.12			
						10-21-92	6.62			
						07-07-93	5.00			
						08-25-93	6.3			
B-89 (G98)	N33 E47 19CDCD1 404247116431901	4,561	19	--	--	07-29-91	*6.74	Y	LS	U
						03-05-92	5.62			
						10-21-92	6.96			
						07-07-93	5.70			
						08-25-93	6.7			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
B-90 (G100)	N32 E46 10ABDC1	4,534	--	--	--	07-29-91	*7.7	Y	LS	U
	404000116462501					11-13-91	8.69			
						03-05-92	6.53			
						10-07-92	7.94			
						05-18-93	5.55			
						08-25-93	7.40			
B-91 (G99)	N32 E46 11DAAD1	4,541	30	14	30	06-20-51	12	Y	LS	U
	403939116452501					07-29-91	*8.85			
						11-13-91	7.55			
						03-05-92	7.96			
						10-07-92	9.48			
						05-18-93	6.26			
						08-25-93	8.84			
B-92	N32 E46 22BBDD1	4,535	855	--	--	04-19-82	*7.19	Y	LS	U
	403816116465301									
B-93 (G101)	N33 E45 26DAC 1	4,718	403	--	--	09-19-91	*198.40	Y	LS	U
	404210116515901					11-12-91	198.3			
						03-04-92	197.4			
						07-30-92	198.07			
						10-07-92	197.9			
						05-17-93	196.6			
						08-24-93	198.2			
B-94	N33 E45 35BBAB1	4,515	--	--	--	07-29-49	18.00	Y	LS	U
	404155116524101					04-30-82	*22.20			
B-95	N32 E45 01CDBB1	4,525	300	55	90	02-05-68	13.00	Y	LS	U
	404022116512201			127	290	04-07-82	*10.80			
B-96	N32 E45 02DCDA1	4,523	141	105	225	03-27-61	8.00	Y	LS	U
						04-07-82	*12.84			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
B-97	N32 E45 11DACC1 403920116520001	4,518	197	--	--	04-11-78	9.40	Y	LS	U
						03-22-79	7.91			
						03-19-80	8.04			
						03-18-81	9.34			
						03-07-82	7.51			
						03-25-87	8.98			
						04-18-88	9.22			
						04-04-89	7.33			
						04-11-90	*9.53			
						03-18-91	10.12			
						02-27-92	10.16			
						04-13-93	6.17			
Crescent Valley, Whirlwind Valley, and Reese River Valley										
S0-1	N31 E44 01DACA1 403520117181101	4,557	52	--	--	05-28-64	32.48	Y	LS	U
						08-05-64	29.88			
						10-04-66	29.90			
						03-19-68	30.06			
						04-30-69	30.15			
						03-24-70	29.81			
						04-13-71	29.81			
						03-20-72	29.89			
						04-11-73	30.08			
						04-03-74	30.17			
						03-04-75	30.35			
						03-19-76	30.47			
						03-01-77	30.38			
						04-11-78	30.54			
						03-22-79	30.67			
						03-19-80	30.82			
						03-18-81	30.92			
						04-13-82	31.13			
						04-14-83	31.30			
						04-17-84	31.09			
						03-26-85	30.87			
						04-18-88	30.46			
						04-04-89	*30.70			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
SO-2	N31 E45 08DCAD1	4,538	17	--	--	05-27-64	3.70	Y	LS	U
	403407116553001					05-29-64	3.70			
						08-05-64	4.32			
						10-05-66	4.61			
						03-29-82	*4.27			
S0-3	N32 E45 25CDAC1	4,521	14	--	--	04-10-46	8.38	Y	LS	U
	403649116511501					08-18-46	8.60			
						10-25-46	8.50			
						12-12-46	8.25			
						03-20-47	8.01			
						04-24-47	7.93			
						05-22-47	8.03			
						06-19-47	8.25			
						07-24-47	8.80			
						09-09-47	9.10			
						10-24-47	9.15			
						01-07-48	8.90			
						04-22-48	8.60			
						06-26-48	8.83			
						08-26-48	9.38			
						09-28-48	9.42			
						11-12-48	9.24			
						03-16-49	8.74			
						06-23-49	8.50			
						07-25-49	8.90			
						08-24-49	9.18			
						09-19-49	9.23			
						10-26-49	9.17			
						03-21-50	8.68			
						06-15-50	8.45			
						07-17-50	8.74			
						08-15-50	**8.96			
S0-4	N31 E45 01CABA1	4,535	32	--	--	05-27-64	29.52	Y	LS	U
	403520116511801					08-05-64	12.97			
						10-05-66	12.70			
						04-14-82	*12.79			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
S0-5	N31 E46 05CCBB1	4,540	32	--	--	05-28-64	27.28	Y	LS	U
	403507116492401					08-05-64	14.27			
						10-05-64	14.06			
						04-15-82	*13.42			
S0-6	N32 E46 27BCCD1	4,550	431	--	--	11-06-47	19.68	Y	LS	U
	403709116470001					01-07-48	19.45			
						03-16-49	19.53			
						03-21-50	19.56			
						05-25-50	19.34			
						06-16-50	19.37			
						07-17-50	19.59			
						08-15-50	19.89			
						03-16-51	19.30			
						09-14-51	19.88			
						09-11-52	19.22			
						03-19-53	18.95			
						03-10-54	19.34			
						09-14-54	20.18			
						03-11-55	19.86			
						09-06-55	19.86			
						03-28-56	19.63			
						08-29-56	20.02			
						03-11-57	19.81			
						09-11-57	20.34			
						03-17-58	19.75			
						09-02-58	20.14			
						03-11-59	19.75			
						09-11-59	20.48			
						03-15-60	19.85			
						08-17-60	24.73			
						03-22-61	19.98			
						09-20-61	20.53			
						09-20-62	19.93			
						09-18-63	20.17			
						09-21-64	19.86			
						09-16-65	18.97			
						10-21-66	19.26			
						04-19-82	*19.80			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
SO-7	N32 E47 03DAAC1	4,582	16	--	--	08-16-60	8.30	Y	LS	U
	404032116391101					03-22-61	7.17			
						09-20-62	7.74			
						09-19-63	7.28			
						09-18-64	7.10			
						09-17-65	6.33			
						09-28-66	5.83			
						03-18-68	6.51			
						04-30-69	2.32			
						03-23-70	5.82			
						04-07-71	4.66			
						04-05-72	3.97			
						04-11-73	4.54			
						03-05-74	5.92			
						03-04-75	5.97			
						03-19-76	5.94			
						03-01-77	7.94			
						04-11-78	5.95			
						03-22-79	2.78			
						03-19-80	5.42			
						03-18-81	6.11			
						04-20-82	*3.84			
SO-8 (G85)	N33 E48 27CCCC1	4,631	50	--	--	08-22-91	*26.22	Y	LS	U
	404151116332301					09-18-91	26.28			
						11-12-91	26.69			
						03-05-92	26.01			
						07-28-92	26.70			
						05-15-93	24.90			
						07-08-93	24.8			
						08-24-93	**25.88			
S0-9 (G84)	N33 E48 33BDDB1	4,617	--	--	--	07-29-91	*20.56	Y	LS	U
	404131116340501					11-10-91	21.45			
						03-05-92	21.00			
						07-28-92	19.75			
						05-15-93	20.80			
						08-24-93	**20.12			
S0-10	N32 E48 12DCAD1	4,660	75	26	72	07-26-50	12.00	Y	LS	U
	403924116302101					04-26-82	*9.18			

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
SO-11	N32 E48 25DBDD1 403653116301801	4,660	197	14	192	03-17-51 04-27-82	6.00 *4.94	Y	LS	U
SO-12	N32 E48 32CDCD1 403548116352101	4,848	132	--	--	07-27-53 04-26-82	85.00 *81.63	Y	LS	U
SO-13	N31 E48 10BAB 1 403448116330701	4,770	53	--	--	04-26-82	*4.30	Y	LS	U
SO-14	N31 E49 06AAD 1 403537116285401	4,700	262	100	262	12-23-66 04-26-82	18.00 *19.29	Y	LS	U
SO-15	N31 E49 05C 1 403448116283601	4,698	10	--	--	08-25-56	*7.57	Y	LS	U
SO-16	N31 E49 17B 1 403327116284101	4,708	12	--	--	09-13-50	*4.73	Y	LS	U
				Clovers Area						
C-1 (G106)	N37 E44 14BDCC1 410507116590001	4,608	161	138	171	10-26-54 04-28-82 09-19-91 05-21-92 07-31-92 10-08-92 05-17-93 08-24-93	135 117.00 *116.2 116.8 119.70 120.10 116.6 116.96	Y	LS	U
C-2 (G105)	N36 E44 26DDDA1 405742116581701	4,635	187	--	--	09-19-91 03-04-92 05-21-92 07-31-92 10-08-92 05-17-93 08-24-93	*124.7 124.9 125.2 130.75 125.12 124.9 125.35	Y	LS	U

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
C-3 (G104)	N35 E45 02CBCD1 405606116524801	4,770	--	--	--	11-12-91 03-04-92 05-21-92 07-30-92 08-13-92 09-24-92 10-07-92 11-06-92 12-15-92 01-25-93 04-28-93 06-17-93 07-19-93 08-17-93 08-24-93 10-21-93 11-29-93	58.1 *53.72 53.9 53.97 53.97 53.96 54.94 53.95 53.97 53.98 53.92 53.90 53.91 53.96 54.00 54.01 54.03	Y	LS	U?
C-4	N35 E45 16ABBB1 405501116543501	4,690	37	26	36	07-05-75	*26.00	Y	LS	U
C-5	N35 E44 36ACAA1 405209116575001	4,558	--	--	--	04-28-82	*29.98	Y?	LS	U
C-6 (G103)	N34 E45 02AAAD1 405126116515301	4,980	370	--	--	09-19-91 03-04-92 05-17-93 08-24-93	*319.7 320.05 321.4 322.3	Y	LS	U
C-7	N34 E45 04CCBA1 405050116550801	4,595	225	55 107	77 220	04-07-70 08-24-71 01-28-76 12-21-77 12-21-78 12-26-78 04-09-79 04-28-82	35.00 41.00 40.62 46.95 45.00 47.52 50.33 *43.57	Y	LS	U
C-8	N34 E45 30ABCC1 404754116563401	4,540	400	160	400	04-27-82	*46.71	Y	LS	U
C-9	N34 E45 32BACA1 404703116555801	4,562	405	120	405	04-27-82	*83.65	Y	LS	U

Appendix 4. Water levels and other data for wells, Carlin trend area, north-central Nevada—Continued

Site name[1] (alternate name)	Local identification and standard identification[2]	Altitude of land[3] surface or measuring point	Well depth	Open intervals		Water levels		Hydrogeologic unit		Aquifer type
				Depth to top	Depth to bottom	Date[4]	Depth[5]	Type	Depth to top	
C-10	N34 E45 32ADDD1	4,610	405	120	405	--	--	Y/O?	LS	U
C-11 (G102)	N34 E45 33CCB 1 404627116551001	4,620	200	180	200	03-04-92 07-30-92 10-07-92 05-17-93 08-24-93	*135.0 149.71 149.19 146.5 150.9	Y	LS	U
C-12	N33 E45 28ABCA1 404238116543001	4,500	147	--	--	04-06-82	*3.65	Y	LS	U
C-13	N33 E45 30ABDD1 404234116564001	4,490	420	20	40	08-30-74 04-06-82	9.50 *7.89	Y	LS	U
C-14	N32 E45 17DADA1 403843116551201	4,505	145	90	140	12-10-68 04-07-82	3.00 *3.26	Y	LS	U
C-15	N32 E44 24ACAA1 403813116574401	4,515	120	--	--	10- -57 04-13-82	14.00 *7.53	Y	LS	U

[1] Number used for wells shown on plate 3 and figures 20 and 21. Alternate designation beginning with "G" is number assigned by USGS in Ground-Water Site Inventory data base; other alternate designations assigned by Newmont Gold Co. in Susie Creek, Maggie Creek, and Marys Creek Areas and by Barrick Goldstrike Mines Inc., in Rock Creek Valley and Boulder Flat, or are informal field names.

[2] In this table, each site also is identified by a local number that consists of the Nevada site-identification system and a standard identification number. The two designations are usually the most convenient means of identifying and retrieving information for a specific site from computer databases operated by the U.S. Geological Survey. The local site-identification system is based on an index of hydrographic areas in Nevada (Rush, 1968) and on the rectangular subdivision of the public lands referenced to the Mount Diablo base line and meridian. Each number consists of four units separated by spaces: First unit is hydrographic area number. Second unit is township, preceded by an N to indicate location north of the base line. Third unit is range, preceded by an E to indicate location east of meridian. Fourth unit consists of section number and letters designating quarter section, quarter-quarter section, and so on (A, B, C, and D indicate northeast, northwest, southwest, and southeast quarters, respectively), followed by a number indicating sequence in which well was recorded. For example, the local identification for site S-8 in this table is 50 N33 E52 13BD1. This site is in Susie Creek Area (50) and is first site recorded in the southeast quarter (D) of northwest quarter (B) of section 13, Township 33 North, Range 52 East, Mount Diablo base line and meridian.

The standard identification for each site is based on grid system of latitude and longitude. Number consists of 15 digits. The first six digits denote degrees, minutes and seconds of latitude; the next seven digits denote degrees, minutes, and seconds of longitude; and the last two digits (assigned sequentially) identify sites within a 1-second grid. For example, standard identification for site S-8 in this table is 404452116043701. This number refers to 40°44'52" latitude and 116°4'37" longitude, and is first site recorded in that 1-second grid. This 15-digit number is retained as a permanent identifier even if a more precise latitude and longitude are determined later.

[3] Altitudes reported to nearest foot are for land surface for wells measured by USGS and Newmont Gold Co., and were estimated from 1:24,000-scale topographic maps or were surveyed by Newmont Gold Co. Altitudes reported to nearest hundredth of a foot are for measuring point and were surveyed by Barrick Goldstrike Mines Inc.; land-surface altitude at these wells is not known.

[4] Date is approximate for sites with water-level altitude reported to hundredth of a foot. Measurement date may have differed from date shown by one or two days.

[5] "*" indicates water level measured on that date used to construct water-level contours on plate 3. "**" indicates water level measured on that date used to construct water-level contours and lines of equal water-level change on figures 20 and 21.

[6] Water-level measurements made by Newmont Gold Co.

[7] Supplemental water-level measurements made by USGS.

[8] Water-level measurements made by Barrick Goldstrike Mines Inc.

Appendix 5. Chemical and isotopic data for ground water, Carlin trend area, north-central Nevada

[Hydrogeologic unit: Y, younger basin-fill deposits; O, older basin-fill deposits; V, volcanic rocks; S, siltstones; C, carbonate rocks; PZ, undifferentiated siltstones and carbonate rocks, and ?, uncertain. Other abbreviations and symbols: °C, degrees Celsius; ntu, nephelometric turbidity units; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; µg/L, micrograms per liter; permil, parts per thousand; pCi/L, picocuries per liter; --, constituent not measured; <, less than; >, greater than.]

Site name[1]	Hydro-geologic unit	Date	Water temper-ature (°C)	Turbid-ity (ntu)	Specific conduct-ance (µS/cm)	Oxygen, dis-solved (mg/L)	Field pH, whole water (standard units)	Lab pH, whole water (standard units)	Bicar-bonate, dissolved (mg/L as HCO_3)[2]	Nitrogen, ammonia, dissolved (mg/L as N)
					Willow Creek Valley					
W-4	Y	09-01-92	10	0.6	259	3.9	7.2	7.6	107	<0.01
					Rock Creek Valley					
SP-1	Y	08-26-90	15.5	2	675	1.8	7.3	7.5	271	.04
R-1	V	01-30-92	--	--	--	--	--	--	--	--
		09-02-92	28.5	440	682	--	6.7	6.9	95	.58
R-6	O	08-31-92	20	2.8	418	3.1	6.9	7.5	150	.02
R-12	Y	08-31-92	21	4.7	405	4.2	7.3	7.7	143	.53
					Clovers Area					
SP-2	Y,V	01-30-92	--	--	--	--	--	--	--	--
		09-02-92	28.5	.4	363	5.5	7.3	7.5	132	<.01
C-10	Y,O	09-01-92	19	3	419	5.6	7.9	8	152	.01
					Boulder Flat					
B-2	S,C	08-27-90	35	.7	948	.5	6.5	7.0	573	.68
B-7	O,PZ	08-27-90	>45	1	981	--	6.4	6.9	537	1.0
B-14	O,S	08-28-90	--	.3	--	--	--	7.5	--	<.01
B-17	C	08-29-90	51.5	3	976	--	6.2	6.8	548	1.3
B-19	C?	08-29-90	49	.6	1,000	--	6.4	6.8	525	1.2
B-22	PZ	08-29-90	28	52	860	.4	6.7	7.0	381	1.3
B-23	O,PZ	08-29-90	18	3.5	389	1.6	6.6	7.2	152	<.01
B-30	PZ	08-28-90	18	.4	456	3.1	7.1	7.4	184	.01
B-32	S	08-28-90	19.5	2	336	1.4	6.8	7.1	131	<.01
B-45	Y,PZ	08-26-90	22.5	1	339	3	7.5	7.9	160	.04
B-53a	Y,O	08-25-90	15.5	.4	624	5.7	6.8	7.5	251	.04
B-53	Y	09-01-90	15	.3	567	4.9	7.1	7.5	239	<.01
B-57	Y	08-24-90	14.5	.3	1,030	4.3	7.4	7.7	268	.04
B-67	Y	08-24-90	26	.3	554	1.5	7.3	7.5	234	.25
SP-5	Y	01-29-92	--	--	--	--	--	--	--	--
		09-03-92	24	.3	418	6.1	7.6	7.7	152	<.01
B-85	Y	08-21-91	14.5	0.4	610	0.9	7.3	7.8	273	<0.01
B-75	Y	08-21-91	17.5	.9	418	3.1	7.6	8.0	168	.01
SP-11	V	08-22-91	17.	.5	542	6.5	7.1	7.6	195	<.01

Appendix 5. Chemical and isotopic data for ground water, Carlin trend area, north-central Nevada—Continued

Site name[1]	Hydro-geologic unit	Date	Water temper-ature (°C)	Turbid-ity (ntu)	Specific conduct-ance (μS/cm)	Oxygen, dis-solved (mg/L)	Field pH, whole water (standard units)	Lab pH, whole water (standard units)	Bicar-bonate, dissolved (mg/L as HCO_3)[2]	Nitrogen, ammonia, dissolved (mg/L as N)
					Maggie Creek Area					
M-4	S	01-27-92	--	--	--	--	--	--	--	--
SP-3	S	08-30-90	16	2	1,740	1.1	6.6	7.	270	.02
M-12	O?	08-28-90	14	4.5	382	5.6	6.9	7.2	116	<.01
SP-4	Y,C	08-30-90	18.5	12	108	4.7	6.6	7.	51	.01
M-19	O	08-28-90	16	.5	379	6.1	7.4	7.7	226	<.01
M-21	Y	04-10-89	17	--	360	.9	7.8	7.9	146	--
M-22	Y,O	04-10-89	22	--	326	1.4	7.7	7.7	126	--
M-23	Y,O	11-17-89	--	--	--	--	--	--	--	--
		09-03-92	--	--	--	--	--	--	--	--
M-36	S,C	04-11-89	31.5	--	634	3.2	7.4	7.5	318	--
M-40	S,C	08-25-90	29	1.9	476	.5	7.1	7.3	244	.04
M-50	O	04-11-89	15	--	403	6.2	7.9	7.9	196	--
M-49	O	04-11-89	16.5	--	401	5.9	7.9	7.9	196	--
M-51	V	08-20-91	13.5	82	610	2.6	7.7	7.1	210	.12
M-56	V?	08-20-91	14.5	83	495	2.6	7.5	7.1	205	.06
M-60	Y,V	06-12-90	12	--	466	5.0	7.3	7.7	196	--
SP-6	C	11-16-89	--	--	--	--	--	--	--	--
M-61	Y	04-12-89	14.5	--	2,490	3.3	7.7	7.8	512	--
					Marys Creek Area					
SP-7	S	11-16-89	--	--	--	--	--	--	--	--
M-62	Y,O	11-15-89	12	--	455	3.2	7.1	7.6	185	--
SP-8	Y	04-10-89	15	--	458	4.4	7.5	7.9	195	<.01
		09-01-90	18.5	.30	456	3.4	7	7.6	200	<.01
SP-9	Y	11-16-89	--	--	--	--	--	--	--	--
SP-10	V	06-13-90	22	--	406	--	7.5	7.9	180	--
		01-27-92	--	--	--	--	--	--	--	--

Appendix 5. Chemical and isotopic data for ground water in the Carlin trend area, north-central Nevada—Continued

Site name[1]	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, ammonia+ organic dissolved (mg/L as N)	Nitrogen, NO^2+NO^3, dissolved (mg/L as N)	Ortho-phos-phorus, dissolved (mg/L as P)	Carbon, organic, dis-solved (mg/L as C)	Cyanide, total (mg/L as CN)	Cyanide, dis-solved (mg/L as CN)	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)
					Willow Creek Valley					
W-4	<0.01	<0.2	0.36	0.05	--	<0.01	--	22	4.9	22
					Rock Creek Valley					
SP-1	<.01	<.2	.3	<.01	0.3	--	<0.01	51	22	44
R-1	--	--	--	--	--	--	--	--	--	--
	.01	.5	<.05	.02	--	<.01	--	83	14	37
R-6	.01	<.2	3.3	.01	--	<.01	--	39	4.0	32
R-12	.02	.7	1.5	<.01	--	<.01	--	33	5.9	38
					Clovers Area					
SP-2	--	--	--	--	--	--	--	--	--	--
	<.01	<.2	.66	<.01	--	<.01	--	35	4.2	36
C-10	<.01	<.2	1.3	<.01	--	<.01	--	27	6.4	43
					Boulder Flat					
B-2	<.01	.7	<.1	<.01	.5	--	<.01	100	27	72
B-7	<.01	1.2	<.1	<.01	.5	--	<.01	100	25	77
B-14	<.01	<.2	.2	<.01	.3	--	<.01	46	20	23
B-17	<.01	1.3	<.1	.01	.6	--	<.01	96	22	80
B-19	<.01	1.2	<.1	<.01	.6	--	<.01	94	23	81
B-22	.08	1.6	5.9	.06	.7	--	<.01	95	26	58
B-23	<.01	.5	.4	.03	.3	--	<.01	37	14	27
B-30	.01	.2	.9	.02	.4	--	.01	45	20	18
B-32	<.01	<.2	.6	.03	.2	--	<.01	30	10	26
B-45	.01	<.2	<.10	.02	.2	--	<.01	29	18	14
B-53a	<.01	.2	1.2	.01	.3	--	<.01	56	12	39
B-53	<.01	<.2	1.3	.01	.4	--	<.01	54	13	39
B-57	<.01	<.2	.8	.02	.7	--	<.01	74	19	110
B-67	.04	.3	.2	.02	.7	--	<.01	56	11	47
SP-5	--	--	--	--	--	--	--	--	--	--
	<.01	<.2	2.1	<.01	--	<.01	--	33	12	38
B-85	<.01	<.2	.05	.03	--	--	<.01	61	12	46
B-75	<.01	<.2	1.3	.02	--	--	<.01	30	7.4	40
SP-11	<.01	<.2	1.2	.02	--	--	<.01	52	13	38

Appendix 5. Chemical and isotopic data for ground water in the Carlin trend area, north-central Nevada—Continued

Site name[1]	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Arsenic, dissolved (μg/L as As)	Barium, dissolved (μg/L as Ba)	Beryllium, dissolved (μg/L as Be)	Cadmium, dissolved (μg/L as Cd)	Chromium, dissolved (μg/L as Cr)
					Maggie Creek Area					
M-4	--	--	--	--	--	--	--	--	--	--
SP-3	7.2	180	400	.6	17	17	48	<.5	1	<1
M-12	4.3	23	46	.3	38	15	100	<.5	<1	1
SP-4	2.3	3.9	5.7	<.1	26	17	170	<.5	<1	<1
M-19	2.1	7.3	6.3	.2	47	7	100	<.5	<1	3
M-21	10	14	37	.4	75	--	92	<.5	<1	<5
M-22	11	10	34	.5	85	--	89	<.5	<1	<5
M-23	--	11	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--
M-36	11	14	50	.6	28	--	100	<.5	<1	<5
M-40	8.7	11	46	1.2	19	52	110	<.5	2	<1
M-50	8.9	12	27	.3	68	--	150	<.5	<1	<5
M-49	9.6	12	28	.3	71	--	180	<.5	<1	<5
M-51	23	25	65	.5	44	10	96	1	6	2
M-56	15	27	56	.5	50	12	81	.9	3	<1
M-60	8.8	19	51	.5	50	--	110	<.5	<1	<5
SP-6	--	11	--	--	--	--	--	--	--	--
M-61	14	170	530	1	56	--	31	<2	<3	<20
					Marys Creek Area					
SP-7	--	6.2	--	--	--	--	--	--	--	--
M-62	10	16	53	.4	46	--	140	<.5	<1	<5
SP-8	8.5	15	46	.4	54	9	110	<.5	<1	<5
	8.4	18	45	.2	53	8	120	<.5	<1	<1
SP-9	--	--	--	--	--	--	--	--	--	--
SP-10	7.6	17	38	.5	67	--	100	<.5	<1	<5
	--	--	--	--	--	--	--	--	--	--

Appendix 5. Chemical and isotopic data for ground water in the Carlin trend area, north-central Nevada—Continued

Site name[1]	Cobalt, dis-solved (µg/L as Co)	Copper, dis-solved (µg/L as Cu)	Iron, dis-solved (µg/L as Fe)	Lead, dis-solved (µg/L as Pb)	Manga-nese, dissolved (µg/L as Mn)	Molyb-denum, dissolved (µg/L as Mo)	Nickel, dis-solved (µg/L as Ni)	Silver, dis-solved (µg/L as Ag)	Stron-tium, dissolved (µg/L as Sr)	Vana-dium, dissolved (µg/L as V)	Zinc, dis-solved (µg/L as Zn)
					Willow Creek Valley						
W-4	<3	<1	7	<1	<1	<10	<1	<1	190	7	<3
					Rock Creek Valley						
SP-1	<3	<1	26	<1	<1	<10	<1	<1	200	<6	<3
R-1	--	--	--	--	--	--	--	--	--	--	--
	<3	<1	2,000	<1	340	<10	3	<1	360	<6	490
R-6	<3	<1	140	2	40	<10	3	<1	260	<6	900
R-12	<3	<1	540	<1	140	<10	3	<1	250	<6	16
					Clovers Area						
SP-2	--	--	--	--	--	--	--	--	--	--	--
	<3	<1	4	<1	<1	<10	1	<1	160	<6	19
C-10	<3	<1	12	<1	<1	<10	<1	<1	280	23	30
					Boulder Flat						
B-2	<3	<1	320	<1	28	<10	4	<1	620	<6	18
B-7	<3	<1	180	1	13	<10	<1	<1	660	<6	<3
B-14	<3	<1	23	<1	2	<10	1	<1	250	12	31
B-17	<3	<1	370	<1	17	<10	1	<1	680	<6	4
B-19	<3	<1	540	1	64	<10	2	<1	680	<6	<3
B-22	4	1	110	<1	29	20	24	<1	530	8	39
B-23	<3	3	92	2	49	<10	5	<1	230	<6	64
B-30	<3	<1	150	<1	45	<10	<1	<1	160	<6	10
B-32	<3	<1	380	<1	51	<10	5	<1	150	<6	12
B-45	<3	<1	50	<1	2	10	1	<1	150	<6	<3
B-53a	<3	1	5	<1	<1	<10	<1	<1	330	<6	<3
B-53	<3	<1	5	<1	<1	<10	1	<1	350	<6	11
B-57	<3	1	4	<1	<1	10	<1	<1	530	17	<3
B-67	<3	<1	9	<1	110	<10	<1	<1	600	16	3
SP-5	--	--	--	--	--	--	--	--	--	--	--
	<3	<1	8	<1	<1	<10	<1	<1	280	8	14
B-85	<3	<1	34	<1	32	20	<1	<1	370	<6	14
B-75	<3	2	18	<1	4	<10	<1	<1	250	16	400
SP-11	<3	<1	15	<1	27	<10	<1	<1	410	15	31

Appendix 5. Chemical and isotopic data for ground water in the Carlin trend area, north-central Nevada—Continued

Site name[1]	Cobalt, dissolved (µg/L as Co	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Manganese, dissolved (µg/L as Mn)	Molybdenum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)
					Maggie Creek Area						
M-4	--	--	--	--	--	--	--	--	--	--	--
SP-3	<3	<1	18	<1	180	<10	59	<1	680	<6	23
M-12	<3	3	16	1	<1	<10	1	<1	160	7	210
SP-4	<3	1	120	1	38	<10	2	<1	59	<6	610
M-19	<3	1	19	<1	<1	<10	<1	<1	150	11	190
M-21	<3	<10	9	<10	<1	<10	<10	<1	130	23	9
M-22	<3	<10	34	<10	4	<10	<10	<1	110	27	<3
M-23	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--
M-36	<3	<10	69	<10	4	<10	<10	2	350	<6	16
M-40	4	<1	97	<1	60	<10	11	<1	240	<6	160
M-50	<3	<10	9	<10	1	<10	<10	1	330	10	4
M-49	<3	<10	6	<10	<1	<10	<10	<1	360	8	<3
M-51	<3	7	43	1	31	<10	3	<1	270	8	220
M-56	<3	4	17	<1	9	10	1	<1	280	11	78
M-60	<3	<10	4	<10	<1	<10	<10	<1	260	9	4
SP-6	--	--	--	--	--	--	--	--	--	--	--
M-61	<9	<30	15	<10	<1	70	<10	<3	720	56	<9
					Marys Creek Area						
SP-7	--	--	--	--	--	--	--	--	--	--	--
M-62	<3	<10	53	10	90	<10	<10	<1	260	8	12
SP-8	<3	<10	5	<10	1	<10	<10	2	290	9	4
	<3	<1	3	<1	<1	<10	1	<1	280	8	<3
SP-9	--	--	--	--	--	--	--	--	--	--	--
SP-10	<3	<10	4	<10	<1	<10	<10	<1	270	8	<3
	--	--	--	--	--	--	--	--	--	--	--

Appendix 5. Chemical and isotopic data for ground water in the Carlin trend area, north-central Nevada—Continued

Site name[1]	Aluminum, dissolved (µg/L as Al)	Lithium, dissolved (µg/L as Li)	Selenium, dissolved (µg/L as Se)	Mercury, dissolved (µg/L as Hg)	Solids, residue at 180°C, dissolved (mg/L)	Delta deuterium stable isotope ratio (permil)	Delta oxygen-18 stable isotope ratio (permil)	Tritium, total (pCi/L)	Tritium 2 sigma water, whole, total (pCi/L)	Delta carbon-13 stable isotope ratio (permil)	Carbon 14 (percent modern carbon)
					Willow Creek Valley						
W-4	<10	16	<1	<0.1	200	-127	-16.4	7.6	0.8	--	--
					Rock Creek Valley						
SP-1	<10	43	<1	<.1	366	-129	-16.4	1.3	.3	--	--
R-1	--	--	--	--	--	-132	-16.7	<.3	.6	--	--
	10	100	<1	<.1	447	--	--	--	--	-10.3	--
R-6	20	24	<1	<.1	310	-126	-15.6	<.6	.6	-10.9	50
R-12	<10	29	<1	<.1	273	-125	-15.8	<.3	.6	-11.8	50
					Clovers Area						
SP-2	--	--	--	--	--	-127	-16.2	<.3	.6	--	--
	40	60	<1	<.1	237	--	--	--	--	-10.3	42
C-10	20	89	<1	<.1	292	-125	-15.8	.9	.6	-10.4	29
					Boulder Flat						
B-2	<10	290	<1	<.1	571	-130	-15.9	--	--	--	--
B-7	<10	330	<1	<.1	582	-132	-16.2	3.1	.3	--	--
B-14	<10	25	1	<.1	321	-129	-16	.6	.3	--	--
B-17	<10	350	<1	<.1	589	-130	-16.4	--	--	--	--
B-19	<10	350	<1	<.1	561	-131	-16.2	<.3	.3	--	--
B-22	20	150	5	3.3	559	-128	-15.8	<.3	.3	--	--
B-23	<10	15	2	<.1	281	-125	-16	--	--	--	--
B-30	<10	11	1	<.1	280	-125	-15.5	19	.6	--	--
B-32	<10	6	1	<.1	241	-125	-15.5	<.3	.3	--	--
B-45	<10	23	<1	<.1	192	-129	-16.6	<.3	.3	--	--
B-53a	<10	81	<1	<.1	364	-130	-16.4	--	--	--	--
B-53	<10	67	<1	<.1	357	-129	-16.1	<.3	.3	--	--
B-57	<10	82	2	<.1	662	-123	-13.6	--	--	--	--
B-67	<10	88	1	<.1	379	-132	-16.7	<.3	.3	--	--
SP-5	--	--	--	--	--	-125	-15.6	<.3	.6	--	--
	20	38	<1	<.1	277	--	--	--	--	-12.8	61
B-85	<10	45	<1	<.1	362	-122	-15.6	59	3.8	--	--
B-75	10	24	<1	.3	290	-125	-15.6	--	--	--	--
SP-11	10	24	<1	.2	344	-125	-15.8	--	--	--	--

Appendix 5. Chemical and isotopic data for ground water in the Carlin trend area, north-central Nevada—Continued

Site name[1]	Aluminum, dissolved (µg/L as Al)	Lithium, dissolved (µg/L as Li)	Selenium, dissolved (µg/L as Se)	Mercury, dissolved (µg/L as Hg)	Solids, residue at 180°C, dissolved (mg/L)	Delta deuterium stable isotope ratio (permil)	Delta oxygen-18 stable isotope ratio (permil)	Tritium, total (pCi/L)	Tritium 2 sigma water, whole, total (pCi/L)	Delta carbon-13 stable isotope ratio (permil)	Carbon 14 (percent modern carbon)
Maggie Creek Area											
M-4	--	--	--	--	--	-132	-17.2	<.3	.6	--	--
SP-3	10	34	<1	<.1	1240	-123	-15.7	--	--	--	--
M-12	10	10	4	<.1	233	-125	-16	37	1.3	--	--
SP-4	150	<4	<1	<.1	96	-123	-15.6	60	1.9	--	--
M-19	<10	13	<1	.2	230	-131	-16.6	--	--	--	--
M-21	--	24	--	--	--	-137	-17.9	<.3	.6	--	--
M-22	--	28	--	--	--	-139	-17.8	6	3.2	--	--
M-23	--	--	--	--	--	-141	-18	--	--	--	--
	--	--	--	--	--	--	--	--	--	-8.8	4.3
M-36	--	190	--	--	--	-128	-16.9	6	3.8	--	--
M-40	<10	110	19	<.1	288	-132	-16.6	--	--	--	--
M-50	--	24	--	--	--	-127	-17.1	<.5	.6	--	--
M-49	--	22	--	--	--	-127	-16.8	<.3	.6	--	--
M-51	50	61	<1	1.6	368	-123	-16	--	--	--	--
M-56	20	54	1	<.1	345	-128	-16.2	--	--	--	--
M-60	--	49	--	--	--	-127	-16.2	33	1.9	--	--
SP-6	--	--	--	--	--	-127	-16.2	--	--	--	--
M-61	--	64	--	--	--	-125	-15.8	29	4.5	--	--
Marys Creek Area											
SP-7	--	--	--	--	--	-128	-16.5	12	.4	--	--
M-62	--	48	--	--	--	-128	-16.2	49	3.2	--	--
SP-8	--	36	2	<.1	--	-127	-16.4	22	4.5	--	--
	<10	39	2	<.1	293	-128	-16.2	--	--	--	--
SP-9	--	--	--	--	--	-133	-16.4	<.3	.3	--	--
SP-10	--	28	--	--	--	--	--	<.3	.6	--	--
	--	--	--	--	--	-128	-16.4	--	--	--	--

[1] See figure 15 for site locations and appendixes 2 and 4 for site information.

[2] Measured by incremental titration.

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