Baseline Characterization Report for Clark, Lincoln, and White Pine Counties Groundwater Development Project

January 2008

PREFACE

This report was prepared by the Southern Nevada Water Authority. The U.S. Geological Survey served as technical advisor to the Bureau of Land Management in the review of this report.

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ACRONYMS

BLM	Bureau of Land Management
DEM	digital elevation model
DRI	Desert Research Institute
EPA	Environmental Protection Agency
ET	evapotranspiration
GBNP	Great Basin National Park
GIS	geographic information system
GMWL	global meteoric water line
GSLDFS	Great Salt Lake Desert Flow System
GVFS	Goshute Valley Flow System
HA	hydrographic area
LMWL	local meteoric water line
MAT	mean annual air temperature
MCL	Safe Drinking Water Act Maximum Contaminant Level
MVFS	Meadow Valley Flow System
NBMG	Nevada Bureau of Mines and Geology
NDWR	Nevada Division of Water Resources
NWIS	National Water Information System
PDF	Portable Document Format
SMCL	Safe Drinking Water Act Secondary Maximum Contaminant Level
SNWA	Southern Nevada Water Authority
TDS	total dissolved solids
UDWR	Utah Division of Water Rights
URL	Uniform Resource Locator
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
WRFS	White River Flow System

ABBREVIATIONS

°C	degrees Celsius
°F	degrees Fahrenheit
afy	acre-feet per year
amsl	above mean sea level
bgs	below ground surface

ABBREVIATIONS (CONTINUED)

cfs	cubic feet per second
ft	foot
Ga	billion years
gpm	gallons per minute
L	liter
Ma	million years
mg	milligram
µg	microgram
mi	mile
mL	milliliter
pCi	picocurie

1.0 INTRODUCTION

This report describes the baseline geologic and hydrologic data compilation and analysis efforts conducted by the Southern Nevada Water Authority (SNWA) in support of the Clark, Lincoln, and White Pine Counties Groundwater Development Project. This report includes descriptions of the geology, streams and springs, wells, water chemistry, and water rights for selected basins of eastern Nevada and western Utah.

1.1 Project Background

The Clark, Lincoln, and White Pine Counties Groundwater Development Project (hereafter referred to as the Project) proposes to develop unused groundwater resources within selected basins of eastern Nevada where SNWA holds groundwater rights and applications. These basins include Coyote Spring, Delamar, Dry Lake, Cave, Spring, and Snake valleys (hereafter referred to as the Project Basins) and are depicted in Figure 1-1.

In 2004, SNWA applied to the Bureau of Land Management (BLM) for issuance of rights-of-way to construct project facilities, most of which will be located on public lands administered by the BLM. These facilities include groundwater production wells, water conveyance facilities, water storage and regulating reservoirs, and power facilities. BLM issuance of these rights-of-way to construct, maintain, and operate these facilities requires a federal action for which the National Environmental Policy and Endangered Species Acts must be considered. BLM has determined that preparation of an environmental impact statement is required to assess the potential environmental effects that may result from permitting the rights of way, including the potential indirect effects of the proposed groundwater development.

1.2 Purpose

The purpose of this summary report is to document the current baseline conditions of geology, streams, springs, groundwater levels, water chemistry, and water rights for the Project Basins as well as a larger study area (Figure 1-1). This work will support the development of an Environmental Impact Statement for the Project as well as provide baseline information for incorporation into a groundwater flow model for the region.

1.3 Document Organization

This document consists of eight sections, one appendix, and a CD-ROM containing four electronic data volumes and associated data sets. A brief description of the contents of each is provided:

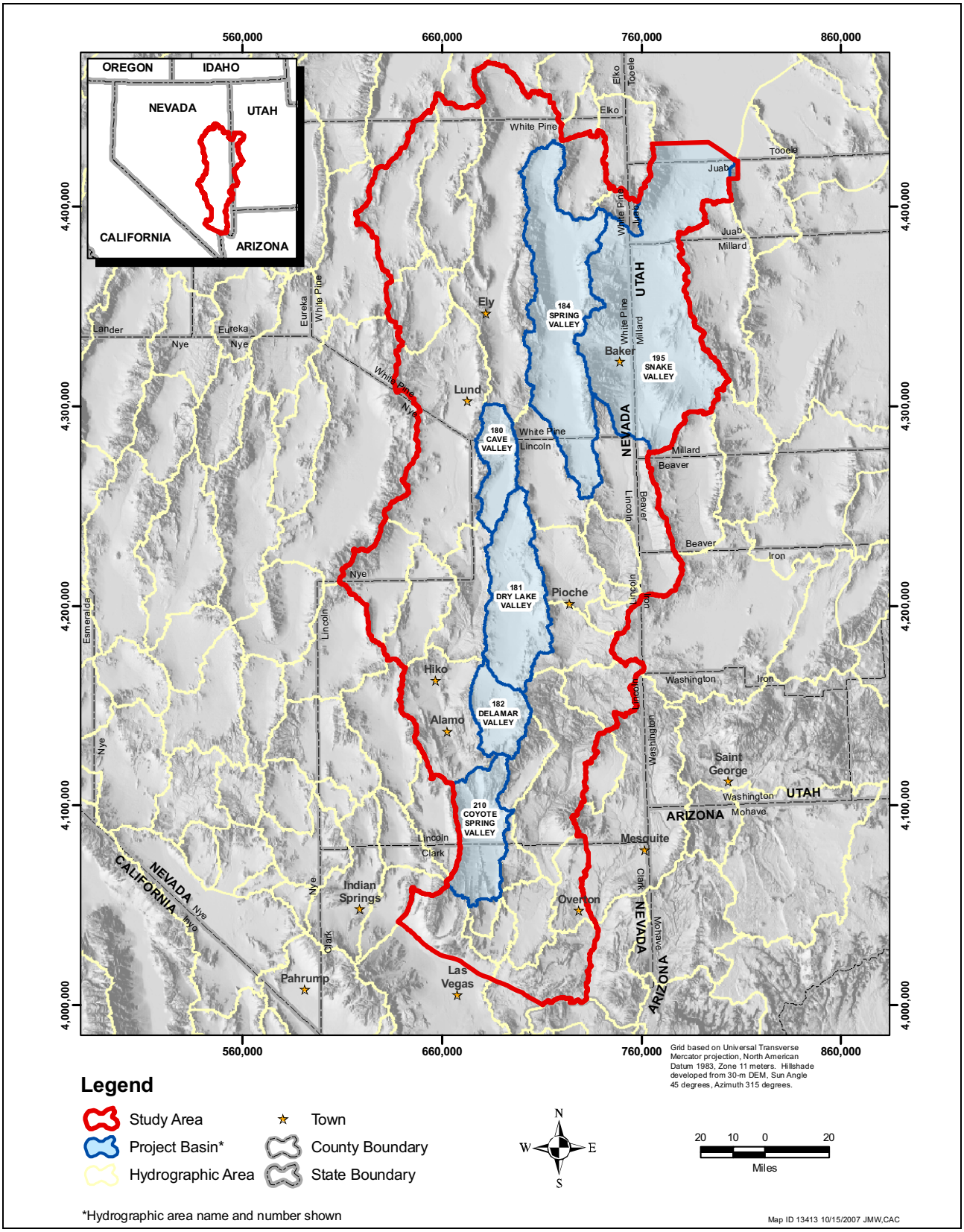

Figure 1-1
Location of Project Basins and Study Area

- Section 1.0 provides a description of the project background, the purpose of the investigations, and an overview of the contents of this report.

- Section 2.0 describes the study area and provides a discussion on physiography, climate, vegetation, and regional flow systems.

- Section 3.0 briefly describes the geology of the study area and references the *Geology of White Pine and Lincoln Counties and Adjacent Areas, Nevada and Utah: The Geologic Framework of Regional Groundwater Flow Systems* report that has been provided as Volume 1 on the CD-ROM accompanying this report.

- Section 4.0 briefly describes the surface water resources of the study area and references the *Physical Settings of Selected Streams in Clark, Lincoln, and White Pine Counties Groundwater Development Project* report that has been provided as Volume 2 and *Physical Settings of Selected Springs in Clark, Lincoln, and White Pine Counties Groundwater Development Project* report that has been provided as Volume 3 on the CD-ROM accompanying this report.

- Section 5.0 briefly describes the groundwater resources of the study area and references the *Water-Level Data Compilation and Evaluation for Clark, Lincoln, and White Pine Counties Groundwater Development Project* report that has been provided as Volume 4 on the CD-ROM accompanying this report.

- Section 6.0 describes the water chemistry of the Project Basins.

- Section 7.0 describes the water rights within the Project Basins.

- Section 8.0 provides a list of references used in this report.

- Appendix A provides a description of the contents of the CD-ROM.

  - Volume 1 is a data volume titled *Geology of White Pine and Lincoln Counties and Adjacent Areas, Nevada and Utah: The Geologic Framework of Regional Groundwater Flow Systems* (SNWA, 2007a) that is included on the CD-ROM.

  - Volume 2 is a data volume titled *Physical Settings of Selected Streams in Clark, Lincoln, and White Pine Counties Groundwater Development Project* (SNWA, 2007b) that is included on the CD-ROM.

  - Volume 3 is a data volume titled *Physical Settings of Selected Springs in Clark, Lincoln, and White Pine Counties Groundwater Development Project* (SNWA, 2007c) that is included on the CD-ROM.

  - Volume 4 is a data volume titled *Water-Level Data Compilation and Evaluation for Clark, Lincoln, and White Pine Counties Groundwater Development Project* (SNWA, 2007d) that is included on the CD-ROM.

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2.0 DESCRIPTION OF HYDROLOGIC STUDY AREA

The area of study for the baseline characterization investigation encompasses the Project Basins and the additional basins contained within the study area shown on Figure 2-1. A description of each of the Project Basins and a description of the physiographic setting, climate, vegetation, and regional flows systems is provided for the study area.

2.1 Project Basins

The following sections provide a brief description of the Project Basins that are shown on Figure 2-1.

2.1.1 Spring Valley

Spring Valley is approximately 120 mi long and averages 16 mi wide. This project basin is part of the Great Salt Lake Desert flow system. Spring Valley is bounded by the Schell Creek Range to the west, the Antelope Range to the north, the Snake Range and the Limestone Hills to the east, the Wilson Creek Range to the south, and the Fortification Range to the southwest. Most of Spring Valley is in White Pine County except for the very southern portion located in Lincoln County. U.S. Highway 50 bisects the valley and U.S. Highway 93 runs along the valley's western flank. The predominant uses of water in the valley are for irrigation and stockwater (see Section 7.0).

2.1.2 Snake Valley

Snake Valley is approximately 95 mi long and 40 mi wide near Garrison, Utah. This project basin is part of the Great Salt Lake Desert flow system. Snake Valley is bounded by the Snake Range to the west, the Confusion Range, Conger Range, and Burbank Hills to the east, and a low-alluvial divide to the south. To the north, Snake Valley opens to the Great Salt Lake Desert. U.S. Highway 50 traverses the southern one-third of the valley and runs east-west through the Snake Range, then exits the valley in the east. The predominant use of water in the valley is for irrigation and stockwater (see Section 7.0).

2.1.3 Cave Valley

Cave Valley is approximately 40 mi long and averages approximately 12 mi in width. This project basin is part of the White River Flow System (WRFS). The valley is bounded in the east by the southern portion of the Schell Creek Range and the smaller Fairview Range, and in the west by the Egan Range. The southern portion of the valley is truncated where the Egan and Schell Creek ranges merge. Cave Valley is accessible using improved gravel roads that enter the valley through Shingle Pass (west side from SR 318), Sidehill Pass (east side from U.S. Highway 93), and other smaller and

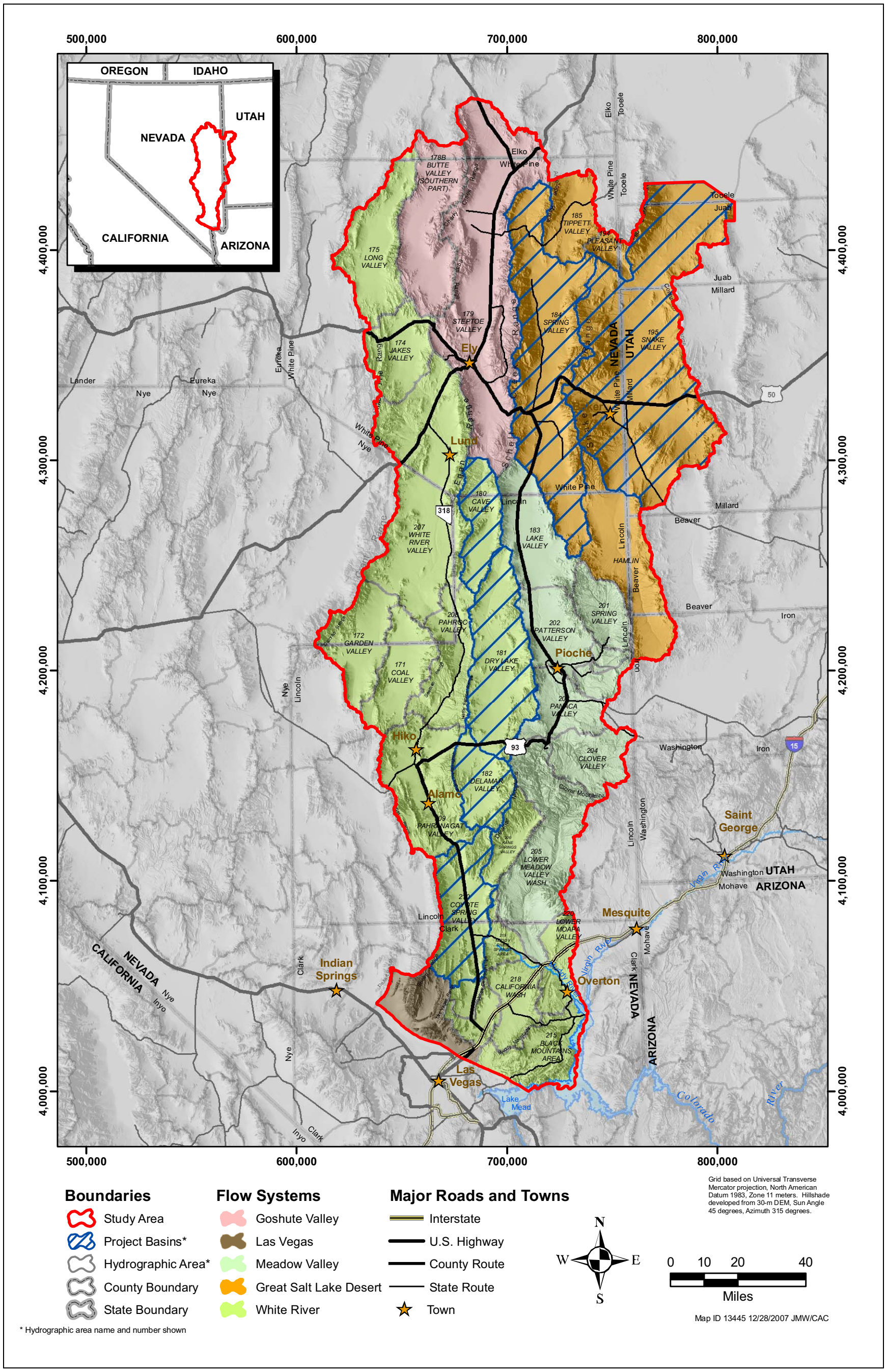


Figure 2-1
Project Basins

less maintained dirt roads. The predominant use of water in the valley is for stockwater (see Section 7.0).

2.1.4 Dry Lake Valley

Dry Lake Valley is approximately 60 mi long and averages approximately 20 mi wide. This project basin is part of the White River flow system. The valley is bounded to the west by the southern extension of the Schell Creek Range. The Pahroc, Fairview, Bristol, and Highland Peak ranges bound the valley to the east. Dry Lake Valley is accessible using improved gravel roads that enter the valley from the south via U.S. Highway 93, and from the east via U.S. Highway 93 in Lake Valley through Bristol Pass. There has been minimal development of water in this valley with the predominant use being for stockwater (see Section 7.0).

2.1.5 Delamar Valley

Delamar Valley is approximately 25 mi long and averages approximately 17 mi wide. This project basin is part of the WRFS. The valley is bounded to the east by the Delamar Mountains and to the west by the Pahroc Range. Delamar Valley is accessible from U.S. Highway 93, which crosses the valley in the north. There has been minimal development of water in this valley with the predominant use being for stockwater (see Section 7.0).

2.1.6 Coyote Spring Valley

Coyote Spring Valley is approximately 45 mi long and approximately 14 mi wide. This project basin is part of the WRFS. The valley is bounded to the west by the Sheep Range. The Delamar Mountains, Meadow Valley Mountains, and Arrow Canyon Range bound the valley to the east. U.S. Highway 93 traverses the valley from north to south. The predominant uses of water in the valley are industrial and municipal (see Section 7.0).

2.2 Physiographic Setting

The Project Basins are within the Basin and Range Physiographic Region described by Fenneman (1931). The Basin and Range Region is a series of parallel to subparallel, north-trending mountain ranges separated by elongated alluvial valleys (basins). The basins and ranges are formed by generally north-striking normal faults that elevated the ranges above the valleys. According to Rowley and Dixon (2001), the Basin and Range Province has undergone the most severe structural extension of the continental crust in the world. The alluvial valleys are further classified by Heath (1984) as being in the Alluvial Basins Ground Water Region. The basins of interest are also part of the carbonate rock province of eastern Nevada and western Utah described by Plume and Carlton (1988). Figure 2-2 depicts the relation of the Project Basins to the Basin and Range and carbonate rock provinces.

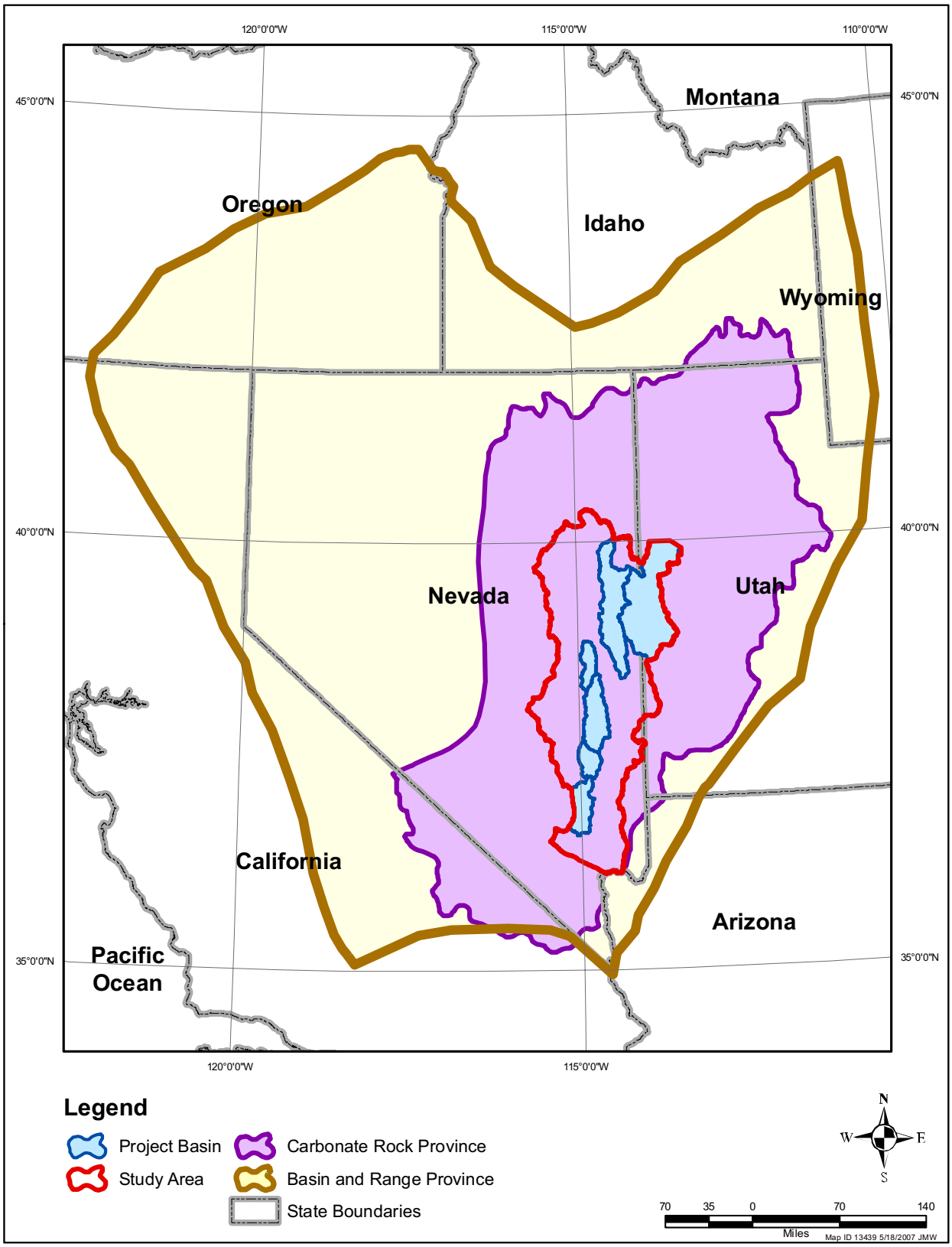


Figure 2-2
Physiographic Setting of Project Basins

2.3 Climate

The climate within the study area is characterized as being predominantly dry, with large ranges in daily temperature, infrequent severe storms, and great variation associated with elevation changes. There are three geographic factors influencing the region's climate: latitude, elevation, and the barrier provided by Pacific mountain systems to the west, which prevent winds off the Pacific Ocean from reaching Nevada (Houghton et al., 1975). Precipitation in the area varies by season and is the result of Pacific fronts, Great Basin lows, and summer thundershowers. For much of the study area annual precipitation ranges from 8 to 12 in. The amount of precipitation varies across the study area with Ely, Nevada, receiving 9 in. per year while Las Vegas receives 4.2 in. (NDWR, 2007a). Large precipitation events are more common in the winter months, but short duration and high intensity rainfall events associated with isolated thunderstorms are common in the summer. Temperatures within the study area have large annual variations. The mean annual temperatures across the area vary by approximately 20°F and range from the mid-40s to the mid-60s. This temperature variability is also observed on a daily basis. The clear skies of Nevada allow for heating of the ground in the day and radiational cooling at night. This results in temperature variability in local areas over a 24-hour period. Wind speed and direction are controlled by prevailing storm tracks and orographic effects induced by basin and range topography. Evaporation rates within the study area are controlled by low humidity, abundant sunshine, and dry winds. Within the study area annual evaporation rates range from approximately 45 to 72 in. (Houghton et al., 1975). Additional information and analysis of climatological data will be presented in the report titled Conceptual Model of Groundwater Flow for Clark, Lincoln, and White Pine Counties Groundwater Development Project (SNWA, 2007e).

2.4 Vegetation

The study area encompasses the Mojave Desert and the Great Basin ecological systems. The exact boundary between the Mojave Desert and the Great Basin is vague, but the two systems can be distinguished by the occurrence of differing vegetation communities and plant species.

The Mojave Desert scrub, or creosote bush scrub, is the dominate vegetation community within the Mojave Desert. The occurrence of this vegetation community is one of the main characteristics distinguishing the Mojave Desert from the Great Basin. Creosote bush (*Larrea tridentata*) and white bursage (*Ambrosia dumosa*) dominate this community; however, the Mojave Desert is a diverse landscape with a variety of other shrubs, yuccas (*Yucca spp.*), cholla (*Opuntia spp.*) and cacti.

The valley floors of the Great Basin are typical of a xeric sagebrush-shrubland community with big sagebrush (*Artemisia tridentata*) as the dominant species. Big sagebrush is not typically found in the Mojave Desert. Common companions include greasewood (*Sarcobatus vermiculatus*), green and rubber rabbitbrush (*Chrysothamnus viscidiflorus* and *Chrysothamnus nauseosus*), snakeweed (*Gutierrezia sarothrae*), spiny hopsage (*Grayia spinosa*) and littleleaf and gray horsebrush (*Tetradymia glabrata* and *Tetradymia canescens*). More saline-tolerant species include shadscale (*Atriplex confertifolia*), saltgrass (*Distichlis spicata*), and winterfat (*Ceratoides lanata*). Greasewood can also be found to occur on and around playas or in salt-encrusted soils. Riparian species such as cottonwood (*Populus fremontii*), willow (*Chilopsis linearis*), tules (*Scirpus spp.*), and cattails (*Typha spp.*) occur within the spring complexes. The pinyon-juniper community dominates the higher elevations of the Great Basin. The dominant trees are pinyon pine (*Pinus monophylla*) and Utah

juniper (*Juniperus osteosperma*). Shrubs in this community can include snakeweed, green and rubber rabbitbrush, western serviceberry (*Amelanchier alnifolia*), various currants and gooseberries and snowberry (*Symphoricarpos spp.*) (Mozingo, 1987).

Of particular interest are a group of plants that are referred to as phreatophytes. Phreatophytes were first defined by Meinzer (1927) as plants that are able to obtain a perennial and secure supply of water by sending their roots down to the groundwater table. This plant assemblage is composed primarily of greasewood, saltgrass, and rabbitbrush. Spiny hopsage, shadscale, and big sagebrush, although not generally considered phreatophytic, can occur within this assemblage. The riparian species mentioned above are also of interest. Phreatophytes have the ability to use both soil moisture and shallow groundwater to survive in desert environments via transpiration. Evapotranspiration (ET), a combination of evaporation and transpiration of water, is a key component when estimating groundwater discharge in a basin; therefore, identifying the location of phreatophytes within a basin and quantifying their groundwater use are important when evaluating basin water budgets.

The distribution of the phreatophytic areas for each valley within the study area will be described in further detail in the report titled Conceptual Model of Groundwater Flow for Clark, Lincoln, and White Pine Counties Groundwater Development Project (SNWA, 2007e).

2.5 Regional Flow Systems

The regional groundwater flow systems prevailing within the study area and vicinity are composed of multiple hydrographic areas (HA), also called valleys or basins. In many of the northern valleys, ET is the principal source of groundwater discharge. However, the valleys that are in the central-southern part of the system, have a significant amount of groundwater discharge as subsurface outflow through the carbonate aquifer. Although numerous structural features (Dettinger et al., 1995; SNWA, 2003a) compartmentalize different parts of the carbonate aquifer system, the hydraulic connectivity of the valleys is believed to be expansive.

A flow system is comprised of a set of hydraulically connected valleys. A single valley that is not hydraulically connected to other valleys can form its own flow system. Several flow systems, defined by Harrill et al. (1988) and Nichols (2000), occur within the study area. The primary flow systems of interest to this project are the White River, Goshute Valley, Great Salt Lake Desert, and Meadow Valley flow systems (Figure 2-1).

2.5.1 White River Flow System

The WRFS is the longest flow system in Nevada. Eakin (1966) and Harrill et al. (1988) consider this flow system to be part of the Colorado Flow System which also includes the Meadow Valley Flow System (MVFS). For the purpose of this report, however, the WRFS and MVFS will be addressed separately.

This flow system extends from Long Valley in the north to Lower Moapa Valley in the south, and is comprised of eighteen HAs. The HAs that make up this flow system are Long, Jakes, White River, Cave, Dry Lake, Delamar, Garden, Coal, Pahroc, Pahranagat, Kane Springs, Coyote Spring, Muddy

River Springs Area, Hidden, Garnet, California Wash, Black Mountain, and Lower Moapa valleys. The straight-line distance from the northern end of Long Valley to the Colorado River is about 250 mi. The maximum width of the flow system is from the western edge of Garden Valley to the eastern edge of Dry Lake Valley, nearly 60 mi. The flow system is bounded by Maverick Springs, White Pine, Granite, Quinn Canyon, Pahranagat, and Sheep mountain ranges to the west; and by the Egan, Schell Creek, Bristol, Highland, and Chief ranges, and the Clover, Delamar, and Muddy mountains to the east.

Groundwater moves through carbonate rocks that comprise parts of the surrounding mountain ranges and underlie basin fill. Flow is generally from north to south, from areas of recharge on high altitude mountain ranges to areas of groundwater discharge. Planert and Williams (1995) state that 70 percent of the recharge to the WRFS is estimated to occur in the northern half of the WRFS because of the higher altitudes and lower temperatures. Major areas of groundwater recharge in the WRFS include the Egan Range, Butte Mountains, and White Pine Range (Harrill and Prudic, 1998). North-south trending normal faults and permeability within the carbonate rocks provide the most likely conduits for groundwater movement.

A dominant hydrologic feature of this flow system is the large groundwater discharge from numerous carbonate springs scattered throughout the area. For example, the springs located in Pahranagat Valley and the Muddy Rivers Springs Area. In Pahranagat Valley, Hiko, Crystal, and Ash springs have a combined spring discharge of approximately 35 cfs or about 25,000 afy (Eakin, 1963). In the Muddy Rivers Springs Area, the Muddy Springs discharge about 37,000 afy (adjusted for ET) and are virtually unchanged since first estimated by Eakin (1966). The Muddy Springs form the headwaters of the Muddy River, a tributary to the Colorado River and present-day Lake Mead.

2.5.2 Meadow Valley Flow System

Nine valleys comprise the MVFS: Lake, Patterson, Spring (HA 201), Eagle, Rose, Dry, Panaca, Clover, and Lower Meadow Valley Wash. This flow system is tributary, both in groundwater and surface water, to the WRFS and is part of the Colorado Flow System previously mentioned. The MVFS is roughly parallel to the WRFS starting in Lake Valley and ending where Meadow Valley Wash joins the Muddy River (WRFS) in Upper Moapa Valley.

The MVFS is bounded to the west by the Bristol, Highland Peak, and Chief ranges, and the Delamar and Meadow Valley mountains; and by the Fortification and Wilson Creek ranges, and the Clover and Mormon mountains to the east. Groundwater flow in the MVFS is generally north to south through both basin-fill materials and the underlying carbonate rock, where present. Areas of groundwater recharge in the MVFS include the Fairview, Fortification, and Wilson Creek Ranges in Lake Valley, and the Highland Range and the Clover Mountains in Panaca Valley (LVVWD, 2001).

2.5.3 Goshute Valley Flow System

Southern Butte, Goshute, and Steptoe valleys comprise this three-valley system as defined by Harrill et al. (1988). Though SNWA does not have groundwater applications in the Goshute Valley

Flow System (GVFS), baseline conditions have been established in Steptoe and Butte valleys to evaluate future changes in the groundwater system.

The Cherry Creek Mountains and Egan Range bound Steptoe Valley to the west, and the Schell Creek Range forms the eastern boundary of the flow system. Groundwater discharge in Steptoe Valley is primarily through ET by phreatophytes, with a minor amount of groundwater outflow to the north to Goshute Valley. Major areas of groundwater recharge for the GVFS include the Egan Range, Cherry Creek Mountains, and the Schell Creek Range (Harrill and Prudic, 1998). No surface-water outflow occurs from Steptoe Valley. Butte Valley is bound by the Butte Mountains to the west and the Cherry Creek Mountains and Egan Range to the east.

2.5.4 Great Salt Lake Desert Flow System

Twenty HAs were considered by Harrill et al. (1988) to comprise the Great Salt Lake Desert Flow System (GSLDFS). The hydrographic areas include Grouse Creek Valley, Pilot Valley, Deep Creek Valley, Snake Valley, Pine Valley, Wah Wah Valley, Tule Valley, Fish Springs Flat, Dugway-Government Creek Valley, West Park Valley, West Part of Great Salt Lake Desert, Spring Valley, Tippett Valley, Northern and Southern Antelope valleys, Herrell-Brush Creek, Toano-Rock Spring, Rocky Butte Area, Montello-Crittenden, and Pilot Creek Valley. Rush (1968), however, considered the Snake Valley hydrographic area to be composed of 3 separate hydrographic areas including Hamlin, Snake, and Pleasant valleys. Only Spring, Hamlin, and Snake valleys were extensively studied as part of the baseline characterization for this report.

The GSLDFS found in the study area is bounded to the west by the Schell Creek Range and to the east by the San Francisco, House, and Fish Springs mountain ranges. Other major mountain ranges throughout the area include the Wilson Creek, Snake, Deep Creek, and Confusion ranges. There are no perennial streams that connect any two of the GSLDFS valleys, and the only interbasin ephemeral drainage is from Hamlin Valley Wash to Snake Valley. According to Harrill et al. (1988), groundwater flow in the GSLDFS is generally from the south to the north-northeast in the carbonate-rock aquifer, and northerly from Snake Valley to the Great Salt Lake Desert in the basin-fill. Major areas of groundwater recharge for the GSLDFS include the Schell Creek Range, Snake Range, and Deep Creek Range (Harrill and Prudic, 1998).

3.0 GEOLOGIC CONDITIONS

The SNWA has studied and thoroughly described the stratigraphy, structural geology, and hydrogeology of the study area in a report titled "Geology of White Pine and Lincoln Counties and Adjacent Areas, Nevada and Utah: The Geologic Framework of Regional Groundwater Flow Systems" (SNWA, 2007a). An electronic version of the report has been attached as Volume 1 on the CD-ROM accompanying this report. This section provides an overview of the geologic information presented in that report.

3.1 Geology and Stratigraphy

The geology of the geologic study area (Plates 1 and 2, in Volume 1) is characterized by a thick stratigraphic sequence of rocks from Proterozoic to Holocene age that has been structurally deformed during several tectonic episodes. The thick sequence includes three major assemblages that are important aquifers:

- Carbonate aquifer of Paleozoic age
- Volcanic rocks of Tertiary age
- Basin-fill sediments of Tertiary to Quaternary age.

Along with the aquifers are moderate to thick confining units or low-permeability units, including:

- Early to Late-Proterozoic metamorphic and igneous rocks
- Late Proterozoic to Lower Cambrian quartzite and shale
- Shale, sandstone, and conglomerate of Mississippian age
- Triassic to Cretaceous shale, siltstone, and sandstone
- Mesozoic to Cenozoic plutons.

Three tectonic episodes, plus an intervening episode of extensive volcanism, have affected the hydrogeology of the region. The oldest tectonic episode is the Antler deformation (Late Devonian to Late Mississippian). This episode included east-verging thrust sheets. The second tectonic episode was the Sevier deformation (Jurassic through early Cenozoic) that resulted in east-verging thrust sheets in which Paleozoic carbonate rocks were placed over each other and over younger rocks.

In Eocene to middle Miocene time, volcanism resulted in the development of thick blankets of ash-flow tuff and related lava flows, including many scattered calderas that were the sources of the tuff. The caldera margins formed new groundwater flow paths and barriers.

The third tectonic episode is the middle Miocene to Holocene basin-range deformation that shaped the current topography of the Great Basin, including most of Nevada and parts of western Utah and

southeastern California. Basin-range faulting produced graben and horst topography, resulting in deep basins and relatively high mountain ranges, generally oriented north-south. In general, the mountain ranges provide areas of groundwater recharge, and accumulations of alluvial fill within the basins provide areas of aquifer storage and avenues of groundwater flow. Basin-range faults may provide hydrogeologic barriers to groundwater flow. But it has also been interpreted that more commonly, basin-range faults provide conduits to groundwater flow, especially from north to south. These north-south conduits may double as barriers to east or west flow in certain flow systems such as the GSLDFS.

The age of the rocks in the geologic study area is summarized in a Geologic Time Scale chart (Figure 3-1). The oldest rocks are Early and Late Proterozoic metamorphic and igneous units. These rocks are overlain by thick sequences of quartzite and subordinate shale, which are locally metamorphosed to slate and schist, of Late Proterozoic age. The Proterozoic rocks pass conformably upward into rocks of similar type and thickness, though less metamorphosed, that are Late Proterozoic to Early Cambrian in age. During Middle Cambrian time, carbonate deposition was initiated, and thick sequences of marine limestone and dolomite were deposited from the Middle Cambrian through the Permian Periods. These rocks make up the carbonate aquifer of Nevada and adjacent parts of Utah and range in thickness between 5,000 and 30,000 ft throughout this area (Harrill and Prudic, 1998).

Locally, marine sandstone and shale are intertongued with the carbonates. These units are not interpreted to form significant impediments to regional groundwater flow, with the exception of the Chainman Shale and related shale and sandstone of Late Mississippian age. This unit locally exceeds 2,000 ft in thickness, and in all but the southern part of the geologic study area, this unit divides the carbonate aquifer into two distinct aquifers, the lower and upper carbonate aquifers. The Chainman Shale and related clastic units were derived from erosion of a structural highland, the Antler Highland, in and northwest of the geologic study area. The highland, made up in large part of the Roberts Mountain allochthon, was produced by the Antler compressive deformational event.

Mesozoic rocks in the geologic study area are largely clastic, nonmarine, and thin where deposited, but in most places they have been removed by erosion. They and older rocks were deformed during the Sevier deformational event. At this time, the geologic study area was a highland, also known as a hinterland, and an episode of erosion of the area removed most Mesozoic rocks.

Plutons of Late Jurassic to Paleocene age were intruded during pulses during Sevier deformation. These plutons probably had associated extrusive volcanic units, but all of these units have been removed by erosion. Mesozoic plutons commonly led to significant mineralization in the geologic study area.

Middle Tertiary (Eocene to middle Miocene) time marked the beginning of calc-alkaline intrusion and resulting volcanism, the terminal product of subduction beneath western North America that began in the Triassic Period (Atwater, 1970; Lipman et al., 1972; Hamilton, 1995). Above individual source plutons, vent deposits included andesitic and dacitic lava flows and volcanic mudflow breccia that locally exceeded several thousand feet of thickness. Caldera deposits consist of dacitic to rhyolitic ash-flow tuffs, which are similarly thick within individual calderas. Farther outward from the vents above the plutons, lava flows are sparse because they do not flow more than a few miles

ERA	PERIOD	EPOCH	TIME	PROCESSES AND ROCK TYPES
Cenozoic	Quaternary	Holocene Pleistocene	Present 1.8 Ma	Valley-Fill Alluvium
	Tertiary	Pliocene Miocene Oligocene Eocene Paleocene	*5 Ma* *38 Ma* 65 Ma	Start Basin-Range Faulting (20 Ma) Volcanics and Older Sediments Emplacement of Calderas
Mesozoic	Cretaceous Jurassic Triassic		248 Ma	Sevier Orogeny, Intrusions Continental Sediments
Paleozoic	Permian Pennsylvanian Mississippian Devonian Silurian Ordovician Cambrian		543 Ma	Antler Orogeny, Intrusions Chainman Shale, Carbonates Quartzite and shale
Precambrian			4.5 Ga	

Source: Adapted from Geological Society of America, 1999

Figure 3-1
Geologic Time Scale, Including Rock Type and Tectonic Events

from their vents, but outflow ash-flow tuffs accumulated to aggregate thicknesses exceeding 1,000 ft in most of the geologic study area.

Starting at about 20 Ma ago (middle Miocene), subduction ceased and extensional deformation increased in the map area (Christiansen and Lipman, 1972; Christiansen and Yeats, 1992; Rowley and Dixon, 2001). Basin-range deformation, characterized by vertical (normal) faulting, began to form alternating mountain ranges and valley basins. The main pulse of this basin-range faulting began about 10 Ma ago, during which time the present topography formed. As valleys formed, they were filled by debris eroded from the adjacent mountain range, creating basin-fill deposits.

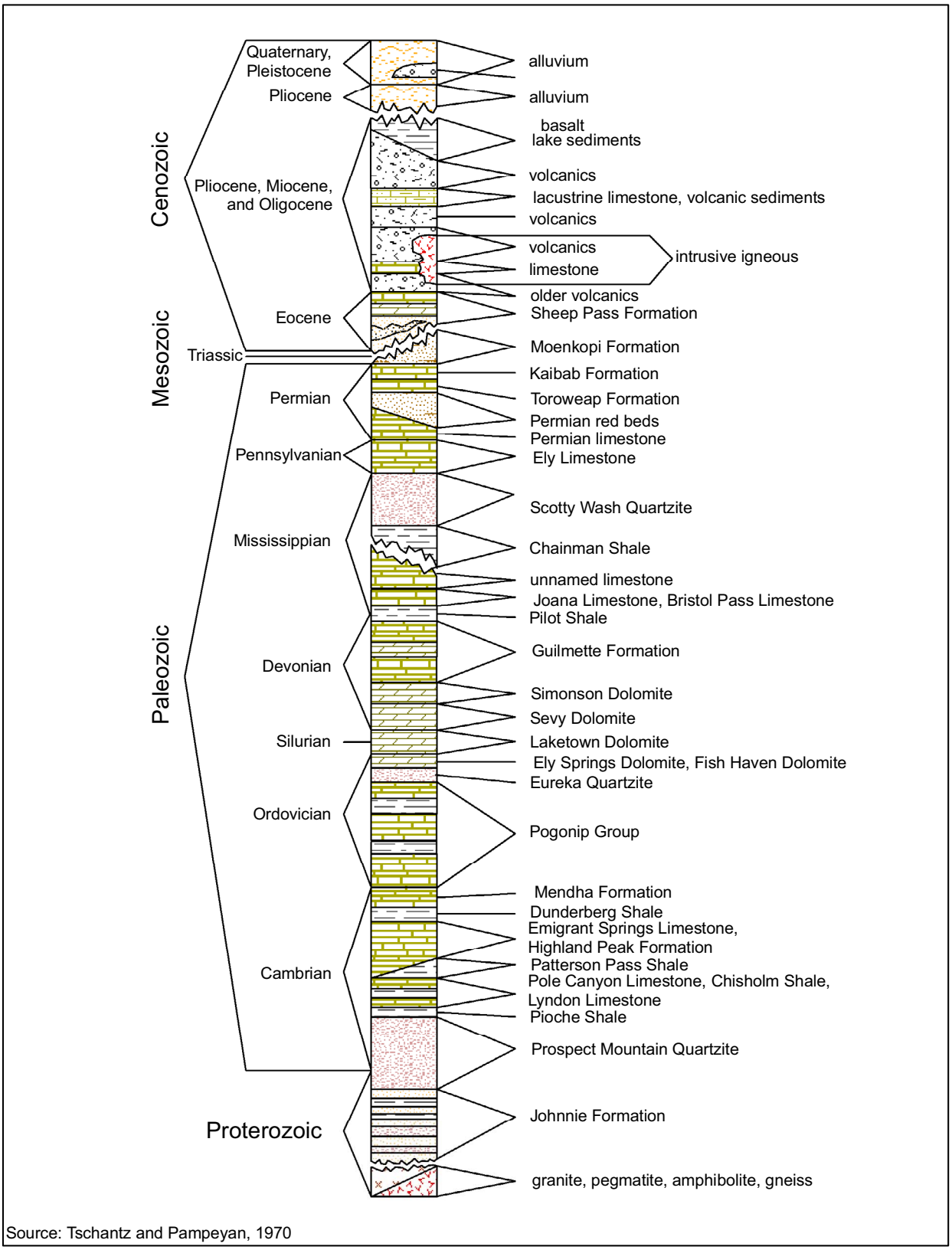
Individual rock units, structures, basins, and ranges are described in detail in Volume 1 on the CD-ROM accompanying this report. Thicknesses of most units are from the county reports of the area where the unit is exposed. The relationships between geologic units in the different areas of the map can be determined from Figures 3-2 to 3-5. These figures illustrate geologic columns for Lincoln (Figure 3-2), White Pine (Figure 3-3), and Clark counties (Figure 3-5), and western Utah (Figure 3-4). The Utah area consists of western Iron, Beaver, and Millard counties and the southwestern corner of Juab County.

3.2 Structural Geology

This section discusses the structural framework of the geologic study area. Three main structural events affected the geologic study area: (1) Late Devonian to Late Mississippian Antler compressive deformation, (2) Late Jurassic to early Tertiary Sevier compressive deformation, and (3) late Cenozoic basin-range extensional deformation. In addition to these structural events, middle Cenozoic time was characterized by mild extension (Rowley, 1998; Miller et al., 1999; Rowley and Dixon, 2001) and voluminous calc-alkaline volcanism that profoundly affected the topography and hydrology of the geologic study area.

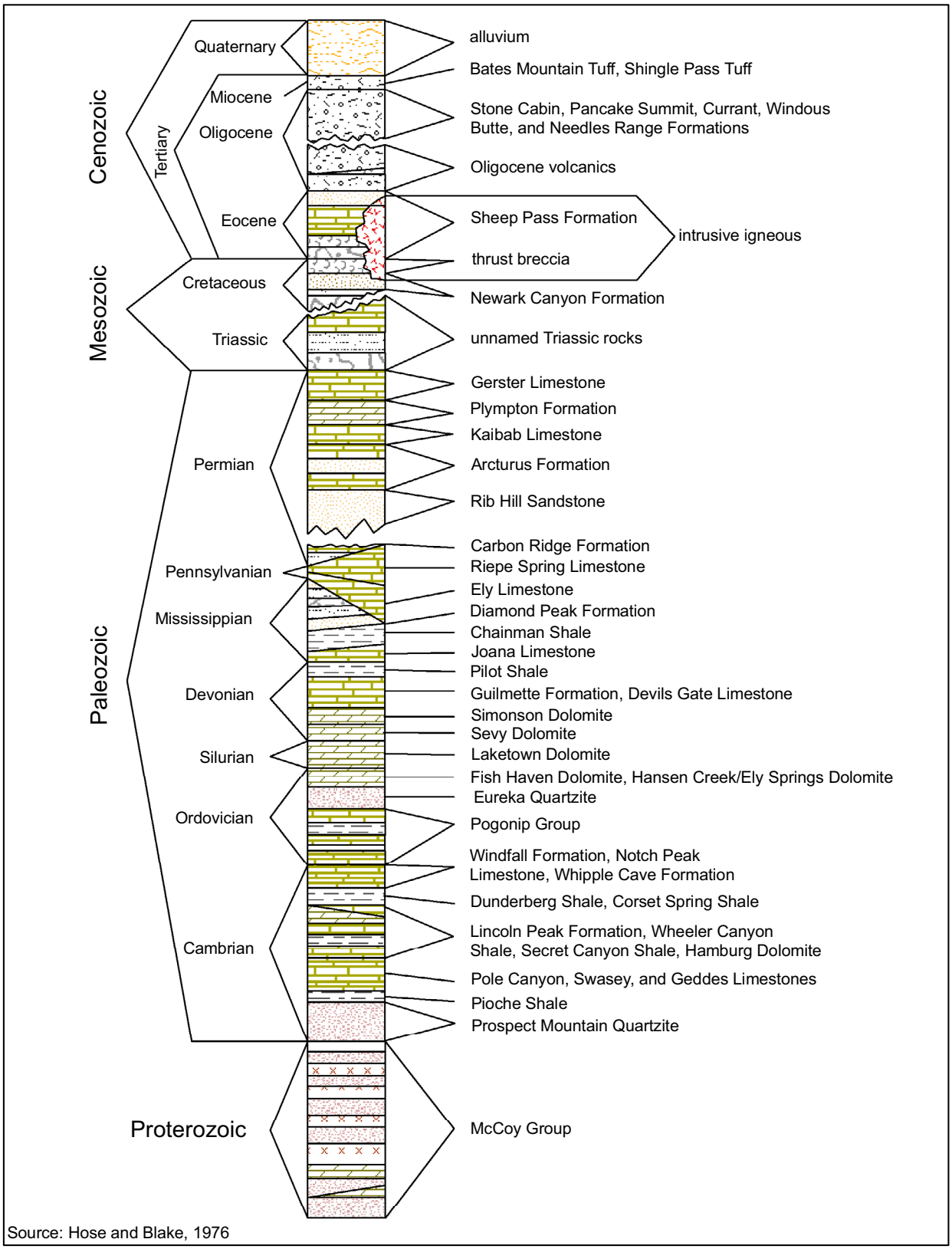
The Late Devonian to Late Mississippian Antler compressive deformation affected the northwestern part of the geologic study area, creating a north-trending highland (Larson and Langenheim, 1979; Carpenter et al., 1994; Poole and Sandberg, 1977 and 1991). This event formed folds and thrusts of the Roberts Mountain allochthon, which was at least 8,000 ft thick and passed through the western side of Eureka, Nevada (Carpenter et al., 1994; Saucier, 1997). The thrusts transported deeper-water sedimentary rocks eastward as much as 100 mi. Coarse synorogenic siliceous clastic detritus was shed from the highland into the foreland basin to the east, transitioning to shale farther east. The main synorogenic rock units that resulted were the Chainman Shale and Diamond Peak Formation, and farther south the Scotty Wash Quartzite.

The second structural event, the Middle Jurassic to early Tertiary Sevier compressive deformation, resulted in generally north- to north-northeast-striking, east-verging folds and thrust faults. Scattered Middle Jurassic to lower Tertiary plutons were emplaced in many mountain ranges of the geologic study area. Eastward-directed overthrusts emplaced Late Proterozoic to middle Paleozoic rocks over Late Proterozoic to Mesozoic rocks (Armstrong, 1968). At least a half dozen large thrusts are well exposed in the Las Vegas area, each with displacements ranging from several to 20 mi (Page et al., 2005b). Tectonic shortening caused by thrusting in southern Nevada is at least 22 to 45 mi (Stewart, 1980; Burchfiel et al., 1974). Except for the southern part of the geologic study area, most of the area



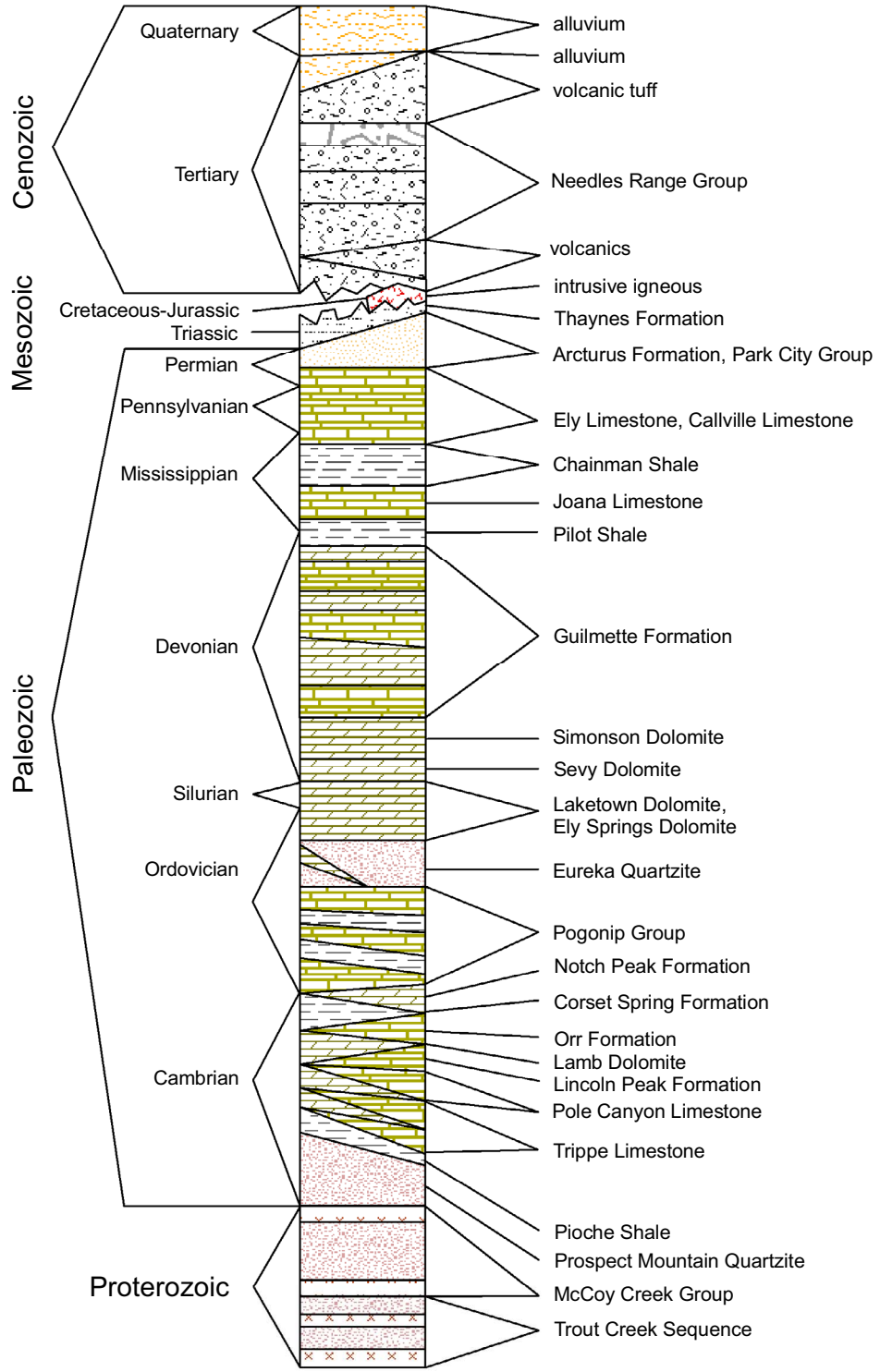
Source: Tschantz and Pampeyan, 1970

Figure 3-2
Geologic Units of Lincoln County, Nevada



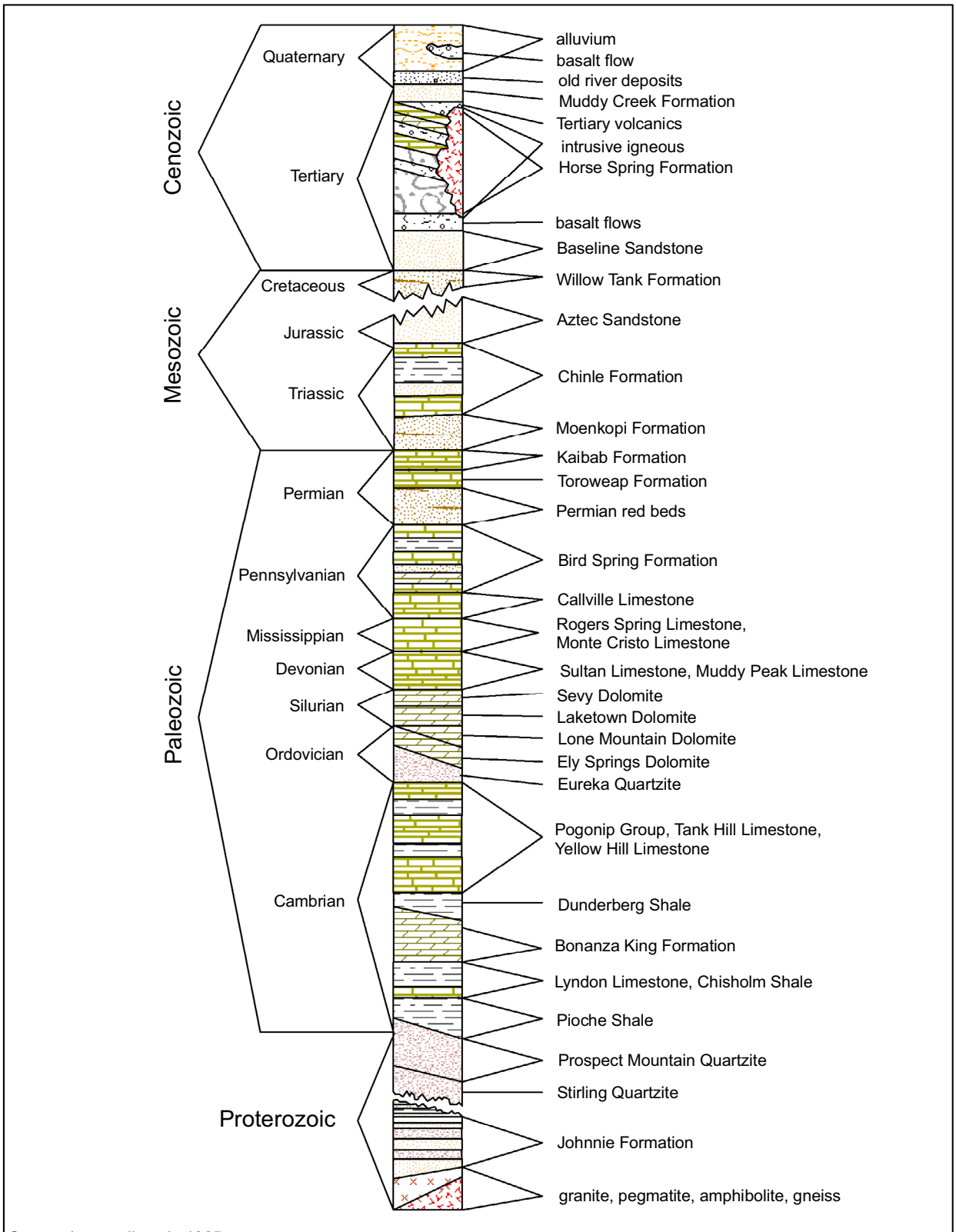
Source: Hose and Blake, 1976

Figure 3-3
Geologic Units of White Pine County, Nevada



Source: Hintze, 1988

Figure 3-4
Geologic Units of Western Utah



Source: Longwell et al., 1965

Figure 3-5
Geologic Units of Clark County, Nevada

has been considered to be the western hinterland of the deformation. In other words, the leading edges of most major thrusts are east of the map area, and the deformation created highlands within the hinterland of the map area that in turn eroded and shed clastic material primarily to the east. Some of the thrusts, including the Gass Peak, however, have been projected northward into the hinterland in the central and northern part of the geologic study area, including the Timpahute Range, Worthington Mountains, Golden Gate Range, Grant Range, Pancake Range, and Newark Valley (Vandervoort and Schmitt, 1990; Dobbs et al., 1994; Taylor et al., 2000). Sevier-type deformation is shown schematically on Figure 3-6, and the Sevier-age Glendale/Muddy Mountains thrust in the Muddy Mountains is shown on Figure 3-7.

East-striking faults and folds, alignments of plutons and volcanic vents, alignments of geophysical anomalies, local alignments of basins and ranges, hot springs, hydrothermally altered rocks, and mineral deposits have been noted in the Great Basin for years, primarily by geologists of the mining industry. Ekren et al. (1976 and 1977), Rowley et al. (1978), and Stewart et al. (1977) called these alignments "lineaments" with an origin similar to transform faults in the ocean basins. Ekren et al. (1976) also suggested that the lineaments began to form in the Cretaceous, if not earlier, and continued to be active throughout both Tertiary calc-alkaline magmatism and basin-range deformation. Like transform faults, these lineaments seem to represent boundaries between areas to the north and south that had different amounts, rates, and types of structural deformation. Rowley (1998) and Rowley and Dixon (2001) referred to them as transverse zones, and we follow their terminology here. They are poorly known and have been mapped in detail only locally, so they are projected with limited evidence between these areas where they are known. Therefore, transverse zones are delineated as speculative zones of potential disruption on Plates 1 and 2 in Volume 1.

Transverse zones bound parts of most igneous belts in the Great Basin. They also define the northern and southern sides of the Caliente caldera complex, representing structures by which this caldera spread east and west to a degree much more profound than most other calderas in the Great Basin. Transverse zones may both provide barriers to the southward flow of groundwater and act as conduits to east or westward flow of groundwater (Prudic et al., 1995; Rowley, 1998; Rowley et al., 2001).

The third structural event, the basin-range episode of extensional deformation, began at about 20 Ma and continues today. It is characterized by east-west extension and resulted primarily in north-striking normal faults. Over some parts of the Great Basin, early phases of this deformation produced north-striking basins and ranges due partly to gentle folding. Sediments were deposited in basins formed by these early faults and broad warps, but these basins were not necessarily in the same locations as they are today. The present topography was produced later, during the main pulse of basin-range deformation that began after 10 Ma for most parts of the Great Basin. The axes of basins and ranges since 10 Ma were commonly different from those created during the early phase of deformation. Some parts of the older basins were uplifted as part of the new ranges and some parts of the older ranges were downthrown as part of the new basins. An example is the presence of Miocene lacustrine limestones and associated clastics in the North Pahroc and Pahranagat ranges (Tschanz and Pampeyan, 1970) that were originally deposited in one or more basins.

The dominant fault type since major deformation began (about 10 Ma) continued to be north-striking normal faults, but locally strike-slip and oblique-slip faults accommodated the east-west extension. Examples of such accommodation zones are the east-northeast, left-lateral Pahranagat shear zone at

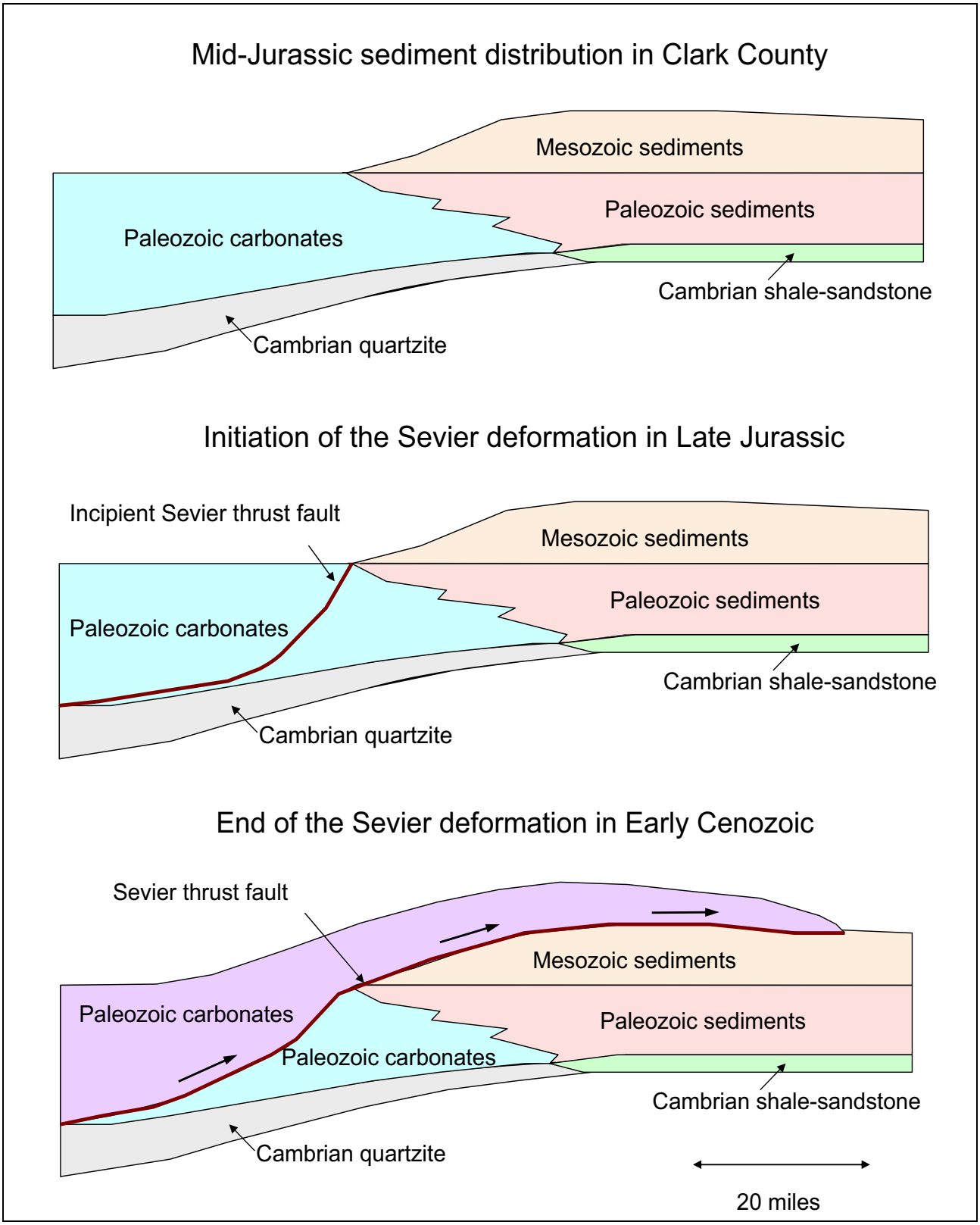
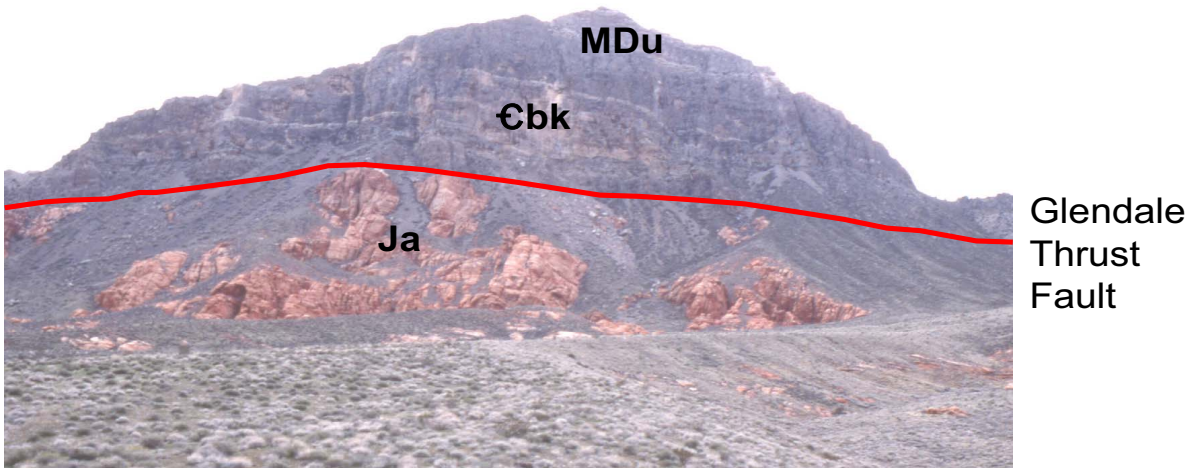


Figure 3-6
Schematic Diagram of Sevier Thrust Sheets, Illustrating the Movement of Paleozoic Carbonates over Cratonic Sediments



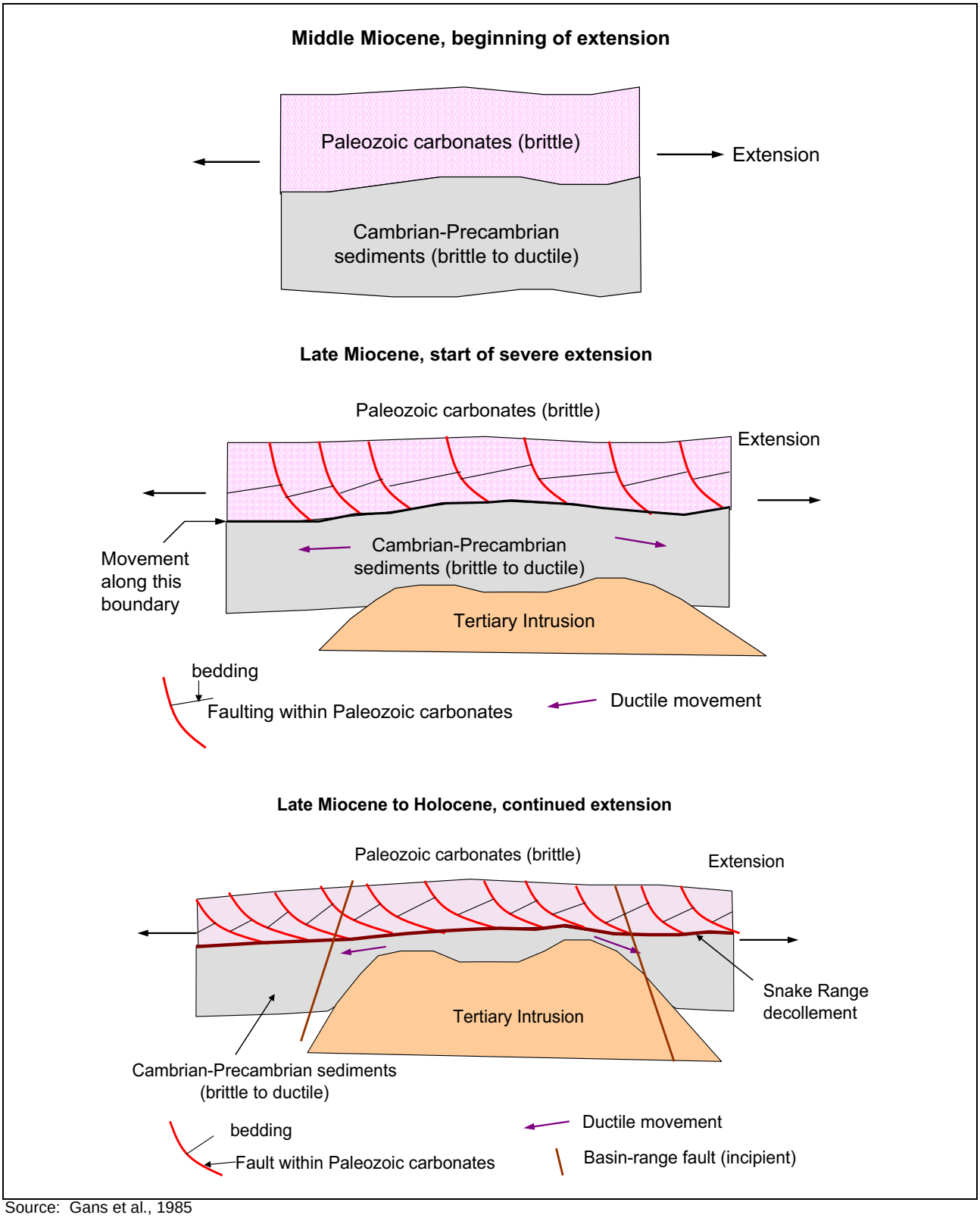
Ja – Jurassic Aztec Sandstone
MDu – Mississippian-Devonian carbonates undifferentiated
Ꞓbk – Cambrian Bonanza King Formation

Figure 3-7
Paleozoic Carbonates Thrust over Jurassic Aztec Sandstone in the Muddy Mountains near Muddy Peak

the southern end of Pahranagat Valley and the northeast trending, left-lateral Kane Spring fault zone west of the Meadow Valley Mountains (Ekren et al., 1977). East-striking transverse faults continued to be active at the same time, segmenting the Great Basin into broad east-trending corridors of different types and amounts of east-west pulling apart.

In some parts of the map area, low-angle faults were previously mapped as thrust faults. These faults, however, place younger rocks on older rocks. In some places, the direction of movement of the upper plates of these faults is westward rather than eastward. Most of these faults are considered to be much younger, Tertiary in age, expressions of structural extension and formed during the basin-range deformational event. The faults are interpreted to be detachment faults, although the general synonyms "attenuation" or "denudation faults" that were used by some early workers who first recognized them (Moores et al., 1968; Armstrong, 1972) are more appropriate in places where many subhorizontal faults are present, notably the Eureka area. In these areas, rapid uplift of ranges resulted in their tops being structurally stripped (or attenuated or denuded) by low-angle faults that verged into the adjacent low areas, much like large gravity slides.

One major fault to which the name "detachment" fault is appropriate is the well-known Snake Range decollement. Although originally considered to be a thrust fault that placed Middle Cambrian and younger rocks over Middle Cambrian and older rocks (for example, Nelson, 1966), the fault was later mapped in greater detail and reinterpreted as an Eocene to middle Miocene low-angle fault caused by stretching and thinning during uplift of a metamorphic core complex (Miller et al., 1983; Gans et al., 1985 and 1989). This detachment may represent the ductile/brittle transition zone uplifted by the core complex (see Figure 3-8 Miller et al., 1983; Gans et al., 1985; Gans, 2000). Rocks have been thinned



Source: Gans et al., 1985

Figure 3-8
One Scenario for Development of the
Snake Range Decollement during Late Cenozoic Extension

by the elimination of strata due to the faulting. Later work indicated that, while the decollement had an older (late Eocene and early Oligocene) history, most displacement on it was middle Miocene and later, coinciding with basin-range deformation (Miller et al., 1999). The core-complex uplift that formed the decollement included the Kern Mountains and southern Deep Creek Range (Miller et al., 1999). Finally, Miller et al. (1999, p. 902) suggested that the Snake Range decollement may not be a normal fault at all but instead a "highly complex structural boundary developed above a rising and extending mass of hot crystalline rocks."

3.3 Geology of the Project Basins

The geology of the Project Basins is summarized in the following sections.

3.3.1 Spring Valley

Spring Valley is an approximately 100-mi-long broad deep graben within the GSLDFS. At its northern end, Spring Valley contains about 2,000 ft of basin-fill sediments. The amount of basin-fill increases in the south to as much as 6,000 ft of material.

In the north, the Antelope Range separates Spring Valley from Tippett Valley. The Antelope Range is a relatively small, low range of faulted, mostly Tertiary volcanic rocks that unconformably overlie mostly west-dipping Silurian to Permian sedimentary rocks, dominantly carbonate rocks.

On the west, the approximately 120 mi long Schell Creek Range bounds the valley, separating it from Steptoe Valley to the west. The northern part of the Schell Creek Range is made up of a west-dipping sequence of Precambrian through Permian rocks (Lumsden et al., 2002), with overlying Tertiary volcanic rocks along the faulted western flank of the range. Small Tertiary intrusions are exposed locally along the range.

On the southwestern side of Spring Valley, the Fortification Range separates the valley from Lake Valley to the southwest. The Fortification Range is a series of faulted, upper Paleozoic carbonate rocks including, at the northern end, a narrow, low, north-northwest-trending, northeast-dipping cuesta that joins the eastern side of the Schell Creek Range. Despite the small size of the Fortification Range, it is complexly faulted and contains repeated sections of the Mississippian Chainman Shale beneath the surface, probably more than 1,000 ft thick.

To the east, the broad, high, north-trending Snake Range separates Spring Valley from Snake Valley to the east. It contains Wheeler Peak, more than 13,000 ft high and within Great Basin National Park. The range is about 65 mi long, nearly all of it in White Pine County, but with the low southern end in Lincoln County. The range is a horst, bounded on both sides by major high-angle normal fault zones. Except for the southern end, the Snake Range is cored by Late Proterozoic to Cambrian quartzite, intruded by a massive batholith of apparent Jurassic age (Whitebread, 1970; Miller et al., 1994 and 1995). The range is a metamorphic core complex, which rose rapidly and formed the Snake Range decollement, a detachment fault (Miller et al., 1999). This low-angle Tertiary detachment formed over an extended period as the range uplifted and stretched the roof rocks apart (Gans, 2000). The fault places complexly faulted Middle Cambrian carbonate and younger rocks over a lower plate of

Middle Cambrian carbonate rocks, Lower Cambrian clastic rocks, and older rocks. The decollement is exposed on the top and eastern side of the northern half of the range. The central part of the Snake Range is narrower and lower. On the eastern side of Sacramento Pass, north-striking, down-to-the-east listric normal faults drop down a thick section of Tertiary volcanic and basin-fill rocks (Gans et al., 1989; Miller et al., 1994, 1995, and 1999). The southern end of the range consists of south-plunging tilt blocks of Paleozoic rocks as young as Mississippian. These tilt blocks become lower in elevation to the south, and the eastern tilt blocks plunge beneath the valley fill. The western tilt blocks continue southward to become the Limestone Hills, which consist mostly of east-dipping Devonian carbonate rocks bounded by normal faults on the western and eastern sides.

3.3.2 Snake Valley

Snake Valley, east of the Snake Range, is a long, broad, deep graben containing about 5,000 ft of basin-fill deposits but local holes in the basin contain thicker deposits than this (Allmendinger et al., 1983; Saltus and Jachens, 1995; Kirby and Hurlow , 2005). The Deep Creek Range makes up the northwest side of Snake Valley and is a horst, bounded by north-striking normal faults on either side. The Snake Range is located on the western side of the valley, and was described in the previous section. Snake Valley is bounded on the eastern side by the Confusion Range. The Confusion Range and small ranges of similar rocks form the entire eastern (Utah) side of Snake Valley. The area includes hills (Middle Range) connected to and east of the northern end of the Confusion Range. The Confusion Range proper is 60 mi long, with a general northerly trend. The Conger Range is a 15-mi-long, southwest-diverging fork in the southern Confusion Range. Except for the southern portion of the Confusion Range, the Mississippian Chainman Shale, 1,000 to 2,000 ft thick in the area, is repeated and thus exposed on both sides of and beneath all these ranges because it is deformed into north-striking folds (Hintze and Davis, 2002a and b, and 2003).

3.3.3 Cave Valley

Cave Valley is part of the WRFS and consists of two distinct but connected portions, separated by an oblique-slip fault at Shingle Pass. One of these portions, northern Cave Valley, is a narrow graben with mostly east-dipping Cambrian rocks at shallow depth and containing relatively thin basin-fill sediments. The southern portion, south of Shingle Pass, generally contains less than 3,000 ft of basin-fill sediments and volcanic rocks but in a narrow, central, north-trending axial part, these Cenozoic rocks are 6,000 ft or more thick.

Along the western side of Cave Valley, the Egan Range is a complexly faulted horst of east-dipping Cambrian to Permian rocks, overlain by Tertiary volcanic rocks. The Egan Range separates Cave Valley from White River Valley to the west. Halfway southward down Cave Valley a northeast-striking oblique-slip fault passes through the Egan Range at Shingle Pass. This fault has effectively partitioned the valley into two sub-basins by displacing a section of the Egan Range and forming an east-dipping tilt block that extends northeast across and beneath Cave Valley where it terminates against the range-front fault of the Schell Creek Range. Based on oil test well drilling and gravity surveys, this block contains the Mississippian Chainman Shale (Hess, 2004; Mankinen et al., 2006; Scheirer, 2005).

Farther south, the Egan Range remains an east-tilted horst of Cambrian through Tertiary rocks, then bends southeast to join the southern end of the Schell Creek Range. Here Cave Valley terminates where the Egan and Schell Creek ranges join each other in a complex of north-northeast- and north-northwest-striking normal and oblique-slip faults.

To the east, the Schell Creek Range separates Cave Valley from Lake and northern Dry Lake (Muleshoe) Valleys. This section of the Schell Creek Range contains a narrow, heavily faulted sequence of Precambrian through Tertiary rocks that dips east. Here the dominant fault is on the western flank of the range. In the northeast portion of the valley, the Schell Creek Range is cored by Precambrian to Cambrian quartzite. West of the Geyser Ranch, the rocks are mostly Late Proterozoic and Cambrian quartzite (Van Loenen, 1987), but farther south the rocks are dropped down along an east-trending fault at Patterson Pass and are mostly of middle to upper Paleozoic and Tertiary age. In the south, where Cave Valley terminates at the intersection of the Schell Creek Range and the Egan Range, a Tertiary pluton has mineralized adjacent carbonate rocks at the Silver King Mine.

3.3.4 Dry Lake Valley

Dry Lake Valley is a deep graben that contains in most places 3,000 to 5,000 ft of basin-fill sediments (Mankinen et al., 2006), but locally along the axis of the graben as much as 10,000 to 25,000 ft of sediments and underlying downfaulted volcanic and carbonate rocks are present (Scheirer, 2005).

Along the western side of Dry Lake Valley at the junction with the southern Egan and Schell Creek ranges, the North Pahroc Range extends south for about 40 mi separating the valley from Pahroc Valley to the West. The North Pahroc Range consists of upper Paleozoic rocks overlain by Tertiary volcanic rocks. These rocks dip west off major faults along the eastern side of the range. The North Pahroc Range is separated from the smaller South Pahroc Range at the southern end of the valley by an east-trending belt of faulted rocks of low relief formed by the east-striking Timpahute transverse zone. The belt of faulted rocks is the boundary between Dry Lake Valley and Delamar Valley to the south. The Seaman and the North Pahroc ranges join together at their southern ends, and the Hiko Range continues south of this intersection.

On the east side and from north to south, the Fairview, Bristol, Highland, and Chief Ranges are a 60-mi-long group of north-trending, heavily-faulted ranges of mostly east-dipping rocks that separate Dry Lake Valley from Lake, Patterson and Panaca Valleys to the east. The northern portion of Dry Lake Valley (Muleshoe Valley) is bounded on the east by the Fairview Range. The Fairview Range is a horst made up of Devonian to Pennsylvanian rocks at both the northern and southern ends of the range. The central part of the range consists of the western lobe of the Indian Peak caldera complex. To the south, the valley is bounded on the east by the Bristol, Highland, and Chief ranges. A low pass between the Fairview Range and the Bristol Range is cut by numerous east-striking faults of the Blue Ribbon transverse zone, which crosses the entire Great Basin at about this latitude (Rowley, 1998; Rowley and Dixon, 2001). The small horsts due west of this area are named the West, Ely Springs, Black Canyon, and Burnt Spring Ranges.

The Bristol Range is a horst that consists mostly of an east-dipping sequence of Cambrian carbonate rocks. The range is cored by a Tertiary pluton on the northern end that is associated with silver deposits of the Jackrabbit and Bristol districts. A low angle, west-dipping detachment or

gravity-slide fault that placed Devonian rocks on Cambrian rocks is exposed in the northwestern part of the range (Page and Ekren, 1995). The Highland Range, the southward continuation of the Bristol Range, consists of east-dipping Cambrian carbonate rocks, underlain by Precambrian and Cambrian quartzite. A west-dipping, west-verging, moderately dipping fault on the western side of the range, the breakaway part of the Highland detachment fault, placed the younger carbonate rocks on the older quartzite. The Chief Range, south of the Highland Range, is made up of east-dipping Precambrian and Cambrian quartzite that is unconformably overlain by Tertiary volcanic rocks and cut by a Tertiary pluton that controls the small Chief gold district. The faults that lift the range on the western side consist of an oblique-slip fault (right lateral and normal) and the west-dipping Highland detachment fault (Rowley et al., 1994).

The small West Range consists of Devonian sedimentary rocks and Tertiary volcanic rocks on which are Devonian rocks emplaced by a low-angle fault that can be interpreted as either a detachment fault or a gravity-slide plane (Page and Ekren, 1995). The Ely Springs Range consists of Cambrian through Silurian rocks, overlain by Tertiary volcanic rocks. The Black Canyon Range consists of Cambrian sedimentary rocks and Tertiary volcanic rocks. The Burnt Springs Range consists of Cambrian sedimentary rocks unconformably overlain by Tertiary volcanic rocks.

3.3.5 Delamar Valley

Delamar Valley, just south of Dry Lake Valley, is a graben that deepens to the south with a general maximum thickness of more than 5,000 ft of basin-fill sediments east of the South Pahroc Range (Mankinen et al., 2006). Locally as much as 20,000 ft of sediments and underlying downfaulted volcanic and carbonate rocks are present (Scheirer, 2005).

Along the western side of the valley, the South Pahroc Range extends southward from the North Pahroc Range, separating the valley from Pahranagat Valley to the west. The South Pahroc Range is a series of west-titled blocks of volcanic rocks; the main faults are on the eastern side of the range. The South Pahroc Range terminates against the east-northeast-trending Pahranagat shear zone, which also terminates Pahranagat and Delamar Valleys at their southern extent.

Along the eastern side of the valley, the Delamar Mountains bound the eastern side of the valley, extending southward for 40 mi from the Burnt Springs Range in southern Dry Lake Valley. The boundary between the two ranges can be placed at the northern caldera wall of the Caliente caldera complex, here controlled by the east-trending Timpahute transverse zone (Ekren et al., 1976; Rowley, 1998; Swadley and Rowley, 1994). The Delamar Mountains consists of east-dipping Late Proterozoic to Cambrian rocks and Tertiary volcanic rocks. The range, however, is dominated by Tertiary caldera complexes. The western end of the Caliente caldera complex is in the northern part of the range, and the Kane Springs Wash caldera complex is in the central part of the range (Rowley et al., 1995; Scott et al., 1995 and 1996). The main bounding fault of the Delamar Mountains is the down-to-the-west normal fault on the western side, and this is joined from the southwest by several splays of the left-lateral Pahranagat shear zone (Ekren et al., 1977).

3.3.6 Coyote Springs Valley

Coyote Spring Valley is underlain by thin basin-fill sediments, generally less than 1,000 ft deep with carbonates directly below (Burbey, 1997). The northern Sheep Range is located on the west side of Coyote Spring Valley, and is a simple, narrow, and abrupt horst of Cambrian and Ordovician sedimentary rocks. The northeast side of Coyote Springs Valley contains the Delamar Mountains as described for Delamar Valley in the previous section. The east side of Coyote Spring Valley is comprised of the Meadow Valley Mountains and the Arrow Canyon Range. The southern end of the Meadow Valley Mountains, just east of Coyote Spring Valley, is made up of mostly thrust-faulted and normally faulted Paleozoic rocks. The Arrow Canyon Range is a sharp, narrow north-trending range consisting of a syncline of Cambrian to Mississippian carbonate rocks. It is uplifted along its western side by normal faults of the Arrow Canyon Range fault zone (Page and Pampeyan, 1996; Schmidt and Dixon, 1995; Page, 1998).

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4.0 SURFACE WATER RESOURCES

The SNWA has studied and thoroughly described perennial streams of the study area in *Physical Settings of Selected Streams in Clark, Lincoln, and White Pine Counties Groundwater Development Project* (SNWA, 2007b). Selected springs and seeps have also been studied and thoroughly described in *Physical Settings of Selected Springs in Clark, Lincoln, and White Pine Counties Groundwater Development Project* (SNWA, 2007c). Electronic versions of the reports have been attached as Volume 2 (streams) and Volume 3 (springs) on the CD-ROM accompanying this report. This section provides an overview of the surface water resource information presented in the two reports.

4.1 Streams

Perennial streams within the Project Basins are principally found within Spring and Snake valleys. The Muddy River and Meadow Valley Wash are the principal drainages found within the larger study area. This report summarizes the perennial streams within Spring and Snake valleys and briefly describes the Muddy River and Meadow Valley Wash drainages. More detailed descriptions of the streams in these areas can be found in Volume 2 (SNWA, 2007b).

4.1.1 Streams Inventory

Data sources include published reports, published and preliminary data from the U.S. Geological Survey (USGS), and field investigations conducted by SNWA.

Investigations conducted by SNWA of the perennial streams included compilation of existing data and information, including published and unpublished reports and databases; photographic documentation; discharge measurements; and a written description of the physical setting of the stream, including a basic description of the surficial geology of each drainage area.

4.1.1.1 Discharge Measurements

Miscellaneous discharge measurements for perennial streams were compiled from:

- USGS National Water Information System (NWIS)
- USGS Water-Supply Papers regarding Surface Water Supply of the United States from 1914 to 1963
- Water Resources for Nevada annual data reports from 1964 to 2005

- Water Resources Bulletins and Biennial Reports, published by the Office of the Nevada State Engineer

- Reports prepared by Ertec Western, Inc. for the U.S. Air Force's MX Missile-Siting Investigation (Ertec Western, Inc., 1981a through e).

Data from these sources augment the miscellaneous discharge measurements conducted by SNWA since 1993. Suitable sites for SNWA's miscellaneous discharge measurements were selected based on access to the channel, channel geometry, bed material, and observations of flow.

Discharge ratings for gaging stations are calculated through a stage-discharge relationship developed by the USGS. Discharge measurements are made, and the observed stage during the measurement is recorded. Once a sufficient number of measurements are made, a rating cure is developed by plotting the stage against the discharge. Once this rating is developed, routine visits to the gaging station are made to measure the discharge and to verify the validity of the rating in use at that station. Mean daily discharges are computed using the gage height record (usually 96 or 24 measurements of stage) at the station in conjunction with the discharge rating. From these mean daily values, monthly and annual discharges and statistics are computed. If the stream channel is subjected to frequent changes, thereby affecting the stage-discharge relationship, then the discharge is computed using the shifting-control method, in which correction factors are applied to the stage- discharge relationship based on physical discharge measurements. A more detailed explanation of rating development and the computation of discharge records can be found in Rantz et al. (1982a and b).

In the study area, there are currently 15 active gaging stations: 7 on the Muddy River and its tributaries, and 8 elsewhere in the study area. The period of record varies greatly from station to station. Several of the streams have had gaging stations through the years. Published records of annual discharges including the mean, minimum, and maximum annual discharges are listed in this report by stream and station number.

4.1.1.2 Drainage Area Characteristics

Physical characteristics were determined for the drainage areas discussed in this report, using geographic information system (GIS) applications. All area calculations (including total drainage area, area above 8,000 ft-amsl, and minimum, maximum and average elevations) for each drainage area were derived using the National Elevation Data Set (USGS, 2006), which is a 30-m digital elevation model (DEM) maintained by the USGS. These values are reported in square miles. Stream length was determined by measuring the distance from the measurement site closest to the mountain block and above any diversions to the basin divide. This value is reported in miles. The channel slope was calculated by the same methods as used by Hess and Bohman (1996), Hess (2002) and Ries et al. (2007). The channel slope was measured at two points along the stream: at 10 and at 85 percent of the stream's total length, measured upstream from the measurement cross section nearest the mountain block and above any diversions. Stream slope is reported in feet per mile and was also derived using the National Elevation Data Set.

An estimate of the proportions of surficial geologic deposit lithologies was made. Using GIS applications and a digital version of the geologic map available in Volume 1, estimates of volcanic, clastic, metamorphic, carbonate, and intrusive rocks, and alluvial deposits were calculated.

4.1.2 Spring Valley

SNWA inventoried 27 perennial streams in Spring Valley, the locations of the measurement sites on these streams and the Cleve Creek gaging station are depicted in Figure 4-1 and listed in Appendix A of Volume 2. A majority of the streams in Spring Valley occur in the mountains along the northwestern side of the valley. Table 4-1 contains a listing of the physical characteristics of drainage areas in Spring Valley. The 27 streams are described in detail in Volume 2. As shown in Table 4-1 the average stream length in Spring Valley is approximately 4.4 mi with the longest being Cleve Creek at 11 mi. The average drainage area for the streams is approximately 6.4 mi^2 with Cleve Creek having the largest at 32 mi^2. The surficial geology of the drainage areas is dominated by either carbonate rocks or a combination of clastic and metamorphic rocks. Appendix C of Volume 2 contains 596 miscellaneous discharge measurements for 80 stream measurement sites within Spring Valley. Estimated average annual streamflows for the ungaged perennial streams are shown in Table 4-2.

The USGS maintains a gaging station (10243700) on Cleve Creek within Spring Valley. This gaging station has operated intermittently since 1914 and has a long-term mean annual discharge of 10.5 cfs. The mean annual discharge for this stream was 14.4 cfs in 2006 (USGS, 2006).

4.1.3 Snake Valley

SNWA inventoried 20 streams in Snake Valley, the locations of the measurement sites are depicted in Figure 4-2 and listed in Appendix A of Volume 2. A majority of the streams in Snake Valley occur within the mountains along the western side of the valley. Table 4-3 contains a listing of the physical characteristics of the 20 streams that are described in detail in Volume 2. As shown in Table 4-3 the average stream length in Snake Valley is approximately 8.4 mi with the longest being Big Wash at 15.3 mi. The average drainage area for the streams is approximately 15.7 mi^2 with Smith Creek having the largest at 56.2 mi^2. The surficial geology of the drainage areas is dominated by carbonate, clastic, or intrusive rocks. Appendix C of Volume 2 contains 179 miscellaneous discharge measurements for 74 stream locations within Snake Valley. Estimated average annual streamflows for some of the ungaged perennial streams in Snake Valley are shown in Table 4-4.

The USGS maintains several gaging stations within Snake Valley. The USGS-Utah District has published mean daily discharge values from June 2003 to present for the Granite Creek gaging station (10172875). The mean annual discharge for Granite Creek is 4.33 cfs (USGS, 2006). The USGS also operated a gage on Strawberry Creek from October 2003 through September 2004. A gage on Lehman Creek has operated intermittently since October 1947. The mean annual discharge for Lehman Creek is 5.67 cfs (USGS, 2005). Baker Creek has been measured by USGS at two different gaging stations. The Baker Creek near Baker, Nevada (10243250) gaging station operated from August 1913 to November 1916 with an average annual discharge of 19 cfs for the period of record (Wells, 1960). The second gage on Baker Creek was the Baker Creek at Narrows near Baker, Nevada

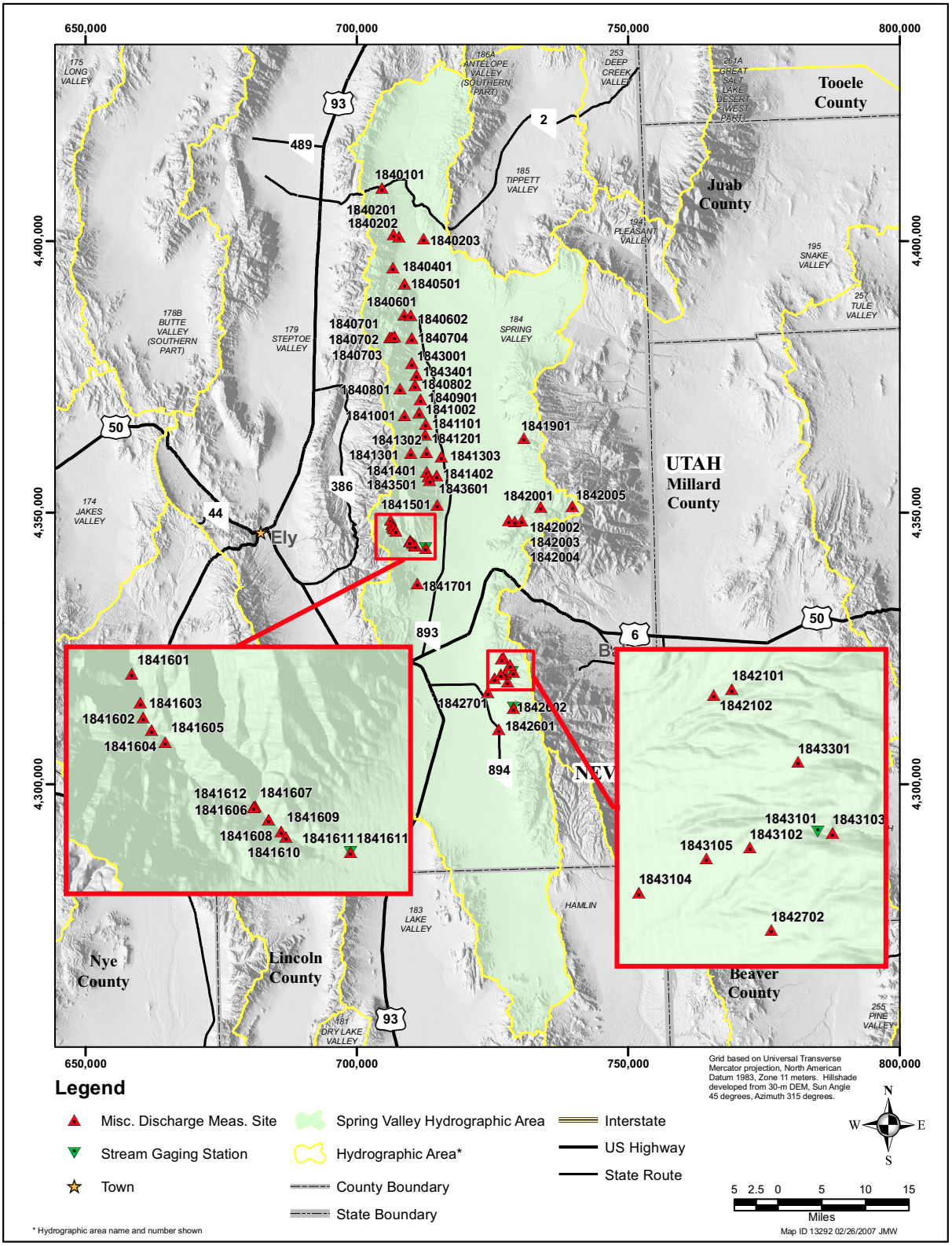


Figure 4-1
Measurement Sites on Streams in Spring Valley, White Pine and Lincoln Counties, Nevada

Table 4-1
Physical Characteristics of Drainage Areas in Spring Valley, NV--HA 184
(Page 1 of 2)

Site Name	Site Number	Stream Length (mi)	Slope (ft/mile)	Minimum Altitude (ft)	Maximum Altitude (ft)	Average Altitude (ft)	Total Area (mi^2)	Area Above 8,000 ft-amsl (mi^2)	Area Above 8,000 ft-amsl (%)	Alluvium (%)	Volcanic (%)	Carbonate (%)	Clastic (%)	Metamorphic (%)	Intrusive (%)
Siegel Creek	1840201	4.5	519	6,680	10,170	8,210	5.5	2.9	53	18	12	65	4	1	0
Frenchman Creek	1840501	4.1	487	6,520	8,970	7,700	4.8	1.3	27	4	33	63	0	0	0
North Creek at Sunkist	1840401	3.8	535	6,950	10,260	8,620	3.2	2.6	81	0	9	78	13	0	0
Muncy Creek	1840602	7.4	368	6,180	9,820	8,270	14	9.6	69	8	28	59	3	1	1
Kalamazoo Creek	1840704	7.1	362	6,220	10,900	8,250	14.6	9.3	64	4	40	39	13	4	0
Cooper Creek	1842501	7.6	262	6,520	10,730	7,820	25.9	8.7	34	8	16	60	16	0	0
Stage Canyon	1840101	5.5	296	6,550	9,060	7,440	8.6	1.2	14	56	28	16	0	0	0
Horse Canyon	1845201	3.3	475	7,020	9,770	8,210	2.1	1.4	67	4	0	84	12	0	0
Silver Creek	1840301	2.8	910	7,160	10,280	8,890	2.4	2	83	0	0	75	20	5	0
Trail Canyon	1844201	2.8	1,077	6,470	10,060	8,230	1.9	1.1	58	0	0	20	68	12	0
Fandango Creek	1842901	2.3	1,175	6,460	9,320	7,700	0.9	0.3	33	0	0	0	48	52	0
Meadow Creek	1843001	3.3	1,041	6,590	10,940	8,740	2.8	2.2	79	0	0	34	44	22	0
Rams Horn Canyon	1844001	3.1	1,225	6,750	10,920	8,560	1.3	0.9	69	0	0	8	54	38	0
North Creek above Robinson	1843401	3.5	1,033	6,620	10,890	8,820	2.7	2	74	0	0	23	47	30	0
Piermont Creek	1840802	5.4	656	6,510	11,070	8,900	7.5	6.1	81	0	0	19	54	27	0
Garden Creek	1840901	3.2	1,306	6,250	10,830	8,400	2.9	1.8	62	0	0	0	12	88	0
Bassett Creek	1841002	4.6	852	6,600	11,880	9,440	6.3	5.4	86	0	0	0	65	35	0
Little Negro Creek	1841101	4	1,183	6,320	11,810	8,610	3	2	67	0	0	0	32	68	0
Odgers Creek	1841201	4.1	1,005	6,500	11,790	9,140	3.9	3.2	82	11	0	0	49	40	0
McCoy Creek	1841302	4.2	898	6,620	11,770	9,400	6.2	5.3	85	10	0	0	53	37	0
Taft Creek	1841401	4.1	991	6,980	11,740	9,800	4.3	4	93	20	0	0	55	25	0

Table 4-1
Physical Characteristics of Drainage Areas in Spring Valley, NV--HA 184
(Page 2 of 2)

Site Name	Site Number	Stream Length (mi)	Slope (ft/mile)	Minimum Altitude (ft)	Maximum Altitude (ft)	Average Altitude (ft)	Total Area (mi^2)	Area Above 8,000 ft-amsl (mi^2)	Area Above 8,000 ft-amsl (%)	Alluvium (%)	Volcanic (%)	Carbonate (%)	Clastic (%)	Metamorphic (%)	Intrusive (%)
Ranger Creek	1843501	3.3	1,332	6,570	11,460	8,490	1.6	1.1	69	20	0	0	20	60	0
South Taft Creek	1843601	3.3	1,179	6,570	11,730	9,190	3.2	2.3	72	37	0	0	41	22	0
Stephens Creek	1841501	3.3	1,346	6,560	11,480	8,970	2.9	2.2	76	0	0	0	58	42	0
Cleve Creek	1841611	11	391	6,200	11,760	8,860	31.8	23.2	73	2	0	41	57	0	0
Bastian Creek	1841701	3.4	989	6,360	10,450	8,180	2.7	1.4	52	1	0	99	0	0	0
Eight Mile Creek	1841901	2.8	769	6,570	9,330	8,090	3.1	1.8	58	3	0	13	68	0	16
Negro Creek	1842003	9.6	359	6,200	12,010	8,220	27.4	15.1	55	9	0	78	13	0	0
Willard Creek	1842101	3.3	723	6,980	11,510	8,830	3.8	3.1	82	10	0	0	1	76	13
Board Creek	1843301	3.1	1,364	7,370	11,550	9,060	0.8	0.7	88	13	0	0	1	81	5
Shingle Creek	1843103	3.3	1,179	7,400	11,730	9,550	2.2	2	91	5	0	0	6	88	1
Swallow Creek	1842201	3	1,201	6,380	10,890	8,470	3.5	2.3	66	2	0	98	0	0	0
Dry Canyon	1842601	3.3	1,209	7,150	11,730	9,630	2.9	2.6	90	0	0	4	96	0	0
Pine and Ridge Creeks	1842701	3.4	1,532	7,190	12,930	9,100	4	3	75	14	0	0	15	64	7
Williams Canyon	1842801	3.2	1,048	7,340	11,760	9,680	3.2	3	94	1	0	0	49	0	50

Table 4-2
Estimated Average Annual Streamflow for Ungaged Perennial Streams Within Spring Valley

Station Number	Stream Name	Average Annual Streamflow (cfs)
1840201	Siegel Creek	1.03
1840401	North Creek	1.24
1840501	Frenchman Creek	0.54
1840602	Muncy Creek	1.90
1840704	Kalamazoo Creek	6.00
1840802	Piermont Creek	1.68
1840901	Garden Creek	0.39
1841002	Bassett Creek	4.99
1841101	Little Negro Creek	0.86
1841201	Odgers Creek	2.37
1841302	McCoy Creek	6.74
1841401	Taft Creek	2.62
1841501	Stephens Creek	1.04
1841701	Bastian Creek	2.75
1841901	Eight Mile Creek	0.98
1842003	Negro Creek	2.62
1842101	Willard Creek	0.92
1842201	Swallow Creek	7.65
1842601	Dry Canyon and Williams Canyon	1.02
1842701	Pine and Ridge Creeks	1.18
1843001	Meadow Creek	0.78
1843101/02	Shingle Creek	0.96
1843301	Board Creek	0.03
1843401	North Creek	0.01
1843501	Ranger Creek	0.06
1843601	South Taft Creek	0.69

(10243240) gaging station. This gage was in operation from October 1947 to September 1955 and October 1992 to September 1997. The average annual discharge for the period of record was 9.08 cfs (USGS, 2006).

4.1.4 Muddy River and Meadow Valley Wash

The Muddy River drains parts of central, southern, and eastern Nevada and is the relic portion of the White River. The total drainage area before the Muddy River discharges into Lake Mead is over 8,000 mi^2, and can be divided into two main drainage sub-areas: the Muddy River and Meadow Valley Wash. The Muddy River drainage area extends from Coyote Spring Valley (HA 210), which is

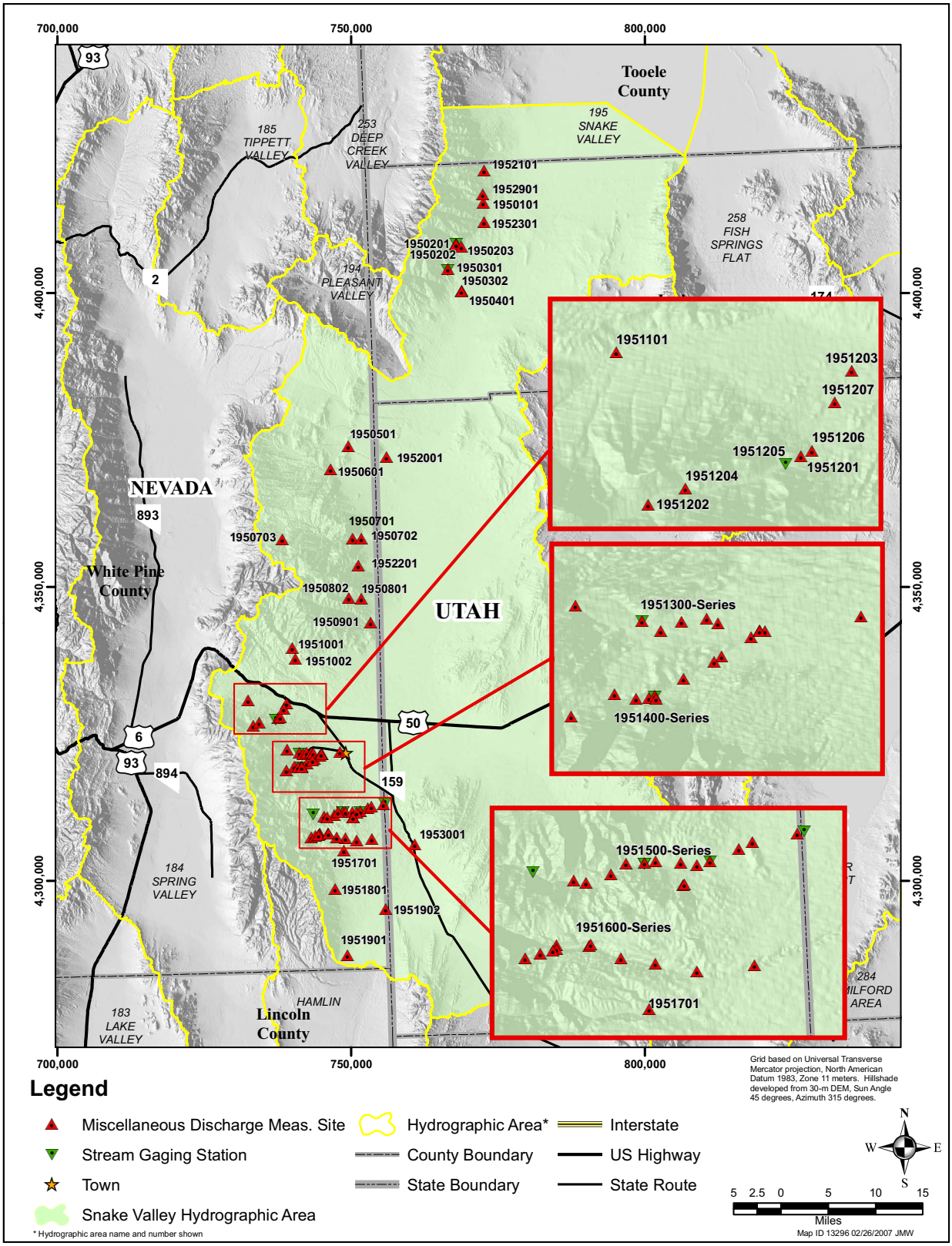


Figure 4-2
Measurement Sites on Streams in Snake Valley, Nevada and Utah

Table 4-3
Physical Characteristics of Drainage Areas in Snake Valley, NV and UT--HA 195

Site Name	Site Number	Stream Length (mi)	Slope (ft/mile)	Minimum Altitude (ft)	Maximum Altitude (ft)	Average Altitude (ft)	Total Area (mi^2)	Area Above 8,000 ft-amsl (mi^2)	Area Above 8,000 ft-amsl (%)	Alluvium (%)	Volcanic (%)	Carbonate (%)	Clastic (%)	Metamorphic (%)	Intrusive (%)
Indian Farm Creek	1950101	5.6	1,112	5,515	11,995	8,536	5.6	3.3	58	20	0	0	0	0	80
Granite Creek	1950201	5	877	6,346	12,066	9,073	8.1	6	73	17	0	0	3	35	45
Birch Creek	1950401	8.7	540	5,206	11,291	8,624	9.7	7.1	73	8	0	0	92	0	0
Lehman Creek	1951306	8.1	574	6,399	13,034	9,333	11.4	8.9	78	33	0	1	55	9	2
Lexington Creek	1951701	7.5	375	6,393	10,992	8,074	11.7	6	51	16	0	67	1	0	16
Trout Creek	1950301	6.2	617	6,191	11,562	9,199	8.4	6.8	81	20	0	0	0	80	0
Strawberry Creek	1951201	6.2	530	6,735	11,514	8,850	7.8	6	76	14	0	0	20	44	22
Weaver Creek	1951101	4.1	589	6,794	10,134	8,127	6.6	3.3	50	21	0	0	17	44	18
Swan Creek	1950501	13	209	5,838	9,563	7,131	23.9	3.4	14	16	0	84	0	0	0
Smith Creek	1950701	13.7	220	5,667	12,036	8,492	56.2	39.6	70	2	0	62	33	0	3
Snake Creek	1951508	14.2	299	5,560	11,861	7,996	28.4	14	49	14	0	40	19	0	27
Big Wash	1951606	15.3	218	5,873	11,646	8,369	27.9	16.1	58	24	0	72	2	0	2
Marble Wash	1950601	10.4	281	6,102	10,088	7,957	22.1	9.7	44	0	0	98	2	0	0
Hampton Creek	1950802	5.7	767	6,388	11,026	8,830	7.5	5.6	74	0	0	37	63	0	0
Hendrys Creek	1950901	10.6	471	5,640	12,041	8,989	23.6	17.6	75	0	0	38	62	0	0
Silver Creek	1951002	8.4	240	6,481	11,797	8,805	23	19.2	83	0	0	61	10	0	29
Baker Creek	1951407	8	402	6,590	13,064	9,518	16.8	14.3	85	1	0	5	77	0	17
Red Cedar Creek	1952301	6.7	927	5,360	12,070	9,060	6.2	4.5	73	24	0	0	0	0	76
Toms Creek	1952901	8.1	622	5,060	11,680	8,530	6.7	4.2	63	4	0	0	0	0	96
Choke Cherry Creek	1951801	3	738	6,669	9,797	8,132	2.5	1.4	55	0	0	100	0	0	0

Table 4-4
Estimated Average Annual Streamflow for Perennial Streams within Snake Valley

Station Number	Station Name	Average Annual Streamflow
1950101	Indian Farm Creek near Callao, UT	4.24
1950401	Birch Creek above Trout Creek near Trout Creek, UT	4.39
1950701	Smith Creek above Diversion and Trail Head	4.66
1950801	Hampton Creek above Forest Boundary	0.728
1950901	Hendrys Creek at Bridge to Rock Quarry	2.62
1951002	Silver Creek 0.8 miles above Forest Boundary	5.10
1951101	Weaver Creek above Sage Creek	0.383
1951201	Strawberry Creek at National Forest Boundary	1.46
1951508	Snake Creek (Site 8)	9.50
1951605	Big Wash at Hidden Canyon Guest Ranch	1.44
1951701	Lexington Creek at National Forest Boundary	0.226

drained by Pahranagat Wash, then enters Arrow Canyon and finally joins the Muddy River in the Muddy River Springs Area (HA 219). The second drainage area is the Meadow Valley Wash drainage area. This area drains Spring Valley (HA 201), Eagle Valley (HA 202), Dry Valley (HA 198), Panaca Valley (HA 203), Clover Valley (HA 204), and Lower Meadow Valley Wash (HA 205). Below the confluence with Meadow Valley Wash, the Muddy River drains California Wash (HA 218).

The Muddy River is a perennial stream from its source springs near Moapa, Nevada, until completely diverted at Wells Siding by the Moapa Valley Irrigation Company. The flow is steady throughout the year except when affected by floods. While floods are infrequent events on the Muddy River, they can greatly influence annual discharge totals.

Gaging stations have been operated on the Muddy River and its tributaries since the early 1900s. The gaging stations have been described in Volume 2 and their locations are shown on Figure 4-3. Annual discharges for the gaging stations are reported in Appendix B of Volume 2.

4.2 Springs

Springs are found within all of the Project Basins but in greater numbers in Spring and Snake valleys than in Cave, Dry Lake, Delamar, and Coyote Spring valleys. The sections that follow provide a summary of the springs documented in the Project Basins. Additional descriptions and details for these springs as well as additional springs within the larger study area are provided in Volume 3.

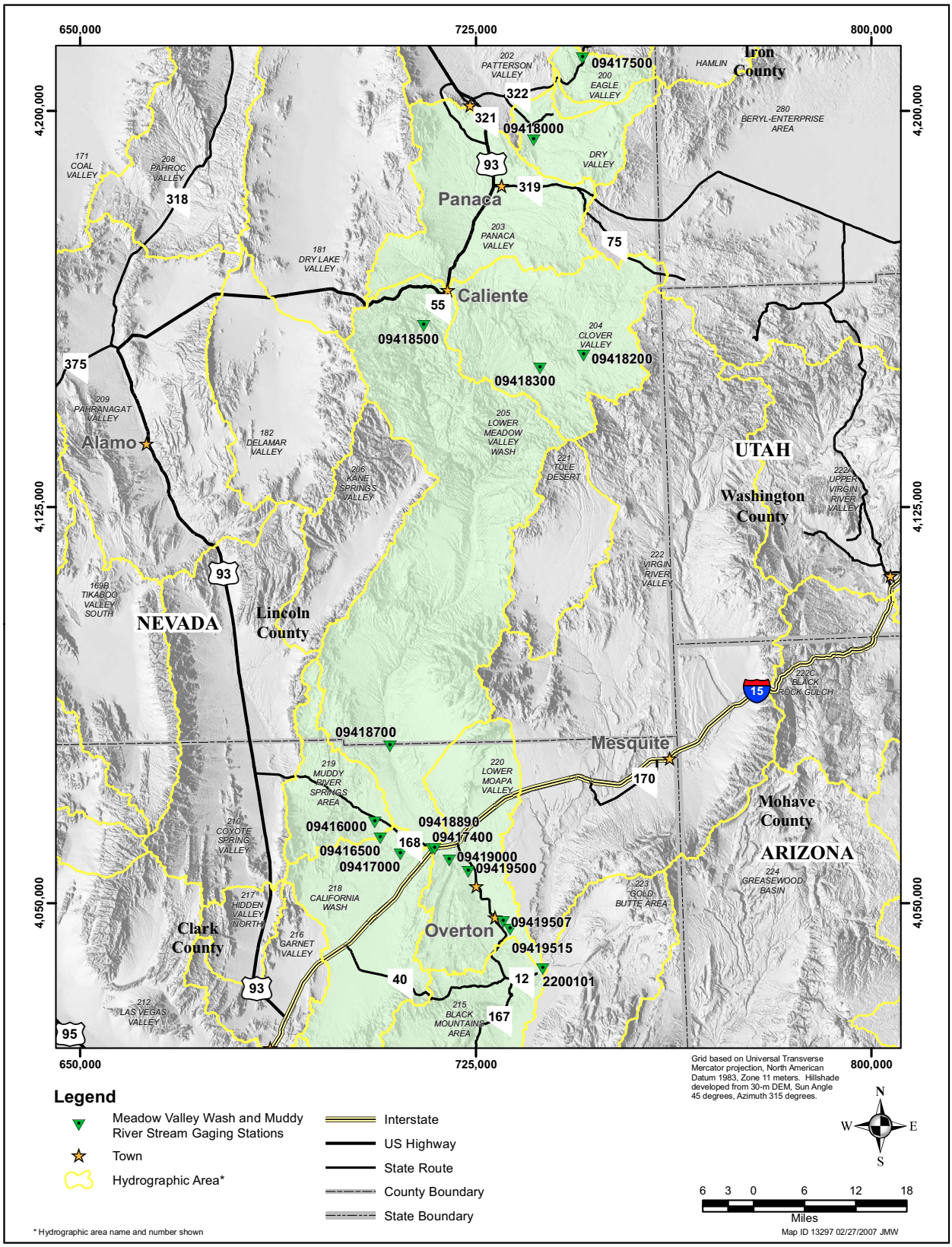


Figure 4-3
Measurement Sites on Muddy River and in Meadow Valley Wash

4.2.1 Classification of Springs

Springs have been classified in many different ways, including discharge, temperature, and the geologic unit from which discharge occurs. In this report, as well as in Volume 3, they are classified by discharge rates, as proposed by Oscar Meinzer in 1923 (Meinzer, 1942), and by temperature.

4.2.1.1 Discharge

Table 4-5 is taken after the system proposed by Oscar Meinzer in 1923 and is used in this report.

Table 4-5
Classification of Spring Size Based on Volume of Discharge

Order of Magnitude	Discharge	
	cfs	gpm
First	>100	> 44,883
Second	10 to 100	4,448 to 44,883
Third	1 to 10	449 to 4,488
Fourth	0.223 to 1	100 to 449
Fifth	0.022 to 0.223	10 to 100
Sixth	0.002 to 0.022	1 to 10
Seventh	0.0003 to 0.002	0.125 to 1
Eighth	< 0.0003	<0.125

after Meinzer, 1942

4.2.1.2 Temperature

Defining what constitutes a "thermal spring" versus warm and cold springs is arbitrary at best. It is a general practice to use the mean annual air temperature (MAT) at the location of the spring as a baseline from which to compare the temperature of spring discharge. If the temperature of the spring discharge is warmer than the MAT, a spring is said to be a warm spring. If it is cooler than the MAT, a spring is considered a cold spring. A more accurate temperature classification depends on several variables, including the initial temperature of the recharge water, heating or cooling during near surface movement, heating while moving to greater depths, cooling while returning to shallower depths, and the cooling or heating while mixing with other groundwater (Garside and Schilling, 1979). Table 4-6 lists the temperature classifications used in this report and their stereotypical occurrences.

4.2.2 Project Basin Springs Inventory

This section provides a brief description of the springs located within each of the project basins. The springs were identified by field investigations, database searches, and from 1:24,000 USGS topographic maps. Data sources for the inventoried springs include published reports, published data

Table 4-6
Classification of Springs Based on Physical Temperature

Description	Temperature (°C)	Stereotypical Occurrences
Hot	>32.2	Thermal springs associated with deep circulation
Warm	21.1 to 32.2	Springs in the central part of valleys
Cold	<21.1	Springs near recharge areas in mountain blocks

from the USGS, and field investigations conducted by SWNA. The selection of springs for field investigation was made through a collaborative effort by a team of professional hydrologists and geologists who have numerous years of experience in the project area. A list of criteria were developed by the team and considered the following:

- Aerial distribution
- Discharge
- Lithologic setting

Springs were chosen to represent each hydrographic basin in both aerial extent and elevation. This was difficult to achieve because spring locations are generally not equally spaced in each valley. Springs of different magnitudes of discharge were considered for inclusion in the data set. The lithologic setting was also considered. Springs in alluvial materials, and different types of consolidated rocks were observed.

Data collection procedures were established to ensure consistent and accurate compilation and collection of data during the field investigations. Key points of the data collection program were as follows:

- Photographic documentation
- Discharge measurement
- Water-chemistry sampling
- Written description of each spring
- Detailed geologic mapping (for selected springs).

4.2.2.1 Spring Valley

The inventory of springs within Spring Valley included a total of 503 springs. Of these, 9 were investigated and documented by SNWA personnel, 11 were found within the USGS NWIS or Desert Research Institute (DRI) database, and 483 were identified from additional location only data sets and topographic maps. A majority of the spring locations in Spring Valley occur along the western side of the northern half of the valley (Figure 4-4).

The 9 springs documented by SNWA in Spring Valley included Willow, North Millick, South Millick, South Bastian, Layton, North, Swallow, and Blind springs as well as The Cedars. Table 4-7 provides a summary of the location, discharge magnitude, and temperature of these springs. The majority of

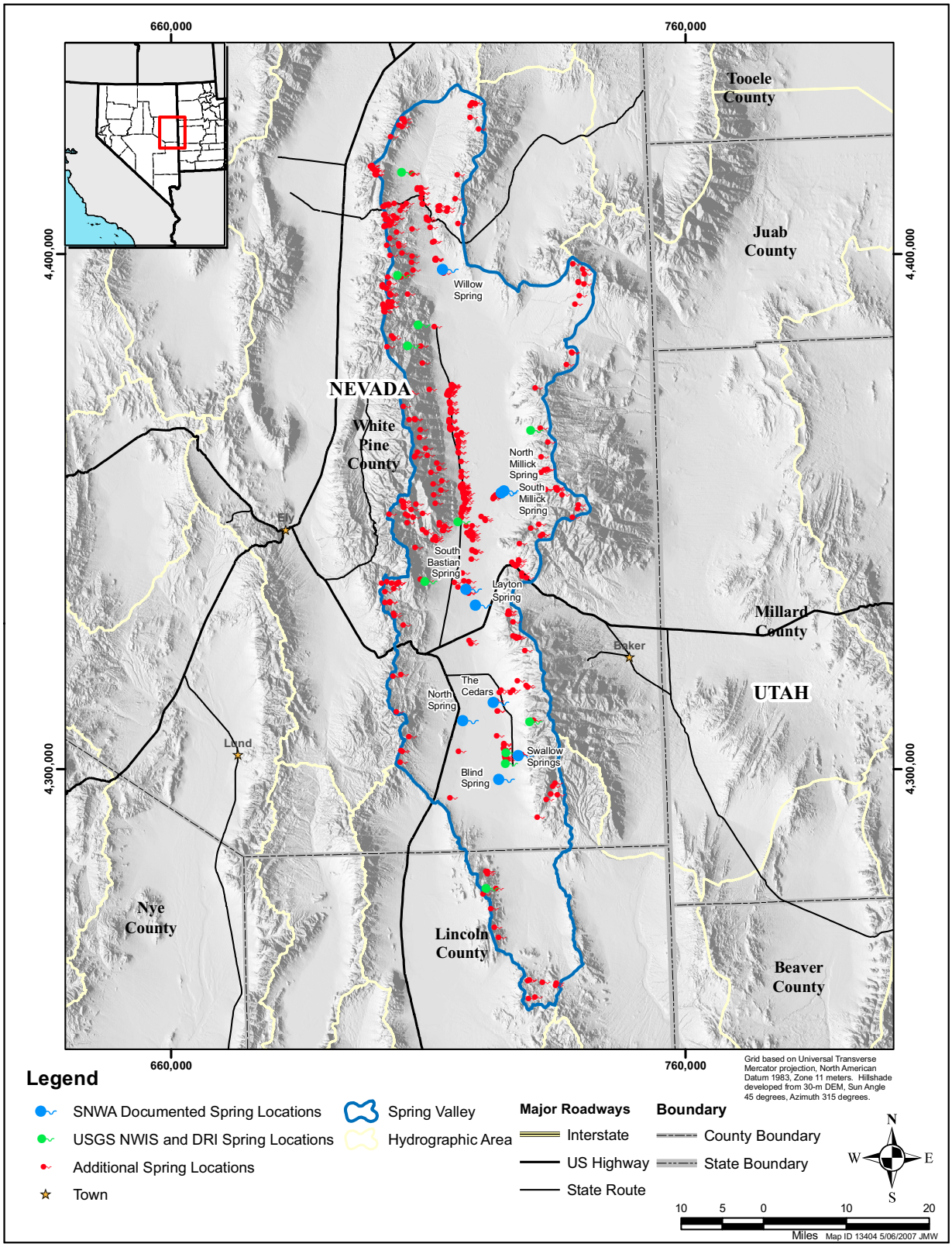


Figure 4-4
Spring Valley Spring Locations

Table 4-7
SNWA Documented Spring Locations in Spring Valley

Spring Name	UTM Easting[a] (m)	UTM Northing[a] (m)	Elevation[b] (ft-amsl)	Discharge Magnitude	Temperature Class.
Willow Spring	713,830	4,397,068	5,982	6	Cold
North Millick Spring	725,523	4,354,156	5,590	4	Cold
South Millick Spring	725,031	4,353,754	5,592	4	Cold
South Bastian Spring	718,388	4,334,865	5,660	6	Cold
Layton Spring	720,204	4,331,794	5,698	7	Cold
North Spring	717,768	4,309,388	5,763	6	Warm
The Cedars	723,712	4,312,911	5,783	5	Warm
Swallow Springs	728,597	4,302,920	6,080	4	Cold
Blind Spring	724,717	4,298,025	5,773	8	Cold

[a]Coordinates are in UTM Zone 11 and North American Datum of 1983
[b]Elevations are in North American Vertical Datum of 1988

the springs documented by SNWA for Spring Valley were valley floor or near valley floor springs in the central portion of the valley. Appendix B of Volume 3 contains 64 discharge measurements for the 9 springs.

4.2.2.2 Snake Valley

The inventory of springs within Snake Valley included a total of 359 springs. Of these, 3 were investigated and documented by SNWA personnel, 32 were found within the USGS NWIS or DRI database, and 324 were identified from additional location only data sets and topographic maps. A majority of the spring locations in Snake Valley occur at higher elevations along the western side of the southern half of the valley (Figure 4-5).

The 3 springs documented by SNWA in Snake Valley included Big Springs, Caine Spring, and Warm Springs. Table 4-8 provides a summary of the location, discharge magnitude, and temperature of these springs. Appendix B of Volume 3 contains 67 discharge measurements for the 3 springs.

4.2.2.3 Cave Valley

The inventory of springs within Cave Valley included a total of 47 springs. Of these, 2 were investigated and documented by SNWA personnel, 5 were found within the USGS NWIS or DRI database, and 40 were identified from additional location only data sets and topographic maps. A majority of the spring locations in Cave Valley occur at higher elevations in the northern half of the valley (Figure 4-6).

The 2 springs documented by SNWA in Cave Valley included Cave Spring and Sidehill Spring. Table 4-9 provides a summary of the location, discharge magnitude, and temperature of these springs. Appendix B of Volume 3 contains 14 discharge measurements for the 2 springs.

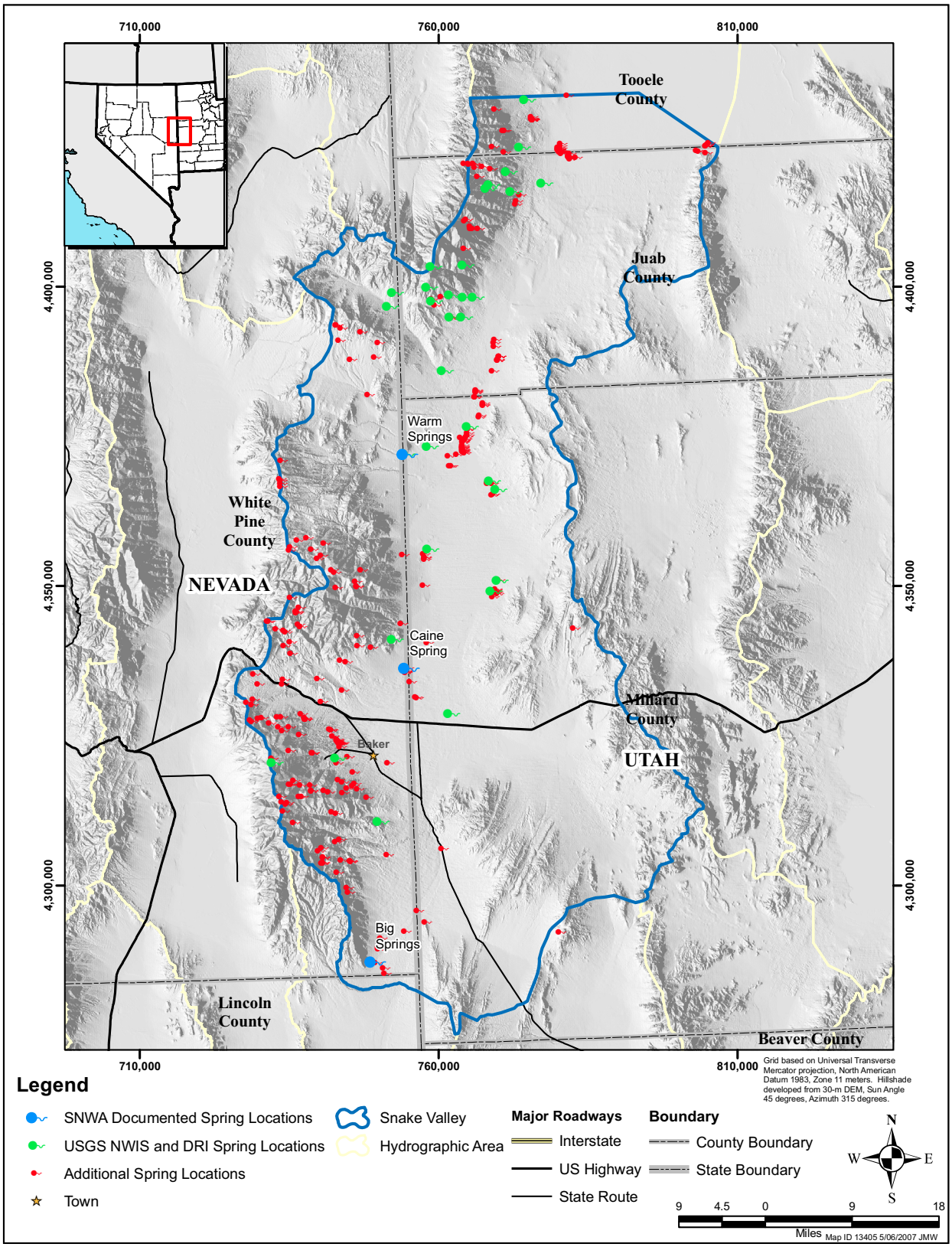


Figure 4-5
Snake Valley Spring Locations

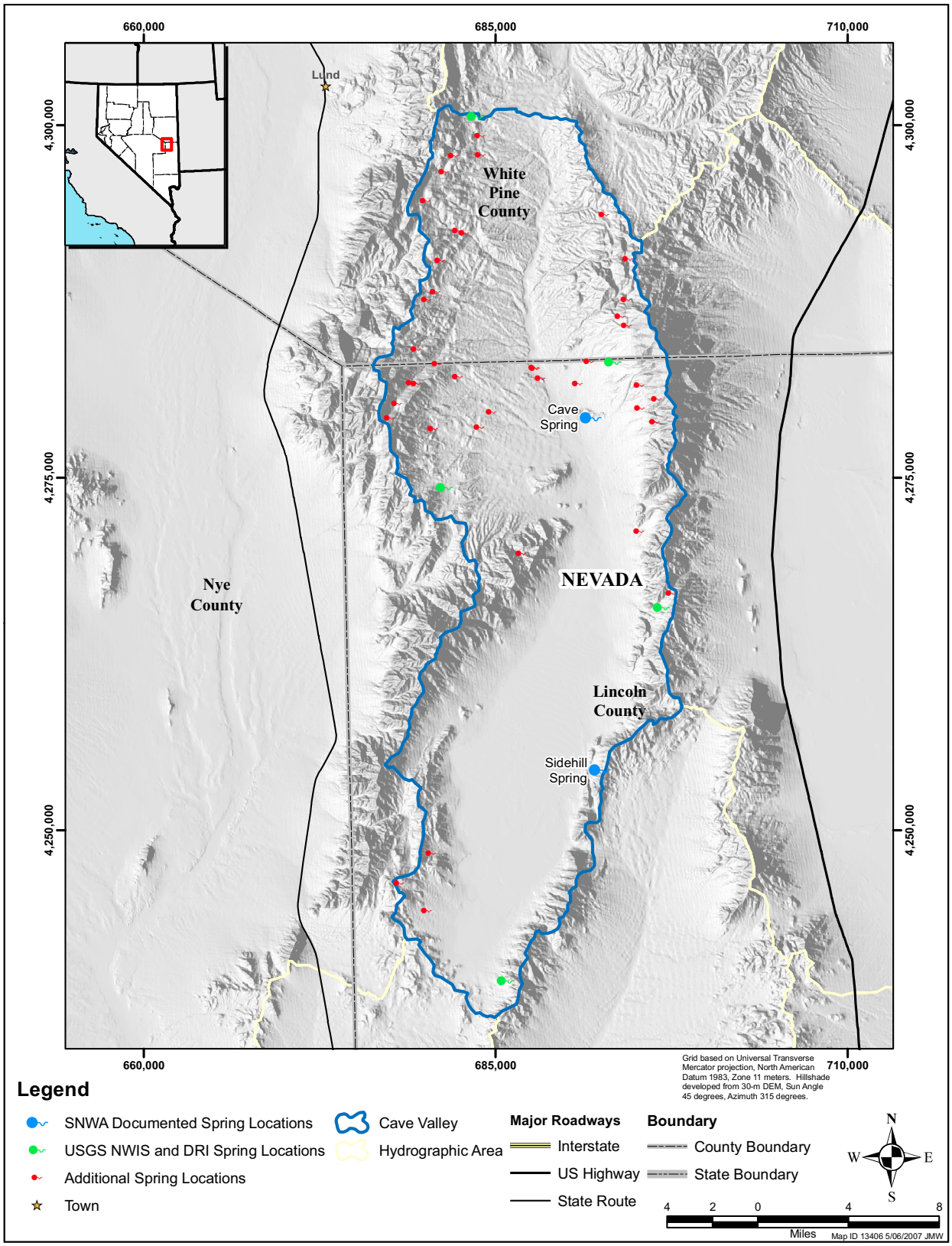


Figure 4-6
Cave Valley Spring Locations

Table 4-8
SNWA Documented Spring Locations in Snake Valley

Spring Name	UTM Easting[a] (m)	UTM Northing[a] (m)	Elevation[b] (ft-amsl)	Discharge Magnitude	Temperature Class.
Big Springs	749,422	4,287,293	5,568	3	Cold
Caine Spring	755,138	4,336,186	5,028	6	Cold
Warm Springs	754,812	4,371,945	5,252	2	Warm

[a]Coordinates are in UTM Zone 11 and North American Datum of 1983
[b]Elevations are in North American Vertical Datum of 1988

Table 4-9
SNWA Documented Spring Locations in Cave Valley

Spring Name	UTM Easting[a] (m)	UTM Northing[a] (m)	Elevation[b] (ft-amsl)	Discharge Magnitude	Temperature Class.
Cave Spring	691,760	4,279,249	6,488	4	Cold
Sidehill Spring	692,407	4,254,280	6,527	6	Cold

[a]Coordinates are in UTM Zone 11 and North American Datum of 1983
[b]Elevations are in North American Vertical Datum of 1988

4.2.2.4 Dry Lake Valley

The inventory of springs within Dry Lake Valley included a total of 98 springs. Of these, 4 were investigated and documented by SNWA personnel, 13 were found within the USGS NWIS or DRI database, and 81 were identified from additional location only data sets and topographic maps. A majority of the spring locations in Dry Lake Valley occur at higher elevations (Figure 4-7).

The 4 springs documented by SNWA in Dry Lake Valley included Meloy, Bailey, Littlefield, and Coyote springs. Table 4-10 provides a summary of the location, discharge magnitude, and temperature of these springs. Appendix B of Volume 3 contains 14 discharge measurements for the 4 springs.

4.2.2.5 Delamar Valley

The inventory of springs within Delamar Valley included a total of 31 springs. Of these, 1 was investigated and documented by SNWA personnel, 2 were found within the USGS NWIS or DRI database, and 28 were identified from additional location only data sets and topographic maps. A majority of the spring locations in Delamar Valley occur at higher elevations on the eastern side of the valley (Figure 4-8).

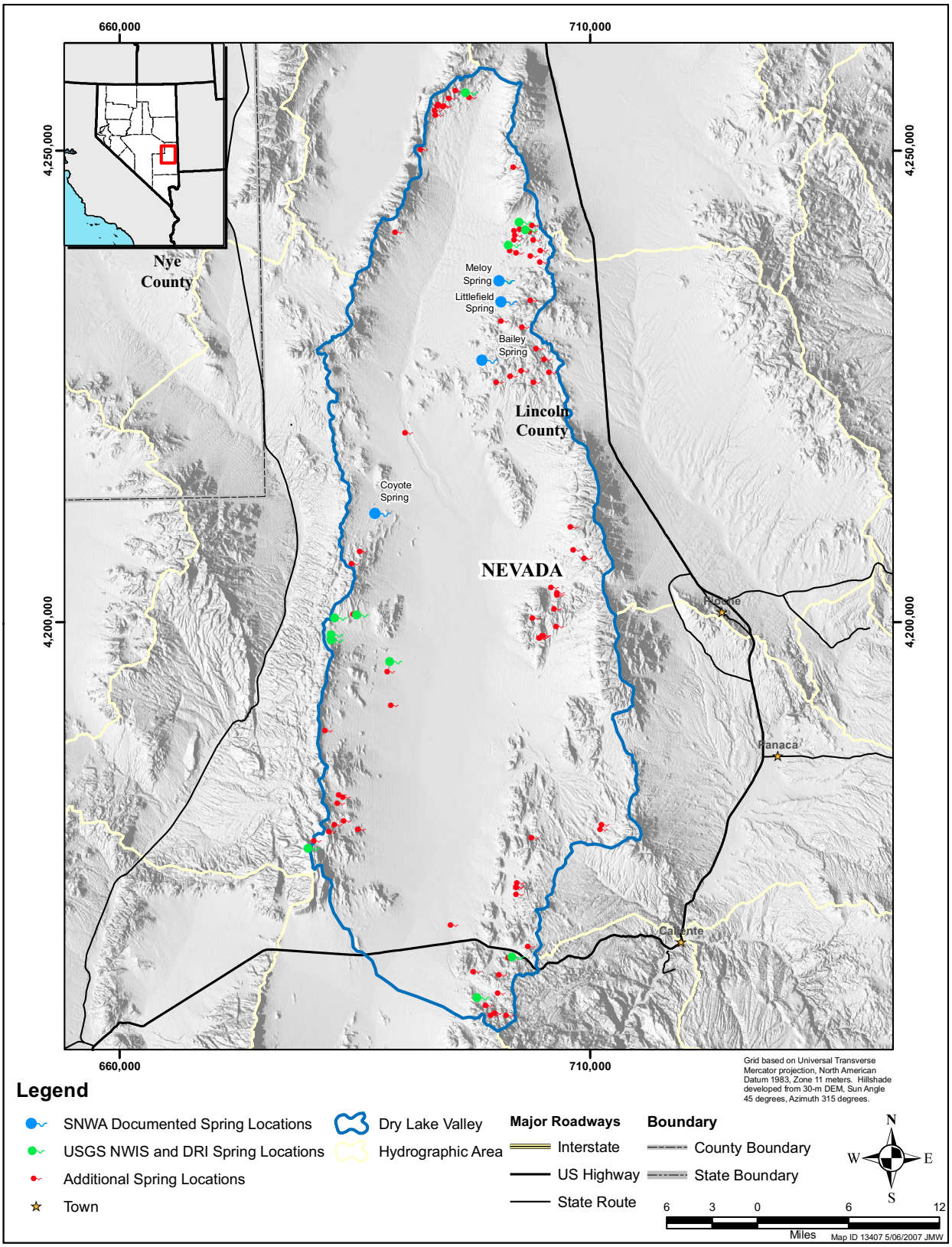


Figure 4-7
Dry Lake Valley Spring Locations

Table 4-10
SNWA Documented Spring Locations in Dry Lake Valley

Spring Name	UTM Easting (m)	UTM Northing (m)	Elevation (ft-amsl)	Discharge Magnitude	Temperature Class.
Meloy Spring	700,888	4,236,201	6,174	5	Cold
Bailey Spring	699,080	4,227,795	6,089	6	Cold
Littlefield Spring	701,112	4,233,949	6,146	5	Cold
Coyote Spring	687,693	4,211,513	5,220	6	Cold

[a]Coordinates are in UTM Zone 11 and North American Datum of 1983
[b]Elevations are in North American Vertical Datum of 1988

Grassy Spring was documented by SNWA in Delamar Valley. Table 4-11 provides a summary of the location, discharge magnitude, and temperature of this spring. Appendix B of Volume 3 contains 4 discharge measurements for Grassy Spring.

4.2.2.6 Coyote Springs Valley

The inventory of springs within Coyote Springs Valley included a total of 13 springs. Of these, 3 were found within the USGS NWIS or DRI database, and 10 were identified from additional location only data sets and topographic maps (Figure 4-9).

4.3 Summary of Surface Water Resources

This section has provided a brief summary of the detailed descriptions of streams and springs provided in Volumes 2 and 3 found on the CD-ROM accompanying this report. Additional site descriptions, discharge measurements, and site characteristics are found within the data volumes.

Table 4-11
SNWA Documented Spring Locations in Delamar Valley

Spring Name	UTM Easting[a] (m)	UTM Northing[a] (m)	Elevation[b] (ft-amsl)	Discharge Magnitude	Temperature Class.
Grassy Spring	695,124	4,157,193	5,783	6	Warm

[a]Coordinates are in UTM Zone 11 and North American Datum of 1983
[b]Elevations are in North American Vertical Datum of 1988

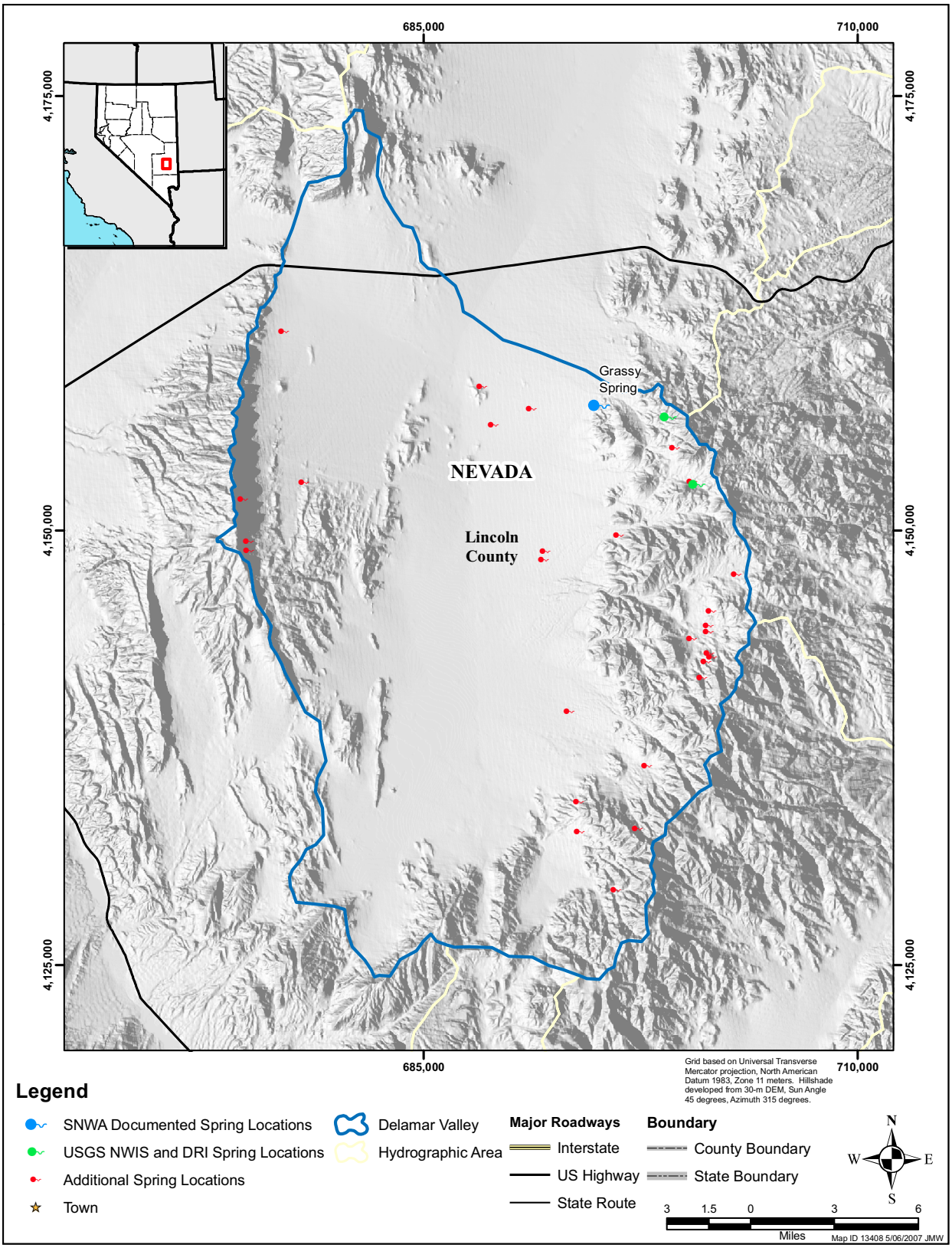


Figure 4-8
Delamar Valley Spring Locations

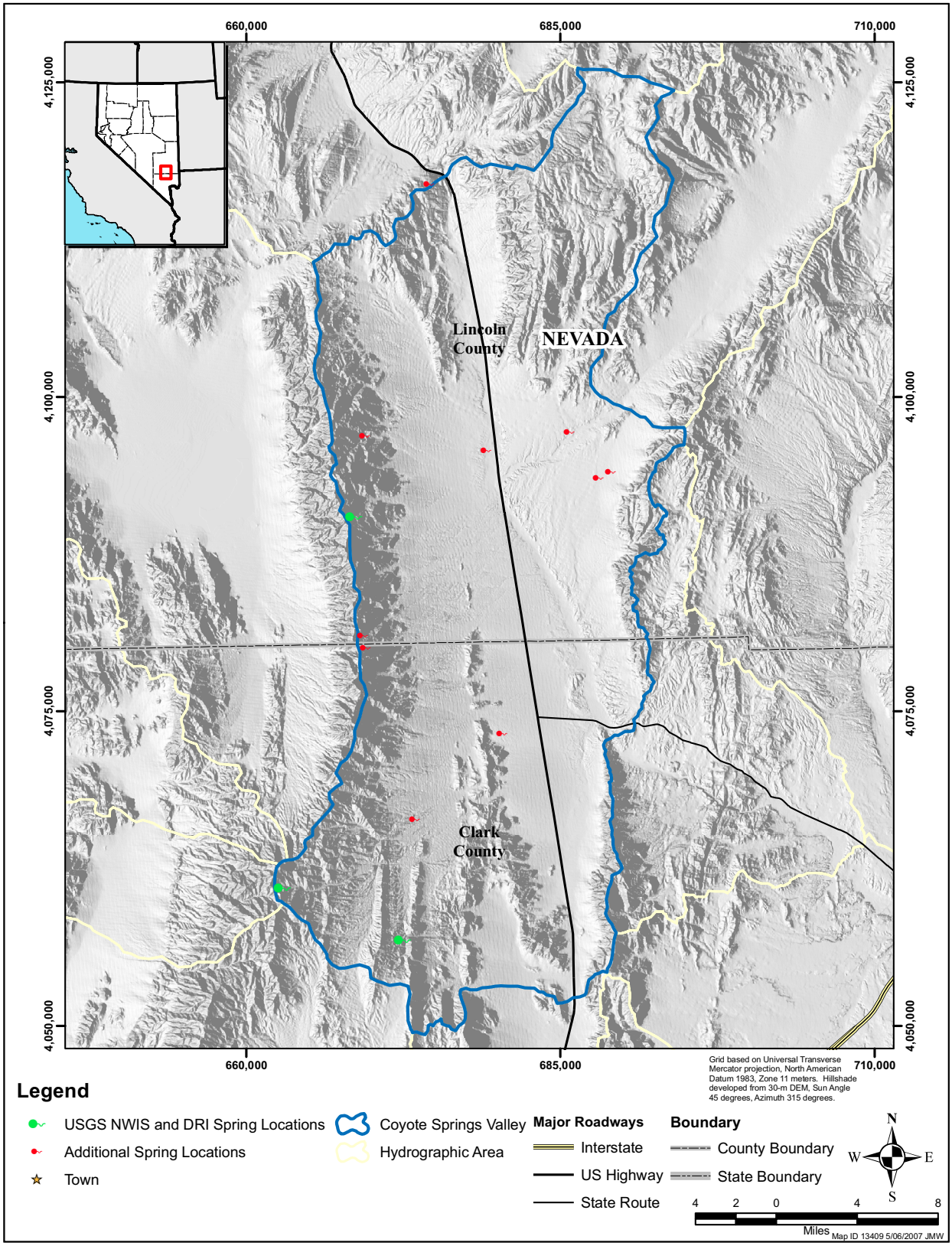


Figure 4-9
Coyote Springs Valley Spring Locations

5.0 GROUNDWATER RESOURCES

The SNWA has studied and thoroughly described the wells and water levels of the study area in a report titled "Water-Level Data Compilation and Evaluation for the Clark, Lincoln, and White Pine Counties Groundwater Development Project" (SNWA, 2007d). In the report, SNWA documented the development of a comprehensive and updated water-level database. The database was then used to accomplish several objectives including:

- Characterization of hydraulic head within aquifers in the study area for evaluation of conceptual flow paths and gradients.
- Prepare data sets from which a numerical groundwater flow model may be calibrated, including interpretations of steady-state water levels and identification of non-steady-state conditions that might be present in the study area.
- Characterize depths to water for use in reviewing groundwater discharge by evapotranspiration.

An electronic version of the report has been attached as Volume 4 on the CD-ROM accompanying this report. This section provides an overview of the water-level information presented in that report.

5.1 Data Compilation and Evaluation

Approximately 17,000 individual depth-to-water measurements were compiled for 1,719 groundwater sites in the study area. The data were assembled from a variety of sources including published and unpublished reports, and from databases or spreadsheets maintained by different agencies and documented in Volume 4. In addition to the site location and depth-to-water data, well construction and lithologic information were also compiled for each site, if available. The compiled data were then integrated into a Microsoft Access® 2000 database.

After compilation of the site location and depth-to-water data, the compiled data were evaluated to check for duplicate data, inconsistencies in a site's reported land-surface elevation in comparison to a DEM, and inconsistencies in a site's data in comparison to data for the surrounding area.

5.2 Data Reduction

Prior to the analysis of the compiled water-level data, the water-level data set was reduced to a data set appropriate for analysis. This data reduction consisted of determining the effective open interval of a well, calculating water-level elevations from the depth-to-water data, identifying outlier and non-steady state water-level measurements, and determining the hydrogeologic unit in which a given

well is completed. Volume 4 discusses each of these steps in greater detail. The process of determining water-level elevations and identifying outlier and non-steady state water-level measurements, however, are summarized in the following sections.

5.2.1 Water-Level Elevation Calculation

For each individual depth-to-water measurement, a corresponding water-level elevation was calculated as the land-surface elevation (or reference point elevation) minus the depth-to-water measurement, as shown by the following equation:

$$H = LSE - DTW \qquad \text{(Eq. 5-1)}$$

where,

H = Water-level elevation or hydraulic head value (ft-amsl)
LSE = Land-surface elevation (ft-amsl)
DTW = Depth to water (ft)

Water-level elevations are necessary for the creation of the water-level elevation contour maps and to construct hydrographs that can be used for additional data analysis including the calculation of mean steady-state water-level elevations for a given site. The hydrographs are used to examine steady-state trends and to identify abnormal or inconsistent depth-to-water measurements that would be unsuitable for inclusion into a steady-state hydraulic head data set.

5.2.2 Identification of Outlier or Non-Steady-State Water-Level Measurements

In Volume 4, "steady state" was defined as there being no trend in the available water-level elevations for a well other than natural fluctuations. "Transient conditions," or non-steady state, were defined as water-level elevations collected during pumping or elevations affected by pumping. To identify water-level measurements that are outliers, or non-steady state, and, therefore, not representative of predevelopment groundwater flow conditions, a temporal and spatial data analysis was performed for each site with ten or more water-level measurements. For wells with less than ten water-level measurements, it could not be determined which measurements represented steady state; therefore, all measurements were included for completeness and qualified.

The identification of non-steady-state water-level measurements consisted of constructing hydrographs for each well with ten or more water-level measurements in the study area. The hydrographs were reviewed to identify outlier and non-steady-state data. The non-steady-state measurements were flagged in the compiled data set, and an additional flag was assigned to those measurements, documenting the inconsistency. For example, individual depth-to-water measurements might be flagged as being "anomalously low," "anomalously high," or as "not representative of steady-state or predevelopment conditions." Anomalously low or high measurements were defined as the water level being lower or higher in magnitude than equivalent data at the same site. The water-level measurements that were flagged as "inconsistent" were then excluded from further steady-state data analysis (i.e., mean hydraulic head calculations). Wells

having non-steady-state measurements that could be attributed to groundwater pumping were flagged to indicate transient-state behavior.

5.3 Data Analysis

Analysis of the site location and water-level data for this study consisted of (1) calculating mean steady-state hydraulic heads and evaluating the uncertainty associated with the steady-state hydraulic heads, and (2) using the mean steady-state hydraulic heads to investigate the predevelopment groundwater conditions in the study area by creating basin-fill composite water-level maps, depth-to-water maps in phreatophyte areas, and a carbonate-rock water-level contour map that shows the locations of well and spring locations that penetrate the carbonate-rock aquifer system.

5.3.1 Steady-State Hydraulic Heads

To prepare a water-level data set for use in the calibration of a steady-state numerical groundwater flow model, it was necessary to determine the predevelopment hydraulic head value from the water-level data for each site. This process consisted of first excluding hydraulic head data from the complied data set that were not considered representative of steady-state conditions. Data that were not considered representative of steady-state conditions included water-level elevation data qualified as "pumping," "recently pumping," or "a nearby site is pumping," Other data considered abnormal or inconsistent with the steady-state conditions for a given site were also removed from the data set. Once the process of excluding non-representative data was completed, a mean steady-state hydraulic head value for a given site was calculated as follows:

$$\overline{H} = \frac{\sum H_t}{n} \qquad \text{(Eq. 5-2)}$$

where,

$\overline{H}$ = Mean hydraulic head value representative of steady-state conditions (ft-amsl)
H_t = Hydraulic head value for a given time (ft-amsl)
n = Number of water-level elevation measurements available for the period of record.

For sites with only one water-level elevation, that value was assumed to represent the steady-state value for that site. In addition, for springs that were included in the compiled data set, the land-surface elevation of the location was used as an approximate steady-state hydraulic head value.

An assessment of the uncertainty associated with the mean hydraulic head value for a given site was also completed for this study. This assessment of uncertainty was based on methods documented by IT Corporation (1996) and D'Agnese et al. (2002). A mean hydraulic head value for a site is derived from the land-surface elevation and the average water-level elevation measurement. As a result, the uncertainty associated with a mean water-level elevation for a given site results from four main sources of error: (1) the error associated with estimating the land-surface elevation, (2) the error associated with the location of a site, (3) the error associated with measuring the depth to water, and (4) the error associated with reducing multiple water-level measurements to a mean value

(i.e., water-level variability). To quantify the overall accuracy of the mean hydraulic head measurements, estimates of the variances associated with the hydraulic head errors are summed and used to assign weights to the hydraulic head values. More information on the quantification of the uncertainty associated with the mean hydraulic head measurements can be found in Volume 4.

5.3.2 Characterization of Predevelopment Groundwater Conditions

The characterization of predevelopment groundwater conditions consisted of creating basin-fill composite water-level maps, creating depth-to-water maps in phreatophyte areas, and creating a carbonate-rock water-level contour map of well and spring locations that penetrate the regional carbonate-rock aquifer system. The characterization of predevelopment groundwater conditions in the study area was complicated due to the lack of a consistent temporal distribution of measurements in the study area. For example, water levels range from 1912 to 2006 for the most recent water-level measurement. For the purpose of this study, predevelopment groundwater conditions in the study area were examined using the mean water-level elevation values determined as calibration targets for the groundwater flow model. Due to the fact that there has been relatively limited groundwater development in most areas of the study area, it was felt that the steady-state hydraulic heads were analogous to predevelopment conditions. It is noted, however, that significant pumping occurs in Steptoe, Snake, Lake, and Panaca valleys.

Basin-fill composite water-level maps were drafted by hand at 100-ft intervals for most basins. Water-level data used in the development of the water-level contour maps consisted of water-level elevations from 1,755 wells and 83 spring heads in the study area. The contours incorporated several factors including geologic structures, topography, and data point reliability. The 100-ft contour intervals were based on the quantity and inferred quality of the data set. Contour lines are dashed where uncertain or inferred. The drafted water-level contour lines were then transferred to digital base maps that included both well or spring location and the water-level elevation for each point.

Depth-to-water maps were prepared for those hydrographic areas in the study area generally containing over 300 acres of phreatophytes. The depth-to-water maps were created by hand-contouring the depth-to-water data at 50-ft contours for most of the hydrographic areas. Contour lines are dashed where uncertain or inferred. The depth-to-water contours also incorporated several factors including geologic structures, topography, and data point reliability.

The carbonate-rock water-level contour map was constructed by plotting the well and spring locations that are known to penetrate or emanate from the regional carbonate-rock aquifer (see Figure 5-1). Water-level data used in the development of the regional carbonate-rock water-level map consisted of water-level elevations from 109 wells and 19 spring heads in the study area. Contour lines for the regional carbonate-rock aquifer system were hand drafted at 500-ft intervals for the entire study area. The contours incorporated several factors including geologic structures, topography, data point reliability, and the extent of the carbonate-rock aquifer in the study area. The 500-ft contour intervals were based on the quantity and inferred quality of the data set. Contour lines are dashed where uncertain or inferred. Previous investigations by Thomas et al. (1986), Bedinger and Harrill (2004), Prudic et al. (1995), and Wilson (2007) were used as guides to supplement the limited amount of data in the study area.

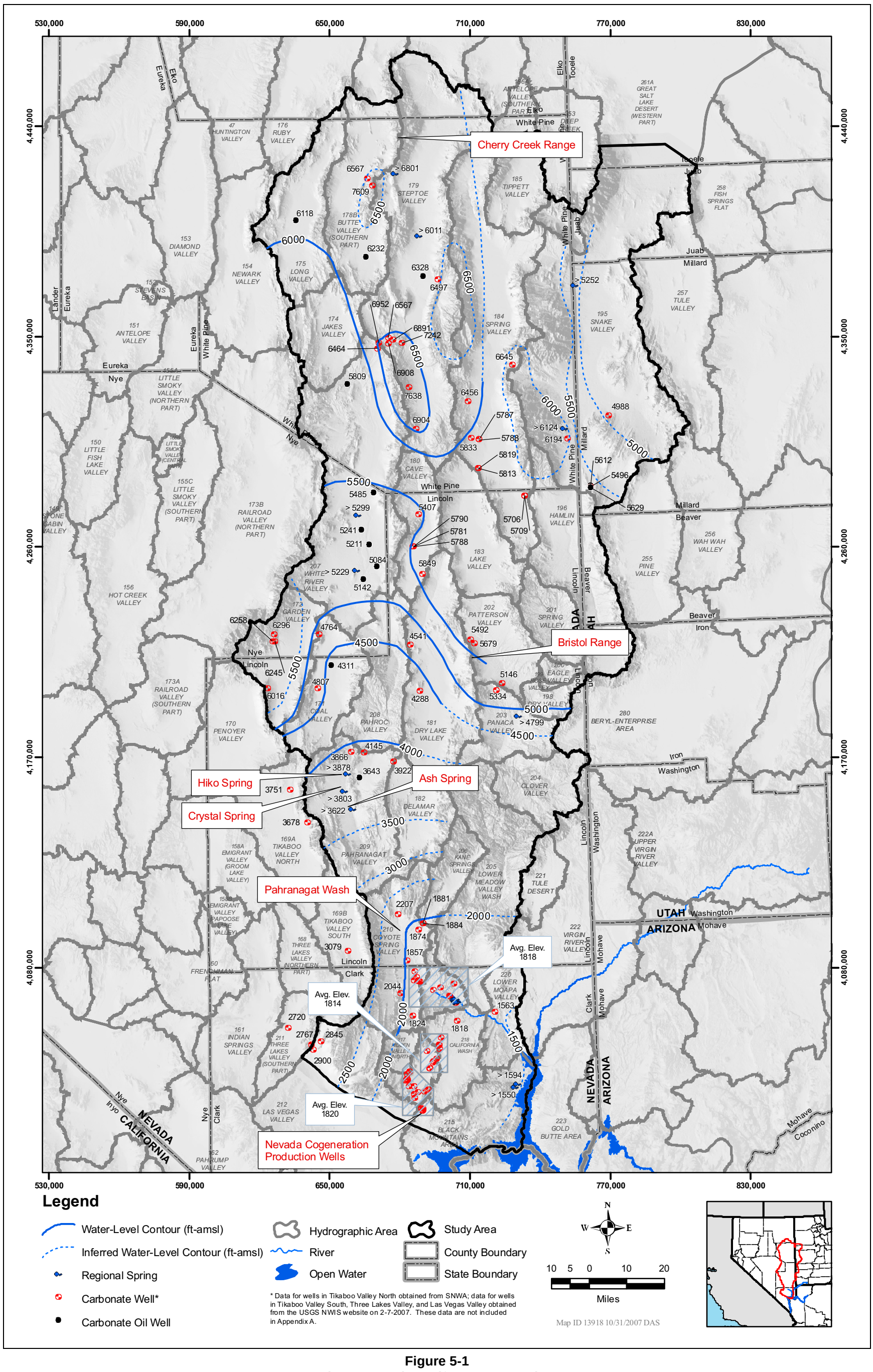


Figure 5-1
Carbonate-Rock Aquifer Water-Level Map

5.4 Project Basin Water-Level Analysis Results

The following sections describe the water-level analysis results for the Project Basins.

5.4.1 Spring Valley

Most wells in Spring Valley are relatively shallow, less than 300 ft in depth, with about a third less than 100 ft in depth. Two wells, however, have depths greater than 900 ft in depth. Production rates from large-diameter wells reported on the driller's logs are in the range of a few hundred to 2,000 gpm. Most lithologic descriptions reported on the drillers' logs contain references to interbedded sands, gravels, and clays. These descriptions support the characterization of the basin-fill sediments described by previous investigators including Rush and Kazmi (1965). The lithology of the basin-fill and the flowing wells that can be found in the southern half of the valley (e.g., the flowing wells near The Cedars) suggest that the primary aquifers are confined or semi-confined. A shallow unconfined aquifer is also likely to exist.

Basin-Fill Aquifer

Groundwater occurs at shallow depths throughout most of Spring Valley. For example, depths to water in Spring Valley range from above ground surface (i.e., flowing wells) to depths over 400 ft-bgs. It can be seen from Figure 5-2 that depths to water in Spring Valley are shallow over much of the central valley floor, and there are a number of ponds, small playa lakes, and springs in the central portion of the valley. Depths to water are greatest on the alluvial fans and increase to over 400 ft-bgs in the southernmost portion of the valley east of the Fortification Range. Figure 5-3 shows that water-level elevations in Spring Valley range from approximately 6,600 ft-amsl in the northernmost portion of the valley to approximately 5,500 ft-amsl in the central portion of the valley near the Yelland Dry Lake. The figure also shows that water-level elevations in the southern portion of the valley near the topographic divide with Hamlin Valley are approximately 5,700 ft-amsl. The water-level elevations and contour lines shown on Figure 5-3 indicate that there is a north-to-south hydraulic gradient in the northern portion of the valley and a south-to-north hydraulic gradient in the southern portion of the valley. The hydraulic gradient for the northern portion of the valley is approximately 25 to 30 ft/mi to the south, while the hydraulic gradient in the southern portion of the valley is approximately 5 ft/mi to the north. These gradients suggest that groundwater flows from both the northern and southern portions of the valley toward the central portion of the valley. The water-level contours on Figure 5-3 also show that a groundwater divide exists within the southern portion of the valley, north and west of the Limestone Hills near the topographic divide with Hamlin Valley.

Carbonate Aquifer

Prior to 2006, there were three wells in Spring Valley known, or assumed, to be completed in carbonate rocks. The wells were identified based on driller's logs and their location relative to carbonate-rock outcroppings. All three wells are located south of U.S. Highway 50 along the mountain range fronts as shown on Figure 5-1. The water-level elevations for the three wells range from approximately 5,800 to 6,600 ft-amsl. Well 184 N15 E68 17DD 1, located on the east side of the valley near Sacramento Pass, has a water-level elevation of 6,645 ft-amsl and may be influenced by the underlying clastic rocks, which act as a lower confining unit. Well 184 N12 E66 05ACAB1,

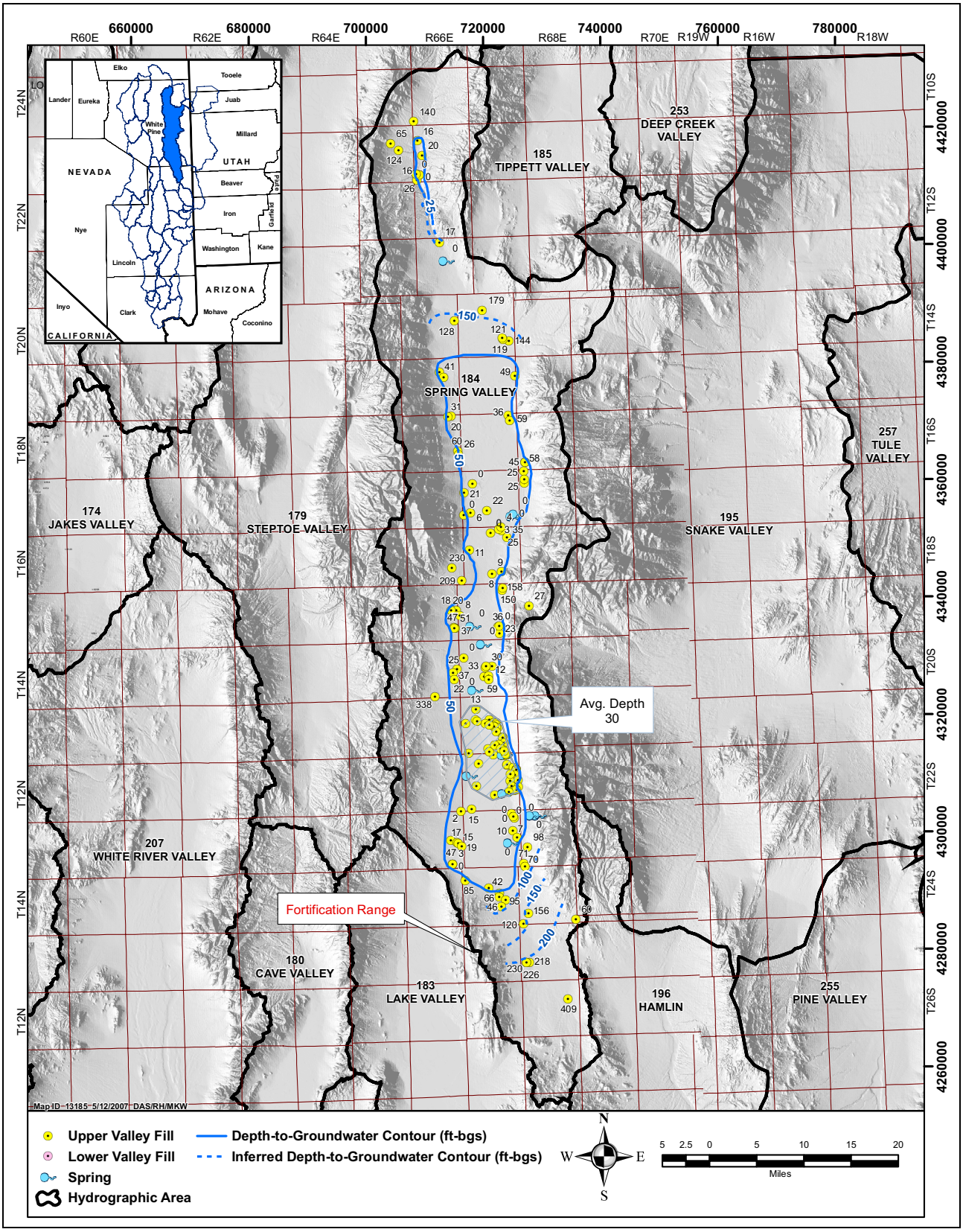


Figure 5-2
Spring Valley Depth to Water Map

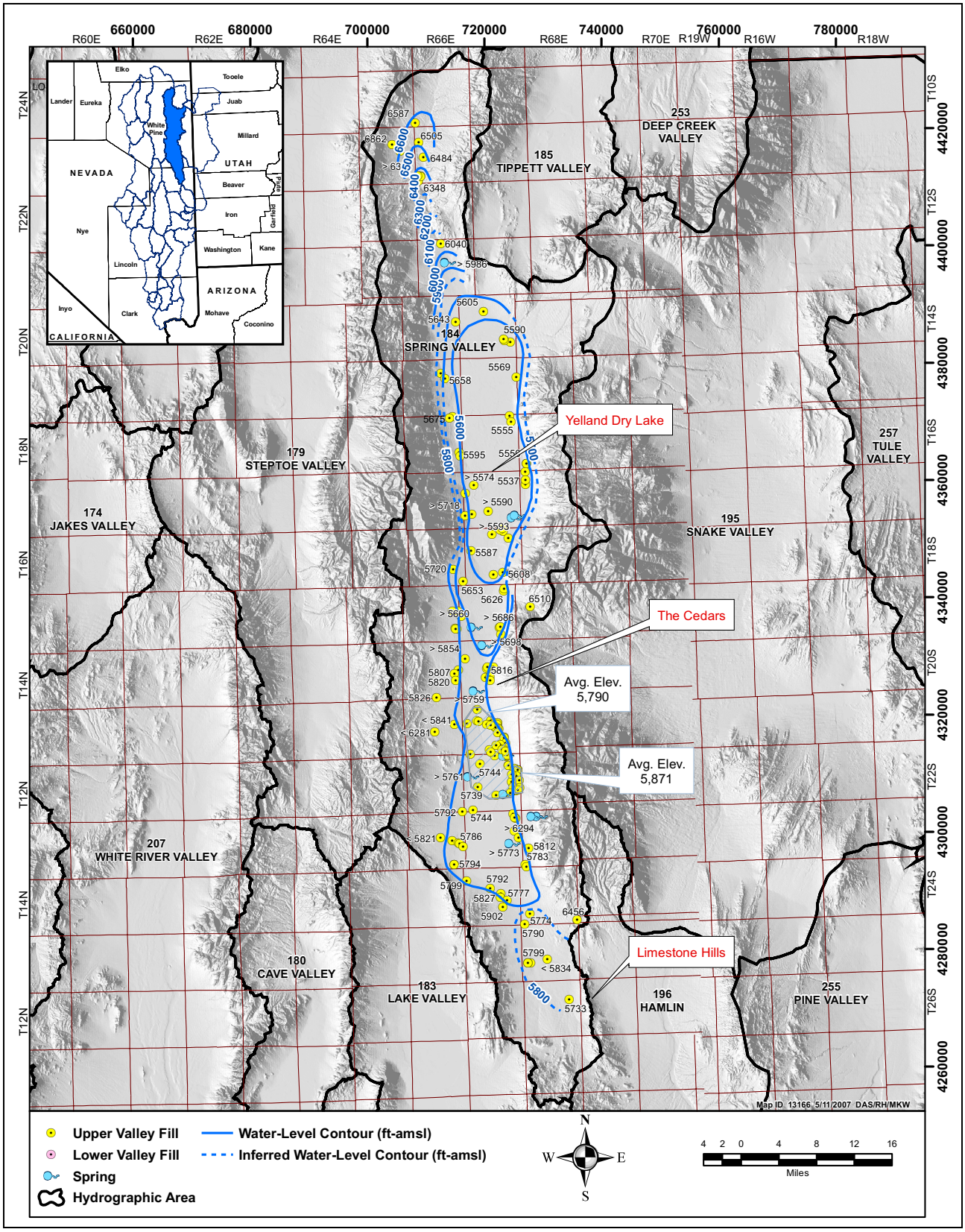


Figure 5-3
Spring Valley Water-Level Elevation Map

located near the intersection of U.S. Highways 50 and 93, has a water-level elevation of 6,456 ft-amsl. This well is assumed to be completed in carbonate rocks based on the driller's log that indicates a borehole penetration of "hard lime" from 20 to 40 ft-bgs. The third well, 184 N12 E66 21CD 1, is located in the southern portion of the valley and has a water-level elevation of 5,833 ft-amsl.

The SNWA installed seven wells in Spring Valley in 2006 and 2007 as part of an exploratory drilling program. Six of the wells were completed in the carbonate-rock aquifer. The six wells consisted of both a test well and a monitoring well at three different locations in southern Spring Valley (i.e., 184W105/184W506M, 184W103/184W504M, and 184W101/184W502M). The preliminary water-level elevations for the three sites are shown on Figure 5-1. The northernmost SNWA sites had carbonate-rock water-level elevations of 5,787 and 5,788 ft-amsl, while the middle SNWA sites had carbonate-rock water-level elevations of 5,819 and 5,813 ft-amsl. The southernmost SNWA sites near Hamlin Valley had carbonate-rock water-level elevations of 5,706 and 5,709 ft-amsl. From the available data shown on Figure 5-1, it appears that the water-level elevations decrease from 6,645 ft-amsl in the middle portion of Spring Valley to approximately 5,700 ft-amsl in the southern portion of Spring Valley.

Water-Level Trends

There are a number of wells in Spring Valley that have more than ten depth-to-water measurements. In general, the hydrographs that were constructed for wells in Spring Valley reveal that water-level trends are dependent on spatial location and proximity to agricultural areas. For example, well 184 N09 E68 30AAAB1 USGS-MX (Spring Valley S.), in the southern portion of Spring Valley, has shown an increase in water-level elevations since the early 1980s (Figure 5-4). This well is not near agricultural areas and there are no groundwater production wells in the vicinity. Well 184 N11 E68 19DCDC1 USGS-MX (Spring Valley), however, is approximately 12 mi north of the previous well and shows a decrease in water-level elevations of approximately 7 ft over the past 15 years (Figure 5-5). This well is still in the southern portion of Spring Valley, but is within two miles of an agricultural area. It can be seen from the figure, however, that approximately three feet of the water-level decline appears to be coincident with the region-wide drought beginning in late 1998. The figure also shows that water-level elevations have increased approximately five feet since the middle of 2006 after a year of above normal precipitation in 2005. Water-level elevations for wells in the northern portion of Spring Valley have shown relatively consistent water-level trends. For example, Figure 5-6 shows that water-level elevations for well 184 N19 E67 13AAAC1 have varied approximately six feet over the last 60 years. Inspection of all the hydrographs for Spring Valley, found within Volume 4, reveals that most hydrographs show variations of 5 to 10 ft over the period of record for a given well. These changes may be related to changes in hydrologic conditions and measurement accuracy rather than anthropogenic effects.

5.4.2 Snake Valley

Over 250 well and spring locations have been compiled for Snake Valley. Even with the relatively large amount of data in Snake Valley, this basin still has some of the most complicated water-level contour interpretations for basins in the study area, particularly with regard to outflows through carbonate bedrock.

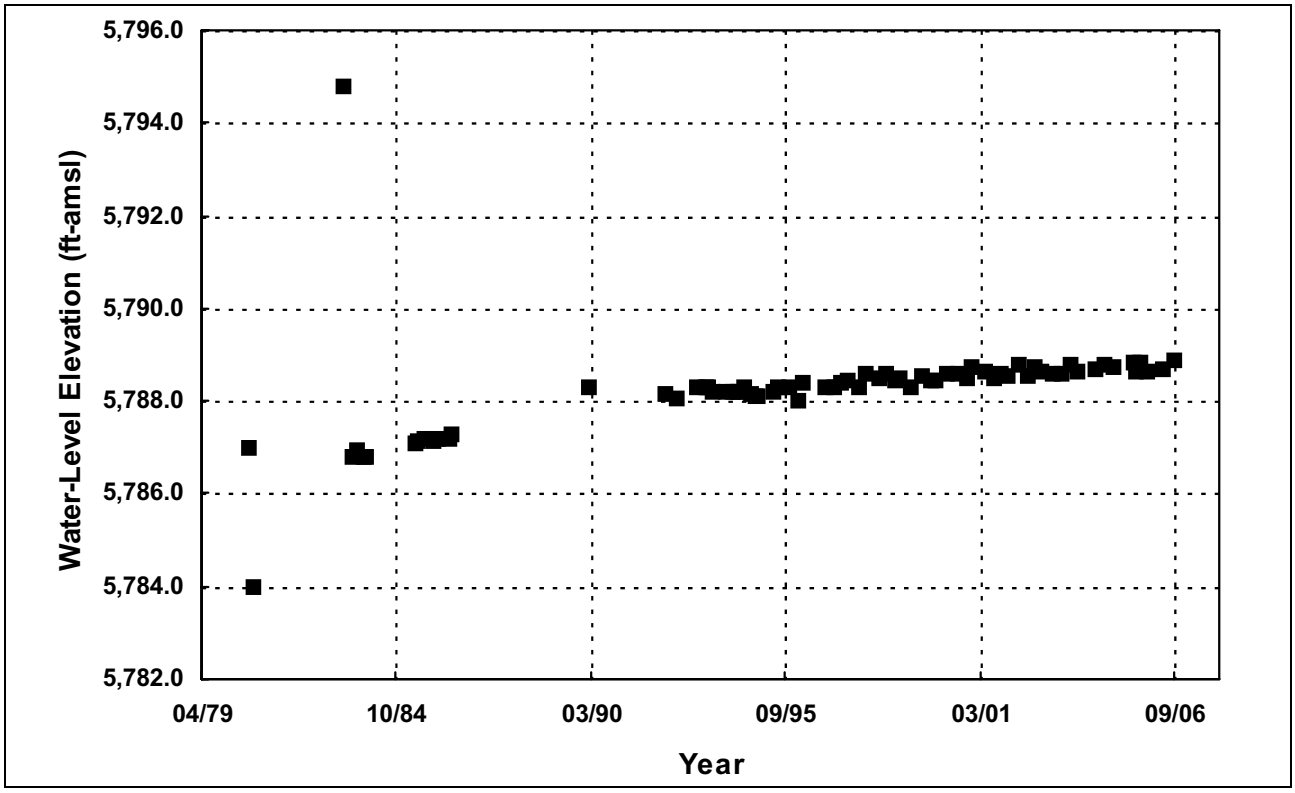


Figure 5-4
Historical Water-Level Elevations at 184 N09 E68 30AAAB1 USGS-MX (Spring Valley)

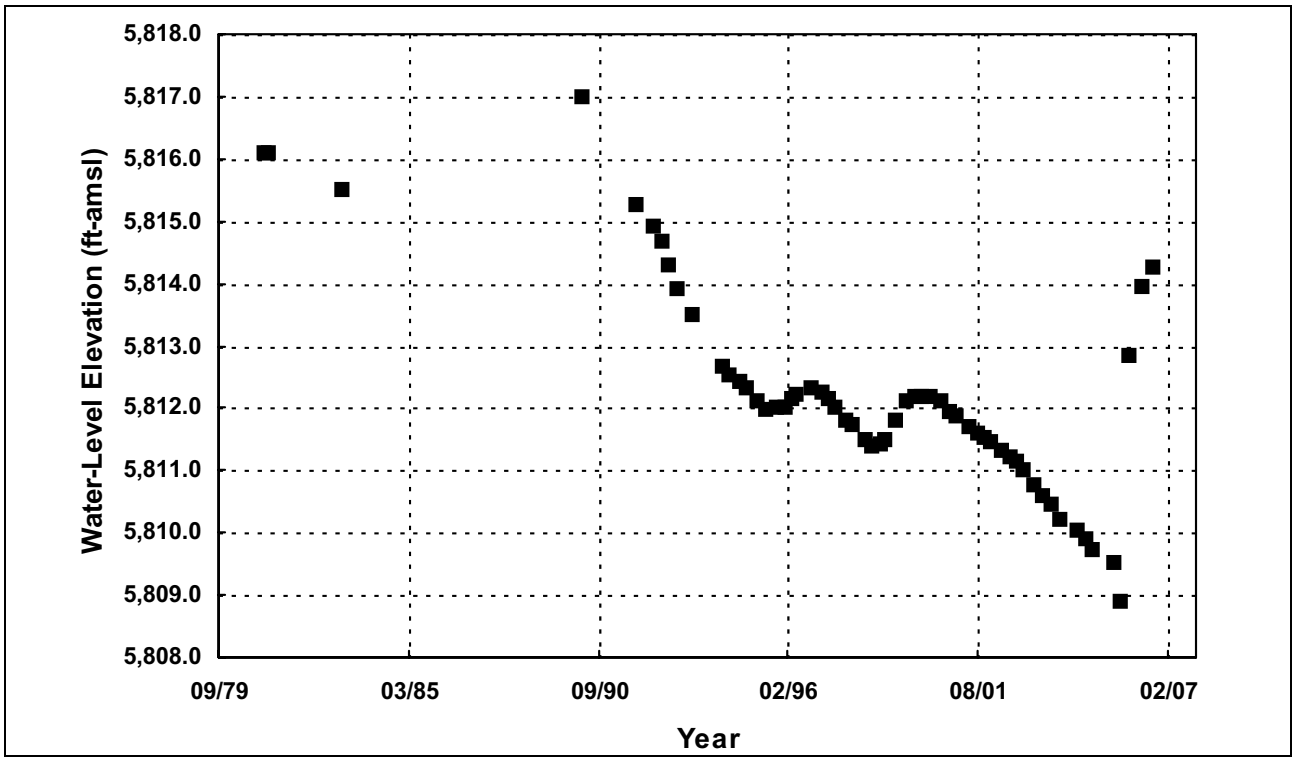


Figure 5-5
Historical Water-Level Elevations at 184 N11 E68 19DCDC 1 USGS-MX (Spring Valley)

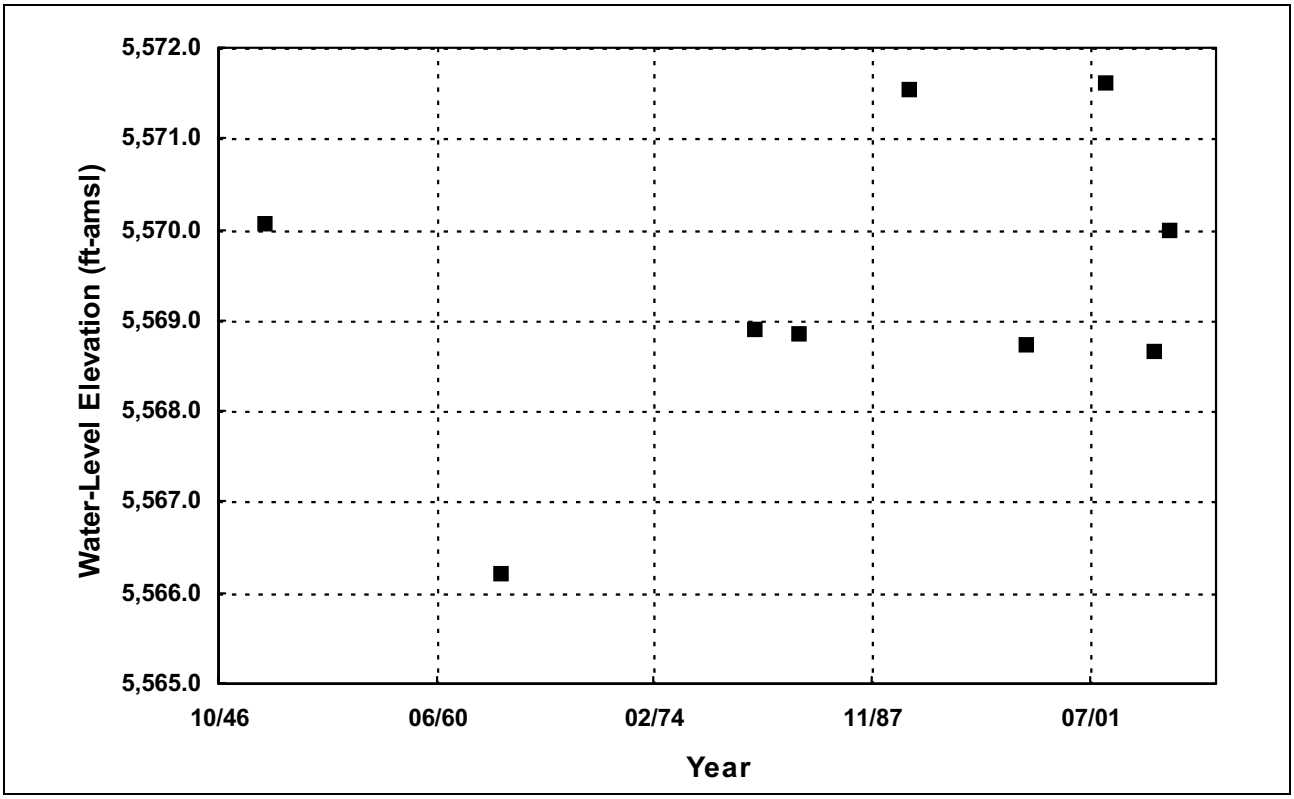


Figure 5-6
Historical Water-Level Elevations at 184 N19 E67 13AAAC1

Basin-Fill Aquifer

According to Ertec Western Inc. (1981c), the valley-fill deposits in Snake Valley consist of clay, silt, and sand in lacustrine areas in the center of the valley, and gravels and sands in the alluvial fan deposits along the valley margins. Groundwater production data that was reported on the NDWR driller's logs for wells in Snake Valley range from 20 gpm to a reported production rate of 950 gpm for one well in the southernmost portion of Snake Valley. Based on the lithology of the basin-fill wells and numerous springs and flowing wells in Snake Valley, groundwater occurs under both confined and unconfined conditions.

Depths to water in Snake Valley for basin-fill wells range from above land surface to greater than 500 ft-bgs. Areas of shallow groundwater can be found throughout the valley especially along the main axis of the valley from the town of Baker in the south to Partoun and Trout Creek in the north (Figure 5-7). Depths to water tend to increase along the valley margins closer to the mountain ranges surrounding the valley. Depths to water are greatest on the east side of the valley and in the southernmost portion of the valley near the Burbank Hills. Figure 5-8 shows that water-level elevations for wells located on the valley floor range from approximately 5,500 ft-amsl in the southern portion of the valley to approximately 4,300 ft-amsl in the northernmost portion of the valley. It can also be seen from the figure that water-level elevations are higher closer to the surrounding mountain ranges than on the valley floor. The water-level elevations and composite water-level contours indicate that there is a south-to-north hydraulic gradient of approximately 11 ft/mi in the valley in the direction of the Great Salt Lake Desert hydrographic area.

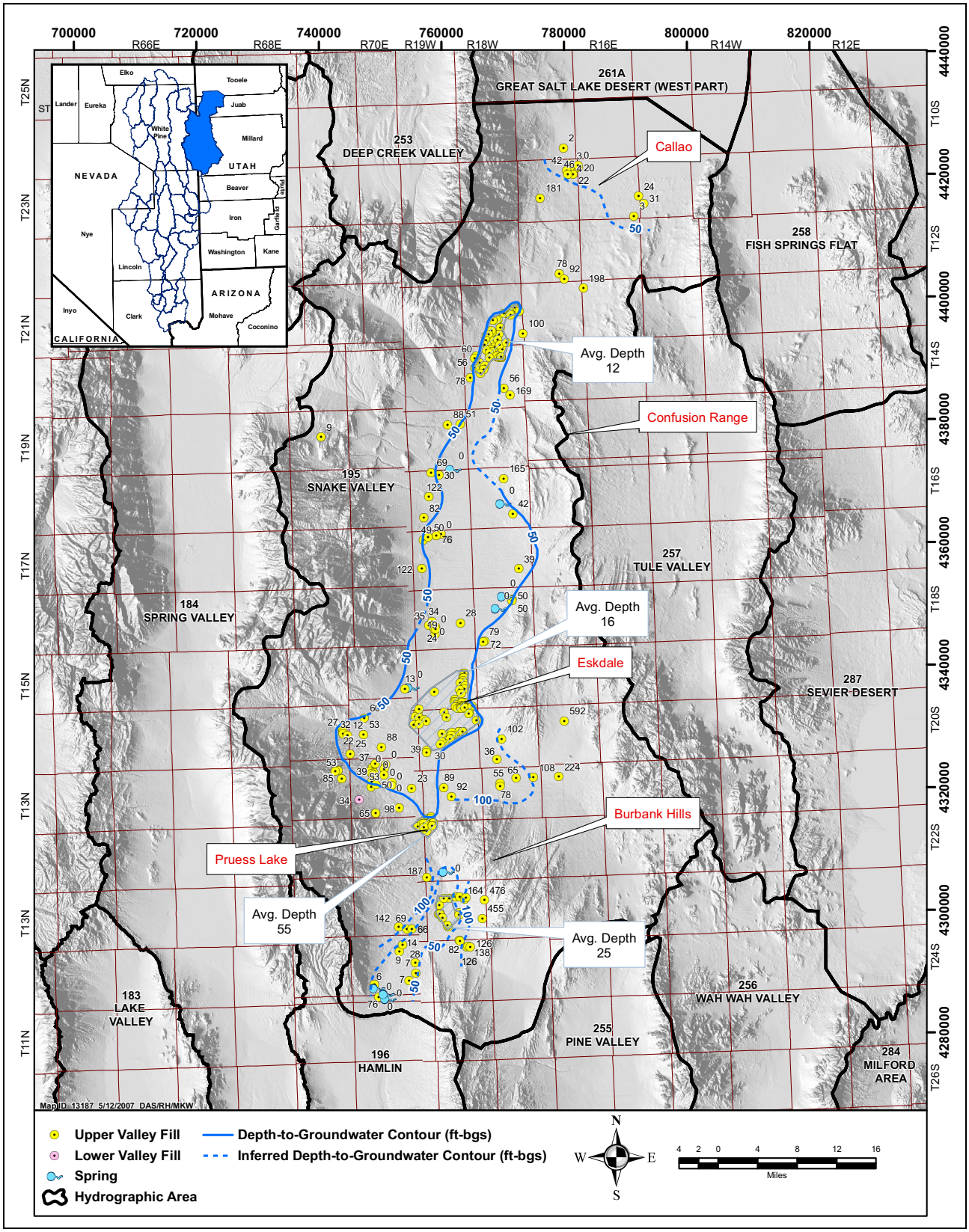


Figure 5-7
Snake Valley Depth to Water Map

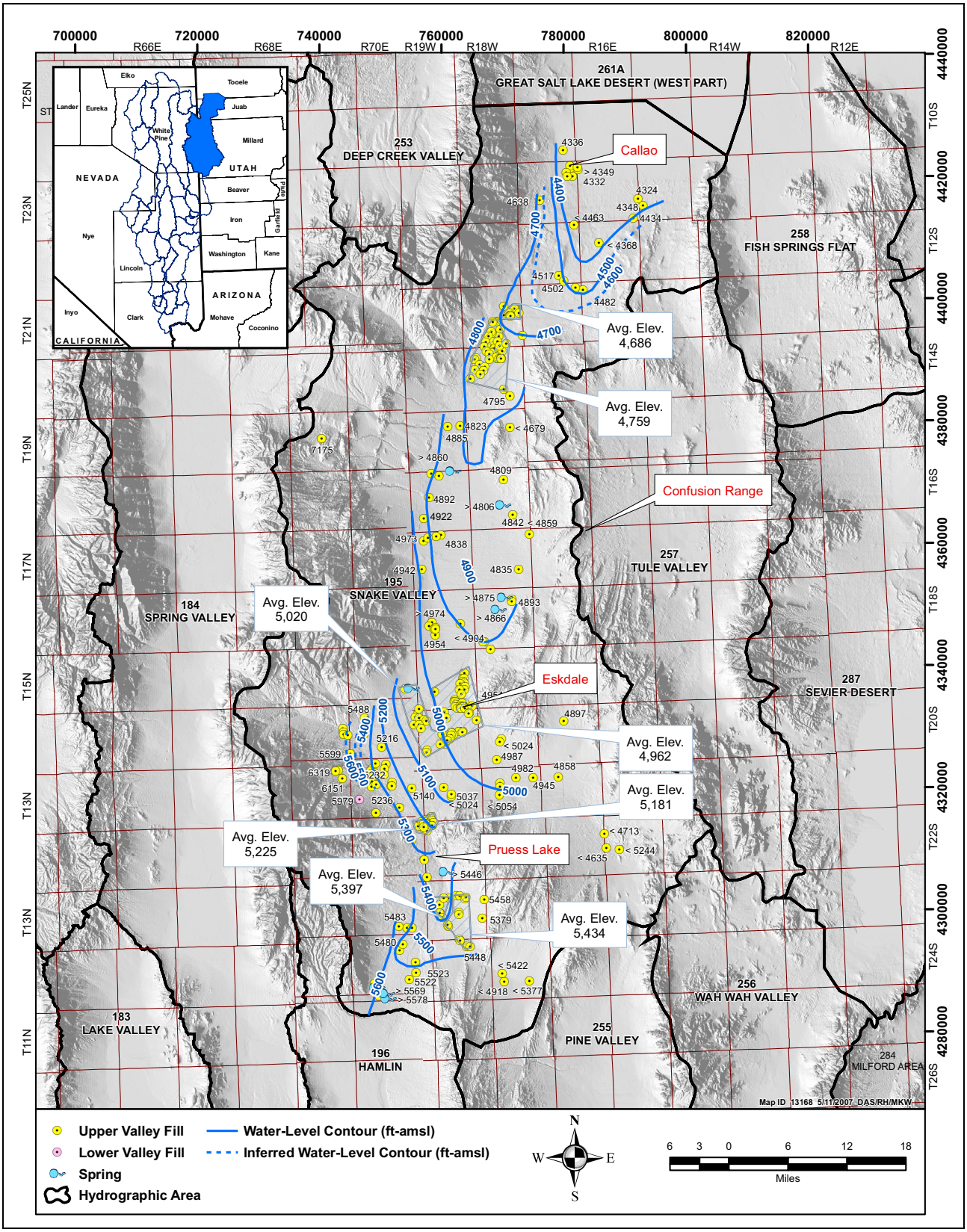


Figure 5-8
Snake Valley Water-Level Elevation Map

Carbonate Aquifer

A number of wells in Snake Valley are known to penetrate the carbonate-rock aquifer including several oil wells in the southern portion of the valley. The water-level elevations for the carbonate-rock wells and regional springs used for control range from approximately 5,000 to 6,200 ft-amsl (Figure 5-1). It can be seen from the figure that the carbonate-rock water-level elevations and spring heads decrease toward the north and northeast suggesting a northeastward groundwater gradient.

Water-Level Trends

Numerous wells exist in Snake Valley with sufficient data to construct water-level hydrographs. The hydrographs constructed for Snake Valley represent the basin-fill aquifer only and do not necessarily reflect trends in the carbonate-rock aquifer. This discussion will only focus on a few select wells to illustrate general observations in the northern, central, and southern portions of Snake Valley. In general, inspection of the hydrographs reveals that water-level elevations vary with time and spatial location within Snake Valley. For example, the hydrographs show that the maximum water-level fluctuations in Snake Valley range from 40 to 50 ft, with most wells commonly having water-level fluctuations less than 10 ft. A subtle upward trend over the past 7 decades can also be observed at some locations, while others have no particular trend or a decreasing trend (see Volume 4 for all of the constructed hydrographs for Snake Valley). Figure 5-9 shows that water-level elevations for well (C-11-17)12cbb-1 in the northern portion of Snake Valley near the town of Callao have varied on the order of 10 ft since the mid 1980s. There are numerous agricultural areas near the town of Callao suggesting that the water-level fluctuations could be attributed to pumping for irrigation. Hood and Rush (1965) stated, however, that the flow of Basin and Thomas Creeks is diverted and used in those areas. Water levels in this area, or any area of significant perennial streamflow, can be affected by the availability of surface waters and supplemental groundwater production. The proportion of either, however, cannot be determined due the limitations of the available data. As a result, it is difficult to determine the exact cause for the observed fluctuations. Another well in the northernmost portion of Snake Valley is well (C-11-16)36cdb-1 (Figure 5-10). This well is approximately 7 mi southeast of the previous well and shows very little change in water-level elevations over the past 25 years. This well is not near any current agricultural area. Another area of significant agriculture is in the central portion of Snake Valley near the community of Eskdale. Wells near this area also show similar water-level variations (i.e., in magnitude) as those in the northern portion of Snake Valley. For example, Figure 5-11 shows that water-level elevations have varied approximately 7 ft for the period of record for well (C-19-19)26aba-1. It can also be seen from the figure that there has been a subtly declining water-level trend for the well since approximately 1985. This well is also located in close proximity to agricultural areas.

Finally, Figure 5-12 shows an increasing water-level trend for the entire period of record for well (C-23-19)9cdb-1. This well is located in the southern portion of Snake Valley approximately 4 mi south of Pruess Lake. It is also located near current agricultural areas. Overall, water-level trends in Snake Valley can likely be attributed to temporal variations in hydrologic conditions.

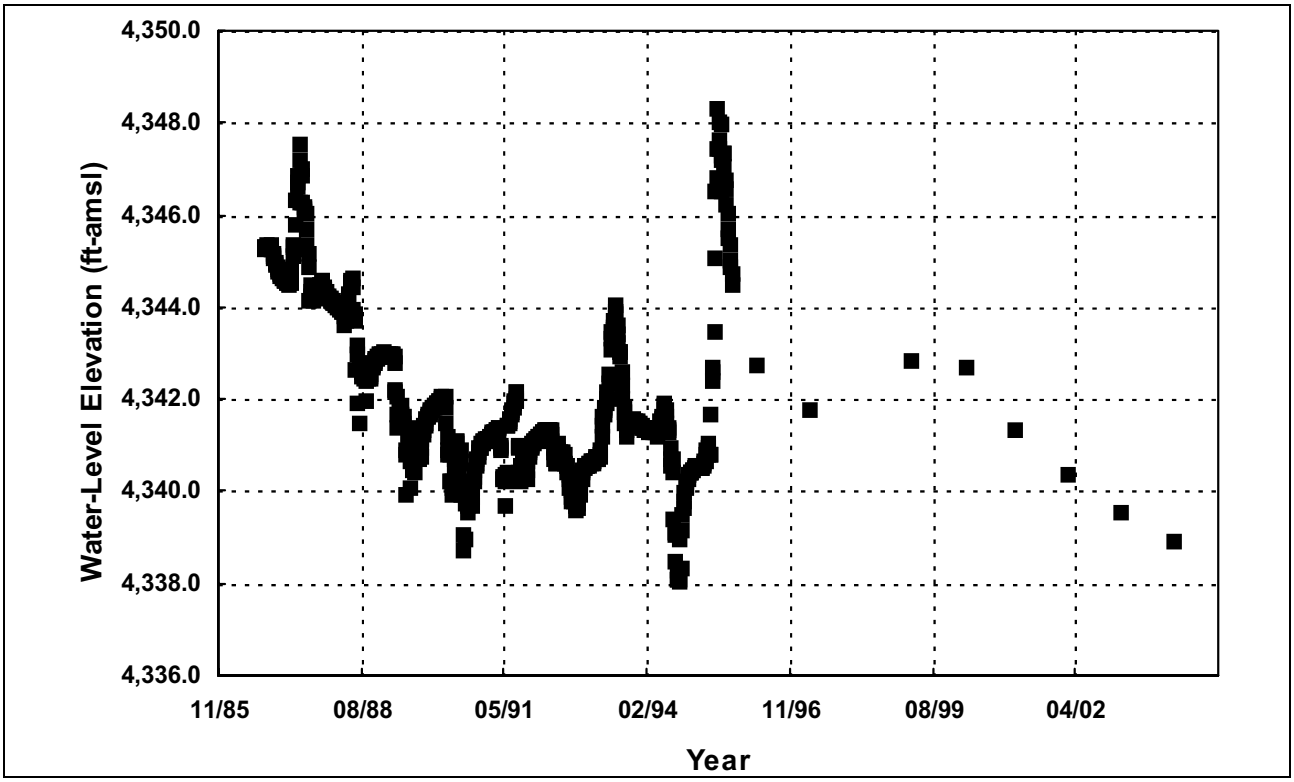


Figure 5-9
Historical Water-Level Elevations at (C-11-17)12cbb-1

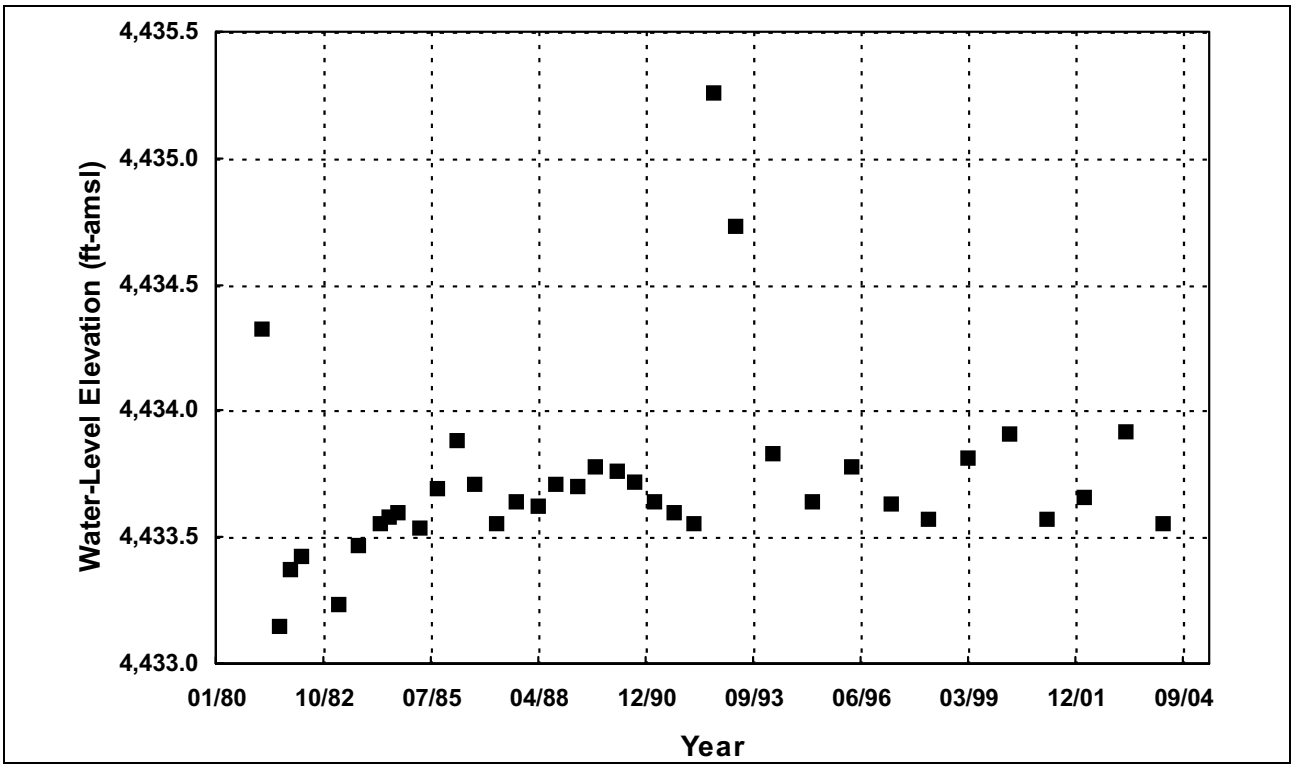


Figure 5-10
Historical Water-Level Elevations at (C-11-16)36cdb-1

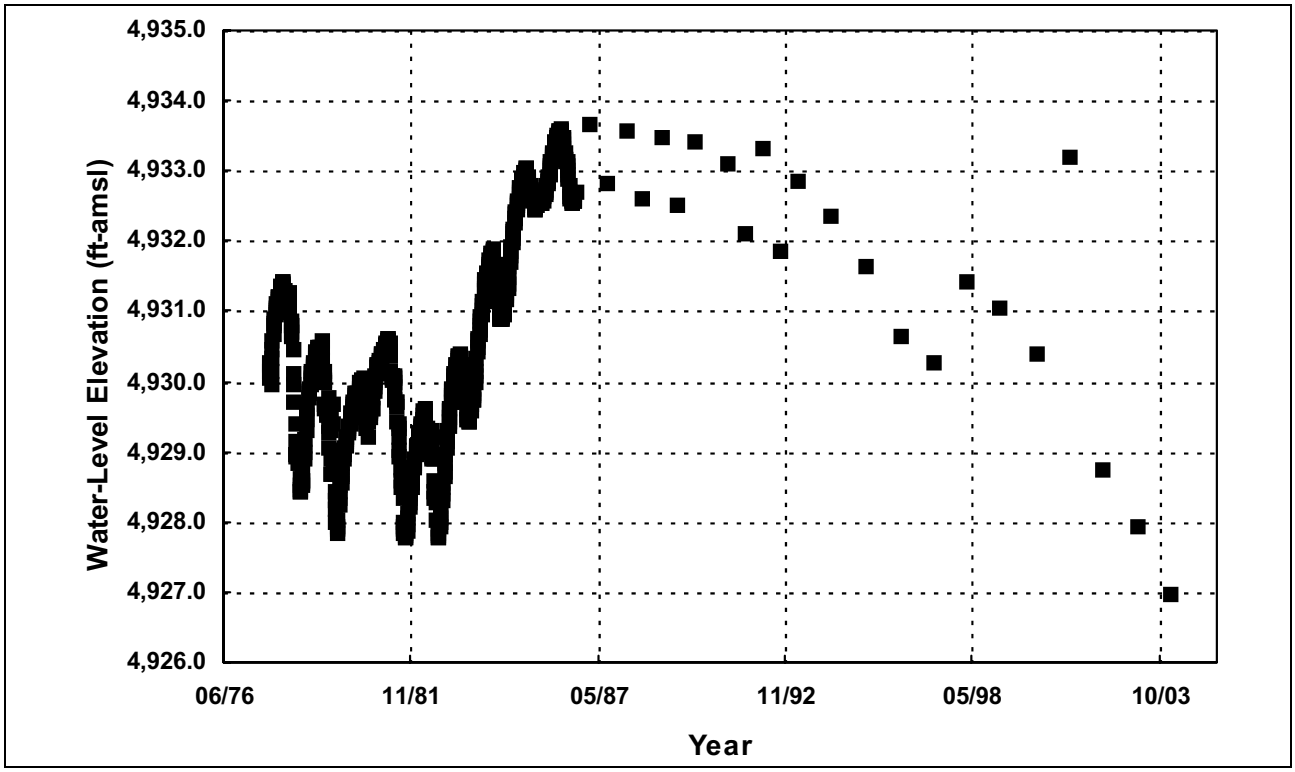


Figure 5-11
Historical Water-Level Elevations at (C-19-19)26aba-1

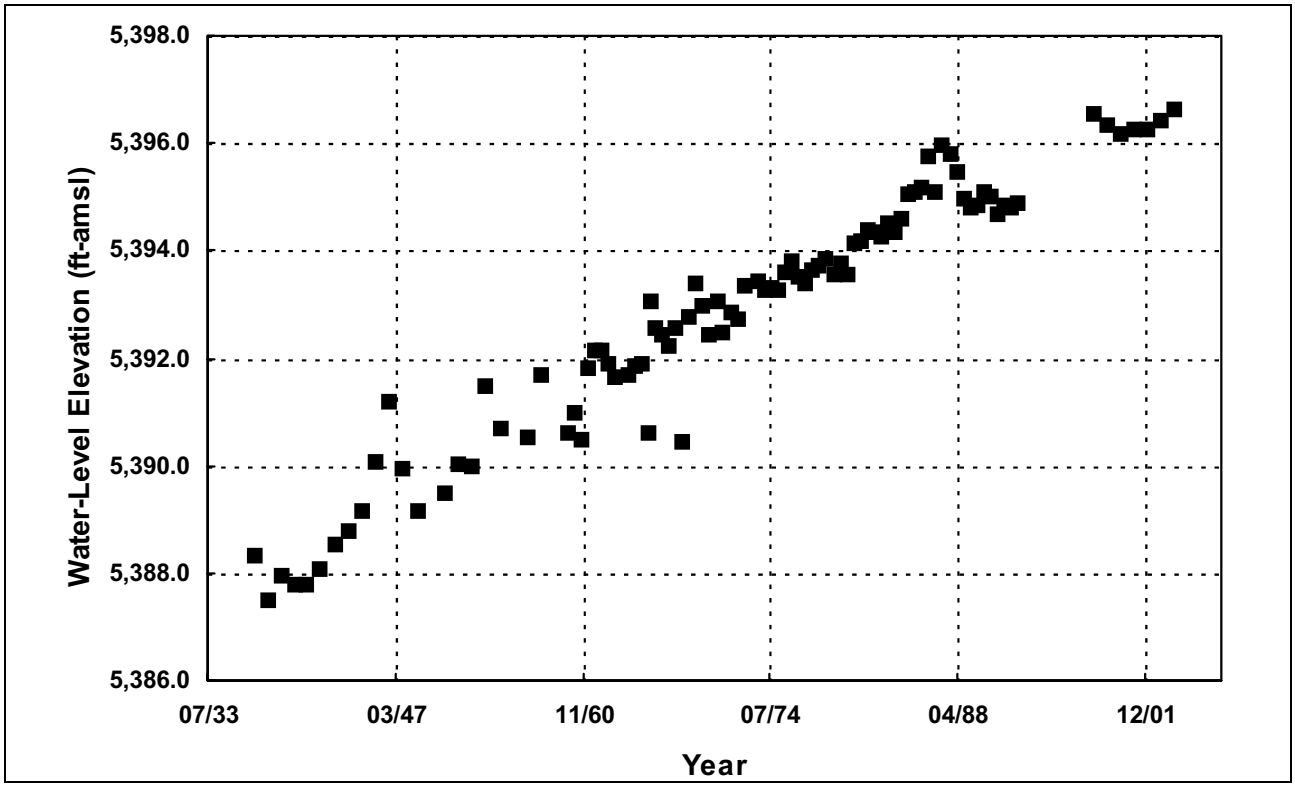


Figure 5-12
Historical Water-Level Elevations at (C-23-19)9cdb-1

5.4.3 Cave Valley

Nevada Division of Water Resources (NDWR) driller's logs for wells in Cave Valley suggest that the basin fill is composed of mostly sand and gravel with significant cemented strata in the northern portion of the valley and interbedded sands and clay in the southern portion of the valley. Lithology reported on a limited number of well logs suggests that the northern portion of Cave Valley may have unconfined to semi-confined aquifer conditions, while the southern portion may be confined to semi-confined. Well 180 N07 E63 14BADD1 USGS-MX [Cave Valley], on the southwestern side of the valley, encountered carbonate rock at 265 ft-bgs and was hydraulically tested at 225 gpm with 118 ft of drawdown after 210 hours. Petroleum exploration drilling in Cave Valley provides additional geologic information to several thousand feet in depth. The SNWA installed two monitor wells in Cave Valley in 2005 (180W501M and 180W902M). The wells were drilled to 1,215 and 915 ft-bgs, respectively, and both wells penetrated the carbonate rock aquifer. Well 180W501M was drilled in the central portion of Cave Valley, while well 180W902M was drilled in the south-east portion of the valley near Sidehill Pass.

Basin-Fill Aquifer

Depths to water in Cave Valley range from near ground surface in parts of northern Cave Valley (i.e., near Cave Spring and Parker Station) to greater than 200 ft-bgs in the southern portion of Cave Valley (Figure 5-13). Depths to water in the vicinity of the south playa are in excess of 150 ft-bgs, suggesting that the standof phreatophytes in the southern portion of the valley subsists on a perched water table. Water-level elevations in Cave Valley range from approximately 7,000 ft-amsl in the far northern portion of Cave Valley to approximately 5,800 ft-amsl in the southern portion of Cave Valley (Figure 5-14). Based on these water-level elevations, it appears that Cave Valley has a north-to-south hydraulic gradient of approximately 48 ft/mi.

Carbonate Aquifer

Water-level elevations for wells that penetrate the regional carbonate-rock aquifer in Cave Valley range from approximately 5,400 ft-amsl for well 180W501M in the central portion of Cave Valley to approximately 5,800 ft-amsl for well 180W902M in the southern portion of Cave Valley. The depth to water for well 180W501M is approximately 1,050 ft-bgs, and during construction it was estimated that the well produced between 3 to 5 gpm. These water-level elevations are generally higher by approximately 200 to 600 ft than the water-level elevations for carbonate-rock wells found in the central and southern portions of White River Valley, and approximately 1,200 ft higher than water-level elevations in Dry Lake Valley (see Figure 5-1). From these water-levels elevations, it appears that there is a south-to-north hydraulic gradient for wells that penetrate the carbonate rock aquifer in Cave Valley. According to Volume 1, however, Cave Valley consists of two distinct but connected portions, separated by the oblique-slip fault at Shingle Pass. This is likely the cause for the discrepancy between the water-level elevations for the carbonate rock aquifer wells in the central and southern portions of Cave Valley. The data also suggest an east-to-west hydraulic gradient exists between Cave Valley and White River Valley consistent with data presented by Harrill et al. (1988).

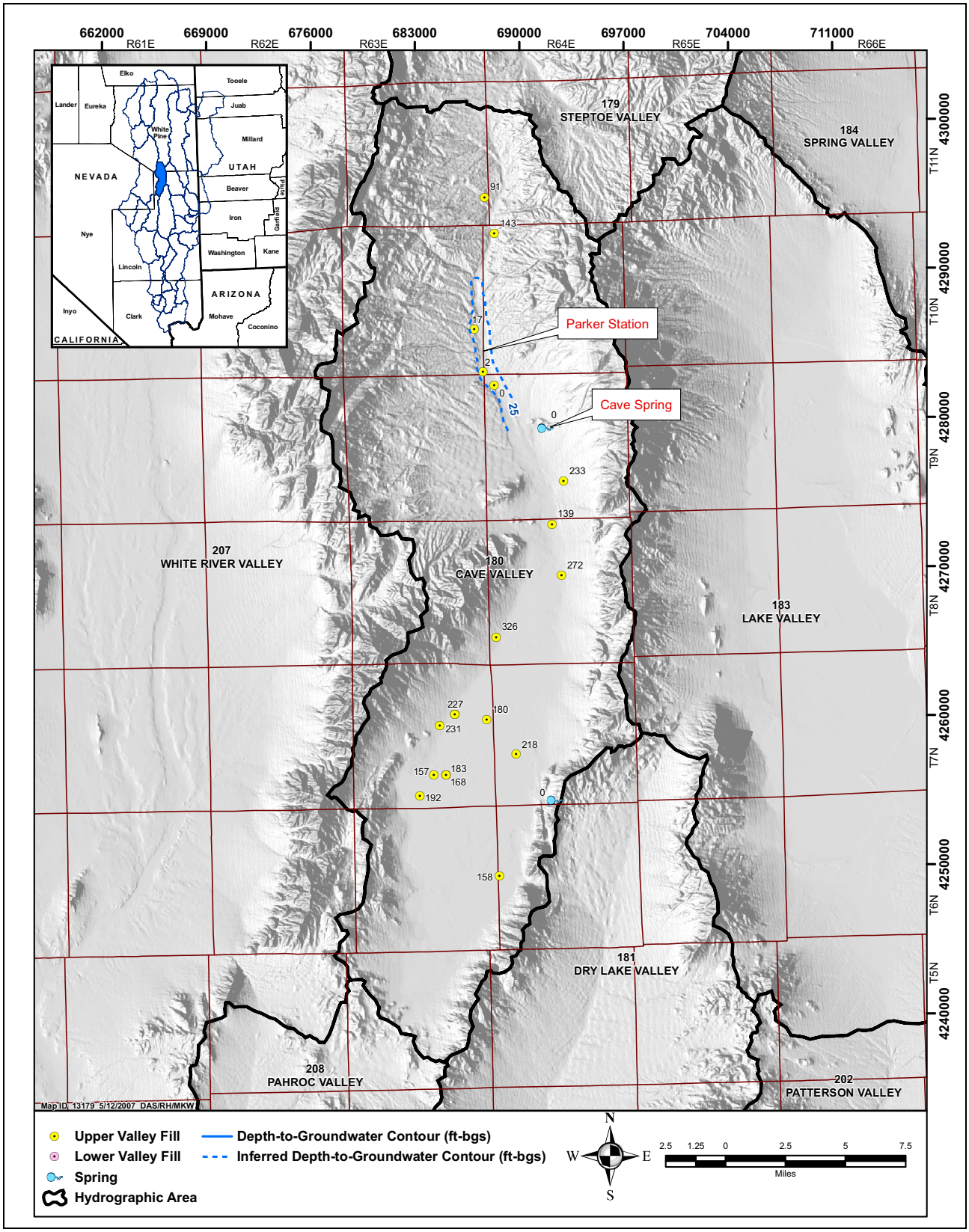


Figure 5-13
Cave Valley Depth to Water Map

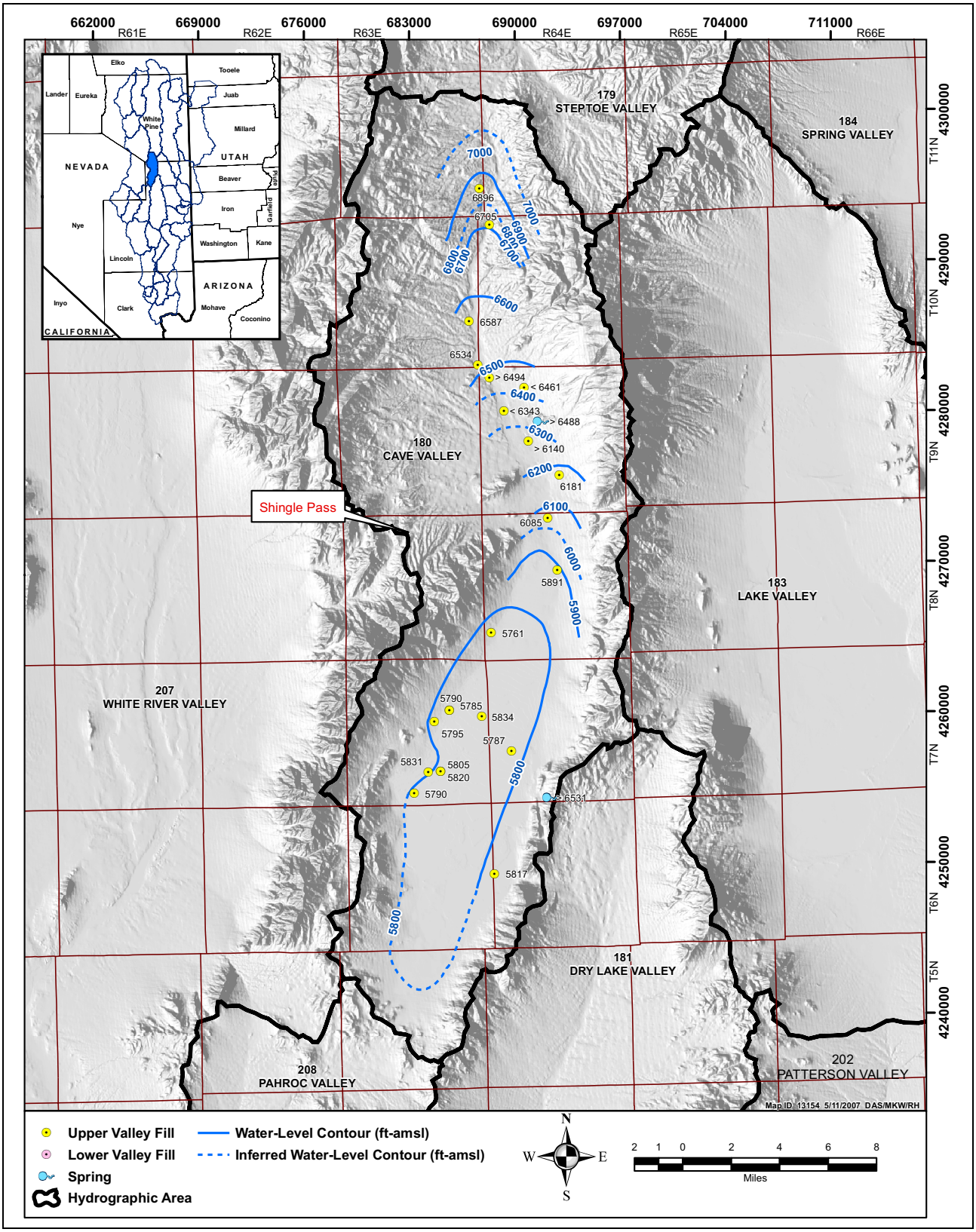


Figure 5-14
Cave Valley Water-Level Elevation Map

Water-Level Trends

The Cave Valley MX well (i.e., 180 N07 E63 14B ADD1 USGS-MX [Cave Valley]), located in the south-central portion of the valley, has shown a subtly rising water-level trend since the early 1980s with about a 10 ft increase in the overall water-level elevation for the well (Figure 5-15). This well was identified as penetrating the carbonate rock aquifer. Inspection of the other hydrographs for Cave Valley found in Volume 4 show a similar type of increasing trend. The other wells for which hydrographs were constructed were identified as penetrating basin-fill materials.

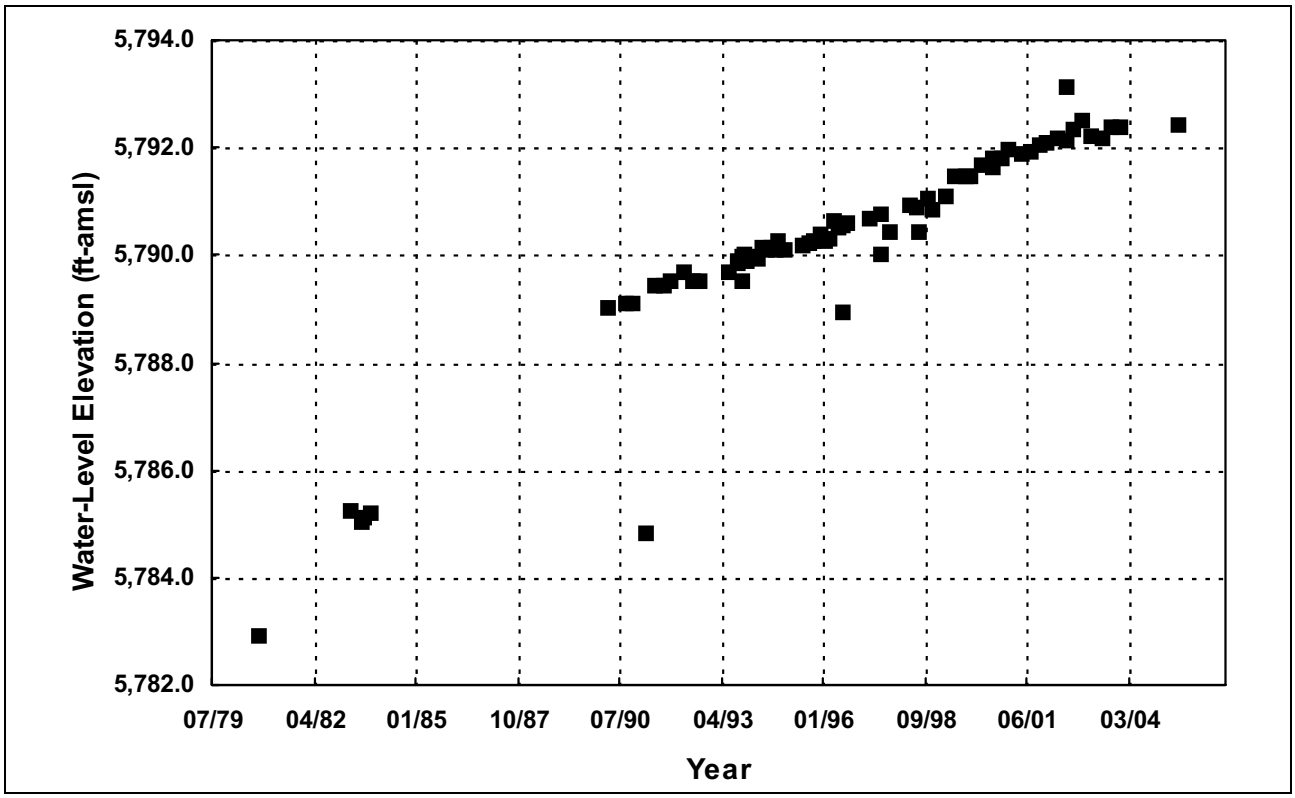


Figure 5-15
Historical Water-Level Elevations at 180 N07 E63 14BADD1 USGS-MX (Cave Valley)

5.4.4 Dry Lake Valley (HA 181) and Delamar Valley (HA 182)

Driller's logs and available gravity data indicate that carbonate bedrock underlies the northwest part of Dry Lake Valley at a relatively shallow depth. For example, the North Dry Lake MX well (181 N03 E63 27CAA 1 USGS-MX [N. Dry Lake]) was drilled to 2,395 ft-bgs and encountered alluvium to 195 ft-bgs, a thin stratum of volcanic rock to 340 ft-bgs, and limestone to the total depth of the well. The Muleshoe Valley MX well (181 N04 E64 07DC 1 USGS-MX [Muleshoe Valley]), in the northern part of Dry Lake Valley, encountered sand and gravels to 1,253 ft-bgs. This well is reported to have been pumped at 50 gpm for 144 hours resulting in 316 ft of drawdown. The South Dry Lake MX well (181 S03 E64 12AC 1 USGS-MX [S. Dry Lake Well]) was completed to 1,010 ft-bgs and encountered interbedded sands, gravels, and clay. This well is noted as being tested at 500 gpm for 70 hours with 41 ft of drawdown. Some cemented sand strata are also reported in driller's logs in southern Dry Lake Valley. Based on a limited number of well logs, it appears that unconfined aquifer

conditions exist in northern Dry Lake Valley, while semi-confined to confined conditions exist in the south.

Only six wells are incorporated into the compiled data set for Delamar Valley, including two MX wells. The lithology reported on driller's logs indicates the presence of interbedded sands, gravels, and clay, with a considerable quantity of clay noted in the logs to 1,210 ft-bgs. The Delamar MX well (182 S06 E63 12AD 1 USGS-MX [Delamar Well]) is reported to have been pumped for 128.5 hours at a rate of 85 gpm with 62 ft of drawdown.

In 2005, the SNWA installed two monitor wells in Dry Lake Valley and two monitor wells in Delamar Valley. Of the two monitor wells drilled in Dry Lake Valley, one penetrated the basin-fill aquifer system (i.e., 181W909M), while the other well penetrated the carbonate-aquifer system (i.e., 181M-1). The two wells installed by the SNWA in Delamar Valley (i.e., 182M-1 and 182W906M) were drilled to 1,345 and 1,735 ft-bgs, respectively. Both wells penetrated volcanic rocks.

Basin-Fill Aquifer

Water-level data are sparse in these two basins with depths to water on the main axis of the valley floor generally in the range of 200 to 500 ft-bgs in Dry Lake Valley and depths exceeding 800 ft-bgs in Delamar Valley. Figure 5-16 shows that the water-level elevations range from approximately 5,500 ft-amsl in the northern portion of Dry Lake Valley to approximately 4,300 ft-amsl in the southern portion of Dry Lake Valley for wells completed in the basin-fill. Water-level elevations are approximately 3,850 ft-amsl in the central portion of Delamar Valley. The water-level elevations and composite water-level contours shown on Figure 5-16 indicate that there is a north-to-south groundwater gradient for these two basins. Based on the available water-level elevations in Dry Lake and Delamar valleys, the hydraulic gradient from the central portion of one valley to the other is approximately 13 ft/mi.

Carbonate Aquifer

Two wells in the compiled data set were identified as penetrating the carbonate-rock aquifer. Both well are located on the west side of Dry Lake Valley (Figure 5-1). It can be seen from the figure that the water-level elevations for the two wells range from 4,541 to 4,288 ft-amsl. These water-level elevations are approximately 1,300 to 1,500 ft lower in elevation than carbonate-rock wells in Cave Valley to the north, and 650 to 900 ft higher in elevation than carbonate-rock water levels in Pahranagat Valley.

Water-Level Trends

Water-level fluctuations in Dry Lake Valley and Delamar Valley appear to be show a slight upward trend over the past 25 years similar to the trend observed for Cave Valley. The water-level variations can likely be attributed to climatic variability, as there is little to no groundwater development in these two basins. For example, Burbey (1997) stated that development of Delamar Valley has been limited to livestock grazing as the depths to water are prohibitive for other economic activities. Figure 5-17 shows that water-level elevations for the USGS-MX (North Dry Lake Well) have increased approximately five feet from 1986 to the present. This well was identified as penetrating the

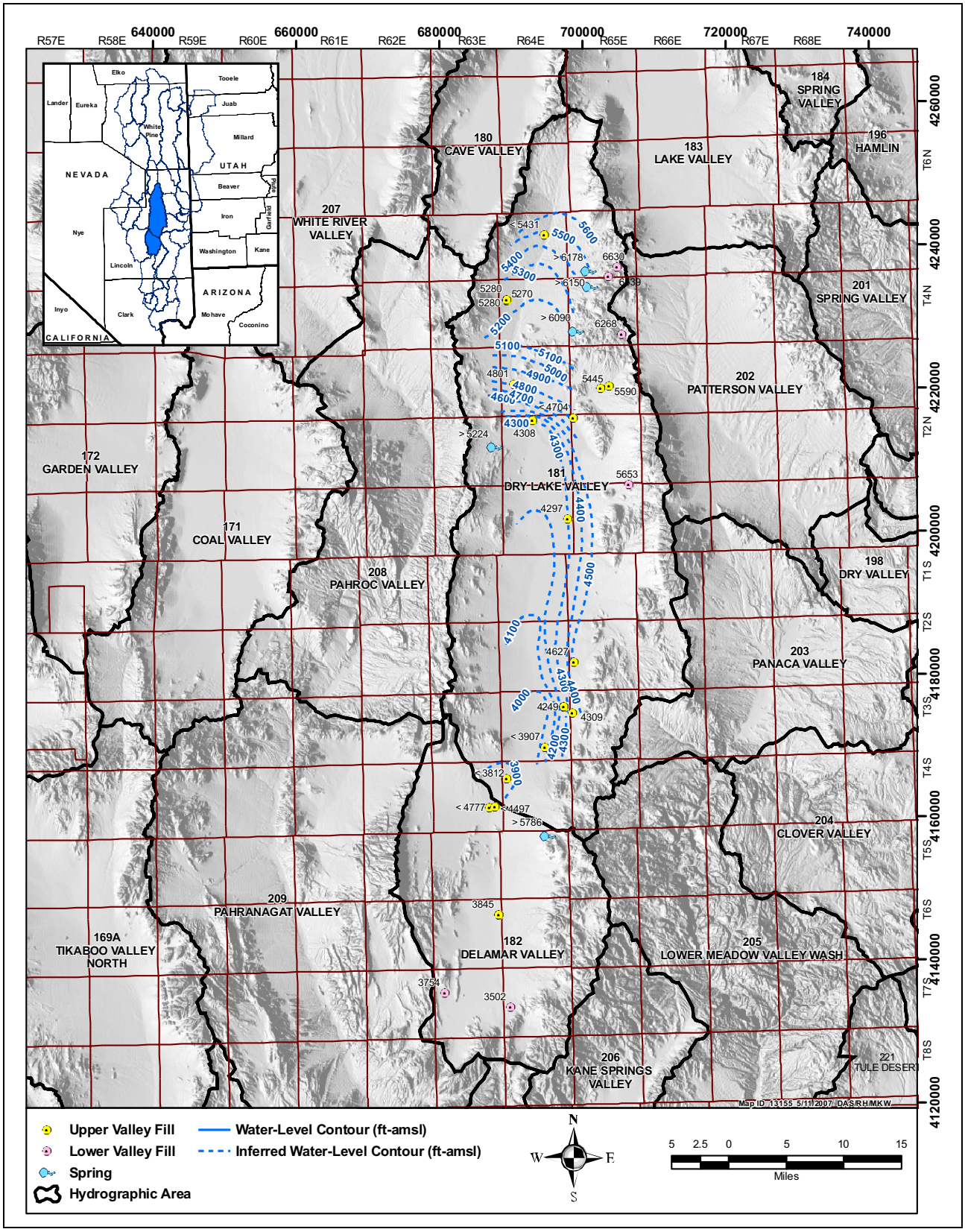


Figure 5-16
Dry Lake and Delamar Valleys Water-Level Elevation Map

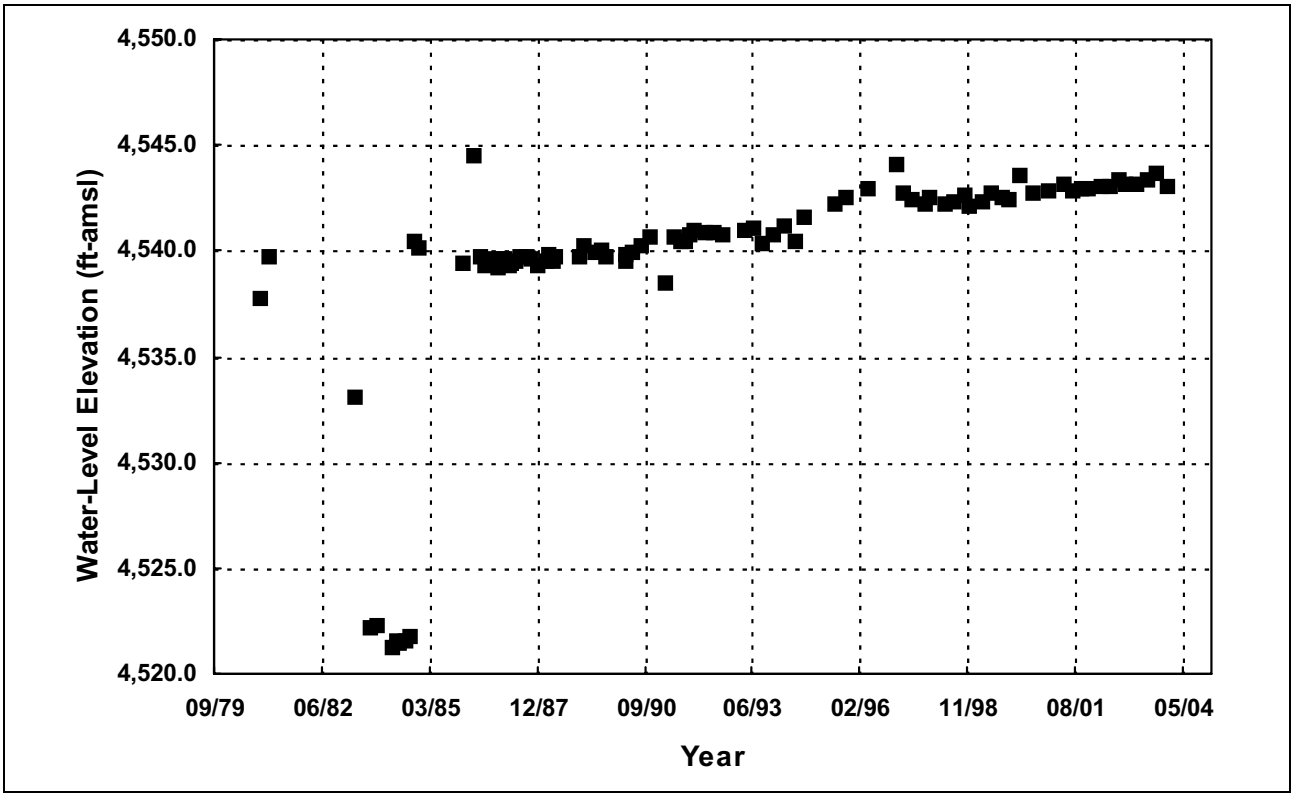


Figure 5-17
Historical Water-Level Elevations at 181 N03 E63 27CAA 1 USGS-MX (N. Dry Lake)

carbonate-rock aquifer. The other wells for which hydrographs were constructed were identified as penetrating the basin-fill aquifer system. The other hydrographs are provided in Volume 4.

5.4.5 Coyote Spring Valley

Coyote Spring Valley contains several monitor wells completed in the early and mid-1980s as part of the MX missile-siting program and by the USGS , including test well MX-4, MX-5, CE-VF-1, and CE-VF-2. Wells MX-4, MX-5, and CE-VF-2 are completed in the carbonate-rock aquifer (Ertec Western, Inc., 1981a; Berger et al., 1988). SNWA installed eight monitor wells in and near the valley in 2003. In addition, many wells in Coyote Spring Valley and down gradient in the Muddy River Springs Area have recently been surveyed for precise location and land-surface elevations by SNWA (SNWA, 2003b).

Basin-Fill Aquifer

Depths to water in the basin-fill aquifer system generally range between 300 and 600 ft-bgs in Coyote Spring Valley. Depths to water in the vicinity of Coyote Spring, however, approach land surface in that localized area. Eakin (1964) postulated that Coyote Spring, prior to development, derived its flow from a semi-perched water-bearing zone in the older valley fill that received recharge from precipitation in the Sheep Range to the west. Eakin (1964) estimated "not more than a few hundred" acre-feet per year of ET from phreatophytes near Coyote Spring. It can be seen from Figure 5-18 that water-level elevations along the main drainage channel of the valley range from approximately

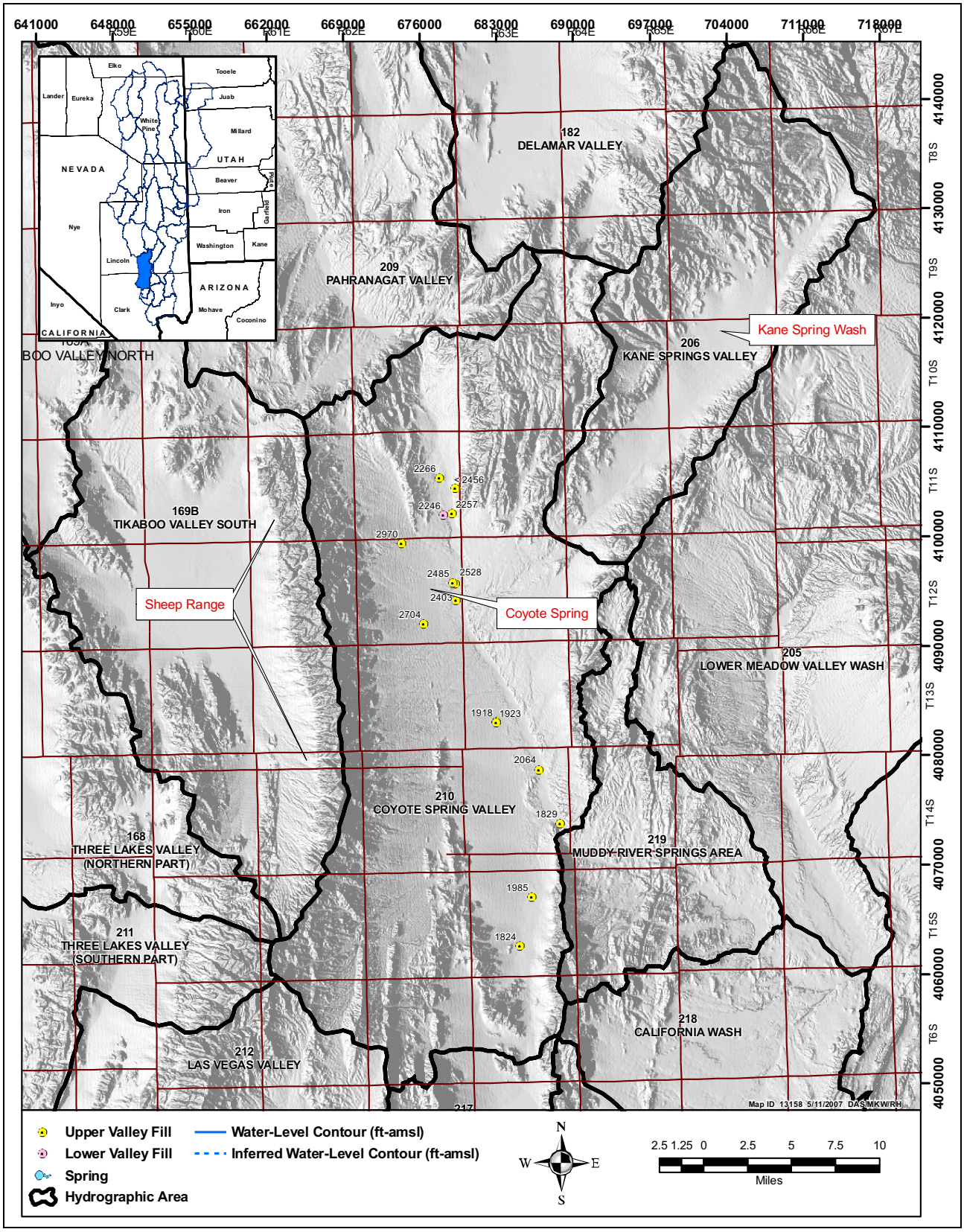


Figure 5-18
Coyote Spring Valley Water-Level Elevation Map

2,300 ft-amsl in the northern portion of the valley to approximately 1,800 ft-amsl in the southeast portion of the valley. This suggests that a general southeastward groundwater gradient off of the Sheep Range into the Muddy River Springs hydrographic area exists in the valley (Figure 5-18). The higher water-level elevations for the wells that are near Coyote Spring are likely the result of either inflow into Coyote Spring Valley from Kane Springs Valley or the result of the semi-perched water-bearing zone identified by Eakin (1964). Current data are not sufficient to generate water-level elevation contours for the basin-fill aquifer system.

Inspection of the driller's logs for the basin-fill wells in Coyote Spring Valley show typical alluvial materials including sandy clays, gravel-boulders, and sands and gravels.

Carbonate Aquifer

Water-level elevations for wells penetrating the carbonate aquifer range from approximately 2,200 ft-amsl in the northern portion of the valley to approximately 1,800 ft-amsl near the hydrographic divide with the Muddy River Springs Area. These water-level elevations suggest that a north-to-south hydraulic gradient generally coincident with Pahranagat Wash exists in the regional carbonate aquifer in this area. Water-level gradients in the carbonate aquifer become very flat near the center of the valley and extending southeast to the Muddy River Springs Area (Figure 5-1).

Water-Level Trends

Water levels for wells completed in the carbonate aquifer in the east-central part of Coyote Spring Valley near the Muddy River Springs Area declined approximately 1.5 to 2.5 ft beginning in early 1999. For example, Figures 5-19 and 5-20, for wells CE-VF-2 and USGS-MX CE-DT-4, respectively, show that water-level elevations declined approximately 1.5 to 2.5 ft. These declining water-level elevations have been interpreted to be the result of climatic factors (i.e., the regional drought starting in 1999) or pumping from the carbonate aquifer at the Arrow Canyon well in the Muddy Rivers Springs Area (Smith et al., 2004). It can be seen from the figures, however, that a recovery of the water-level elevations began in late 2004 and early 2005. Inspection of the hydrographs for wells 210 S10 E62 25AD 1 CSVM-3, 210 S13 E63 11BC 1 CSVM-6, and 210 S13 E63 26AAAA1 USGS-MX CE-DT-5 found in Volume 4 reveals a similar water-level increase for the wells beginning in late 2004. Several of the hydrographs shown in Volume 4 for Coyote Spring Valley, however, have shown an observable decline in water-level elevations beginning in early-to-mid 2006 including 210 S13 E63 11BC 1 CSVM-6, 210 S13 E63 25AD 1 CSVM-1, and 210 S15 E63 03BB 1 CSVM-2.

Piezometers in the east-central portion of the valley (i.e., CE-VF-1 and CE-VF-2) indicate that the basin-fill aquifer has water levels approximately 61 ft higher than the potentiometric water level in the underlying carbonate aquifer (downward gradient), at least for the east-central part of the valley.

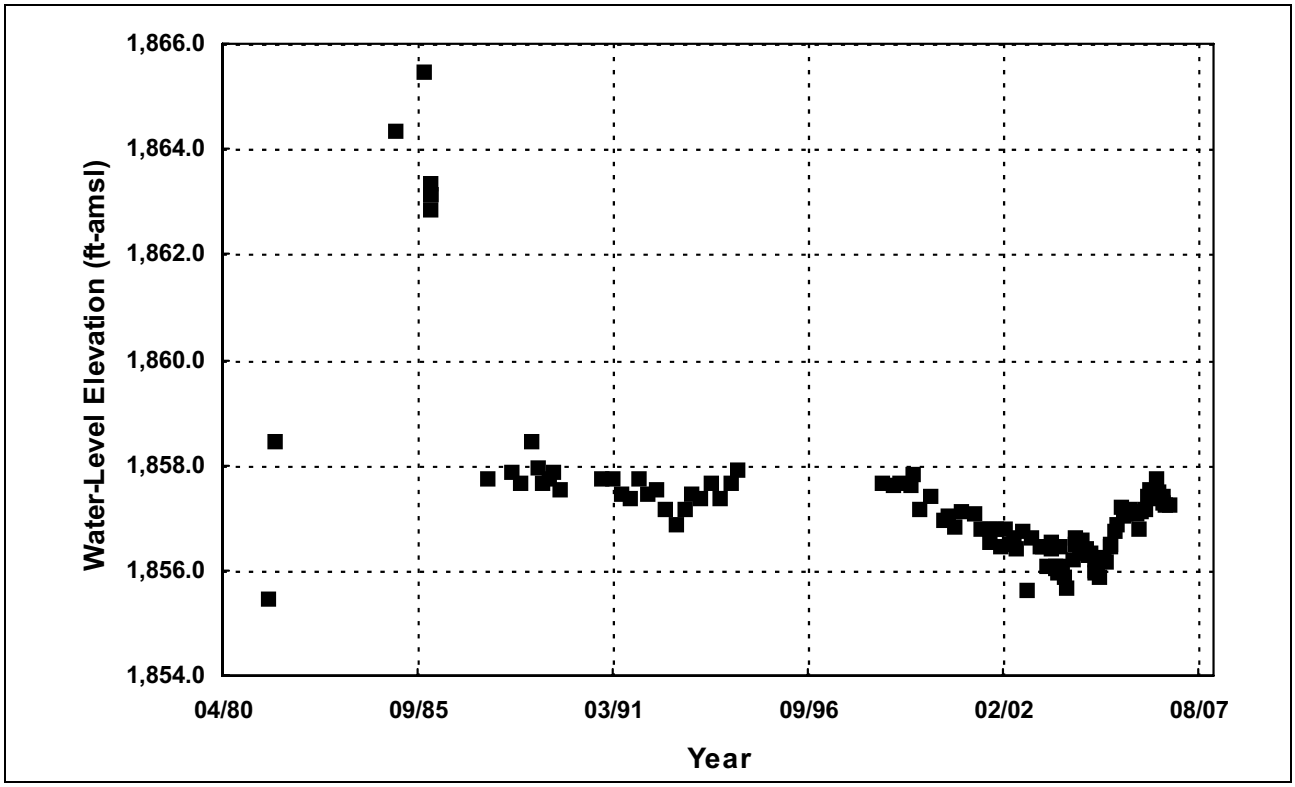


Figure 5-19
Historical Water-Level Elevations at 210 S12 E63 29DABC1 USGS-MX CE-VF-2

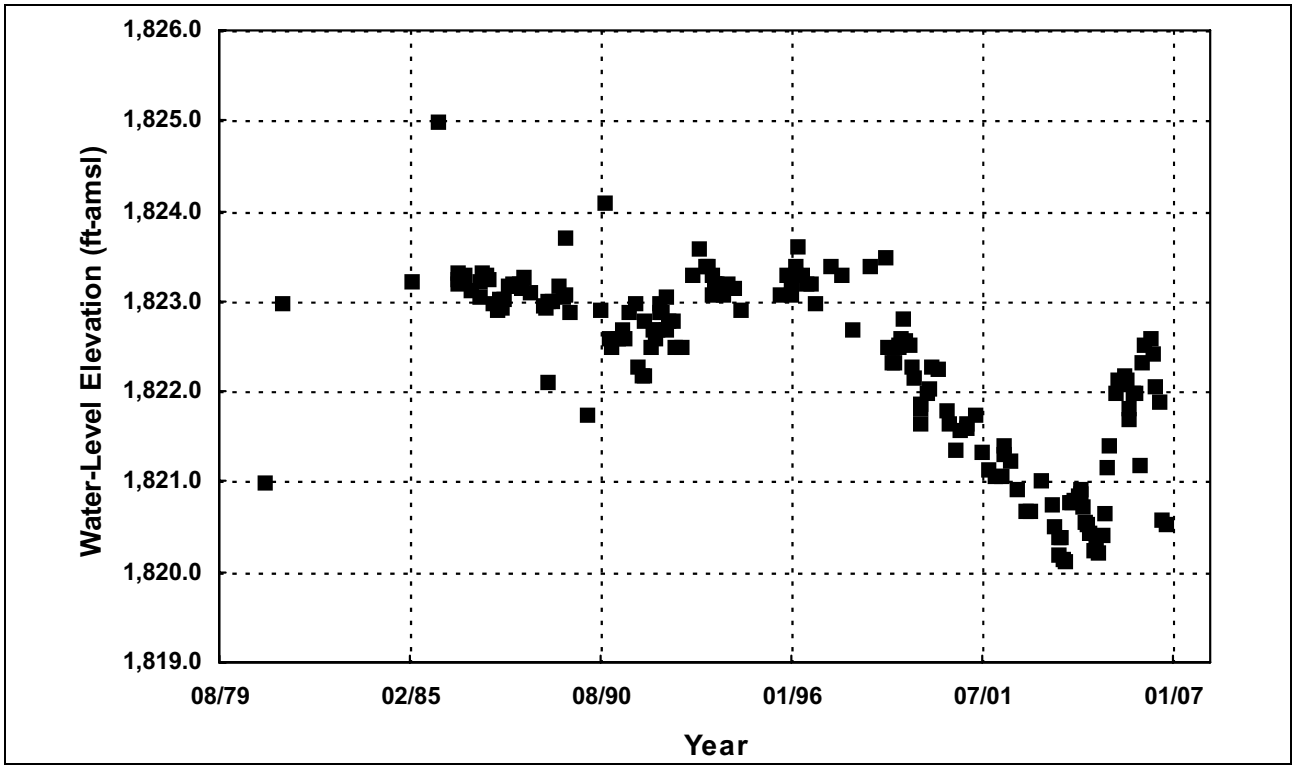


Figure 5-20
Historical Water-Level Elevations at 210 S13 E63 23DDDC1 USGS-MX CE-DT-4

6.0 WATER QUALITY

6.1 Introduction

This section describes the baseline aqueous geochemistry and stable isotope data compiled as part of the hydrogeological evaluation of groundwater in parts of Clark, Lincoln, and White Pine counties, Nevada. Data were compiled for hydrographic basins in four regional flow systems (Figure 2-1) and are provided electronically on the attached CD-ROM. Data in the Project Basins of Spring, Snake, Cave, Dry Lake, Delamar, and Coyote Spring valleys are briefly discussed in the following sections.

6.2 Geochemical Characterization of Groundwater

The chemical composition of most natural waters is controlled by the mineralogic composition of the surrounding rocks. Rock-water reactions play a significant role in the chemical characteristics of groundwater. The equilibrium water chemistry is a function of the bedrock type and contact time between water and the rock.

Processes of mineral dissolution, alteration, and genesis exert strong controls on the chemical species in natural waters. The chemistry of groundwater in carbonate-rock (limestone or dolomite) aquifers is typically a calcium-bicarbonate-type water with varying amounts of magnesium and sulfate, depending on the amounts of dolomite and gypsum or anhydrite present (White, 1988; Macpherson and Townsend, 1998). Barium, strontium, iron, and manganese are some of the common trace elements in carbonate-rock aquifers.

The groundwater chemistry of alluvial aquifers typically reflects the chemistry of the dominant rock type in the surrounding mountains. Calcium-bicarbonate-type water is found in valley-fill aquifers that are composed chiefly of carbonate-rock detritus. Sodium, chloride, sulfate, and trace constituents such as bromide, lithium, and boron are prevalent in valley-fill aquifers dominated by volcanic rocks.

Groundwater in volcanic rocks sometimes has relatively higher sodium and potassium concentrations and a relatively lower pH than those found in carbonate-rock aquifers. Where the depositional environment is saline or brackish, especially for Tertiary lacustrine deposits, evaporite minerals such as gypsum and halite are common, and groundwater flowing in such a medium usually has high concentrations of sulfates and chlorides with very high total dissolved solids (TDS).

Major-ion concentrations of groundwater have been used to distinguish the different types of water in the study area and in parts of the carbonate-rock aquifer province in Nevada. Schoff and Moore (1964) distinguished three chemical types of groundwater at the Nevada Test Site. They related a calcium-magnesium water to carbonate rocks, a sodium-potassium water to volcanic rocks, and a mixed cation type to water flowing through the two types of rocks or undergoing cation exchange

reactions. These three hydrochemical facies were confirmed by Winograd and Thordarson (1975), who also identified a playa facies and a sodium-sulfate-bicarbonate facies that occur in parts of the Death Valley Flow System. These hydrochemical facies guide the interpretation of the chemistry of the different waters in the study area for this report.

6.3 Data Compilation

Over 400 analytical results of groundwater and surface water were compiled for springs and creeks in the mountain blocks, and from wells and springs in the valley floor. Many of these sources have been sampled multiple times. The water chemistry and site data are provided as Microsoft Excel® spreadsheet files and are found on the CD-ROM attached to the back page of this report. Also included on the CD-ROM is a 2006 letter report from the DRI on stable isotopes and major-ion geochemistry for East, Central, and Southeastern Nevada.

Data compiled for this report include most of the published and unpublished work on aqueous geochemistry for the hydrographic basins in southern and eastern Nevada. The major sources include data collected by SNWA in the 1990s and from 2003 through 2007. These include data collected on 18 wells drilled in WRFS by SNWA from 2003 to 2005 and wells drilled in Spring Valley in 2006 and 2007. Other sources of data include the USGS NWIS website (USGS, 2007), the Division of Hydrologic Sciences of the DRI, Nevada Bureau of Mines and Geology (NBMG), wells drilled by the Utah Geological Survey in 2007, and other miscellaneous drilling and consulting reports completed by independent consulting firms. The USGS NWIS database contains data compiled from the USGS Regional Aquifer-System Analysis studies, data from the USGS Professional Papers series on the Basin and Range physiographic area (e.g., Thomas et al., 1996; Plume, 1996), the MX Missile-Siting Investigation Program of the early 1980s (Ertec Western, Inc., 1981a to 1981e), the USGS National Water-Quality Assessment Program, the DRI and USGS Basin and Range Carbonate Aquifer System (BARCAS) study (e.g. Hershey et al., 2007), and data from the co-operative work between USGS and the Nevada Department of Conservation and Natural Resources.

6.3.1 Data Limitations

Numerous sources of data were used for this study. The data were typically collected in support of other studies with different purposes and objectives. The majority of the data is from springs because they are easily accessible for sampling. Most of the data from deep wells were collected during drilling, or shortly thereafter. Generally, there is a paucity of wells tapping the carbonate-rock aquifer in the study area. For example, in their study of the water quality in the carbonate-rock aquifer of the Great Basin in Nevada and Utah, USGS sampled only 18 deep wells in 8 regional flow systems (Schaefer et al., 2005). The spring data complement the data collected from wells in representing groundwater resources in the study area, although it is not known how well the springs represent the deep carbonate-rock aquifer. In many instances, the sample suites were limited, making a determination of the hydrochemical facies more difficult.

A great effort was made to evaluate most of these data for completeness and quality; however, the precision and accuracy of all the data could not be ascertained. At a minimum, reaction error calculations were made to assess the quality of water chemistry data. Reaction errors occur because

of analytical errors for the individual parameters or because not all possible ions are commonly measured. Reaction error determination is based on the assumption that the sum of the cation charge in a solution is equal to the sum of the anion charge. Normally, the criterion for acceptability is a maximum reaction error between 2 and 5 percent (Mazor, 1991); however, due to the varied nature of the data sources used for this report, a maximum reaction error of 10 percent was used in some few instances.

6.3.2 Data Collection and Analysis

6.3.2.1 Sample Collection

Data collection by SNWA for this study was conducted in the summers of 2003, 2004, 2005, 2006, and through 2007 at wells, creeks, and spring sites within the study area. Field water-quality parameters were collected at each of the sites during sampling. Water temperatures were measured with either a hand-held mercury thermometer or with a temperature probe attached to a Beckman 255 pH/temperature meter. Electrical conductivity measurements were made using an Orion 130A portable conductivity meter. Dissolved oxygen measurements were made using a YSI 550A meter. All measurement equipment were calibrated according to the manufacturers' calibration procedures. The coordinates of the sample sites were also determined using Trimble GEOXH hand-held Geographic Positioning System.

At all sites, samples were collected for analysis of major ions, trace metals, and light stable isotopes after the field parameters (pH, electrical conductivity, and temperature) had stabilized for at least 5 minutes.

Samples for analysis of major ions and trace metals were collected in high-density polyethylene bottles. Samples were collected using the procedures described by Koterba et al. (1995) and stored at a temperature of approximately 4°C for shipment to the appropriate laboratories for analysis. Trace metal samples were preserved with reagent-grade nitric acid.

Samples for deuterium and oxygen-18 analysis were collected in 25 ml glass bottles with polysealed lids.

6.3.2.2 Documentation and Shipping

A sample collection log was completed for each sampling event, documenting measurement of the parameters described in Section 6.3.2.1. A chain-of-custody record was completed, and chain of custody was maintained for each sample at all times. Each chain-of-custody record was completed based on the type of sample and for the laboratory to which the sample was shipped. A copy of the SNWA sample collection log and the original copy of the chain-of-custody record were shipped with the samples to each laboratory.

6.3.2.3 Sample Analysis

The samples collected by SNWA for major ions and trace elements were analyzed by the Weck Laboratories, Inc. (a State of Nevada-licensed laboratory in California), the Water Chemistry Laboratory of DRI in Reno, or the Southern Nevada Water System Laboratory. Some of the spring and well samples collected in 2004 and 2005 were analyzed by MWH Laboratories at their facilities in Monrovia, California. All the analyses were performed using standard U.S. Environmental Protection Agency (EPA) methods.

Stable isotopes samples were analyzed at the Environmental Isotope Laboratory of the University of Waterloo, Canada.

6.4 Analytical Results and Discussion

The characteristics of the water chemistry in the SNWA Project Basins are briefly discussed in this section.

6.4.1 Great Salt Lake Desert Flow System

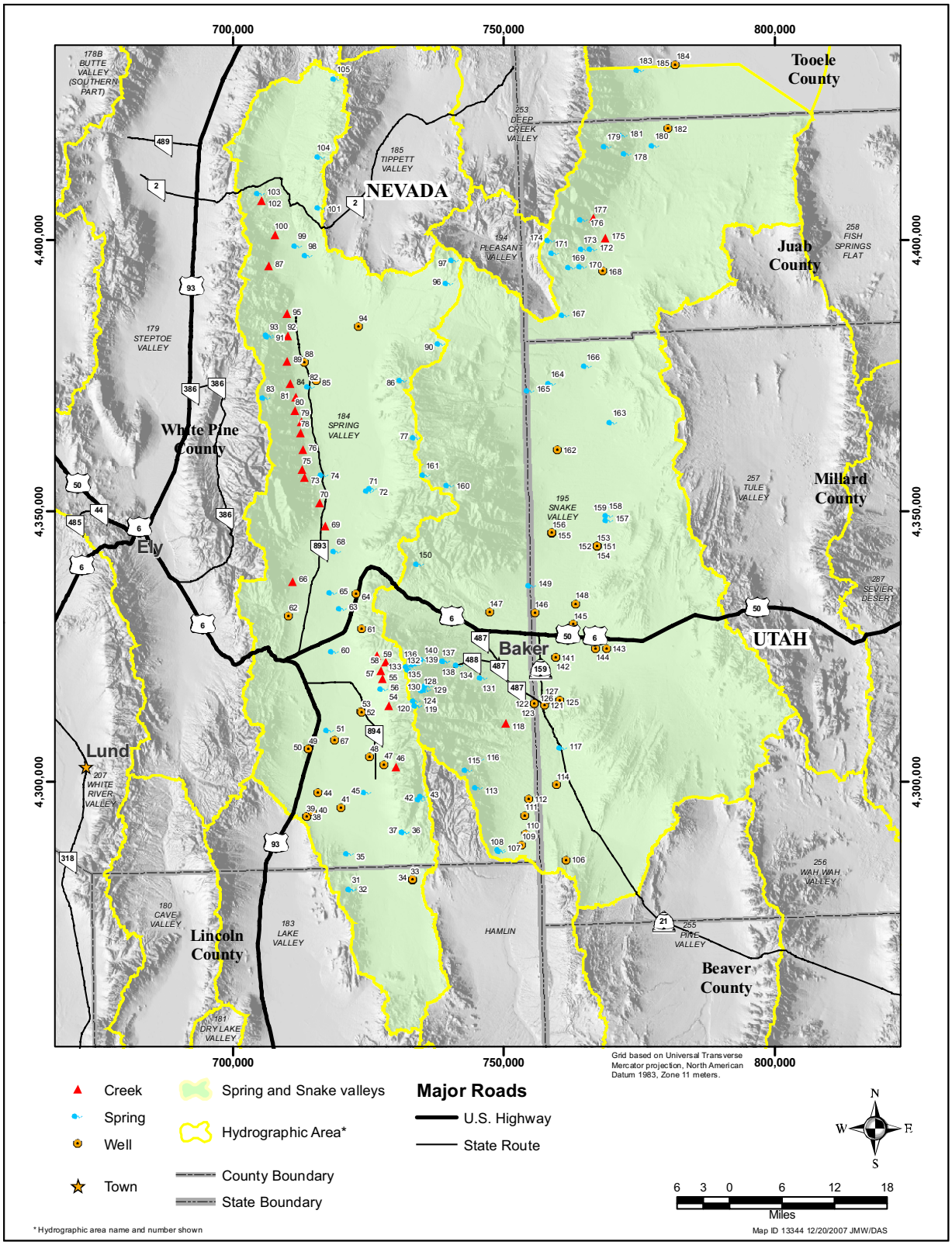
Data for Spring and Snake valleys in GSLDFS were compiled for this report, and are found on the attached CD-ROM. The sample sites within the SNWA project basins in the GSLDFS (Spring and Snake valleys) whose data were used for the analysis are shown on Figure 6-1. The site data are provided in the Site Information Worksheet, and the major-ion data are provided in the Microsoft Excel® "Majors" worksheet described in Appendix A and attached on the CD-ROM.

6.4.1.1 Chemical Composition of Spring Valley Waters

A Piper diagram of samples collected in Spring and Snake valleys is shown on Figure 6-2. The water type is mainly Ca-Mg-HCO_3 for all the springs, creeks, and wells sampled in Spring Valley with the exception of a few which have a Ca-Na-HCO_3-Cl, Ca-Mg-Na-HCO_3 and Ca-Mg-Na-HCO_3-SO_4 facies. The water chemistry of most of the springs reflects the chemistry of the carbonate rocks that underlie most of the valley. The chemical makeup of a majority of the springs and creeks suggests that the weathering of ferromagnesian minerals and carbonate rocks (dolomite and limestone) is the dominant process controlling the chemistry of the springs and creeks in Spring Valley. The Ca-Mg-Na-HCO_3 waters suggest contact with some sodium-rich rocks. The SO_4 facies water probably results from the dissolution of evaporites within the carbonates, or from dissolution of sulfide or sulfate minerals in altered carbonate rocks. The distribution of hydrochemical facies within the aquifers in Spring Valley appears to be controlled by the mineralogy of the aquifer material. In Figure 6-2, most of the samples in Spring Valley are clustered in the Ca-Mg-HCO_3 facies of the Piper diagram.

6.4.1.2 Chemical Composition of Snake Valley Waters

The major-ion chemistry data for Snake Valley waters are provided in the Microsoft Excel® worksheet entitled "Majors" described in Appendix A and attached on the CD-ROM. The dominant



Note: Numbers beside points correspond to the Map ID assigned with the data set provided on the CD-ROM.

Figure 6-1
Locations of Sample Sites in Spring and Snake Valleys, Nevada and Utah

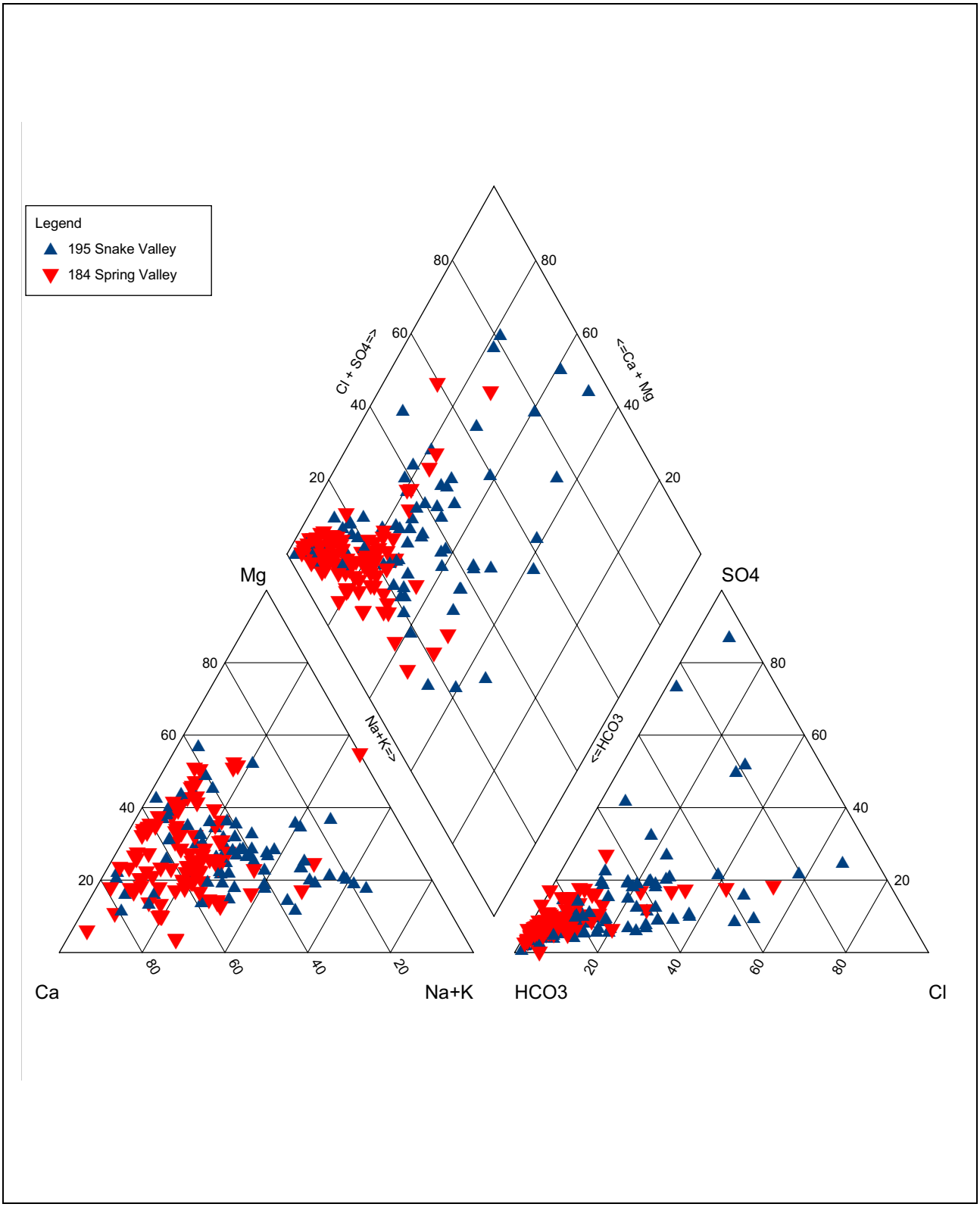


Figure 6-2
Piper Diagram of Spring, Creek, and Well Water Samples Collected in Parts of the Great Salt Lake Desert Flow System

cation for these samples is calcium, and the dominant anions are bicarbonate and chloride. The samples range from Ca-HCO_3 facies through Ca-Mg-Na-HCO_3 to Ca-Mg-Na-HCO_3-Cl to Na-Ca-HCO_3-Cl facies. The increase in sodium could be due to contact with some sodium-rich minerals, cation exchange reactions, or albite weathering. Carbonate and ferromagnesian mineral weathering appears to dominate the chemistry of the Ca-Mg-HCO_3 facies waters.

From Figure 6-2, the hydrochemical facies suggest that there is a greater variation in the chemical composition of basin-fill aquifers in Snake Valley than in Spring Valley. The number of wells tapping the carbonate-rock aquifer was not enough to make any meaningful observations.

6.4.1.3 Trace Element Concentration of Spring and Snake Valley Waters

Trace element concentrations of the waters in Spring and Snake valleys are provided in the Microsoft Excel® worksheet entitled "Traces" described in Appendix A and attached on the CD-ROM. These include springs in the mountain-block areas and the valley floor. The minimum and maximum concentrations of selected trace elements and other parameters regulated by the EPA observed in both valleys are shown in Table 6-1. With the exception of arsenic, the maximum concentrations of the parameters in both valleys were less than the EPA maximum contaminant level (MCL) values. The maximum concentrations of chloride and TDS in both valleys were however, greater than the EPA secondary maximum contaminant level (SMCL) values. The maximum pH and concentrations of aluminum and iron in Spring Valley were also greater than the EPA SMCL values.

6.4.1.4 Deuterium and Oxygen-18 Composition of Spring and Snake Valley Waters

The stable isotope data for Spring and Snake valleys are provided in the Microsoft Excel® worksheet entitled "Stable Isotopes" described in Appendix A and attached on the CD-ROM. A plot of the isotopic composition of the springs, creeks, and wells in Spring and Snake valleys is depicted in Figure 6-3. Also shown is the global meteoric water line (GMWL), available precipitation data, and the local meteoric water line (LMWL) developed using the current data set. The slope of the LMWL is 7.7 and is not significantly different from that of the GMWL (Craig, 1961), which is 8. Samples plotting below the GMWL suggest the water underwent some form of evaporation prior to recharging. There is no remarkable difference between the isotopic composition of the springs, creeks, and wells in Spring and Snake valleys; they all plot around the GMWL. The lack of isotopic difference between the springs, creeks, and wells implies the same source for all of them.

Winter snowmelt and local summer storms produce the runoff and recharge to the area. Summer precipitation is relatively more enriched in isotopic composition than winter precipitation as a result of more partial evaporation during the summer (Figure 6-3). Contribution by summer rainfall to the recharge appears to be small. Using a mass balance analysis of the mean isotopic compositions of summer rainfall, winter snow, and shallow groundwater in Great Basin National Park (GBNP), Acheampong (1992) observed that the shallow groundwater in GBNP was a mixture of about 20 percent summer rainfall, and about 80 percent winter snow. The wells, creeks, and springs sampled for the study are also more depleted in isotopic composition than the volume-weighted precipitation. Thus, based on the isotopic composition, present-day winter precipitation is the major source of recharge to the springs, wells, and creeks in Spring and Snake valleys.

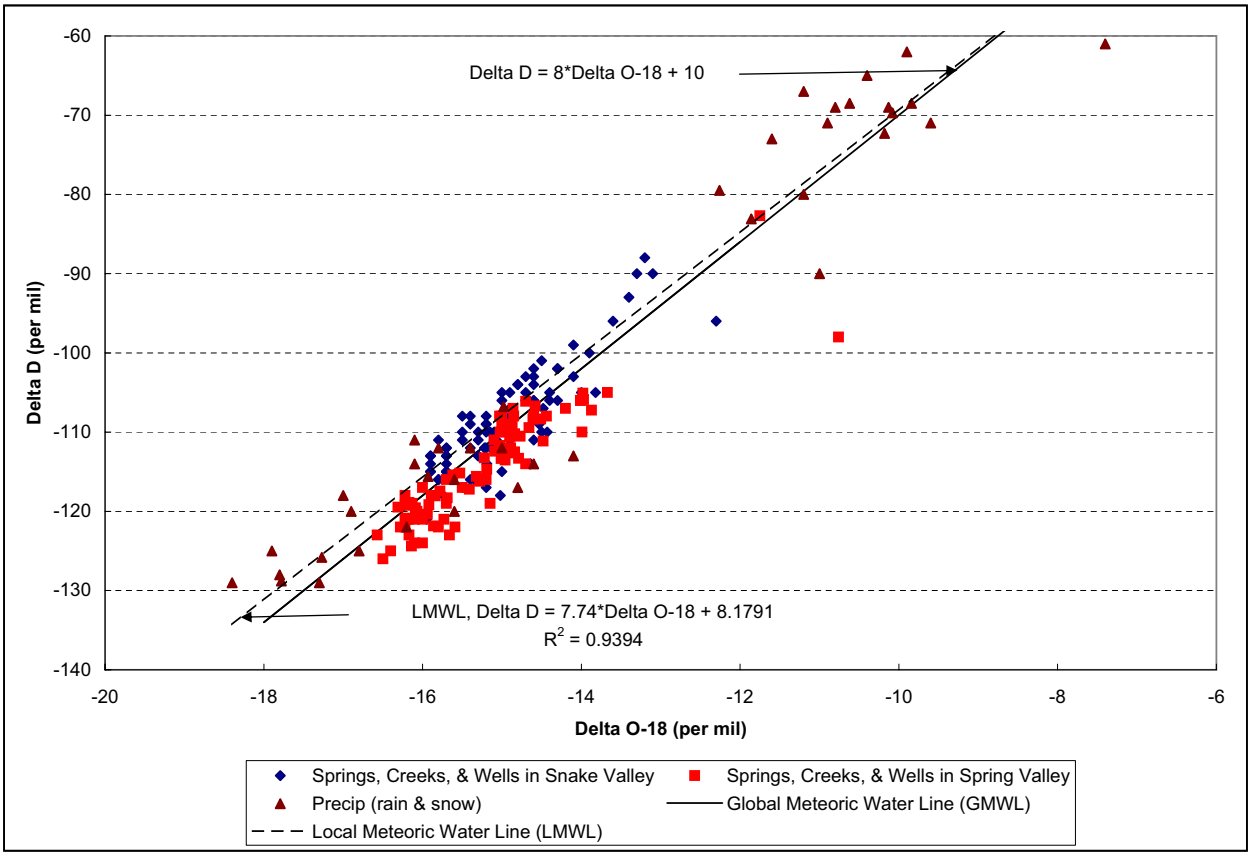
Table 6-1
Range of Concentrations of Selected Parameters for Water Samples Collected in Snake and Spring Valleys, Great Salt Lake Desert Flow System, Nevada and Utah

Constituent	EPA Maximum Contaminant Level	EPA Secondary Maximum Contaminant Level	Minimum Value (Snake)	Maximum Value (Snake)	Minimum Value (Spring)	Maximum Value (Spring)
Antimony	6 µg/L	---	ND	0.38	ND	0.67
Arsenic	10 µg/L	---	ND	30.1	ND	10
Barium	2,000 µg/L	---	ND	120	ND	360
Beryllium	4 µg/L	---	ND	ND	ND	ND
Cadmium	5 µg/L	---	ND	ND	ND	0.17
Chromium	100 µg/L	---	ND	5.7	ND	9
Copper	1,300 µg/L	---	ND	6	ND	5
Fluoride	4 mg/L	2 mg/L	ND	2.9	ND	0.96
Lead	15 µg/L	---	ND	0.5	ND	3.6
Mercury	2 µg/L	---	ND	0.2	ND	ND
Selenium	50 µg/L	---	ND	18	ND	8
Thallium	2 µg/L	---	ND	0.2	ND	0.39
Uranium	30 µg/L	---	0.42	17.6	ND	21.5
Nitrite (as nitrogen)	1 mg/L	---	ND	ND	ND	ND
Nitrate (as nitrogen)	10 mg/L	---	ND	0.93	ND	2.41
Aluminum	---	50 to 200 µg/L	ND	160	ND	1,200
Chloride	---	250 mg/L	ND	490	ND	352
Iron	---	300 µg/L	ND	208	ND	5,700
Manganese	---	50 µg/L	ND	30	ND	88
Silver	---	100 µg/L	ND	ND	ND	ND
Sulfate	---	250 mg/L	ND	1060	ND	162
Zinc	---	5,000 µg/L	ND	11.3	ND	56
pH	---	6.5 to 8.5	6.43	8.4	6.03	9.92
Total Dissolved Solids	---	500 mg/L	198	1794	ND	660

ND = non-detect; NTU = nephelometric turbidity unit

6.4.2 White River Flow System

Groundwater flow and water-quality data have been compiled for the WRFS since the early 1900s. However, there is still a paucity of water chemistry data for many of the valleys within the WRFS. Major-ion chemistry data compiled for WRFS are provided in the Microsoft Excel worksheet entitled "Majors" described in Appendix A and attached on the CD-ROM.



GBNP = Great Basin National Park

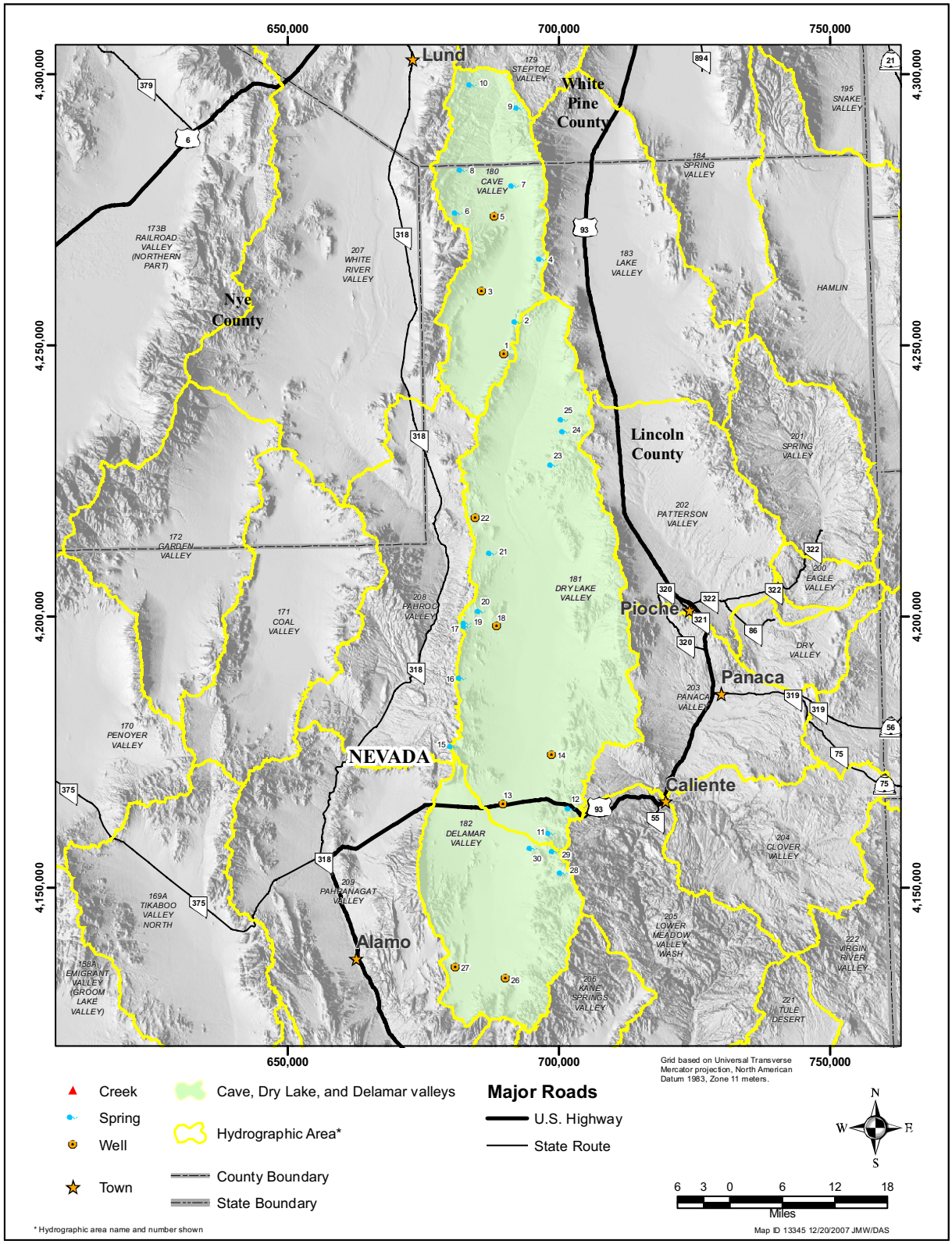
Figure 6-3
δD Versus δ^{18}O Plot of Springs, Creeks, and Wells in Spring and Snake Valleys, Nevada and Utah

6.4.2.1 Chemical Composition of Cave, Dry Lake, Delamar, and Coyote Spring Valleys Waters

Sample locations in Cave, Delamar, and Dry Lake valleys are shown on Figure 6-4, and those in Coyote Spring Valley are shown on Figure 6-5.

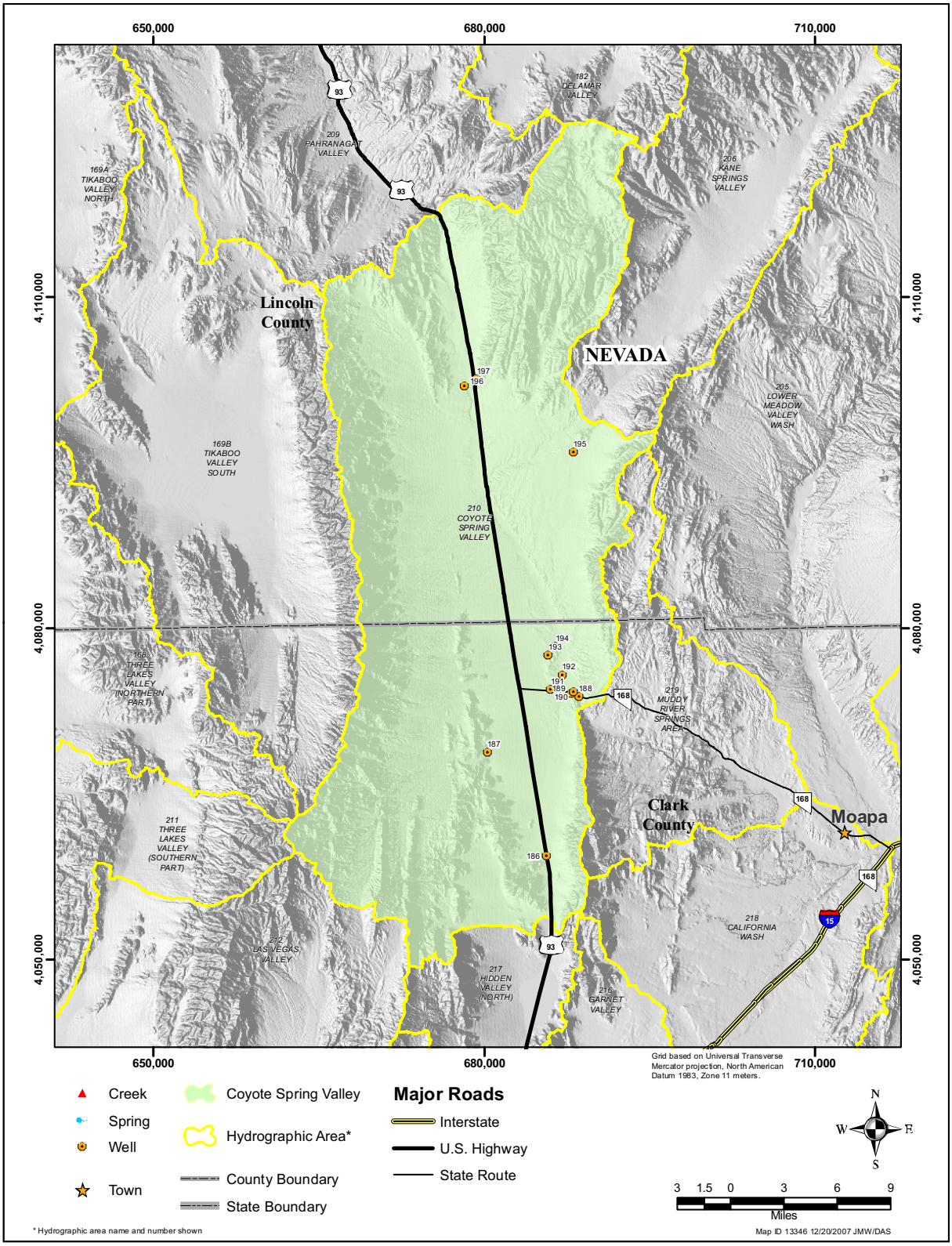
Figure 6-6 is the Piper diagram for groundwater in WRFS. The diagram shows the relationship of the chemical composition of the springs and their positions along the flow path. With a few exceptions of samples in Coyote Spring Valley where some sulfate and chloride salts are encountered, the dominant anion in the majority of the samples in the area is bicarbonate. The dominance of the bicarbonate ion is mainly due to the strong influence of the regional carbonate-rock aquifer that underlies much of the area. Sodium is prevalent in parts of Coyote Spring Valley. The dominant cations in the remaining parts of the area are calcium and magnesium.

Water from the springs and wells in Cave Valley are generally Ca-HCO_3 and Ca-Mg-HCO_3 type and suggest the weathering of limestone and dolomite. The water types in Delamar Valley are Na-Ca-HCO_3 and Ca-Na-HCO_3. These water types result from mineral weathering and suggest the



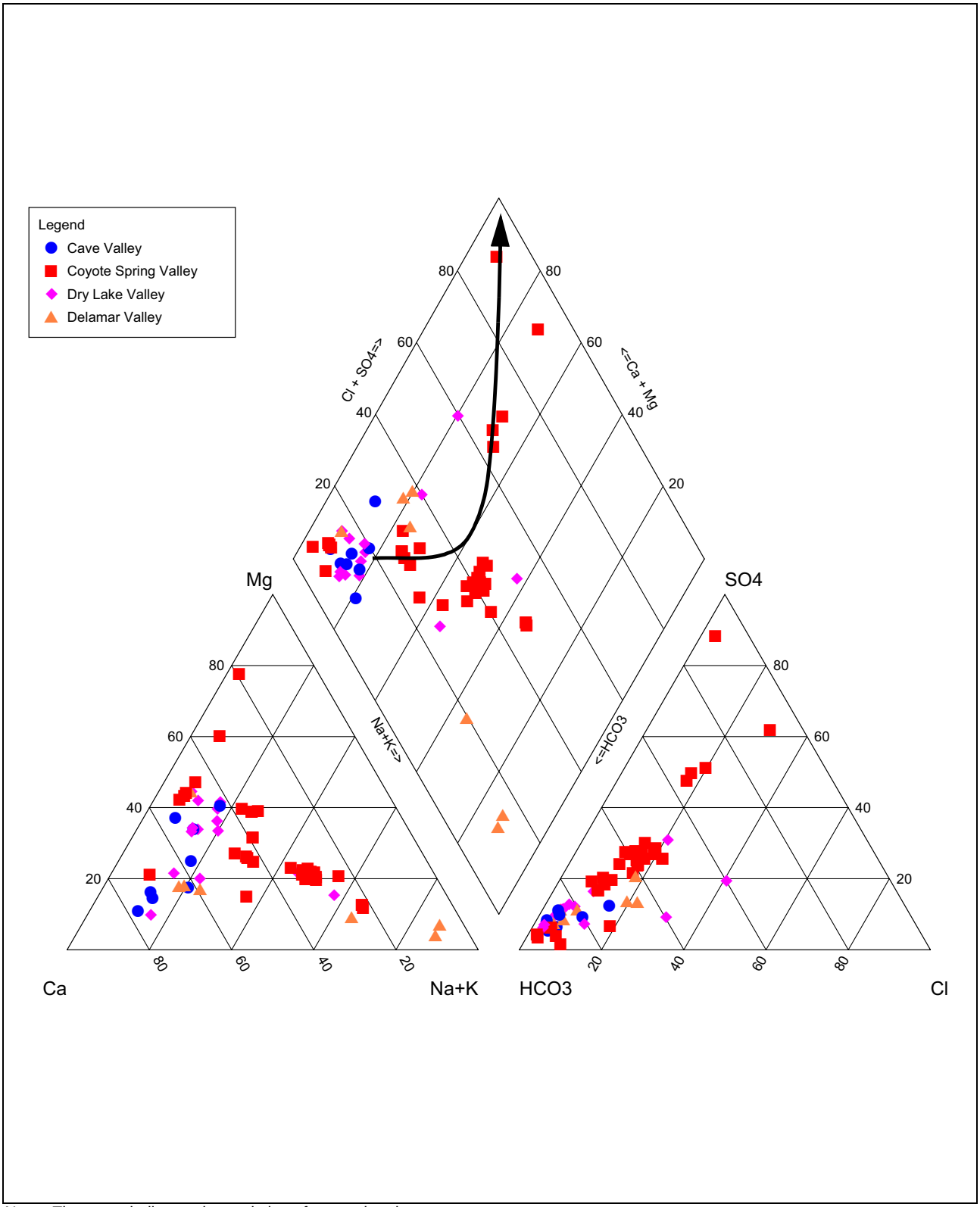
Note: Numbers beside points correspond to the Map ID assigned with the data set provided on the CD-ROM.

Figure 6-4
Locations of Sample Sites in Cave, Delamar, and Dry Lake Valleys, Nevada



Note: Numbers beside points correspond to the Map ID assigned with the data set provided on the CD-ROM.

Figure 6-5
Locations of Sample Sites in Coyote Spring Valley, Nevada



Note: The arrow indicates the evolution of water chemistry.

Figure 6-6
Piper Diagram of Spring, Creek, and Well Water Samples Collected in the White River Flow System, Nevada

influence of both the carbonate rocks near the range front of the Delamar Mountains and the volcanic rocks related to the Caliente Caldera Complex. The water types in Dry Lake Valley are mainly Ca-Mg-HCO_3 and Ca-Na-HCO_3. These water types result from the weathering of carbonate and volcanic rocks. Jacobs Well 7b, which is located at the southern part of Dry Lake Valley, has Na-Ca-mixed anion type water. The water chemistry of the well appears to be affected to a greater degree by evaporite mineral dissolution and interaction with volcanic rocks.

Coyote Spring Valley waters have higher TDS values than those in the other Project Basins. The increase in TDS may result from the dissolution of evaporite minerals in the Muddy Creek Formation, which is known to occur in parts of the valley (Thomas et al., 1996). The water types in Coyote Spring Valley are Na-Ca-Mg-HCO_3-SO_4 and Ca-Na-Mg-SO_4-HCO_3 (Figure 6-6).

Groundwater chemistry in WRFS shows an evolutionary trend from the northern valleys to the southern valleys. The water evolves from Ca-HCO_3 and Ca-Mg-HCO_3 type to Ca-Na-Mg-HCO_3 and Na-Ca-Mg-HCO_3-SO_4 type close to the end of the flow system.

6.4.2.2 Trace Element Data for Cave, Dry Lake, Delamar, and Coyote Spring Valleys Waters

The trace element data compiled for WRFS are provided in the Microsoft Excel® worksheet entitled "Traces" described in Appendix A and attached on the CD-ROM. Most of the trace elements in the four valleys were generally lower than the EPA MCL and SMCL values. Arsenic concentrations in Coyote Spring Valley, however, were generally higher than the EPA MCL of 10 µg/L in some locations. Concentrations of ten of the seventeen samples were in exceedance of the EPA MCL value. The arsenic concentrations of two of the five samples in Dry Lake Valley exceeded the EPA MCL value, and one of the four samples in Delamar Valley was in exceedance of the EPA MCL. None of the 12 samples collected in Cave Valley had arsenic concentrations in excess of the EPA MCL. The range of concentrations of selected parameters in water samples collected from Cave, Dry Lake, Delamar, and Coyote Spring valleys is listed in Table 6-2.

With the exception of maximum concentration of antimony in Coyote Spring Valley which exceeded the EPA MCL, the maximum concentrations of barium, beryllium, cadmium, chromium, copper, lead, mercury, uranium, and zinc were less than the EPA MCL and SMCL values. Two of the five samples in Delamar Valley had fluoride concentrations in excess of the EPA MCL, and concentrations of three of the sixteen samples in Coyote Spring Valley exceeded the EPA MCL value. None of the fluoride concentrations of samples collected in Cave and Dry Lake valleys exceeded the EPA MCL.

Aluminum concentrations of all the samples measured in Coyote Spring Valley were less than the EPA SMCL value. The concentration of one of the twelve samples measured in Cave Valley exceeded the EPA SMCL; one of the four samples each in Dry Lake and Delamar valleys had aluminum concentration in excess of the EPA SMCL.

The maximum concentration of iron in each of the four valleys was higher than the EPA SMCL. Eight of the seventeen samples in Coyote Spring Valley had concentrations in excess of the EPA SMCL, and one of the four samples measured in Delamar Valley exceeded the EPA SMCL. In Dry Lake valley, the concentrations of three of the four samples exceeded the EPA SMCL, and only one of the

Table 6-2
Range of Concentrations of Selected Parameters for Water Samples Collected in Cave, Dry Lake, Delamar, and Coyote Spring Valleys, White River Flow System, Nevada

Constituent	EPA Maximum Contaminant Level	EPA Secondary Maximum Contaminant Level	Min. Value (Cave)	Max. Value (Cave)	Min. Value (Dry Lake)	Max. Value (Dry Lake)	Min. Value (Delamar)	Max. Value (Delamar)	Min. Value (Coyote Spring)	Max. Value (Coyote Spring)
Antimony	6 µg/L	---	ND	1	ND	0.5	ND	ND	ND	6.6
Arsenic	10 µg/L	---	ND	3.8	ND	11.5	ND	17	ND	23
Barium	2,000 µg/L	---	ND	220	ND	198	ND	5.9	29	430
Beryllium	4 µg/L	---	ND	ND	ND	0.11	ND	ND	ND	ND
Cadmium	5 µg/L	---	ND	1	ND	0.02	ND	ND	ND	1.79
Chromium	100 µg/L	---	ND	6	ND	2	ND	4	ND	5.2
Copper	1,300 µg/L	---	ND	6	ND	1.4	ND	6.3	ND	5.6
Fluoride	4 mg/L	2 mg/L	ND	0.21	0.18	0.6	0.2	5.9	0.1	4.7
Lead	15 µg/L	---	ND	10	ND	1.3	ND	3.8	ND	9.6
Mercury	2 µg/L	---	ND	ND	ND	ND	ND	ND	ND	ND
Selenium	50 µg/L	---	ND	2.1	ND	0.8	ND	2	ND	20
Thallium	2 µg/L	---	ND	2.2	ND	2.55	ND	ND	ND	0.35
Uranium	30 µg/L	---	0.13	3.64	2.1	5.65	2.1	4.7	1	3.91
Nitrite (as nitrogen)	1 mg/L	---	ND	ND	ND	0.06	ND	ND	ND	ND
Nitrate (as nitrogen)	10 mg/L	---	ND	1.9	ND	3.94	0.36	3.5	ND	12.2
Aluminum	---	50 to 200 µg/L	ND	430	ND	990	ND	430	ND	180
Chloride	---	250 mg/L	ND	16	2.5	70.3	4.8	70.7	2.1	58
Iron	---	300 µg/L	ND	650	ND	2,400	ND	1,300	ND	3,000
Manganese	---	50 µg/L	ND	120	4.0	94	ND	38	ND	190
Zinc	---	5,000 µg/L	ND	262	ND	25.8	ND	3.2	ND	4,000
pH	---	6.5 to 8.5	6.11	7.81	6.76	9.68	7.01	8.52	6.98	8.25
Total Dissolved Solids	---	500 mg/L	72	260	268	402	210	481	300	630

ND = non-detect; NTU = nephelometric turbidity unit

thirteen samples in Cave Valley had a concentration in excess of the EPA SMCL value of 300 µg/L (Traces Worksheet; Table 2).

6.4.2.3 Stable Isotope Data for Cave, Dry Lake, Delamar, and Coyote Spring Valleys Waters

The stable isotope data for Cave, Dry Lake, Delamar, and Coyote Spring valleys are provided in the Microsoft Excel® worksheet entitled "Stable Isotopes" described in Appendix A and attached on the CD-ROM. Stable isotopic data for the Project Basins in WRFS are plotted on Figure 6-7. The waters are of meteoric origin. Almost all the samples plot to the right of the GMWL, suggesting that water in the Project Basins in WRFS underwent a small amount of evaporation prior to recharging into the underlying aquifers.

6.4.2.4 Nutrient and Radiochemical Concentrations

Very limited data on nutrients and radiochemicals are available for each of the flow systems covered in this report. SNWA is in the process of gathering these types of data in the basins where it has groundwater rights applications. The available data compiled for WRFS is listed in Tables 6-3 and 6-4.

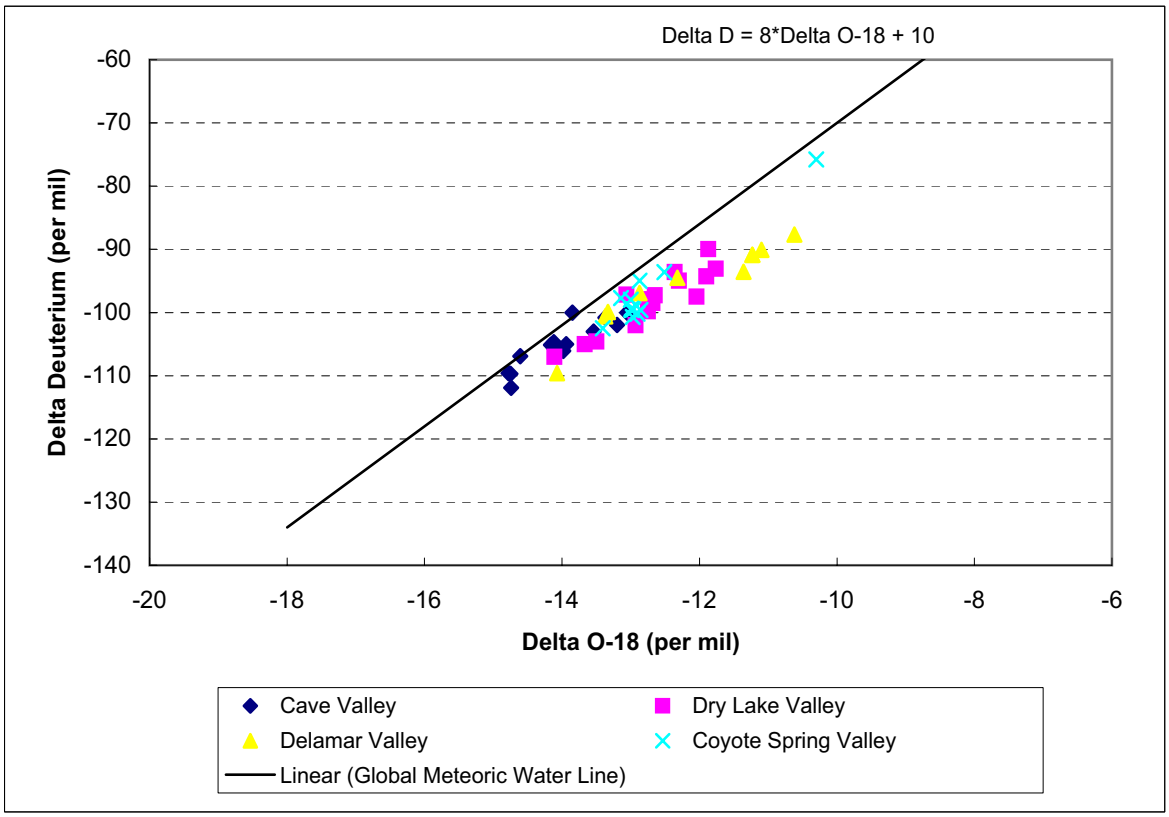


Figure 6-7
δD Versus δ^{18}O Plot of Water Samples Collected in Parts of the White River Flow System, Nevada

Table 6-3
Concentrations of Nutrients in Well and Spring Water Samples in Selected Hydrographic Areas in White River Flow System, Nevada
(Page 1 of 2)

Sample ID	Hydrographic Area	HA No.	Site Type	Sample Date	Source[a]	Nitrate as NO_3	Nitrate as N	Nitrite as N (Dissolved)	$NO_3 + NO_2$ as N	Phosphorous as Total P	O-phosphates as Total P
						mg/L				µg/L	
180W501M	Cave	180	Well	05/17/2006	SNWA06	8.60	1.90	----	---	ND	ND
180W902M	Cave	180	Well	05/18/2006	SNWA06	4.00	0.91	ND	---	ND	7.7
Cave Valley MX	Cave	180	Well	07/10/2003	USGS	---	1.38	E 0.004	1.38	---	E 10
181M-1	Dry Lake	181	Well	05/31/2006	SNWA06	0.93	0.21	ND	---	ND	ND
181W909M	Dry Lake	181	Well	06/05/2006	SNWA06	4.70	1.10	ND	---	39	ND
N. Dry Lake MX	Dry Lake	181	Well	06/19/2003	USGS	---	0.05	ND	0.05	---	E 10
182M-1	Delamar	182	Well	05/23/2006	SNWA06	5.2	1.20	ND	---	30	ND
182W906M	Delamar	182	Well	06/20/2006	SNWA06	---	0.89	ND	---	13	10
209M-1	Pahranagat	209	Well	06/07/2006	SNWA06	2.40	0.54	ND	---	ND	ND
Ash Springs	Pahranagat	209	Spring	05/25/2004	SNWA04	---	0.24	ND	---	---	10
Crystal Springs	Pahranagat	209	Spring	06/03/2003	USGS	---	0.26	ND	---	---	ND
CSI-1	Coyote Spring	210	Well	05/31/2005	SNWA05	1.20	0.27	---	0.27	---	---
CSI-3	Coyote Spring	210	Well	09/13/2006	SNWA06	1.10	0.25	---	---	ND	6.5
CSVM-2	Coyote Spring	210	Well	01/10/2006	SNWA06	ND	ND	ND	---	ND	10
CSVM-2	Coyote Spring	210	Well	01/10/2006	SNWA06	ND	0.12	ND	---	ND	10
CSVM-3	Coyote Spring	210	Well	01/06/2006	SNWA06	2.80	---	---	---	ND	ND
CSVM-3	Coyote Spring	210	Well	01/05/2006	SNWA06	---	0.60	ND	---	---	---
CSVM-4	Coyote Spring	210	Well	01/16/2006	SNWA06	ND	ND	ND	ND	ND	2.8
CSVM-4	Coyote Spring	210	Well	01/16/2006	SNWA06	---	0.14	ND	---	<10	2.8
CSVM-5	Coyote Spring	210	Well	01/08/2006	SNWA06	4.90	1.11	ND	---	ND	ND

Table 6-3
Concentrations of Nutrients in Well and Spring Water Samples in Selected Hydrographic Areas in White River Flow System, Nevada
(Page 2 of 2)

Sample ID	Hydrographic Area	HA No.	Site Type	Sample Date	Source[a]	Nitrate as NO_3	Nitrate as N	Nitrite as N (Dissolved)	$NO_3 + NO_2$ as N	Phosphorous as Total P	O-phosphates as Total P
						mg/L				µg/L	
CSVM-5	Coyote Spring	210	Well	01/08/2006	SNWA06	---	1.10	ND	...	ND	<10
CSVM-6	Coyote Spring	210	Well	01/11/2006	SNWA06	0.95	0.21	---	---	---	8.1
CSVM-6	Coyote Spring	210	Well	01/11/2006	SNWA06	---	0.26	ND		ND	8.1
CSVM-7	Coyote Spring	210	Well	01/23/2006	SNWA06	5.90	1.33	---	---	---	---
MX-5	Coyote Spring	210	Well	02/16/2005	SNWA05	---	ND	---		---	<20
CSV-2	Coyote Spring	210	Well	07/08/2003	USGS	---		ND	0.48	---	<20
MX-5	Coyote Spring	210	Well	05/28/2003	USGS	---		ND	0.29	---	<20
RW-2	Coyote Spring	210	Well	03/06/2002	NPC	---	<1	<1	1.20	---	---
Mirant	Garnet	216	Well	06/04/2003	USGS	---	0.10	ND	0.10	---	ND
Arrow Canyon	MRSA	219	Well	03/15/2006	SNWA06	4.50	---	---	---	---	---
Pederson Spring	MRSA	219	Spring	07/08/2003	USGS	---	---	0.008	0.4	---	ND

[a]References:
NPC: Unpublished data collected by the Nevada Power Company in 2002.
SNWA04: Unpublished data collected by SNWA in 2004; SNWA05: Unpublished data collected by SNWA in 2005; SNWA06: Unpublished data collected by SNWA in 2006.
USGS: Published data by USGS for the National Water -Quality Assessment Program.

MRSA = Muddy River Springs Area; ND = non-detect; E = Reported value is an estimate

Table 6-4
Radiochemical Activities (in pCi/L) in Well and Spring Water Samples in Selected Hydrographic Areas in White River Flow System, Nevada[a]

Sample ID	Hydrographic Area	HA No.	Sample Date	Alpha		Beta		Radium-226	Radium-226 Error	Radium-228	Radium-228 Error	Radium Total Gross	Combined Radium Total Error	Radon	Radon Error	Strontium-90	Uranium	Tritium
				Gross	2σ Error	Gross	2σ Error											
180W501M	Cave	180	05/17/2006	6.20	1.30	3.00	0.92	2.40	0.20	ND	N/A	2.40	0.20	269	29	ND	0.67	ND
180W902M	Cave	180	05/18/2006	3.40	1.20	1.70	0.76	0.70	0.10	ND	N/A	0.70	0.10	237	26	ND	1.30	ND
Cave Valley MX	Cave	180	07/10/2003	---	---	---	---	---	---	---	---	---	---	360	23	---	---	ND
181M-1	Dry Lake	181	05/31/2006	10.50	1.07	3.60	0.92	1.20	0.10	ND	N/A	1.20	0.10	213	23	ND	2.70	ND
181W909M	Dry Lake	181	06/05/2006	8.17	0.97	5.00	0.83	ND	N/A	ND	N/A	ND	N/A	373	39	ND	3.10	ND
N. Dry Lake MX	Dry Lake	181	06/19/2003	---	---	---	---	---	---	---	---	---	---	400	23	---	---	0.3
182M-1	Delamar	182	05/23/2006	2.10	1.10	7.00	0.78	ND	N/A	ND	N/A	ND	N/A	696	71	ND	2.10	ND
182W906M	Delamar	182	06/20/2006	7.40	1.30	0.56	0.61	ND	N/A	ND	N/A	ND	N/A	445	46	ND	4.70	ND
KPW-1	Kane Springs	206	12/15/2005	6.30	2.20	16.00	1.90	---	---	---	---	---	---	---	---	---	---	---
209M-1	Pahranagat	209	06/07/2006	6.33	0.88	5.20	0.75	0.80	0.10	ND	N/A	0.80	0.10	99	12	ND	1.50	ND
Crystal Springs	Pahranagat	209	06/03/2003	---	---	---	---	---	---	---	---	---	---	60	17	---	---	---
CSI-3	Coyote Spring	210	09/13/2006	2.95	0.82	13.00	1.00	0.60	0.10	ND	N/A	0.60	0.10	227	24	ND	2.60	ND
CSVM-2	Coyote Spring	210	01/10/2006	6.00	1.60	3.30	2.40	0.80	0.10	0.60	0.30	1.40	0.30	226	29	ND	0.74	ND
CSVM-3	Coyote Spring	210	01/06/2006	9.60	2.10	11.00	1.00	0.30	0.10	ND	N/A	0.30	0.10	---	---	ND	3.50	ND
CSVM-4	Coyote Spring	210	01/16/2006	0.57	2.30	11.00	1.50	0.30	0.10	ND	N/A	0.30	0.10	192	21	ND	1.80	ND
CSVM-5	Coyote Spring	210	01/08/2006	10.00	1.40	5.40	0.57	0.20	0.10	ND	N/A	0.20	0.10	486	50	ND	1.70	ND
CSVM-6	Coyote Spring	210	01/11/2006	4.70	1.90	10.00	0.98	0.50	0.10	ND	N/A	0.50	0.10	192	21	ND	2.10	ND
MX-5	Coyote Spring	210	02/16/2005	3.40	1.90	9.40	1.60	---	---	---	---	---	---	---	---	1.44	1.54	ND
CSV-2	Coyote Spring	210	07/08/2003	---	---	---	---	---	---	---	---	---	---	740	29	---	---	---
MX-5	Coyote Spring	210	05/28/2003	---	---	---	---	---	---	---	---	---	---	480	25	---	---	---
Mirant	Garnet	216	06/04/2003	---	---	---	---	---	---	---	---	---	---	530	26	---	---	---
Pederson Springs	MRSA	219	07/30/2003	---	---	---	---	---	---	---	---	---	---	550	26	---	---	---

[a] Source: Acheampong et al. (2007)
MRSA = Muddy River Springs Area; ND = non-detect
N/A = Not applicable

6.5 Summary

Calcium and bicarbonate are the dominant cation and anion within all of the four flow systems for which chemistry data have been compiled. The data suggest that chemical composition of groundwater within Spring and Snake valleys within the GSLDFS is controlled by the mineralogy of the aquifer materials. The chemical composition of groundwater in WRFS shows an evolutionary trend evolving from Ca-Mg-HCO_3 water in the mountainous recharge areas to Na-Ca-Mg-SO_4 water close to the end of the flow system.

Most of the trace elements are in very minute concentrations in the creeks, springs, and well water samples compiled for the study. Concentrations of antimony, beryllium, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, thallium, vanadium, and zinc are generally very low and are non-detect in most of the samples analyzed in Spring and Snake valleys within GSLDFS and also in Cave, Delamar, Dry Lake, and Coyote Spring valleys in the WRFS. Arsenic concentrations in parts of Coyote Spring Valley are, however, greater than the EPA MCL of 10 µg/L. Despite the numerous mining activities that have taken place in Nevada over the past several decades, it appears that the generally low concentrations of trace elements in the study area are a natural occurrence and their abundances lie within values expected in natural systems. No anthropogenic sources are identified.

The stable isotope compositions of all the types of water in the flow systems studied show that the waters are of meteoric origin. The stable isotopic data also suggest that modern-day precipitation is a major source of recharge to the groundwater in Spring and Snake valleys.

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7.0 WATER RIGHTS AND WATER USE

7.1 Introduction

This water rights summary describes the compilation of water rights for each hydrographic area in the hydrologic study area, and tabulates the reported underground active water rights for each of the Project Basins based on information from the NDWR and the Utah Division of Water Rights (UDWR). This data compilation can be used to understand the locations of existing water rights and the quantities of committed water rights. The compiled data can also be used to assess the current and historic groundwater withdrawals for a given basin.

7.2 Background

Nevada has a prior appropriations water rights system, administered by the office of the State Engineer. Nevada water law was established in 1905, to regulate uses of surface waters. In 1913, law regarding underground waters was enacted, but the complete groundwater law was not established until 1939. Claims of "vested" water rights can be made for appropriations of water prior to the establishment of Nevada water laws in 1905 for surface water and 1939 for underground water (claims of pre-statutory rights). Some vested rights in Nevada have been adjudicated and therefore the quantity and extent have been confirmed by the court, but many have not been through this process.

In Nevada, all water ultimately belongs to the public, although water rights permits are treated like real property. The process of obtaining a water right begins with filing an application with the State Engineer to appropriate water. If the applicant is granted a permit, then the process of perfecting the water right begins. "Proof of Completion of Work" must be filed and accepted by the State Engineer, followed by "Proof of Beneficial Use." Once "Proof of Beneficial Use" is accepted by the State Engineer, then a Certificate of Appropriation of Water is issued.

Most water rights have a surveyed point of diversion, designated place of use, manner of use, rate and duty of diversion, period of use, and often contain specific conditions of water use as dictated by the State Engineer. Applications to change the point of diversion, place of use and/or manner of use of existing water right permits is a common practice as operations and demands for water change over time. Water rights are considered real property and can be sold. Water rights remain appurtenant to the place of use but may be severed by deed (sold separate from the appurtenant land).

Rulings, orders and adjudications may be issued by the State Engineer or judicial courts to resolve disputes regarding water rights. Most of the major streams and rivers in Nevada have been subject to adjudication.

The Nevada State Engineer manages groundwater by individual hydrographic basin, of which there are 232 defined (NDWR, 2005). The perennial yield of a hydrographic basin establishes the total duty of groundwater rights which are issued on a permanent basis as per the policy of the State Engineer (NDWR, 1977). While this sounds simple, it becomes complex, as defining perennial yield always involves estimation and uncertainty, and there are often other complicating issues, including interactions between basins, quantity of consumptive water use versus pumped quantity, ability to develop groundwater at the location of interest without detrimental impacts, and many other issues. The State Engineer reviews each application on a case-by-case basis, and where the State Engineer interprets a basin to be fully appropriated, the basin often becomes designated for preferred uses.

At times, water rights are issued which are supplemental to other water rights. For example, an underground water right might be issued to provide water to irrigate a pasture that is normally irrigated with surface water. Groundwater will only be used if the flow in the stream is inadequate. In some cases, water rights have been issued on the basis of a combined duty, whereby the total annual duty of several permits cannot exceed a combined total amount. These stipulations are not addressed in the State of Nevada abstracts. Each water right must be read to determine if a limitation has been placed on it. A complicating issue which is also encountered is the result of multiple water rights having been granted covering the same place of use. In some cases, a determination of the amount of water rights that are supplemental has not been made, to date. This tends to occur more frequently in cases where claims of vested rights have been filed that incorporate places of use which already have permitted water rights.

This brief overview touches only on the highlights of Nevada water law. Water rights overviews and regulations can be reviewed from the NDWR on the World Wide Web at the uniform resource locator (URL) http://water.nv.gov. In addition, copies of "Nevada Water Laws" are available through the Division of Water Resources (Ricci, 2001). More detailed summaries of Nevada water law and policies are presented by Davenport (2003) and in publications from the Division of Water Resources (Ricci, 2004; Ricci, 2003; NDWR, 1974). Nevada water law is also discussed in several short course manuals, prepared by groups such as the Nevada Water Resources Association (Buschelman and Ricci, 2004), The Cambridge Institute (de Lipkau et al., 1995), and CLE International (1994).

In addition to rulings on water right applications from the Nevada State Engineer, under the Lincoln County Conservation, Recreation, and Development Act of 2004, an agreement between the States of Nevada and Utah is required prior to any transbasin diversion from groundwater basins located within both states. Thus, for Snake Valley, a portion of which is located in both states, Nevada and Utah need to reach an agreement prior to the diversion of groundwater out of out of the basin by the project. The two states have been in discussions on an agreement since 2006.

7.3 Data Compilation

7.3.1 Nevada Water Rights

Nevada water rights data were obtained from the NDWR on the World Wide Web at URL http://water.nv.gov/water%20Rights/permitdb/permitdb_index.cfm. Preliminary basin abstracts, digital copies of application permits and certificates, maps, and underground active abstracts can all

be obtained from this web site. Both water right abstracts and underground active abstracts were downloaded for each hydrographic area within the hydrologic study area for this task on March 7, 2007 (NDWR, 2007b; NDWR, 2007c). In addition, updated water rights abstracts and underground active abstracts were obtained for Spring Valley on December 4 and December 18, 2007, respectively, to reflect Nevada State Engineers Ruling 5726 (NDWR, 2007d; NDWR, 2007e). The water rights abstracts contain basic information about a water right including the file date for the application, status, source, point of diversion, diversion rate, type of use, duty, and owner of record. The water rights abstracts were downloaded and saved into a Microsoft Excel® workbook for future reference. The downloaded water right abstracts can be found on the enclosed CD-ROM disc in the file named "NV_Water_Rights_20070307_20071218.xls." The underground active abstracts contain a summary by manner of use of the committed groundwater rights for a given basin. The underground abstracts were printed out from the NDWR website and saved as portable document files (pdf) for future reference. The underground abstracts can be can be found on the enclosed CD-ROM disc in the file named "Underground_Committed_ Water_Rights.pdf".

7.3.2 Utah Water Rights

Utah water rights data were obtained from the UDWR on the World Wide Web at URL http://nrwrt1.nr.state.ut.us/. The UDWR makes available a shapefile of the points of diversion from their water rights database. According to the UDWR website, this shapefile is generated daily from basic information contained in their water rights database. The shapefile contains basic information about a water right including the status, type (i.e., surface water vs. groundwater), the status of the application, the priority date, the uses of the water, and the owner of the water right. The Utah water rights data were downloaded on March 13, 2007 (UDWR, 2007). The downloaded shapefile was then spatially queried for water rights in Pleasant, Snake, and Hamlin valleys. The water rights for the portions of Pleasant, Snake, and Hamlin valleys that are in Utah can be found on the enclosed CD-ROM disc in the file named "Utah_Water_Rights_20070313.xls". In addition to the downloaded point of diversion data, UDWR provided a preliminary estimate of the total committed underground water rights for the Utah portion of Snake Valley (Clayton, 2007). This data can be found on the enclosed CD-ROM disc in the file named "undergrounddiversion_20071204.xls".

7.4 Summary of Underground Water Rights for Project Basins

7.4.1 Spring Valley

Spring Valley is situated mostly in White Pine County, with only the southern end of Spring Valley located in Lincoln County (see Figure 7-1). Spring Valley Creek, Cleve Creek, and numerous other perennial creeks discharge to the valley floor from the eastern slope of the Schell Creek Range. The Snake Range is also a source of numerous additional streams on the eastern side of the valley. Stream and spring water sources in Spring Valley are primarily used for irrigation and stockwatering, with some mining and milling, domestic, or other uses. Some of the larger stream and spring sources with water rights appropriations are Kalamazoo, Piermont, Garden, Bassett, Negro, Odger, McCoy, Taft, Stephens, and Cleve (Cleveland) Creeks on the eastern slope of the Schell Creek range; Spring Valley Creek and Millick Spring on the valley floor; and Dry Gulch, Shingle, Willard, Williams, Lincoln, and Murphy Creeks from the western slope of the Snake Range.

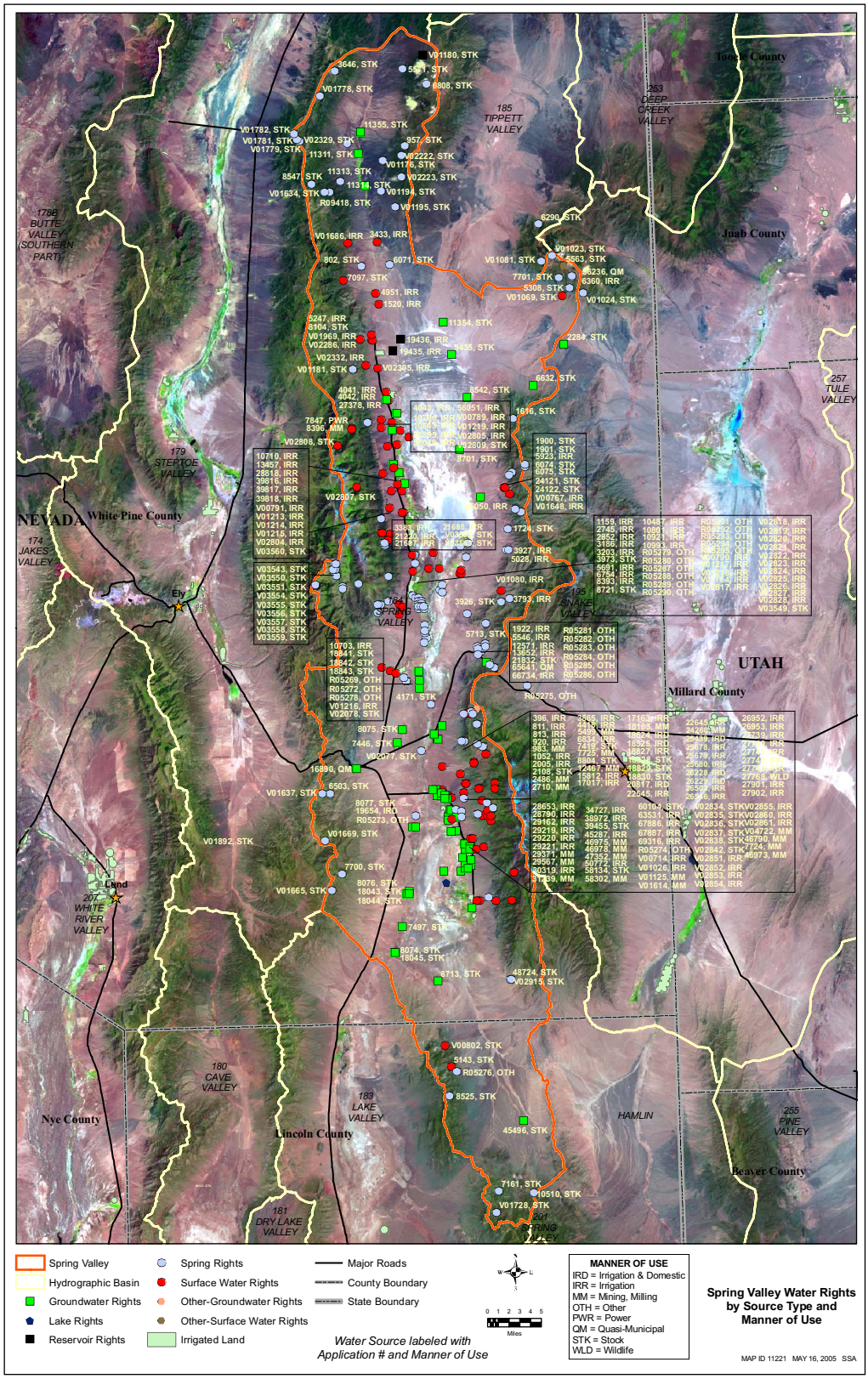

Figure 7-1
Spring Valley Water Rights

A number of streams in Spring Valley have undergone adjudication including Bassett Creek (1938), Kalamazoo Creek (1983), Negro Creek (1949), Odgers Creek (1976), and Piermont Creek (1976). Pending adjudications exists on Cleve Creek, Long Springs, Muncy Creek, Siegel Creek, and Swallow Creek.

Approximately 136 spring water rights have been filed in Spring Valley, including 24 reserved rights filed by the BLM and 16 claims of vested rights by the U.S. Forest Service (USFS). Many of the spring rights owned by BLM and the USFS are located off of the valley floor within the surrounding mountain ranges.

Table 7-1 lists the active underground water rights in Spring Valley which total 82,778 afy. Approximately 64,344 afy, or 78 percent, have a manner of use listed as municipal. The remaining uses are for irrigation, mining and milling, quasi-municipal, stockwatering, and wildlife purposes.

According to records on file with NDWR, major holders of certificated and/or permitted water rights within Spring Valley are Southern Nevada Water Authority, George Eldridge and Son, Inc., Huntsman Ranch, LLC, El Tejon Cattle Company, Nevada Land and Resource Company, LLC, and Robert L. and Fern A. Harbecke.

Table 7-1
Preliminary Estimates of Active Groundwater Rights in Spring Valley

Manner of Use	Preliminary Total (afy)
Irrigation-Desert Land Entry	836.98
Irrigation	15,744.37
Mining and Milling	1,360.7
Municipal	64,343.82
Quasi-Municipal	78.64
Stockwatering	385.61
Wildlife	27.58
Total Underground	**82,777.71**

Source: Hydrographic Basin Summary by Manner of Use (Included on the CD-ROM) (NDWR, 2007d)

7.4.2 Snake Valley

Snake Valley is split between Nevada and Utah (see Figure 7-2). In Nevada, Snake Valley is within White Pine and Lincoln Counties and includes the Snake Range, Great Basin National Park, and the community of Baker. In Utah, a majority of the valley floor is in Millard County, Utah, where Snake Valley supports significant agriculture and the communities of Garrison, Callao, Eskdale, Gandy, and Trout Creek. Portions of the southern basin also reside in Beaver and Iron Counties, Utah, while the northernmost portion of the basin is in Juab County.

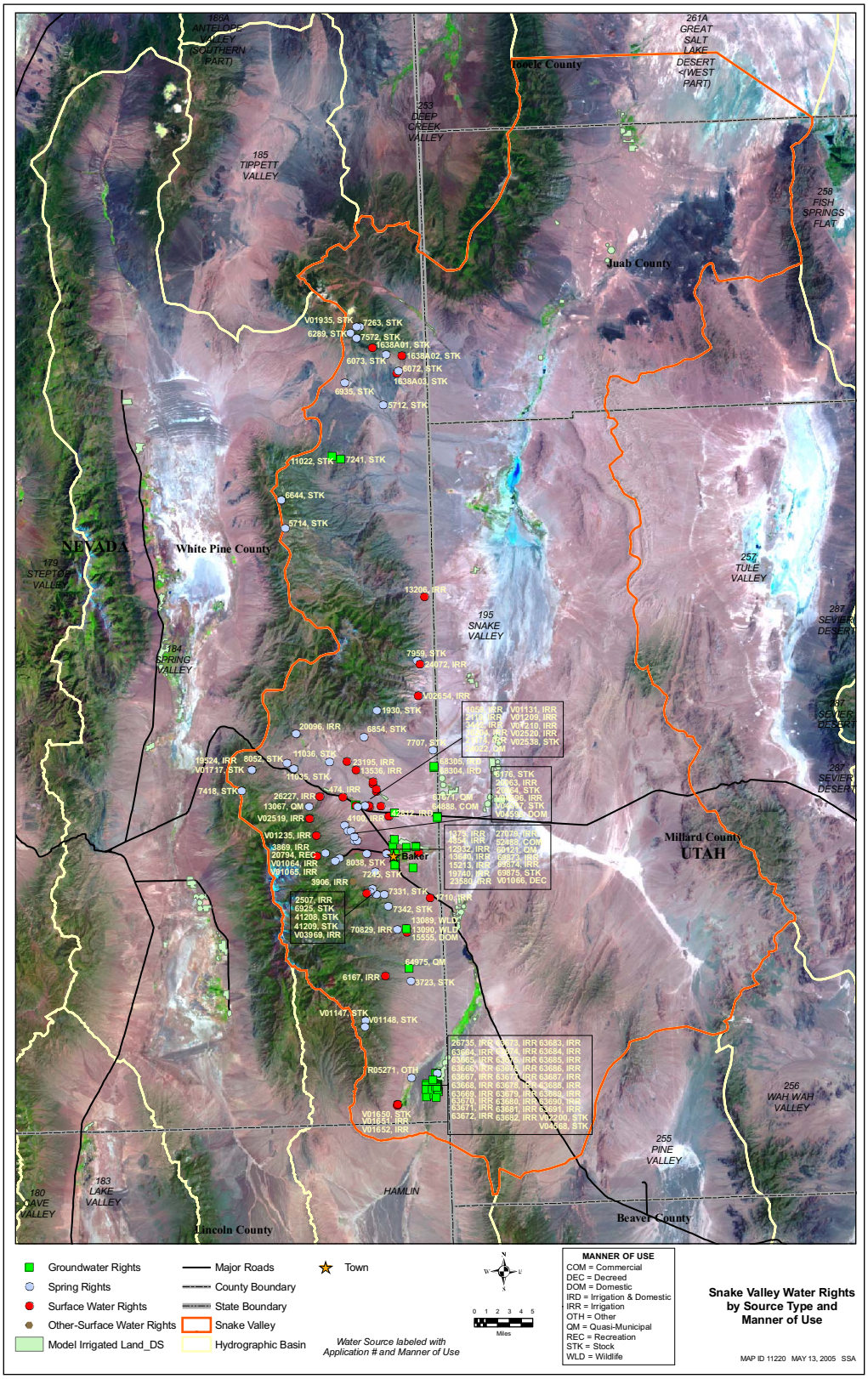

Figure 7-2
Snake Valley Water Rights (Nevada Portion)

Surface water rights have been appropriated on the major perennial streams including Smith, Hendrys, Silver, Weaver, Strawberry, Lehman, Baker, Young Canyon, Snake, and Big Springs. These streams all originate from the eastern slope of the Snake Range. Water rights have also appropriated most of the springs in the Nevada portion of Snake Valley including Lehman, Cave, Robison, Rowland, Big Wash, Eldridge, and Young's Canyon springs. Baker and Lehman Creeks have been adjudicated by the State of Nevada in the Baker-Lehman Creek Decree dated 1934. Civil decrees have also been issued by the State of Nevada for Silver Creek (1911), Six Springs (1890), and Weaver Creek (1984).

Trout Creek is a significant stream in Utah, discharging from the Deep Creek Range, a northern extension of the Snake Range. Warm Creek (Swan Creek in Nevada), discharges from the eastern flank of the Snake Range and has been adjudicated in Utah (Pringle vs. Shingleton, 1917).

A majority of the water resources in Snake Valley are derived from the Snake Range, with roughly 75 percent of surface water resources and 62 percent of groundwater resources of the basin derived in Nevada based on work by Hood and Rush (1965).

7.4.2.1 Nevada Portion

Based on records from NDWR, there are nearly 10,418 afy of active underground water rights in the Nevada portion of Snake Valley. As listed in Table 7-2, irrigation accounts for 99 percent, or 10,325.29 afy, of the total active underground water rights in the Nevada portion of Snake Valley. The next largest manner of use is for quasi-municipal with approximately 56 afy.

Major holders of certificated and/or permitted water rights within the hydrographic basin are Baker Ranches, Inc., and Granite Peak Properties, LLC.

Table 7-2
Preliminary Estimates of Active Groundwater Rights in Snake Valley (Nevada Portion)

Manner of Use	Preliminary Total (afy)
Commercial	0.06
Domestic	1.63
Irrigation-Desert Land Entry	720
Irrigation	9,605.29
Quasi-municipal	55.58
Stockwatering	34.92
Total Underground	**10,417.49**

Source: Hydrographic Basin Summary by Manner of Use (Included on the CD-ROM) (NDWR, 2007c)

7.4.2.2 Utah Portion

A large portion of central and northern Snake Valley resides in Utah (see Figure 7-2). Snake Valley is presently defined by UDWR as a basin open to new appropriations. It is listed, however, as a "focused study area." It should be noted that UDWR has water rights management areas that include multiple hydrographic basins. As such, Snake Valley is one of several hydrographic basins in Management Area No. 18. Approximately 495 water right permits have been issued by the UDWR in the Utah portion of Snake Valley, 286 of which are from an underground source (UDWR, 2007).

While there are some terminology differences between Nevada and Utah, Utah's core water-rights law and processes are very similar to that used in Nevada. However, some subtle differences exist. For example, multiple points of diversion can be specified for one application or claim number. To some degree, this avoids complications in interpreting combined duties of water rights, a difficulty encountered in assessing total committed duties in Nevada. Another difference is that single family domestic wells require water-right permit in Utah, unlike in Nevada.

Based on preliminary water right totals obtained from UDWR, there are 40,440 afy of active underground water rights in the Utah portion of Snake Valley (Clayton, 2007). As listed in Table 7-3, irrigation accounts for approximately 94 percent, or 37,942 afy, of the total active underground water rights in the Utah portion of Snake Valley. The next largest manner of use is for 'Other' uses with approximately 1,563 afy.

Major holders of approved and perfected water rights within the Utah portion of Snake Valley are the Corporation of the President Aaronic Order, and Baker Ranches Inc.

Table 7-3
Preliminary Estimates of Active Groundwater Rights in Snake Valley (Utah Portion)

Manner of Use	Preliminary Total (afy)
Irrigation	37,941.69
Stock	824.22
Domestic	111.03
Municipal	0
Mining	0
Power	0
Other	1,563.24
Total Underground	**40,440.18**

Source: Clayton, 2007; (Included on the CD-ROM)

7.4.3 Cave Valley

Cave Valley is split between White Pine County in the north and Lincoln County in the south (see Figure 7-3). The majority of the water rights in the basin are associated with spring sources. There are, however, water rights associated with the ephemeral Haggerty Wash and the ephemeral Silver Creek emanating from the Egan Range, and the ephemeral North and Sheep Creeks flowing from the western slope of the Schell Creek Range (not to be confused with North and Sheep Creeks on the *eastern* slope of Schell Creek Range, which are in Lake Valley). These creeks flow towards the valley floor on the north end of the valley and enter Cave Valley Wash and proceed to a terminal depression located at the southern end of the valley.

Records from NDWR indicate that there is approximately 47 afy of active underground water rights in the valley in the form of certificates, permits, or vested/reserved rights. All of the active underground water rights for Cave Valley are for stockwatering purposes. The underground active data for Cave Valley is listed in Table 7-4.

Table 7-4
Preliminary Estimates of Active Groundwater Rights in Cave Valley

Manner of Use	Preliminary Total (afy)
Stockwatering	46.58
Total Underground	**46.58**

Source: Hydrographic Basin Summary by Manner of Use (Included on the CD-ROM) (NDWR, 2007c)

7.4.4 Dry Lake Valley

Dry Lake Valley is also located entirely within Lincoln County (see Figure 7-4). Development of water resources in Dry Lake Valley has been minimal, primarily for stock watering. The majority of the water rights in the basin are from springs, however, there are rights associated with the ephemeral washes of Black Canyon and Fairview which originate in the Chief and Fairview ranges, respectively, on the eastern edge of the basin. These washes extend towards the valley floor and proceed to a terminal depression located at the southern end of the valley.

Records from NDWR indicate that there are approximately 57 afy of active underground water rights in the valley in the form of certificates, permits, or vested/reserved rights. Of this total, approximately 18 afy are for mining and milling purposes, while 38 afy are for stockwater purposes. The approximate committed totals by source type are listed in Table 7-5.

The principle water-right holders in Dry Lake Valley include Geyser Ranch Limited Partnership, Church of Jesus Christ-LDS, and Adams McGill Company.

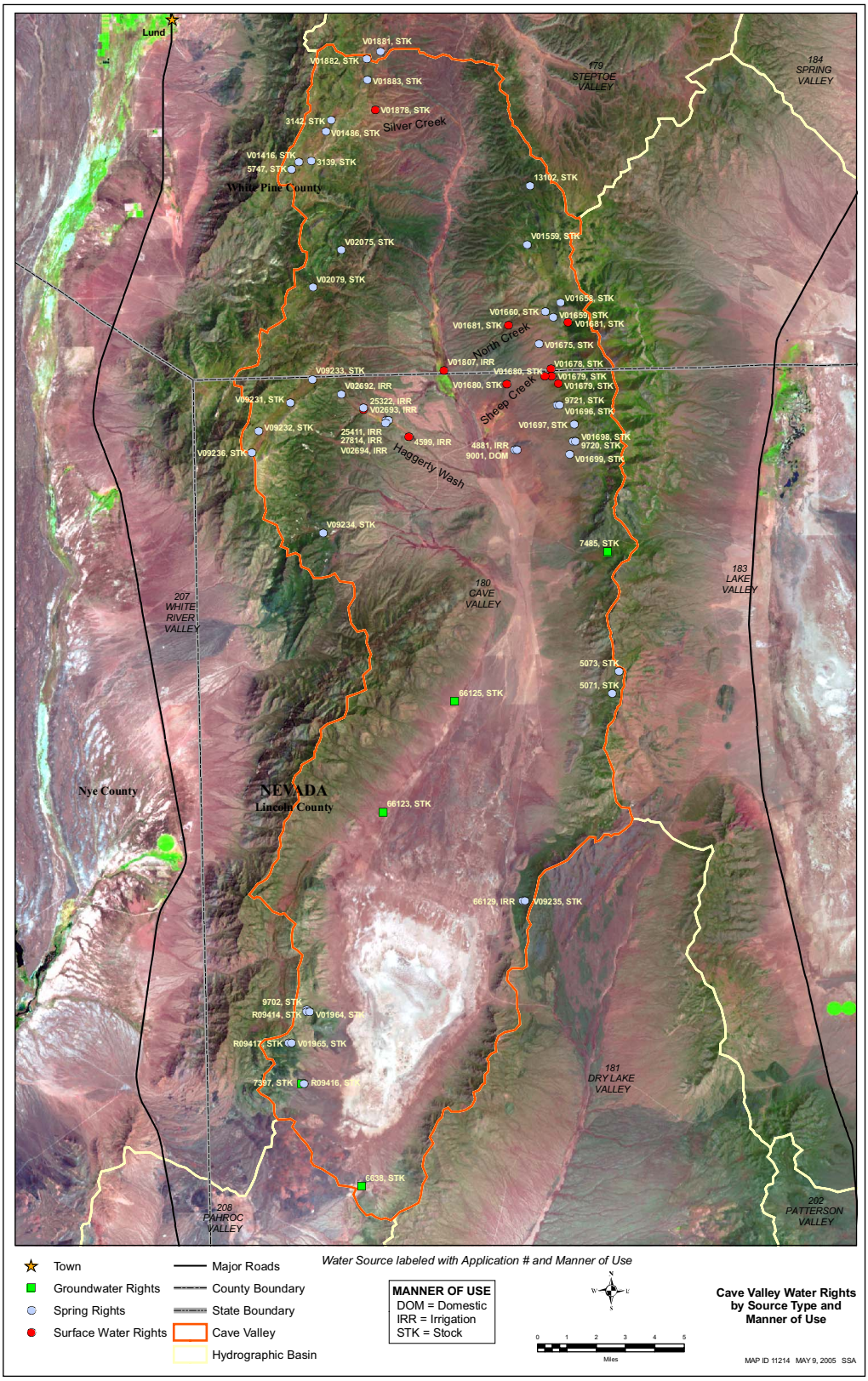

Figure 7-3
Cave Valley Water Rights

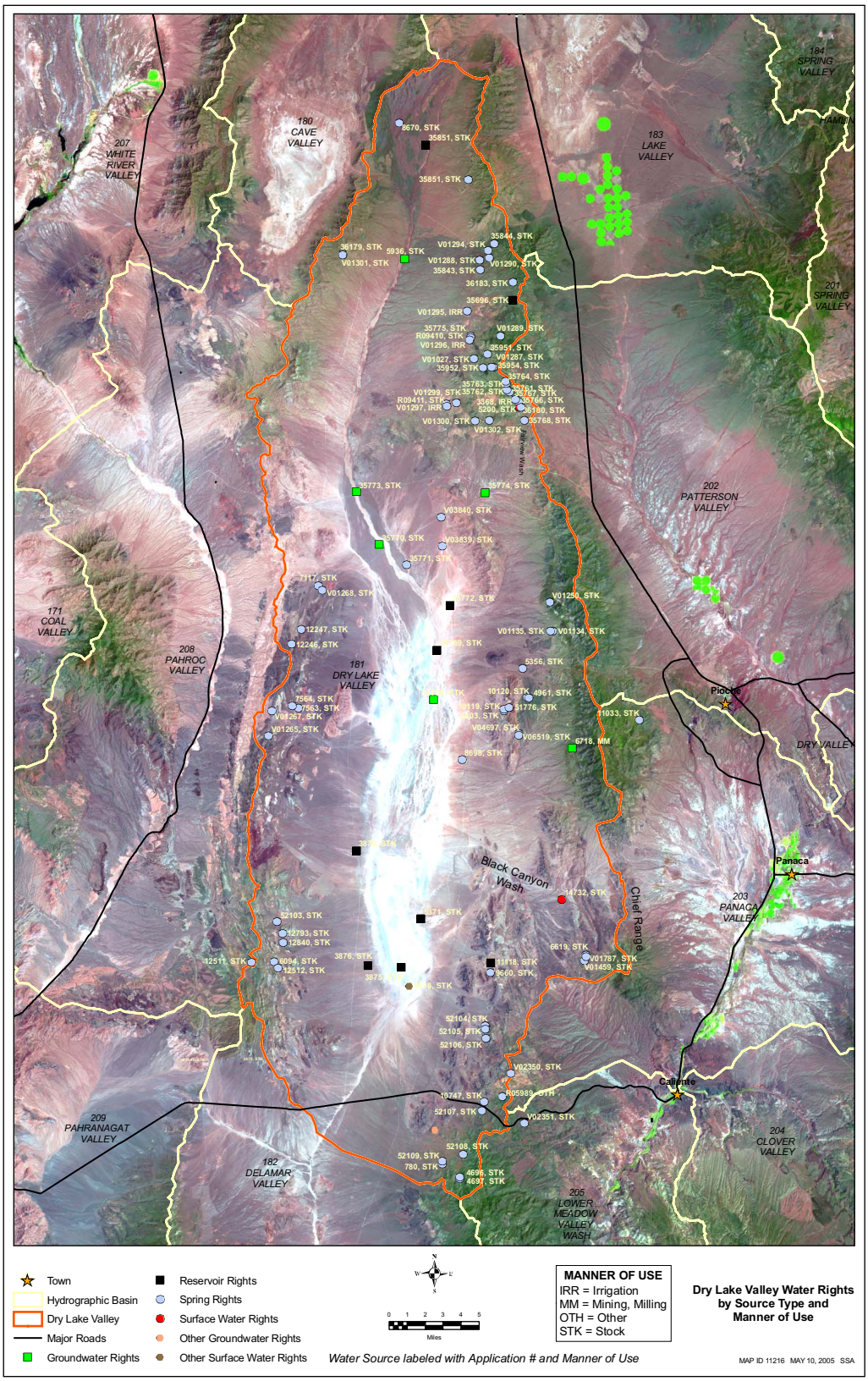

Figure 7-4
Dry Lake Valley Water Rights

Table 7-5
Preliminary Estimates of Active Groundwater Rights in Dry Lake Valley

Manner of Use	Preliminary Total (afy)
Mining and Milling	18.08
Stockwatering	38.48
Total Underground	**56.56**

Source: Hydrographic Basin Summary by Manner of Use (Included on the CD-ROM) (NDWR, 2007c)

7.4.5 Delamar Valley

Delamar Valley is located entirely within Lincoln County (Figure 7-5). Minor water resources have been developed in the basin, primarily the development of small mountain-block springs for stock water uses. The majority of the water rights in the basin are from springs. There are, however, water rights associated with ephemeral washes, including Delamar and Cedar, flowing from the ranges on the eastern edge of the basin. These creeks extend to the valley floor at the north end of the valley and proceed to a terminal depression (i.e., Delamar Lake) located at the southern end of the valley. Only one underground permit has been issued in the basin for stockwater uses.

Records from NDWR indicate that there are approximately 7 afy of active underground water rights in the valley. Table 7-6 shows that the active underground water rights in Delamar Valley are for stockwatering purposes.

Table 7-6
Preliminary Estimates of Active Groundwater Rights in Delamar Valley

Manner of Use	Preliminary Total (afy)
Stockwatering	7.24
Total Underground	**7.24**

Source: Hydrographic Basin Summary by Manner of Use (Included on the CD-ROM) (NDWR, 2007c)

The major water right owners in the valley are the Church of Jesus Christ-LDS and the Duffin family.

7.4.6 Coyote Spring Valley

Coyote Spring Valley is located within both Clark and Lincoln counties (see Figure 7-6). Until recently, only minor water resources have been developed in the basin. These water resources consist primarily of the development of small mountain-block springs for stockwater or wildlife uses. A major residential development relying on underground sources, a portion of which has been permitted, was initiated in 2006. It can be seen from Table 7-7 that according to NDWR there are

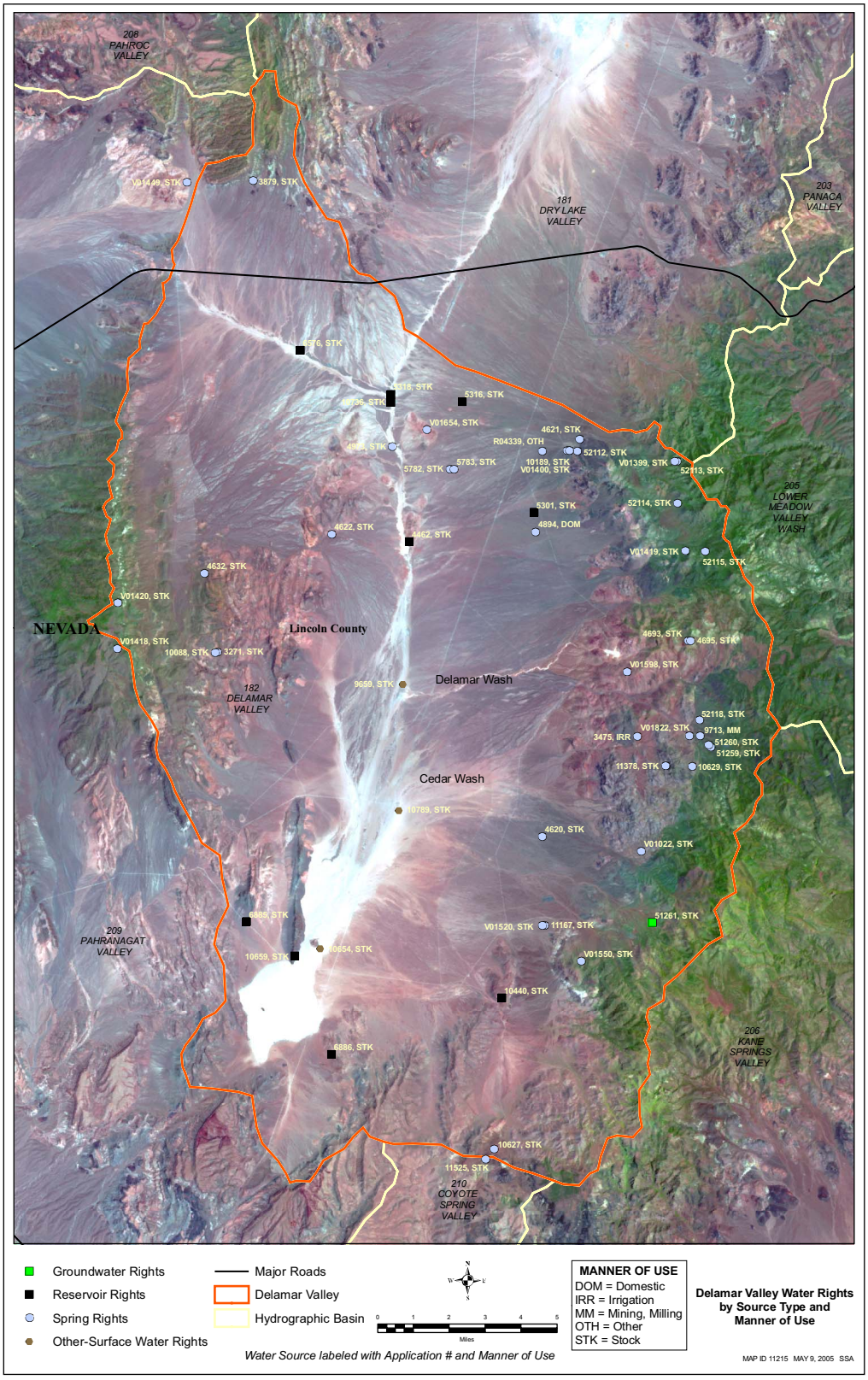

Figure 7-5
Delamar Valley Water Rights

Table 7-7
Preliminary Estimates of Active Groundwater Rights in Coyote Spring Valley

Manner of Use	Preliminary Total (afy)
Industrial	11,500
Irrigation	4.0
Mining and Milling	200
Municipal	4,600
Total Underground	**16,304**

Source: Hydrographic Basin Summary by Manner of Use (Included on the CD-ROM) (NDWR, 2007c)

approximately 16,304 afy of active underground water rights in Coyote Spring Valley. The table also shows that a majority of the water rights are associated with industrial and municipal manners of use. The major water right holders in Coyote Spring Valley are Coyote Springs Investment, LLC and SNWA.

7.5 Water Use in the Hydrologic Study Area

The breakdown of active underground water rights in the hydrologic study area by manner of use is provided on the enclosed CD-ROM in the file named "Underground_Committed_Water_Rights.pdf", and is summarized by Figure 7-7. Agricultural areas were delineated in the hydrologic study area using satellite imagery, and are also plotted on the figure. The agricultural areas were delineated based upon Normalized Difference Vegetation Index (NDVI) values calculated on June 2002 imagery. The imagery was atmospherically corrected and converted to reflectance prior to NDVI calculation. For the study area, the agricultural areas were empirically determined to have NDVI values greater than 0.72 (NDVI values range from -1.0 to +1.0). Figure 7-7 illustrates that not all hydrographic areas in the study area contain irrigated areas. The hydrographic areas with the greatest amount of agriculture include Snake Valley (12,594 acres), White River Valley (6,939 acres), Lake Valley (4,986 acres), Spring Valley (4,101 acres), and Panaca Valley (3,083 acres). As a consequence, these basins tend to have a significantly higher total water right duties than the other hydrographic areas.

Based on the active underground water rights summaries (NDWR, 2007c) (see Figure 7-7), it can also be seen that several hydrographic areas have significant duties as a result of other manners of use including municipal and industrial. For example, Steptoe Valley, Spring Valley, Lower Meadow Valley Wash, Coyote Spring Valley, Muddy River Springs Area, Lower Moapa, and Black Mountains Area all have significant duties associated with municipal and industrial manners of use.

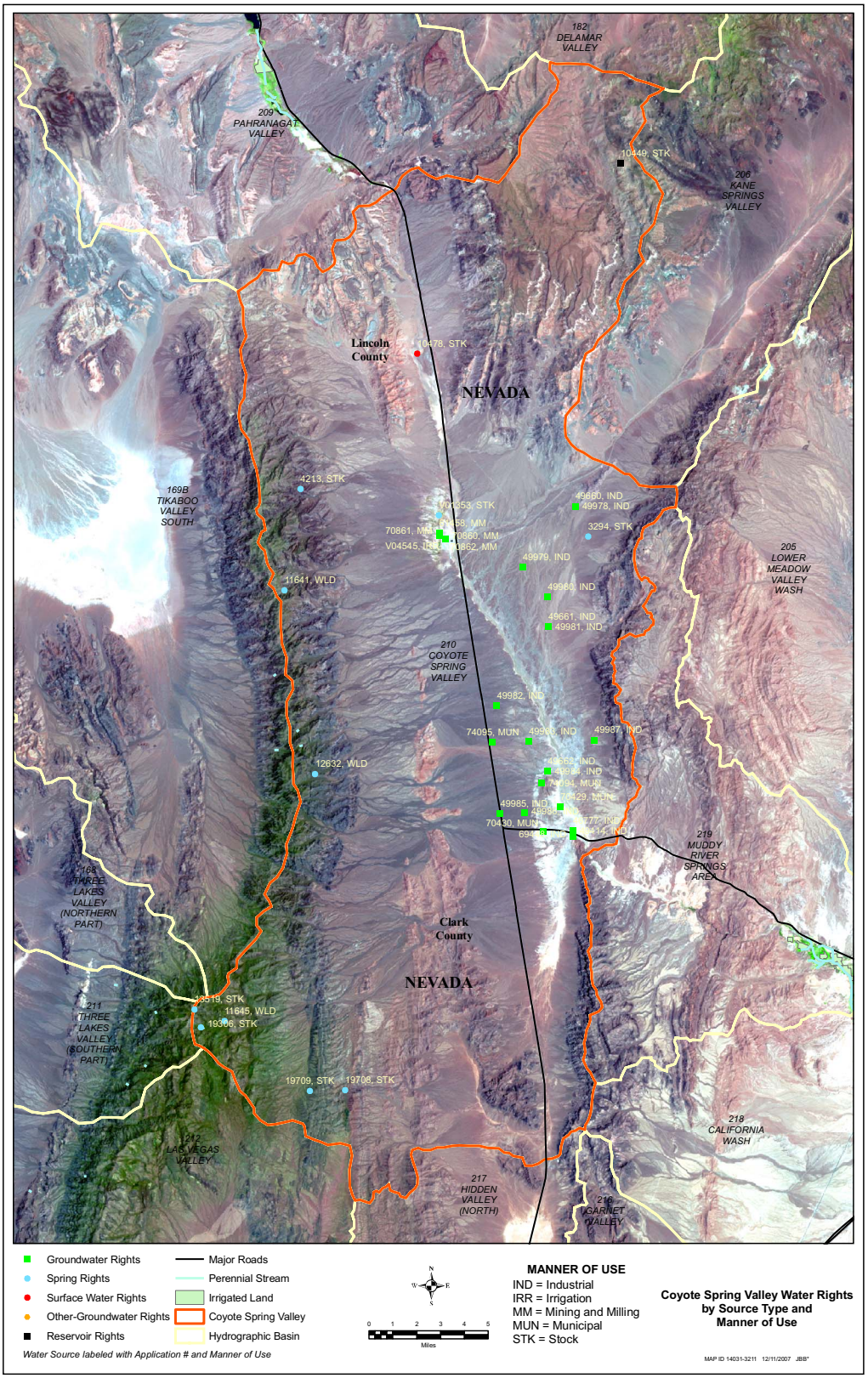

Figure 7-6
Coyote Spring Valley Water Rights

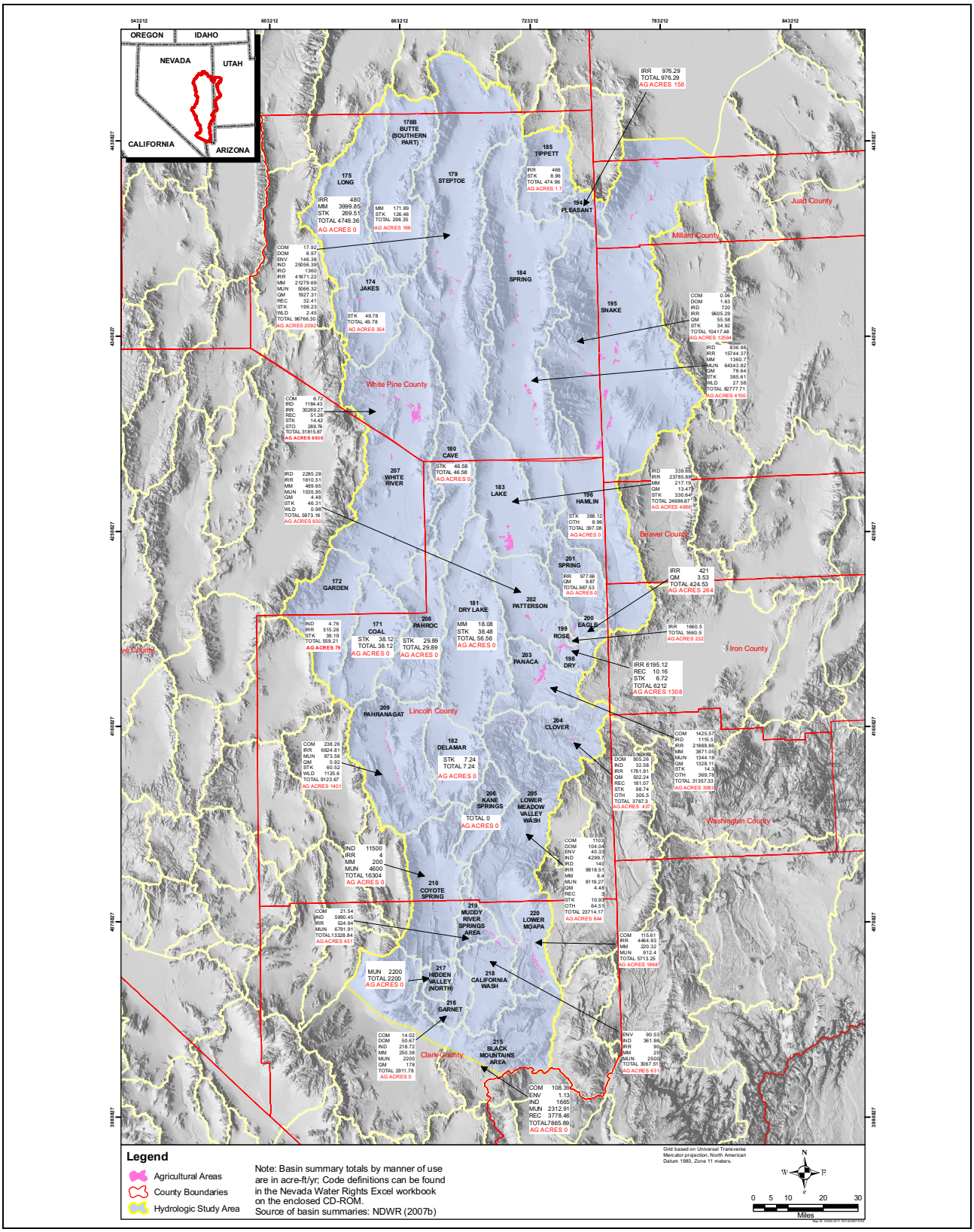

Figure 7-7
Total Active Underground Duties by Manner of Use and Agricultural Areas

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Appendix A

CD-ROM Contents

A.1.0 INTRODUCTION

This appendix has been prepared to describe the digital contents provided on the CD-ROM accompanying this report. The CD-ROM contains the four data volumes described in this report, as well as water chemistry, and water rights information. The CD-ROM contains a folder structure that reflects the headings below.

A.1.1 Read-Me File

Included on the CD-ROM is a text file version of this appendix that describes the contents of the CD-ROM.

A.1.2 Data Volumes

There are four data volumes included on the CD-ROM as Adobe Acrobat PDF's. These volumes contain a more comprehensive review of the base line information than what is provided in this summary document.

- Volume 1: Geology of White Pine and Lincoln Counties and Adjacent Areas, Nevada and Utah: The Geologic Framework of Regional Groundwater Flow Systems.
- Volume 2: Physical Settings of Selected Streams in Clark, Lincoln, and White Pine Counties Groundwater Development Project.
- Volume 3: Physical Settings of Selected Springs in Clark, Lincoln, and White Pine Counties Groundwater Development Project.
- Volume 4: Water-Level Data Compilation and Evaluation for Clark, Lincoln, and White Pine Counties Groundwater Development Project.

A.1.3 Water Chemistry

Water chemistry information has been provided as both a Microsoft Excel spreadsheet as well as a data report from DRI that has been provided in Adobe Acrobat PDF format.

A.1.3.1 Water_Chemistry.xls

The Water_Chemistry.xls file contains individual worksheets with information on site locations, major elements, trace elements, stable isotopes, and a reference list. The worksheets and fields within the worksheets are described in the following sections.

A.1.3.1.1 Site Information

This table describes the basic site information. The fields in this table are described as follows:

- Map ID - Provides a reference ID used on maps within the water quality section of this report.
- Site ID - Unique site identifier for the location.
- Station Name - Commonly, a name based upon the section, township, and range legal description of a particular site.
- Site Name - A more general name for a particular site. Commonly, the same as the Station Name.
- Site Type - Provides a description of the site as either a well, spring, or stream.
- Hydrographic Area - Identifies the specific hydrographic area (by name) where the site is located.
- HA Number - Identifies the hydrographic area by number.
- UTM N (m) - Provides the Universal Transverse Mercator (UTM) Northing of the location in meters. All the coordinates are displayed as UTM Zone 11, North American Datum of 1983.
- UTM E (m) - Provides the UTM Easting of the location in meters. All the coordinates are displayed as UTM Zone 11, North American Datum of 1983.
- Ground Elevation (ft-amsl) - This is the elevation, relative to sea level, of the land surface at the location in feet above mean sea level.
- Well Depth (ft-bgs) - Depth of the well in feet below ground surface.
- Hole Depth (ft-bgs) - The borehole depth of the drilled well.
- Well Diameter (inch) - The diameter of the well in inches.
- Top of Open Screen Interval (ft-bgs) - Top depth of the open screened interval in feet below ground surface.

- Bottom of Open Screen Interval (ft-bgs) - Bottom depth of the open screened interval in feet below ground surface.
- Depth to Water - Depth to water in feet below ground surface.
- Aquifer Material - Water-bearing rock or unconsolidated gravel, sand or silt through which groundwater is transmitted.

A.1.3.1.2 Majors

This table contains information on major element chemistry. The fields in this table are described as follows:

- Map ID - Provides a reference ID used on maps within the water quality section of this report.
- Site ID - Unique site identifier for the location.
- Site Name - A more general name for a particular site. Commonly, the same as the Station Name
- Data Source - The source of the water chemistry information. This field is linked to the references table.
- HA - Identifies the hydrographic area by number.
- Sample Collection Date - The date the sample was collected.
- Water Temperature (deg C) - The temperature of the sample in degrees celsius.
- pH - The pH of the sample in pH units.
- Conductivity (uS/cm) - The conductivity of the sample in microsiemens per centimeter.
- DO (mg/L) - The dissolved oxygen content of the sample in milligrams per liter.
- K (mg/L) - The potassium concentration of the sample in milligrams per liter.
- Mg (mg/L) - The magnesium concentration of the sample in milligrams per liter.
- Na (mg/L) - The sodium concentration of the sample in milligrams per liter.
- Ca (mg/L) - The calcium concentration of the sample in milligrams per liter.
- SO4 (mg/L) - The sulfate concentration of the sample in milligrams per liter.
- Cl (mg/L) - The chloride concentration of the sample in milligrams per liter.

- Br (ug/L) - The bromide concentration of the sample in micrograms per liter.
- F (mg/L) - The fluoride concentration of the sample in milligrams per liter.
- PO4 (mg/L as P) - The phosphate concentration of the sample in milligrams per liter as phosphorus.
- P (mg/L as P) - The phosphorous concentration of the sample in milligrams per liter as phosphorous.
- NO3 (mg/L as N) - The nitrate concentration of the sample in milligrams per liter as nitrogen.
- NO2 (mg/L as N) - The nitrite concentration of the sample in milligrams per liter as nitrogen.
- NO3 + NO2 (mg/L as N) - The sum of nitrate and nitrite concentration of the sample in milligrams per liter as nitrogen.
- HCO3 field (mg/L as HCO3) - Field-determined bicarbonate concentration of the sample in milligrams per liter as bicarbonate.
- CO3 field (mg/L as CO3) - Field-determined carbonate concentration of the sample in milligrams per liter as carbonate.
- HCO3 Lab (mg/L as HCO3) - Laboratory-determined bicarbonate concentration of the sample in milligrams per liter as bicarbonate.
- CO3 Lab (mg/L as CO3) - Laboratory-determined carbonate concentration of the sample in milligrams per liter as carbonate.
- SiO2 (mg/L) - The silica concentration of the sample in milligrams per liter.
- Hardness (mg/L as CaCO3) - The measure of excessive amount of calcium and magnesium present in the sample in milligrams per liter.
- TDS (mg/L) - The total dissolved solids in the sample in milligrams per liter.
- Cation/Anion Balance (%) - Reaction error expressed as a percentage of the total ion concentration.
- Charge Balance Field (%) - Field-determined charge balance.
- Charge Balance Lab (%) - Laboratory-determined charge balance.

A.1.3.1.3 Trace Elements

This table contains information on trace element chemistry. The fields in this table are described as follows:

- Map ID - Provides a reference ID used on maps within the water quality section of this report.
- Site ID - Unique site identifier for the location.
- Site Name - Provides the name of the site and is linked to the Site ID field in the Site Information table.
- Data Source - The source of the water chemistry information. This field is linked to the references table.
- HA - Identifies the hydrographic area by number.
- Sample Collection Date - The date the sample was collected.
- Ag (ug/L) - The silver concentration of the sample in micrograms per liter.
- Al (ug/L) - The aluminum concentration of the sample in micrograms per liter.
- As (ug/L) - The arsenic concentration of the sample in micrograms per liter.
- B (ug/L) - The boron concentration of the sample in micrograms per liter.
- Ba (ug/L) - The barium concentration of the sample in micrograms per liter.
- Be (ug/L) - The beryllium concentration of the sample in micrograms per liter.
- Bi (ug/L) - The bismuth concentration of the sample in micrograms per liter.
- Cd (ug/L) - The cadmium concentration of the sample in micrograms per liter.
- Co (ug/L) - The cobalt concentration of the sample in micrograms per liter.
- Cr (ug/L) - The chromium concentration of the sample in micrograms per liter
- Cu (ug/L) - The copper concentration of the sample in micrograms per liter.
- Fe (ug/L) - The iron concentration of the sample in micrograms per liter.
- Hg (ug/L) - The mercury concentration of the sample in micrograms per liter.
- Li (ug/L) - The lithium concentration of the sample in micrograms per liter.

- Mn (ug/L) - The manganese concentration of the sample in micrograms per liter.
- Mo (ug/L) - The molybdenum concentration of the sample in micrograms per liter.
- Ni (ug/L) - The nickel concentration of the sample in micrograms per liter.
- Pb (ug/L) - The lead concentration of the sample in micrograms per liter.
- Sb (ug/L) - The antimony concentration of the sample in micrograms per liter.
- Se (ug/L) - The selenium concentration of the sample in micrograms per liter.
- Sr (ug/L) - The strontium concentration of the sample in micrograms per liter.
- Tl (ug/L) - The thallium concentration of the sample in micrograms per liter.
- U (ug/L) - The uranium concentration of the sample in micrograms per liter.
- V (ug/L) - The vanadium concentration of the sample in micrograms per liter.
- Zn (ug/L) - The zinc concentration of the sample in micrograms per liter.

A.1.3.1.4 Stable Isotopes

This table contains information on stable isotope chemistry. The fields in this table are described as follows:

- Map ID - Provides a reference ID used on maps within the water quality section of this report.
- Site ID - Unique site identifier for the location.
- Site Name -A more general name for a particular site.
- Data Source - The source of the water chemistry information. This field is linked to the references table.
- HA - Identifies the hydrographic area by number.
- Sample Collection Date - The date the sample was collected.
- $\delta^{18}O$ (per mil) - The $\delta^{18}O$ value of the sample expressed in parts per mil.
- $\delta^{2}H$ (per mil) - The $\delta^{2}H$ value of the sample expressed in parts per mil.

A.1.3.2 DRI Data Report

An Adobe Acrobat PDF of a DRI letter report titled "Annual Data Report for Geochemical, Isotopic, and Biological Monitoring for East Central and Southeastern Nevada" has been included on the CD-ROM.

A.1.4 Water Rights

The water rights folder contains a folder of maps in Adobe Acrobat PDF format as well as folders with information on water rights in both Nevada and Utah.

A.1.4.1 Figures

The figures directory contains the following maps.

- 1_Hydrologic_Study_Area.pdf
- 2_WtrRtsPtDiversion_Coyote_Spring_Valley.pdf
- 3_WtrRtsPtDiversion_Delamar_Valley.pdf
- 4_WtrRtsPtDiversion_DryLake_Valley.pdf
- 5_WtrRtsPtDiversion_Cave_Valley.pdf
- 6_WtrRtsPtDiversion_Spring_Valley184.pdf
- 7_WtrRtsPtDiversion_Snake_Valley.pdf
- 8_Active_Underground_Rights_Summary.pdf

A.1.4.2 Water_Rights_Information

This folder contains information regarding water rights for both Nevada and Utah.

A.1.4.2.1 Nevada_Water_Rights

This folder contains two files that are described as follows:

- Underground_Committed_Water_Rights.pdf - Is an Adobe Acrobat PDF of the Hydrographic Basin Summaries as downloaded from the NDWR web site.

- NV_Water_Rights_20070307_20071218.xls - Is a Microsoft Excel spreadsheet of the water rights abstracts as downloaded from the NDWR web site. The field names and codes used in the spreadsheet are provided within additional worksheets within the file.

A.1.4.2.2 Utah_Water_Rights

This folder contains two files that are described as follows:

- Utah_Water_Rights_20070313.xls - Is a Microsoft Excel spreadsheet of the water rights information for portions of Snake, Hamlin, and Pleasant valleys. The field names and codes used in the spreadsheet are provided within additional worksheets within the file.

- undergrounddiversion_20071204.xls - Is a Microsoft Excel spreadsheet of the preliminary committed underground rights for the Utah portion of Snake Valley.