ANDY ZDON &
ASSOCIATES, INC.

2014 STATE OF THE BASIN REPORT
AMARGOSA RIVER BASIN,
Inyo and San Bernardino Counties, California
& Nye County, Nevada
June 28, 2014

Prepared For:
The Nature Conservancy | 1450 Arroyo View Drive | Pasadena, California 91103

The Nature Conservancy
Protecting nature. Preserving life.™

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EXECUTIVE SUMMARY

In 2009, the Amargosa River between Shoshone and the terminus of the Amargosa Canyon received Wild and Scenic status through an act of Congress. As a result, the BLM is charged with developing a management plan for the Wild and Scenic portion of the River. It is essential that hydrogeologic characterization of the California portion of the basin take place in order for that management plan, and its associated management recommendations, to have a firm basis, and to assure that monitoring is conducted in a meaningful way to identify potential impacts to the river and its feeder springs before potential irreversible impacts from future groundwater development occur.

This 2014 State of the Basin Report (SOBR) was prepared by Andy Zdon & Associates, Inc. (AZI) on behalf of The Nature Conservancy (TNC) as part of a much larger effort that is conducted cooperatively between the TNC, U.S. Bureau of Land Management (BLM), U.S. Geological Survey (USGS), Amargosa Conservancy (AC), and Nye and Inyo Counties. It provides an update of work conducted since the last State of the Basin Report produced in early 2012. The goal of the overall project is to improve the understanding of the water that sustains the Amargosa River and the desert ecosystems that flourish along the river and its adjoining springs, and to provide the knowledge necessary to identify and avert impacts to those water sources. The information herein also provides the basis for recommendations provided for inclusion into a management plan for the Amargosa Wild & Scenic River (WSR). The purpose of the work conducted as part of the current scope is to provide important new information and conduct continuing baseline spring and groundwater-level monitoring, and prepare this SOBR.

In addition to the WSR, the area contains many small springs that provide important watering sources for wildlife. These types of watering holes frequently get overlooked in regional hydrologic investigations because they represent such a small portion of the overall water budget. This is unfortunate as these sensitive receptors are critically important resources for vegetation and resident and migratory wildlife. Identification and monitoring of these watering holes is important in order for future land and water resource management in the area to have a firm ecological basis.

The principal surface water body in the region, the Amargosa River, is an intermittent river with headwaters issuing from springs northeast of Beatty, Nevada, and extending approximately 180 miles to the river's terminus at the playa in Death Valley. Except for portions of the river in the Amargosa Canyon area in California, and near Beatty, Nevada, the Amargosa River typically flows only after periodic storms. In those areas where the river is usually dry, the flow of water, where present, is in the subsurface. In areas where surface flow is more constant, or perennial, the flow is the result of groundwater underflow reaching bedrock or other relatively impermeable constrictions and being driven to the surface. This results in a flow regime highly sensitive to groundwater level changes. Given this condition, it appears that a considerable portion of the underflow moving through the Middle Amargosa system can be accounted for by the flow observed at the surface, for example, in the Amargosa River canyon plus spring discharge and any pumping. This does not result in a substantial amount of underflow, and further highlights the sensitive nature of the river system.

The principal tasks during this recent phase of this project were isotope sampling of selected springs in the Tecopa area, and the continued monitoring of spring flow, river flow and groundwater levels in the Middle Amargosa River Basin, an area encompassing nearly 1,000 square miles. Among the results of the current geochemical work were indications that spring sources within the study area are complex and from multiple sources. Groundwater from Ash Meadows, along with recharge from the Spring Mountains and the Kingston Range all contribute to the groundwater and river system. Flow paths likely include one or more of the following:

- Spring Mountain recharge moving toward Ash Meadows through carbonate rocks and basin fill, then southward toward the Shoshone-Tecopa area;
- Via carbonate rocks at the north end of the Nopah Range into Chicago Valley then toward the Amargosa Valley; and ,
- From Pahrump Valley via the shallow divide into California Valley then toward the Amargosa River.

Among the findings are that the source of heat in the local thermal springs is likely deep circulation of water along deep-seated faults as opposed to the presence of a shallow heat source (e.g. magmatic). The heat associated with this deep groundwater movement likely effects groundwater chemistry as could the surficial deposits from which the springs discharge.

This SOBR closes with technical recommendations for:

- Monitoring (hydrologic, visual, and monitoring current and potential water use):
- Future investigative work (including new monitoring wells, geophysics and additional geochemical studies);
- The development of a management tool (i.e. groundwater flow model); and,
- Recommendations for an adaptive approach to management of the Amargosa WSR that is flexible enough to evolve with our ever-growing knowledge of the Amargosa River and the groundwater system that feeds it.

1.0 INTRODUCTION

This State of the Basin Report (SOBR) was prepared by Andy Zdon & Associates, Inc. (AZI) on behalf of The Nature Conservancy (TNC) as part of a much larger effort that is being conducted between TNC, Amargosa Conservancy (AC), U.S. Bureau of Land Management (BLM), the U.S. Geological Survey (USGS) and Nye and Inyo Counties. The goals of the overall project are to improve the understanding of the water that sustains the Amargosa River and the desert ecosystems that flourish along the river, and its adjoining springs, and to provide the knowledge necessary to identify and avert impacts to those water sources. The purpose of the work conducted as part of the current scope is to improve our understanding of the groundwater flow paths to the Amargosa River and surrounding springs, and to continue to develop baseline spring, river flow, and groundwater-level monitoring, and to prepare a SOBR.

In 2009, the Amargosa River between Shoshone and the terminus of the Amargosa Canyon received Wild and Scenic status through an act of Congress. As a result, the BLM is charged with developing a management plan for the Wild and Scenic portion of the River. It is essential that hydrogeologic characterization of the California portion of the basin take place in order for that management plan, and its associated management recommendations, to have firm basis, and to assure that monitoring is conducted in a meaningful way to identify potential impacts to the river and its feeder springs before potential irreversible impacts from future groundwater development occur.

Many of the springs that feed the Amargosa River are relatively small springs that individually are not significant components to the overall area water budget. Additionally, other small springs and watering holes are present away from the Amargosa River. All of these springs, regardless of size and/or location, are important ecological resources. This SOBR provides up-to-date hydrologic information and a current, real-time snapshot of water resource conditions in the Middle Amargosa Basin area. As mentioned above, springs and watering holes such as those identified in this SOBR are frequently overlooked in hydrologic investigations since their discharges are frequently inconsequential to the overall water budget of the area being studied. This is unfortunate as these sensitive receptors are critically important resources for vegetation, and wildlife (both resident and migratory). It is essential that baseline hydrologic characterization of the region take place in order for future land and water resource management to have a firm basis.

This project is an important starting point into the investigation of the hydrogeology of the Amargosa Basin south of the Nevada state line. Prior to the initial reconnaissance work conducted by the Source Group, Inc. (SGI) during 2010-2011 (SGI, 2011), regional hydrogeologic investigations in the California portion of the basin have been virtually non-existent. The discussions regarding the California portion of the basin therefore have been more conceptual in nature than those regarding the Nevada portion of the basin.

The objectives of the current project described in this report were to:

- Conduct new groundwater geochemical analyses to evaluate potential groundwater flow paths;
- Enhance previous reconnaissance-level information on the springs of the southern half of the Amargosa Basin, generally between Death Valley Junction and Saratoga Spring;
- Continue to develop an understanding of Amargosa River conditions in the southern half of the basin;
- Describe the results of groundwater-level monitoring and evaluate potential future monitoring locations; and,
- Continue to enhance the conceptual model of the Amargosa Basin with an emphasis on the southern half of the basin.

1.1 Current Scope of Work

The current scope of work included the following tasks:

- Task 1 – Comprehensive monitoring of springs, groundwater levels and river flow;
- Task 2 – Sampling and analysis of water from selected springs and one well in the study area; and,
- Task 3 – Data analysis and preparation of this SOBR.

1.1.1 Discharge, Groundwater Level, and Seepage Run Monitoring

Flow discharge and groundwater elevation measurements have been collected on a periodic basis from a select group of springs and wells within the southern Amargosa River area since November 2010 as part of studies conducted by the AC and TNC. The current scope included seepage run monitoring on the stretch of the Amargosa River from Tecopa to the Dumont Dunes area and consisted of five distinct monitoring locations (including the two USGS gauges, and three manual monitoring points). Basic water quality data were also collected at all discharge, elevation and seepage run monitoring points.

1.1.2 Water Chemistry Data Collection

Water samples from four springs, and one well were collected and analyzed for a specific suite of constituents. Noble gas analyses were conducted on water samples from Thom Spring, Tecopa Hot Springs, Borehole Spring, Wild Bath Spring and Monitoring Well ARHS-01. Noble gas laboratory analysis was conducted by the University of Utah. Water samples were collected from ARHS-01, Twelvemile Spring and Dodge City Spring for stable isotope analyses. Stable isotope analyses were conducted by Isotech Laboratories, Inc. A water sample from Dodge City Spring was sampled for general minerals and metals analysis, and was analyzed by Silver State Analytical, Inc., in Las Vegas, Nevada. M.L. Davisson & Associates was retained to provide high-level expert analysis and interpretation.

1.1.3 Data Assessment and Reporting

This task included the time required to analyze the data obtained from the springs and wells, along with the newly collected data from AZI and other sources to be compiled in this updated SOBR. This included updating and expanding the existing "Catalog of Springs" provided in Appendix A.

1.2 Location and Physiographic Setting

The Amargosa River Basin covers an area of 3,124 square miles in east-central California and west-central Nevada (Figure 1-1). The Amargosa River Basin can be subdivided into three basin areas:

- Northern Amargosa Groundwater Basin (Nevada portion of the Basin also referred to as the Amargosa Desert Hydrographic Basin by the Nevada Department of Water Resources);
- Middle Amargosa Valley Groundwater Basin (California); and
- Death Valley Groundwater Basin (California –Nevada).

The Northern Amargosa Valley Groundwater Basin is comprised of the Amargosa River Valley from the river's headwaters northwest of Beatty, Nevada, to the California-Nevada state line. Elevations in this portion of the Amargosa River Basin range from 6,317 feet above mean sea level (ft msl) at Bare Mountain south of Beatty and east of the Amargosa River, to about 2,300 ft msl at the California-Nevada state line near Death Valley Junction, California. The basin is bounded by consolidated rocks of the Yucca Mountain/Pahute Mesa area to the northeast, Bare Mountain on the east, and the Funeral Range to the west. The Northern Amargosa River Basin as defined covers 896 square miles.

The Middle Amargosa Valley Groundwater Basin (Groundwater Basin #6-20 as designated by the California Department of Water Resources) is comprised of the Amargosa River Valley along with Chicago Valley and parts of Greenwater Valley within Inyo and San Bernardino Counties, California. The California-Nevada state line is considered the northern boundary of the Middle Amargosa Valley Groundwater Basin. The elevation of the valley floor generally ranges from about 400 ft msl near Salt Creek in the southern portion of the valley to about 2,300 ft msl at the California-Nevada state line near Death Valley Junction. The basin is bounded by consolidated rocks of the Resting Springs and Nopah Ranges on the east, the Dumont Hills on the south, and the Greenwater Range and Ibex, Black, and Funeral Mountains (collectively known as the Amargosa Range) on the west. The surrounding mountains range in elevation up to 7,335 ft msl at Kingston Peak (within San Bernardino County along the southeast edge of the Basin) and up to 6,725 ft msl at Pyramid Peak, the high point of the Funeral Range to the west. The Middle Amargosa River Basin covers an area of 609 square miles.

The Death Valley Groundwater Basin (Groundwater Basin #6-18 as designated by the California Department of Water Resources) is comprised of the Amargosa River Valley from the Salt Creek area to the sink at Badwater in Death Valley, and northward to the northern physical terminus of Death Valley in Nevada (Oriental Wash Area of the Death Valley Basin as designated by the Nevada State Engineer). Elevations in this portion of the Amargosa River Basin range from -282 ft msl at Badwater, to 11,049 ft msl at Telescope Peak, the highpoint of the Panamint Range along the west side of Death Valley. The combined area of the California and Nevada portions of this lower part of the Amargosa River basin is 1,622 square miles.

1.3 Climate

The climate of the area is arid with low precipitation and high mean annual temperatures and evaporation rates. Summer temperatures can exceed 120 degrees Fahrenheit while winter temperatures can fall below freezing. The average annual precipitation at Shoshone, California is 4.81 inches based on a record from 1972 through 2011 (Western Regional Climate Center, 2014). The average maximum high temperature is 83.2 degrees Fahrenheit and the average minimum is 58.8 degrees Fahrenheit. Mean monthly high temperatures at Shoshone range from 58.8 degrees Fahrenheit in December to 108.7 degrees Fahrenheit in July. Mean monthly low temperatures in Shoshone range from 38.0 degrees Fahrenheit in December to 78.3 degrees Fahrenheit in July.

1.4 Land Use

The principal land uses (not including open space and wild lands) in the project area are agricultural, recreational, wildlife, livestock and domestic/municipal uses. With increasing solar development, industrial use is expected to increase in the future. Agricultural and domestic water is generally supplied with groundwater from private wells. Water for the town of Shoshone, California is supplied by Shoshone Spring. The town of Beatty, Nevada derives its water from groundwater wells. However, some residents obtain their water solely from spring water. Sewage is generally treated by individual septic systems with the exception of at the communities of Beatty, Nevada, and Shoshone and Tecopa (both in California) where sewage systems are present serving some areas. Agricultural land use is primarily crops such as alfalfa (Nevada) and to a much lesser extent dates (California). Recreational uses include the use of spring water at the hot springs in Tecopa, California, and the hot springs northeast of Beatty, Nevada along U.S. Highway 95.

1.4.1 Water Rights

Water rights summaries for California and Nevada are provided in Appendices B and C, respectively. Additional discussion regarding permitted rights, water usage, and estimated recharge for the Amargosa Basin are provided in Section 3.0. In California, there has been no change in the status of water rights in the Middle Amargosa Basin since 2011.

Changes in Nevada water rights for the Amargosa Desert (Nevada Basin #230) during the past three years (since 2011) were a net decrease of approximately 570 acre-feet per year (afy) in annual duty (underground). However, of significance was a net increase of approximately 2,050 afy in permitted and certified groundwater rights and associated decrease in rights with a “ready for action” status (the later resulting in the net loss of annual duty), indicative of further development of those groundwater rights.

A ruling in 2012 (6169) by the Nevada State Engineer included the denial of two applications filed by Rockview Dairies, Inc. Those two applications were to change the manner and place of use of irrigation water previously applied for under applications filed in 2003 and 2006. The denial of those two applications was on the grounds that the water right filings that formed the basis of the changes were no longer in good standing and could not be used to support the applications.

A second ruling during 2012 (6172) by the Nevada State Engineer included the denial of an application by LCF Horticulture, LLC to change the point of diversion and manner of use previously appropriated for commercial purposes. Over time, land use had changed from commercial to residential and change applications transferred water to the residential land owners from the LCF Horticulture permit. Therefore, the Nevada State Engineer denied the application because the application requested a change of an existing groundwater permit than no longer existed. Copies of the two rulings are provided in Appendix C.

Water rights information for Pahrump Valley, Nevada (Groundwater Basin #162) are also provided in Appendix C.

1.4.1.1 Devil's Hole

In 2008, the Nevada State Engineer issued Order 1197 concerning applications to appropriate additional groundwater from the Devil's Hole area. This order stated that:

"…with the following exceptions, any applications to appropriate additional underground water and any application to change the point of diversion of an existing ground-water right to a point of diversion closer to Devil's Hole, described as being within a 25 mile radius from Devil's Hole within the Amargosa Desert Hydrographic Basin, will be denied:

- *Any application within the described area that seeks to change and existing point of diversion closer to Devil's Hole but remains within its existing place of use and is no more than ½ mile from its original point of diversion;*
- *Those applications filed which seek to appropriate 2.0 acre-feet per year or less, may be considered and shall be processed subject to Nevada Revised Statutes (NRS) 533 and 534;*
- *For projects that require changes of multiple existing rights, the State Engineer may compare the net impact to Devil's Hole of the proposed changes to the impacts to Devil's Hole of the base rights. If the net impact of the proposed changes is the same or less than its base right impacts, as determined by the State Engineer, such change applications may be considered and shall be processed subject to NRS 533 and 534. In no such case shall new points of diversion be allowed within ten (10) miles of Devil's Hole.*
- *Those applications for environmental permits filed pursuant to NRS 533.437 and 533.4377, inclusive; and,*
- *Those applications filed pursuant to NRS 533.371.*

For point of reference, NRS 533 and 534 are the chapters of Nevada water law that pertain to adjudication of vested water rights/appropriation of public water and underground water and wells, respectively.

Environmental permits referenced in NRS 533.437 and 533.4377 are temporary permits for wells used for avoidance of groundwater contamination (e.g. remediation wells). A copy of this ruling is also provided in Appendix C.

1.5 Groundwater Management

Groundwater quality issues in the California portion of the basin are regulated by the California State Water Resources Control Board – Lahontan Region (CRWQCB-Lahontan). Within Inyo County, California portion of the Amargosa River Basin, the county conducts water-related activities such as issuing well permits through the Inyo County Environmental Health Department, and water-quality functions such as monitoring groundwater conditions and quality at the Tecopa and Shoshone landfills through the Inyo County Waste Management Department. Other community planning and environmental review activities are conducted through the Inyo County Planning Department. Currently, there is little to no development in the San Bernardino County, California portion of the basin, however similar functions within San Bernardino County's departments exist should development occur in the future.

In Nevada, the Nevada Division of Water Resources (NDWR) manages Nevada's water resources through the appropriation and reallocation of the public waters. In addition, the NDWR is responsible for quantifying existing water rights; monitoring water use; distributing water in accordance with court decrees; licensing and regulating well drillers and water rights surveyors; reviewing flood control projects; monitoring water resource data and records; and providing technical assistance to the public and governmental agencies. The Nevada State Engineer determines the limit and extent of water rights and establishes conditions regarding those rights. The Nevada Department of Environmental Protection manages Nevada's storm water pollution program. Within Nye County, Nevada, the Nye County Water District was established in 2007 to develop sustainable water development planning, characterize the groundwater resource, and to evaluate and mitigate impacts caused by groundwater use. Nye County's Water Resources Plan (Buqo, 2004) provides guidance for ensuring adequate supplies of water remain available in Nye County for the benefit of the county's residents and environment.

Death Valley National Park oversees water-related issues within the Death Valley National Park inclusive of the Devil's Hole section of the park in Nevada. Currently, Death Valley National Park staff monitor selected springs throughout the park, with an emphasis on Saratoga Spring at the south end of Death Valley adjacent to the Amargosa River. Likewise, the BLM oversees water-related issues on BLM lands. As part of those responsibilities, the BLM is also charged with developing a management plan for the wild and scenic portion of the Amargosa River.

1.6 Sources of Information

Information gathered by AZI and used in this report were from the archives and reports by the of the USGS, NDWR, CRWQCB-Lahontan, Nye County Water District, Nevada Bureau of Mines and

Geology, AC, Death Valley National Park, BLM, California Department of Water Resources, and groundwater level and spring data collected by AZI and within AZI's water resources library.

1.6.1 Death Valley Regional Flow System Report

A key foundational document for this effort is the report "Death Valley Regional Ground-Water Flow System, Nevada and California – Hydrogeologic Framework and Transient Ground-Water Flow Model" (Belcher, 2004). This comprehensive volume describes the conceptual model, and numerical modeling of, the Amargosa Groundwater Flow System in its entirety, however with a focus on the Northern Amargosa River Basin. The description of the conceptual model for the Amargosa Basin in this report is largely distilled from this extensive report. The USGS conducted the modeling and prepared the associated report bringing together data collected over decades for the U.S. Department of Energy programs at the Nevada Test Site and at Yucca Mountain. The purposes of the USGS work described in the report were to:

- Provide boundary conditions for site scale models at the Yucca Mountain and Underground Test Area Corrective Action Units on the Nevada Test Site;
- Evaluate the impacts of changes in groundwater flux;
- Provide a decision-making tool with respect to groundwater for defense and economic development on the Nevada Test Site;
- Evaluate potential effects to the Nevada Test Site due to off-site groundwater development;
- Provide a framework for identifying an effective groundwater quality monitoring network; and
- Facilitate the development of a cooperative, regional Death Valley groundwater management district.

1.6.2 Hydrologic Activities – Amargosa River Hydrologic Survey

A considerable amount of hydrologic work has been conducted since the initial baseline hydrologic investigations (SGI, 2011 and 2012) that were sponsored by the AC. That work included geochemical analysis (anions, cations, and metals along with stable and unstable (uranium and strontium) isotopes on two wells, the Amargosa River, and 16 springs. Since that time the following tasks have been completed:

- Periodic river gaging at several locations along the Amargosa River;
- Periodic spring flow and groundwater level measurements at springs and wells throughout the Middle Amargosa River Basin;
- Installation of four shallow monitoring wells 1) north of Shoshone along the Amargosa River, 2) along Willow Creek, 3) at Twelvemile Spring, and 4) at "Married Man's Camp" between Willow Creek and California Valley. This work included sampling and analyzing waters from those wells

and outfitting those wells with transducer/data logger installations and periodic groundwater level data downloading (JWI, 2012 and JWI, 2013a);

- Refined geologic mapping being conducted by the USGS (in progress);
- Geophysical surveys by the USGS at selected locations throughout the Middle Amargosa Basin area (in progress);
- An in depth canvassing of the flow in the Amargosa River by the USGS to evaluate gaining and losing character of the River (conducted in February, 2014);
- Initiation of evapotranspiration studies along the Amargosa River in the Shoshone – Tecopa area (USGS – in progress).

In addition, additional sampling and analysis was conducted to evaluate a source of water for potable water and fire suppression for the Tecopa – Tecopa Hot Springs community (JWI, 2013c).

2.0 CURRENT FIELD AND LABORATORY METHODS

The field activities performed during this project were designed following the previous reconnaissance and cataloging of all of the known springs and wells in and beyond the Middle Amargosa River Basin, an area encompassing nearly 1,000 square miles. The results of the initial reconnaissance published in the 2011 State of the Basin Report (SGI, 2011), were used as the foundation for the design and implementation of more detailed hydrogeologic investigations. Additionally, methodologies for describing spring conditions developed for other areas (Sada & Pohlmann, 2002, and Sky Island Alliance, 2012) formed the basis of field descriptions of springs. The field work for this more detailed hydrogeologic investigation was conducted during May 2014 and included the collection of water chemistry samples at four springs and one well, flow volumes, water levels, and ongoing field water quality monitoring for a select group of springs, wells and points along the Amargosa River. The results from this investigation as described in the following sections will serve to assist in the identification of regional and local groundwater flow paths, and enable the development of an efficient, focused and sustainable groundwater monitoring effort that will be protective of the environmental and cultural resources of the basin. The locations of all points monitored or reconnoitered during this work are shown on Figures 2-1 through 2-3.

2.1 Spring Discharge, Groundwater Level and River Surface Flow Monitoring

During May 2014, spring flow discharge and groundwater elevation data were gathered from springs and wells in the Middle Amargosa River Basin. This work supplements similar data collection efforts that have occurred as part of efforts sponsored by the AC and TNC since 2010. Seepage run monitoring (i.e. the measurement of flow at several distinct locations) was conducted by AZI along the stretch of river from Tecopa to below the Dumont Dunes area where the River crosses California Route 127. The seepage runs were conducted at five distinct monitoring locations along the Amargosa River, including two USGS gauge locations and three manual monitoring points as measured during previous monitoring events. Additional monitoring included following the movement (progression and regression) of the leading edge of the River near the Dumont Dunes area and seepage run monitoring of Willow Creek just upstream of the confluence with the Amargosa River.

The three goals of the ongoing discharge, water level and seepage run monitoring are as follows:

- To quantify spring discharge rates, groundwater elevations, and river surface flow which will provide estimates of seasonal variations;
- To establish a record of discharge from the springs and wells selected for monitoring, including seasonal trend information in order to provide a more robust baseline for future comparisons, and

- To establish flow gains and losses along the perennially flowing portion of the Amargosa River, including seasonal trend information in order to provide a more robust baseline for future comparisons.

2.1.1 Spring Discharge Monitoring

For the current monitoring event, springs not previously visited since the initial baseline work in 2011 were revisited to evaluate changes over the past three years. Previously, springs designated for ongoing quantifiable discharge measurement included Amargosa Canyon Spring 1, Amargosa Canyon Spring 4, Borax Spring, Borehole Spring, Crystal Spring, Horse Thief Spring, Tecopa Hot Spring (as measured near the Amargosa Conservancy trailer), and Willow Spring. Data from other springs were collected as practical, including Resting Spring, Shoshone Spring, Thom Spring and Five Springs. These springs were chosen for long-term monitoring as they were the springs from which reliable water samples could be obtained as opposed to the remaining springs where conditions were such that sampling was not practicable at the time of the initial work (SGI, 2011).

The primary method used to quantify spring discharge was measuring the time it takes for spring flow to fill a bucket of a known volume. In some cases, such as Borax Spring and Tecopa Hot Spring, the spring discharged over a lip or out a pipe which enabled direct measurement of spring flow. At other locations, such as at Crystal Spring and Amargosa Canyon Spring #4, spring discharge was temporarily captured and channeled into a pipe or a flume to facilitate direct measurement using the bucket filling technique. A secondary method used to quantify spring discharge was direct measurement using a Marsh-McBirney Flo-Mate solid-state flow meter placed in a flowing channel of water. Measurements from the flow meter are combined with cross-sectional dimensions of the flow channel to yield spring discharge. This measurement technique was used at Amargosa Canyon Spring #1 and Borehole Spring. All of the spring flow measurements recorded starting with the initial spring survey (including visual estimations of flow) are summarized on Table 1. Spring flow measurements are also found in the Catalog of Springs (Appendix A) and on the individual field reconnaissance data sheets (Appendix D).

There are compromises in the use of both spring flow measurement options that can result in under-estimation or over-estimation of free-flowing discharge. Ideally, all of the flow from a spring would be fully captured and channeled into a pipe or flume, allowing for much greater accuracy in measurement of flow. This is the case for Borax Spring and Tecopa Hot Spring at the Nature Conservancy trailer. Temporarily channeling the spring using a pipe and other non-permanent materials such as mud and rocks can capture most of the flow, but not all, which can lead to inaccuracies in measurement. Measurement of flow using the solid-state flow meter requires estimates of cross-sectional area and the use of one to two flow measurement points as the meter is often large relative to the width of the channel. Ultimately, all of the spring flow measurements within this report should be seen as an estimate for the range of flows emanating from each spring. Significant alteration to spring discharge locations would be required to achieve the accuracy needed to resolve fine, seasonal changes in spring discharge.

2.1.2 Groundwater Level Monitoring

The wells designated for ongoing groundwater elevation measurement include those wells previously installed as part of the Amargosa Hydrologic Survey (wells ARHS-01 through ARHS-04); the Eagle Mountain Well and Cynthia's Well. None of these wells have a surveyed mark for ground level, thus surface elevation has been estimated using USGS topographic maps. Depth to water was measured from the same point during each monitoring event so accurate comparisons between events can be made. All of the depth to water measurements recorded starting with the initial well survey are summarized on Table 2-1. Depth to water measurements are also found in the individual well data sheets included in Appendix D. The four ARHS wells have been outfitted with In-Situ transducer / data-logger set-ups, and collect groundwater level measurements at one-hour intervals. The results of the groundwater level monitoring are discussed later in this report.

2.1.3 Amargosa River Flow Monitoring

River flow was measured at five locations along the Amargosa River from the town of Tecopa south to the California Route 127 undercrossing near Dumont Dunes. Two of the measurement points were flow gauges established by the USGS. The first is the USGS gauging station located in the town of Tecopa, California (station no. 10251300) and the second is located near China Ranch, just above the confluence with Willow Creek (station no. 10251330). The three manual flow measurement stations were located at the intersection with Sperry Wash, the crossing of Dumont Dunes Road and the undercrossing of California Route 127. As the project has progressed, additional measurements have been obtained from the Amargosa River just below the confluence with Willow Creek, and along Willow Creek just upstream of the Amargosa River.

A Marsh-McBirney Flo-Mate electromagnetic velocity meter and associated equipment was used to gauge river flow at each measurement location along the Amargosa River. Surface water flow velocity was measured and recorded at 0.5-foot intervals across the width of the Amargosa River along a measurement transect oriented perpendicular to the direction of river flow. Concurrent with each velocity measurement, depth to river bottom was recorded. The full profile of river velocities and depths for the complete cross-section of the river could then be aggregated to determine total river volumetric flow at the measurement location. Each measurement transect location was recorded using a hand held GPS receiver so subsequent measurements were performed approximately along the same river cross-section.

During the spring reconnaissance field activities conducted during November 2010 and January 2011, the leading edge of the Amargosa River extended to an indeterminate point downstream of the California Route 127 undercrossing. This was also the case during the May 2014 monitoring event. The initial visit to this section of the River in late April 2011 showed that the leading edge had retreated to a point between the California Route 127 undercrossing and the crossing of Dumont Dunes Road. A subsequent visit a week later (early May, 2011) showed the retreat of the River continued such that the leading edge was approximately 1,000 feet upstream of the Dumont Dunes Road crossing. The visit in September 2011 showed the leading edge of the River in approximately the same place. During the December visit, the leading edge of the River had advanced beyond the Dumont Dunes Road crossing, but did not extend as far as the California Route 127 undercrossing. This data, along consistent later observations and with visual observations by long-time residents, provides strong indications that flow in the Amargosa River is generally controlled by evapotranspiration. The increase in evapotranspiration that occurs during the longer, hotter summer days reduces water availability for surface flow resulting in the retreat of the River. The reduction in evapotransipration that occurs during the shorter and cooler winter days increases the water available for surface flow, thus the leading edge of the River advances independent of precipitation. The management of non-native vegetation along the Amargosa River (i.e. tamarisk removal) will likely have a significant effect on the flow of water in the River. Hydrographs of the Amargosa River based on the periodic monitoring events are presented on Figure 2-4.

2.2 Water Quality Analyses

As a continuing step to determine relationships between waters found in the Middle Amargosa River Basin, water samples were collected from a select group of spring and wells, including the following:

- Noble Gas Isotopes (e.g. Helium isotopes) at Thom Spring, Tecopa Hot Springs, Borehole Spring, Wild Bath Spring and well ARHS-01;
- Stable Isotopes at Wells ARHS-01, ARHS-03 (Twelvemile Spring), and at Dodge City Spring; and,
- General minerals and metals at Dodge City Spring.

The noble gas analyses were conducted at the University of Utah. Stable isotope analysis was conducted by Isochem Analytical in Champaign, Illinois. Interpretative work was conducted M. Lee Davisson & Associates, Inc.

2.2.1 Previous Isotope Investigations

A number of previous reports have been published on groundwater geochemistry and isotope abundances in southern Nevada and southeastern California. Notable reports relevant to the Amargosa River area include those of Winograd and Thordarson (1975), Thomas et al. (1996), Davisson et al. (1999), and Larsen et al. (2001). Additional studies that include directly related data can be found in Thomas et al. (2003a) and Hurst (2012).

Winograd and Thordarson (1975) developed one of the early frameworks for groundwater flow in southern Nevada related to the Nevada Test Site, and that included extensive discussion of the Ash Meadows springs discharge area. Based on earlier work, they also summarized types groundwater hydrochemistry that showed calcium magnesium bicarbonate groundwater associated with both the carbonate rock of the Spring Mts. and adjacent Pahrump Valley. In contrast, sodium potassium bicarbonate groundwater drains the largely volcanic rock areas south of the Nevada Test Site (e.g., Oasis

Valley and Jackass Flats). Ash Meadows spring discharge consequently has calcium magnesium sodium bicarbonate water that Winograd and Thordarson inferred as a mixture of recharge of the two latter water types.

Thomas et al. (1996) also compiled and summarized groundwater chemistry types as well as isotope abundances in areas that included groundwater throughout southern Nevada and southeastern California with a focus on the regional carbonate aquifers. They concluded from isotope results that the calcium magnesium sodium bicarbonate water discharging from Ash Meadows springs comprised 60 percent Spring Mountains recharge and 40 percent from Pahranagat Valley to the east. They also argue from radiocarbon data that groundwater velocities ranged approximately from 10 to 144 feet per year.

Davisson et al. (1999) showed that radiocarbon was not a reliable method for age dating groundwater in the regional carbonate aquifer due to continual isotope exchange reactions combined with mixing of local recharge sources during long-range transport. They further showed that stable isotopes of oxygen-18 and deuterium measured in southern Nevada groundwater had been previously evaporated during its original recharge as melted snow in central Nevada (Rose et al., 1999). By applying a methodology that removed the effects of evaporation on oxygen-18 and deuterium they showed a systematic decrease in their abundances with increasing latitude and local elevation throughout southern Nevada, a result inconsistent with previous studies purporting Pleistocene age groundwater recharge during the last glacial period (Claassen et al., 1986).

Larsen et al. (2001) studied the water quality and stable isotope abundances of groundwater in the Tecopa and Death Valley regions of the Amargosa River and related them to groundwater of southern Nevada to delineate potential recharge sources. They recognized three water types comprising a Spring Mountains recharge source, a deep regional groundwater derived from fracture flow of southern Nevada, and groundwater derived from basin-filled groundwater of the Amargosa Desert.

Additional studies providing a greater variety of isotope measurement types have been reported by Thomas et al. (2003a) and Hurst (2012). Thomas et al. (2003a) focused specifically on Oasis Valley and its hydraulic connection to Pahute Mesa, showing that Oasis Valley groundwater is replenished by groundwater flow through Pahute Mesa that was ultimately derived further north. The Oasis Valley groundwater ultimately replenishes the Amargosa Desert basin fill aquifers. Hurst (2012) specifically focused on tritium, oxygen-18, deuterium, strontium isotopes, and uranium isotopes in regions along the Amargosa River. He showed that spring samples are largely tritium absent, the oxygen-18 and deuterium show only limited evaporation, and that strontium and uranium isotopes show mixing along the entire length of the Amargosa River.

Lastly, one study reported by Thomas et al. (2003b) measured dissolved noble gases in the regional carbonate aquifer of southern Nevada. They showed that noble gas abundances that are typically incorporated in recharging groundwater and reflect the local recharge temperature were systematically being lost during long-range transport from Pahrangat Valley in east-central Nevada towards Ash Meadows at its terminal discharge point. They concluded this loss of dissolved gas was due to fault barriers and cavities in the regional carbonate aquifer that forces groundwater to migrate upward and encounter gas loss in air pockets. This subsequently masked the calculated recharge temperatures derived from the noble gases.

2.2.2 Field Methods

Stable Isotopes

Samples for oxygen ($\delta^{18}O$) and deuterium (δD) were collected in 60 milliliter glass bottles equipped with a conical shaped insert inside the cap that forms an airtight seal when the bottle is closed. Samples were shipped to Isotech Laboratories in Champaign, Illinois where the 18O/16O and D/H ratios were measured as a gas using standardized mass spectrometry methods. Results are reported as a normalization to Standard Mean Ocean Water (SMOW), which is an internationally recognized standard in stable isotope analysis. The normalization converted to standard δ ("del") notation following the convention:

$$\delta = \left(\frac{R}{R_{std}} - 1\right)1000$$

Where R is the isotope ratio of the sample and R_{std} is the ratio of the standard.

Noble Gas

Noble gas samples were collected in passive diffusion samplers comprising two sections of 1/4" copper tubing attached by a small section of semipermeable silicon tubing (Figure 2-5). The terminal ends of the copper tubes were pinched closed gas-tight with cold seal. The samplers were placed in the water to be sampled for 24 hours. During this equilibration period, gases dissolved in the water diffused through the semipermeable tube and came into an equilibrium concentration in the tube proportional to that of the water. At the same time, a special meter was used to measure the total dissolved gas in the water. After 24 hours, the sampler was crimped to a cold seal on the semipermeable tube end of the copper to form two separate gas samples. These two samples were then labeled, the end protected with electrical tape and placed into a plastic bag. Samples from five sample sites were collected by this method. All samples were sent to the noble gas laboratory at the University of Utah. The copper tubes were vacuum fitted to an evacuated container, the copper cold seal was uncrimped to release the gas, followed by cryogenic isolation of noble gases of interest. Noble gas abundances and the $^3He/^4He$ ratios were measured on a VG-5400 noble gas mass spectrometer. Results are reported as gas volume per milliliter of water.

2.2.3 Results - Geochemistry

A detailed description of the investigative results and associated laboratory data reports are provided in the report prepared by M.L. Davisson & Associates, Inc., and provided in Appendix E. What follows is a summary of the conclusions of that report.

Stable isotope and other geochemical data indicate that Middle Amargosa River area groundwater appears to be a mixture of Ash Meadows, Spring Mountains and Kingston Range sources (Figures 2-6 and 2-7). The pathways for that groundwater to reach the area probably consist of one or a combination of:

- Water that moves through carbonate rocks from the Spring Mountains to the Ash Meadows and then southward toward the Shoshone-Tecopa area;
- Water that moves through carbonate rocks beneath the northern portion of the Nopah Range into Chicago Valley, then toward the Amargosa River; and,
- Water that moves from Pahrump Valley through the low, faulted divide into California Valley then towards the River.

Most of the spring/groundwater samples have characteristics indicative of having been influenced by Spring Mountain recharge by some route. Most of the mixing is probably occurring via fractured rock at depth, and less so in the alluvium. Water quality in the springs in the Shoshone-Tecopa area likely evolves from a mixture of regional carbonate and Tertiary volcanic rock influences, but acquires increased chloride and sulfate possibly from the Tecopa lake bed deposits. Additionally, regional subsurface heat flow increases groundwater temperature and contributes to increased dissolved silica, decreased bicarbonate, and possibly increased pH, with the latter resulting in the high arsenic concentrations. The source of the arsenic could be from multiple sources, but as pH increases the solubility increases to significantly high levels as presented on Figure 2-8.

Noble gas concentrations of the water in the Shoshone-Tecopa area are strongly similar to those measured in the regional carbonate – Ash Meadows (of southern Nevada) groundwater noted by Thomas, et.al. (2003b). Their conclusions were that dissolved gas loss occurred during subsurface transport across faulted boundaries and compromised recharge temperature/elevation calculations. The noble gas recharge temperatures/elevation calculations for Amargosa River Valley groundwater mostly support the conclusions of Thomas, et.al. (2003b).

The $^{3}He/^{4}He$ ratios for the four measured springs (Thom, Wild Bath, Tecopa and Borehole) were unusually low, indicating old groundwater ages. The values were 5 to 10 times lower than measured groundwater under the Nevada Test Site. These low ratios could be due to high influx of ^{4}He from the Earth's crust caused by deep faults. Otherwise, if the low ratio is due to steady-state accumulation from local deposits, then groundwater ages greater than 100,000 years would be required. Additionally, the helium ratios did not suggest the presence of a shallow magmatic heat source for the Tecopa Hot Springs area, and indicate that the heat source is via deep circulation, probably along the faults that run through the area. The elevated temperature of the Tecopa Hot Spring water is not unusual since similar temperatures are seen at depth under the Nevada Test Site. However, at Tecopa, the warm water is driven to the surface probably by some structural control.

Several recommendations for future work are derived from the results of this work and provided in Section 4.0.

3.0 GROUNDWATER SYSTEM – CONCEPTUAL MODEL

The conceptual model of a groundwater system is the foundation of any analysis of a groundwater basin. The conceptual model describes groundwater occurrence, groundwater movement, hydraulic properties of aquifer materials, and groundwater inflow and outflow components. As described in the previous SOBRs, as new data are gathered in the Middle Amargosa Basin, the conceptual model for the area would be updated as appropriate to reflect those data. This section of the SOBR, provides an updated overview of the conceptual model reflecting the results of new geochemical data, groundwater level data, and river gauging results.

3.1 Regional Setting and Geologic Conditions

The Amargosa River Basin is located in Inyo and San Bernardino Counties, California, and Nye County, Nevada within the Basin and Range geomorphic province. The Basin and Range region is characterized by basins of internal drainage with considerable topographic relief, alternating between narrow faulted mountain chains and flat arid valleys or basins. The ranges generally trend north-northwest parallel to the regional structural regime. The geology of the Amargosa Basin is very diverse containing Precambrian, Paleozoic and Mesozoic metamorphic and sedimentary rocks, Mesozoic-aged igneous rocks, Tertiary and Quaternary-aged volcanic rocks, and playa, fluvial and alluvial deposits (Planert and Williams, 1995). A regional geologic map is provided on Figure 3-1.

The valley areas are covered by coalescing alluvial fans forming broad slopes between the surrounding mountains and the valley floors. The regional gradient of the Northern Amargosa River Basin is generally to the south-southeast with gradients that typically range from five to 15 feet per mile. The basin fill deposits are interpreted to be underlain primarily by Paleozoic sediments although in the central portion of the basin floors, the basin fill sediments have not been fully penetrated by drilling. Generally, the Middle Amargosa Basin is marked by several unique features including the badland-type topography of the Tecopa lakebed deposits and the Amargosa River Canyon. Between Shoshone and Tecopa the slope of the valley floor flattens among the lakebed deposits, and then steepens as the river flows through the Amargosa River Canyon. Downstream of the canyon, the topography reverts to an area of broad, coalescing alluvial fans, eventually reaching the flat playa in Death Valley.

3.2 Hydrogeologic Units

In the Amargosa River Basin, the principal hydrogeologic units consist of unconsolidated basin fill materials, volcanic rocks (primarily in Nevada), and the carbonate rock aquifer. The following provides a summary of these three hydrogeologic units.

3.2.1 Basin Fill

Tertiary and Quaternary-aged basin fill deposits are present throughout the basin as alluvial, fluvial and lacustrine (lakebed) deposits. Coarse-grained deposits (primarily sand and gravel) within the basin fill are responsible for transmitting the greatest quantities of groundwater and are most relied upon for groundwater production in the region. The basin fill is generally unconsolidated, moderately to well-sorted sand, gravel, silt and clay, and wells completed in the basin fill can yield several hundred gallons per minute (Walker and Eakin, 1963). As the axes of the valleys are reached, the sorting of the sediments will increase which can serve to significantly increase the permeability of the sediments. With increasing depth, groundwater production can be expected to decrease in these deposits as increasing lithostatic pressure and infilling of pores coincident with their greater age may occur reducing permeability.

Within the basin fill, the fine-grained (clay and silt) deposits that largely comprise the lakebed deposits (for example in the Shoshone – Tecopa area) serve as aquitards. Aquitards are low permeability geologic units that inhibit groundwater flow and can serve as confining units. Wells and boreholes that are completed in aquifer materials underlying these aquitards may exhibit artesian conditions such as those observed from flowing wells and borings such as at Borehole Spring and Borax Spring in the Shoshone-Tecopa area.

3.2.2 Volcanic Rocks

Tertiary and Quaternary-aged volcanic rocks are present within the Amargosa River Basin particularly in the area of the headwaters of the Amargosa River in the Beatty area of Nevada, and in the Greenwater Mountains immediately west of Shoshone, California. In the California portion of the basin, the volcanic rocks are generally of lesser importance to the overall groundwater system as opposed to the northern portion of the basin in Nevada. Locally, volcanic rocks can be of importance, for example, at the Shoshone Spring area where a basalt flow crossing the Amargosa River course may be driving water to the surface in the river bed and the spring. This will be discussed further in Section 3.3.

3.2.3 Bedrock Units

Bedrock units underlying the alluvial valleys and generally comprising ranges such as the Nopah and Resting Spring Ranges, and portions of the Amargosa Range, consist of Precambrian to Mesozoic-aged metamorphic and sedimentary rocks. These geologic units consist of Paleozoic-age carbonate rocks (the "carbonate rock aquifer"); quartzite, and shale which have been folded and faulted (Figure 3-1). Generally, bedrock units such as these produce little water except where they are fractured and faulted, providing pathways for groundwater movement. Other bedrock units consist of the Mesozoic-aged granitic rocks as found in the Kingston Range. Within the granitic rocks, groundwater flow can be assumed to be negligible except where fracturing is present yielding modest quantities of groundwater.

Where carbonate rocks are present, greater movement of groundwater can occur due to the unique depositional and erosional characteristics of those rocks. Fractures and secondary solution openings along bedding planes can transmit considerable quantities of groundwater. Groundwater that discharges from the springs at Ash Meadows largely involves groundwater moving through these secondary openings in the carbonate rocks. Within the basin, significant groundwater flow through the carbonate rock aquifer occurs within the lower to middle Paleozoic-age carbonate rocks that comprise a package of rocks approximately 26,000 feet thick (Sweetkind, Belcher, et.al., 2004).

Groundwater flow in carbonate rocks can be very complex. Carbonate rocks with extensive solution channels or fractures primarily developed in one direction will have permeabilities that are highly oriented in specific directions. Therefore, the groundwater flow may not be predictable simply by drawing flow lines perpendicular to regional groundwater surface contours representative of the regional carbonate aquifer (Davis & DeWiest, 1966). Although the carbonate rock aquifer likely transmits large volumes of groundwater in the region, permeability is limited to areas of fracturing which proportionally makes up a small portion of the carbonate rock volume. Therefore, despite the potential for wells to obtain large yields from the carbonate rocks, that success is dependent on intersecting those fractured zones.

3.2.4 Geologic Structure

The rocks in the Amargosa River Basin have been extensively deformed by a variety of fault types that have occurred in the distant past as well as the present. These fault types include:

- Normal faulting typical to the Basin and Range with vertical displacement being dominant;
- Strike-slip faulting (lateral displacement dominant) typical of larger-scale regional fault systems such as the Furnace Creek – Fish Lake Valley Fault and Las Vegas Valley Shear Zones; and
- Thrust faults (low angle faults) that during the Paleozoic and Mesozoic resulted in displacing rock units in a manner that can affect groundwater movement in the present.

Springs may issue from the locations of faults due to either the lower fracture permeability of the fault in rock, or the displacement of permeable basin fill or rock adjacent to relatively impermeable materials. For example, The Tecopa Hot Springs rise along a fault (Waring, 1915) that runs north-northwest through the basin (Figure 3-2). Shoshone Spring also rises along the northward extension of the same fault that passes through Tecopa, part of the Furnace Creek Fault Zone (California Division of Mines, 1954). The Death Valley – Furnace Creek Fault System (inclusive of the Furnace Creek Fault Zone) is part of a large, currently active, northwest directed pull-apart zone. Movement along the Furnace Creek Fault Zone is primarily strike-slip (Brogan, Kellog, Slemmons and Terhune, 1991). The Death Valley – Furnace Creek Fault System is the second longest fault system in California (the San Andreas Fault System being the longest).

Thrust faults are present throughout the region, however given their age, in many areas their presence is concealed by overlying volcanic or basin fill deposits. Fracture permeabilities along thrust faults are insignificant due to the age of the structures and fracture filling and the low angle nature of the faulting not supporting fractures with significant apertures. However, in areas where impermeable rocks are thrust against more permeable rock in the subsurface (e.g., quartzite thrust against carbonate rocks), those faults may also serve as a barrier to groundwater flow. This can be seen along the base of the Nopah and Resting Spring Ranges where the carbonate rock sequence outcrops in the upper portions of the ranges and underlying Lower Cambrian and Precambrian clastic rocks outcrop along the base of each of these ranges. A notable exception is north of the Nopah Thrust in the northern portion of the Nopah Range. North of this fault, the carbonate-rock sequence is down-dropped relative to the carbonate rocks south of the thrust fault resulting in a potential pathway for an undetermined amount of water to seep from Pahrump Valley into Chicago Valley. Of note is the presence of Twelvemile Spring situated approximately west of this thrust fault, and an absence of springs along the west base of the Nopah Range further south.

3.3 Surface Water

The principal surface water body in the region is the Amargosa River, an intermittent river with headwaters issuing from springs northeast of Beatty, Nevada, and extending approximately 180 miles to the river's terminus at the playa in Death Valley. Except for portions of the river in the Amargosa Canyon area in California, and near Beatty, Nevada, the Amargosa River typically flows only after periodic storms. In those areas where the river is usually dry, the flow of water is in the subsurface. The perennial reach of the Amargosa River between Shoshone and Dumont Dunes was designated as a National Wild and Scenic River in 2009. Except during runoff events from rainstorms, the perennial flow in the Wild and Scenic section of the river is completely supplied by groundwater.

The Amargosa River rises as spring flow from the southwest side of Pahute Mesa in Nevada. From here, the river flows generally southwest toward Beatty, Nevada, and after passing through the Amargosa Narrows where water is forced to the surface, enters the Amargosa Desert. After crossing the border into California, the river generally runs southward along a valley that follows the trend of the Furnace Creek Fault Zone, adjacent to California State Highway 127 near Death Valley Junction. Here, the river meets with Carson Slough (which drains Ash Meadows and is the chief tributary to the Amargosa River in Nevada), and continues its southward route passing to the east of the community of Shoshone and on to Tecopa. South of Tecopa, the river enters the Amargosa Canyon, being augmented by spring flow on its course. South of the Amargosa Canyon, the river flows by Dumont Dunes, and then heads west and then northward, rounding the Amargosa Range on the south and flowing into Death Valley.

A series of conceptual cross-sections following the course of the Amargosa River from near Oasis Mountain northeast of Beatty, Nevada, to Sperry below the Amargosa River Canyon in California are provided in Appendix F. As can be seen, areas with continual flow are typically where rock units create constrictions to flow, and that flow is driven to the surface. Beyond the constrictions, the flows typically percolate into the subsurface some distance downgradient. This occurs at the narrows southeast of Oasis Mountain, at the Amargosa Narrows south of Beatty, Nevada, at the Shoshone Spring area, and at the Amargosa River Canyon. Between Shoshone and Tecopa, the river can also rise to the surface, most likely the result of permeable zones intersecting clayey, Tecopa lake bed deposits causing flow to surface. As can also be seen in the cross-sections (Appendix F), the groundwater surface tends to flatten upgradient of these constrictions, then steepens once past them, as would be anticipated.

This condition also emphasizes the sensitivity of the relatively constant, or perennial reaches of the Amargosa River to changes in groundwater level. Additionally, given this condition, it appears that a considerable portion of the underflow moving through the Middle Amargosa system can be accounted for by the flow observed at the surface for example in the Amargosa River canyon plus spring discharge and any pumping. This does not result in a substantial amount of underflow, and further highlights the sensitive nature of the river system. More about this is discussed in Section 4.1.

The USGS monitors the flow of the Amargosa River (USGS, 2013) at a gage 0.2 miles west (Gauge no. 10251300) of Tecopa. The USGS has monitored Amargosa River flow intermittently at other locations along the river over the past 50 years, but given the spotty nature of those records, they are of limited utility. The average flow of the river at this station based on 39 full years of data between 1962 and 2013 (some years missing) is 3.44 cubic feet per second (cfs), though is skewed high as a result of flood flows. The maximum mean annual flow recorded there was 14.9 cfs in 1983 when the record peak flow of 10,600 cfs was recorded on August 16, 1983. At times the river has been dry at this station. Mean annual flows at the Tecopa station along with the other stations mentioned are summarized on Table 3-1.

AZI conducted flow measurements at three locations along the river which are provided on the Field Activities Data Summary table (Table 2-1). Field water quality parameters collected by AZI indicated that Amargosa River waters are somewhat intermediate in chemistry between the more saline hot spring waters at Tecopa, and the fresh water springs identified in the area. This monitoring has provided strong indications that the extent of flow in the Amargosa River is significantly controlled by evapotranspiration. The increase in evapotranspiration that occurs during the longer, hotter summer days reduces water availability for surface flow resulting in the retreat of the River. The reduction in evapotransipration that occurs during the shorter and cooler winter days increases the water available for surface flow, thus the leading edge of the River advances independent of precipitation. The management of non-native vegetation along the Amargosa River (i.e. tamarisk removal) will likely have a significant effect on the flow of water in the River.

Other surface water bodies in the area consist of spring-fed ponds in the Ash Meadows area (Nevada), spring-fed Grimshaw Lake in the Tecopa area, and streams that issue from springs only to end where either that flow is utilized by vegetation, or it percolates back into the subsurface. One exception to this is Willow Creek, a significant spring-fed stream that rises northeast of China Ranch (south of Tecopa), and flows into the Amargosa River within the Amargosa River Canyon.

3.4 Regional Groundwater System

The regional groundwater flow system is considerably more extensive than the Amargosa River Basin watershed (Figure 3-3). The reason for this is the extensive area beyond the watershed boundary underlain by the carbonate rock aquifer that drains toward Death Valley. In this large flow system, groundwater recharge results from precipitation in the form of snowmelt and rainfall that falls within the mountains of southern and central Nevada, and reaches the Amargosa River Basin where it is discharged (Planert and Williams, 1995).

The Northern Amargosa River Basin appears to receive much of its carbonate-rock aquifer underflow from central Nevada. As shown on Figure 3-4, groundwater moves southward through Lincoln County, Nevada where it splits with a portion of that flow heading southwest toward the Amargosa Desert and Ash Meadows. The remainder of the flow moves southeast toward Muddy Spring and the Colorado River area.

Within the Middle Amargosa River Basin (between the California-Nevada state line and Salt Creek), it has long been postulated that groundwater moves directly through the carbonate aquifer southwest from the Spring Mountains and beneath Pahrump Valley toward the Tecopa – Shoshone – Chicago Valley – California Valley areas (Faunt, D'Agnese and O'Brien, 2004). However, based on the results of the current geochemical analyses and more recent detailed mapping by the USGS (Workman, et.al., 2002), it appears that the mechanism by which groundwater moves from the Spring Mountains/Pahrump Valley area toward the Shoshone-Tecopa area may be more complicated. Figures 3-5, 3-5a and 3-5b present a portion of the 2002 geologic map indicating that Precambrian to Cambrian bedrock units underlying the carbonate rock units outcrop along the western base of the Resting Spring Range and the portion of the Nopah Range south of the Nopah Peak Thrust. This would indicate that the saturated rocks beneath these ranges are primarily comprised of quartizite, shale, siltstone and dolomite of lesser permeability than would be expected of the Paleozoic-age carbonate rocks. Alternative flow paths likely include one or more of the following:

- Spring Mountain recharge moving toward Ash Meadows through carbonate rocks and basin fill, then southward toward the Shoshone-Tecopa area;
- Via carbonate rocks at the north end of the Nopah Range into Chicago Valley then toward the Amargosa Valley; and ,
- From Pahrump Valley via the shallow divide into California Valley then toward the Amargosa River.

These deeper flowpaths are most likely influential on the spring flows and discharge to the alluvium. The deeper flowpath beneath the northern Nopah Range was previously discussed (JWI, 2013a) as a potential source for Twelvemile Spring. These flowpaths are consistent with that previously proposed by others (Figure 3-6). Beyond the Middle Amargosa River Basin, groundwater moves west in the Death Valley Basin, then north augmented by underflow from the Owlshead Mountains area, to the Death Valley Playa.

The regional groundwater flow system covers an area of nearly 40,000 square miles. The following sections describe the occurrence and movement of groundwater, the aquifer characteristics of the basin fill and carbonate rock aquifers, and groundwater basin inflow and outflow components.

3.4.1 Groundwater Occurrence and Movement

Within the Amargosa River Basin, groundwater occurs primarily within the basin fill deposits and carbonate rock aquifer. Although groundwater occurs with significance in the volcanic rocks in the northern portion of the basin, the focus of this report is the basin south of the Death Valley Junction area (Middle Amargosa River Basin), and therefore is not discussed here. The only materials from which groundwater can be extracted for significant use is within the coarse-grained deposits of the unconsolidated basin fill and within the fractured carbonate rocks (Walker and Eakin, 1963). Volcanic rocks and other bedrock units can generally be assumed to be relatively impermeable except where locally fractured and minor yields can be achieved. As described in Section 3.3., underflow in the basin fill contributes to surface flow in the Amargosa River where constrictions occur due to the presence of less permeable bedrock or other lower permeability deposits. Based on this condition, in the Middle Amargosa River Basin, the amount of underflow moving through the system may largely be represented by the sum of Amargosa River flow (as observed in the Amargosa River Canyon), underflow in river channel deposits, spring discharge and evapotranspiration, and the limited pumping in the area.

In the Northern Amargosa River Basin, groundwater is generally found within the basin fill from which most of the groundwater pumping in the Amargosa River Basin is concentrated. In the Ash Meadows area, the primary aquifer is the carbonate rock aquifer system. Groundwater within the carbonate rocks flows laterally across basins as interbasinal flow as described earlier.

The direction of groundwater movement usually parallels the slope of the ground surface, from points of recharge in the higher elevations to points of discharge such as springs or the Amargosa River in the valley. Within the basin fill aquifer, groundwater movement is from north to south from the northern portion of the basin toward Shoshone and Tecopa. A potentiometric surface map of the shallow basin fill aquifer based on the groundwater levels collected by the USGS, AZI, AC, Nye County and Inyo County (by TEAM Engineering & Management, Inc.) during the 4th Quarter of 2010 is provided on Figure 3-7. This is the same map that was provided in the 2011 SOBR. Based on the continued monitoring of groundwater levels in the area since that time, and the little change observed south of Death Valley Junction, this map is likely still consistent with existing conditions.

Precipitation and snowmelt runoff from the mountains surrounding the Middle Amargosa River Basin collect in the thick packages of alluvium that fill the valleys. The water percolates through the alluvium under the force of gravity, flowing downhill towards the lowest point in the Basin, the Amargosa River. Figure 3-8 shows the conceptualized flow paths of groundwater flowing in the alluvial valleys within the Middle Amargosa River Basin. North of Shoshone, groundwater flows south around Eagle Mountain in the alluvium that forms the floor of the valley through which runs the Amargosa River.

The valley and the Amargosa River are additionally fed from runoff from the east slope of the Amargosa Range and the west slope of the Resting Spring Range. Water from the east slope of the Resting Spring Range and the west slope of the Nopah Range flow into Chicago Valley, following the slope of the valley floor to the south. At the south end of the Resting Spring Range, the alluvial valley turns southwest towards Tecopa and the Amargosa River. Right at this bend is Resting Spring, which likely exists as a result of the change in valley direction and the constriction in the width of the alluvium in the valley between the Resting Spring Range and the Nopah Range, forcing groundwater to the surface at the spring location. Water from the southeastern slope of the Nopah Range and the western slope of the Kingston Range flows into California Valley and west around the southern tip of the Nopah Range. Some of this water likely flows down China Ranch Wash, which in turn is the source of the water from Willow Spring and Willow Creek.

Runoff from the eastern Ibex Hills flows into Greenwater Valley toward the Amargosa River. South of the Sperry Hills, runoff from the north facing slope of the Avawatz Mountains, along with the Salt Spring Hills, Saddle Peak Hills and the Ibex Hills flows into the basin fill of Southern Death Valley, down the middle of which runs the Amargosa River.

Based on the results of AZI's spring reconnaissance, it is clear that a number of distinct spring sources are represented in this concentrated part of the Amargosa River Basin. Based on the current isotopic work, the elevated temperatures of the hot springs around Tecopa indicate that the spring water has most likely been at great depth. This is similar to warm springs in the Furnace Creek area of Death Valley National Park (Pistrang and Kunkel, 1964). The Furnace Creek area warm springs are also present along the Furnace Creek Fault Zone where deep circulation is postulated. This indicates that absent shallow heated igneous rocks, those waters moved at considerable depth (in the range of thousands of feet below ground surface) only to move upward along fractures or faults to the surface where it is discharged. In other springs, field water quality parameters are suggestive of groundwater flow of a more local nature such as at Crystal Spring (Kingston Range source) or Sheep Creek Spring (Avawatz Mountains source).

3.4.2 Aquifer Characteristics

Groundwater within the basin is held within the sand, gravel, silt and clay that make up the valley fill aquifer. Within the Northern Amargosa River Basin, hydraulic conductivity (the ability for a geologic material to transmit water) in the basin fill can range from 0.02 feet per day (f/d) in the low permeability clayey deposits, to 140 f/d in the coarse-grained sands and gravels (Belcher, 2004). AZI is unaware of any aquifer testing that has occurred within the basin fill in the Middle Amargosa River Basin or the Death Valley Basin, but it is likely that hydraulic conductivities generally fall within the same range as those described above.

The aquifer characteristics of the carbonate rock aquifer can be highly variable. Where fractures and solution openings exist, these rocks can be the most permeable materials in the basin. Absent fracturing, hydraulic conductivities can be extremely low. Carbonate rock hydraulic conductivities can range from 30 f/d or greater to much less than 0.001 f/d (Spitz & Moreno, 1996).

3.4.3 Groundwater Basin Inflow Components

Groundwater inflow components within the Amargosa River Basin include recharge from precipitation that falls within the drainage basin and groundwater underflow into the basin, primarily through the carbonate rock aquifer. In this area, large uncertainties exist regarding recharge rates, and currently, groundwater pathways for underflow into the basin. Therefore, best estimates of recharge are probably most available by evaluating groundwater discharge and changes in storage/changing groundwater levels in the area.

3.4.3.1 Recharge

Walker & Eakin (1963) estimated recharge to the Northern Amargosa River Basin from precipitation within the basin plus recharge from precipitation on the northern and western slopes of the Spring Mountains to be approximately 5,000 acre-feet per year (AFY). Within the California portion of the basin, the Middle Amargosa Basin and Death Valley Basin do not have specific recharge estimates associated with them (California Department of Water Resources, 2003).

As part of the water-supply feasibility study for a potable water source for Tecopa, JWI (2013c) estimated a recharge of approximately 700 afy from the Kingston Range using the Maxey-Eakin Method.

3.4.3.2 Groundwater Underflow

Walker & Eakin (1963) estimated that of the 17,000 AFY discharged from the springs at Ash Meadows on an annual basis; approximately 13,000 AFY might be the result of groundwater underflow through the carbonate rocks from the Spring Mountains to the east. The remaining 4,000 AFY being supplied by underflow from areas to the northeast in central Nevada. South of Death Valley Junction, the general absence of previous hydrogeologic investigations in the Shoshone – Tecopa region results in more generalized assumptions regarding underflow. As shown in Figure 3-6, regional groundwater flow enters the California portion of the basin from Ash Meadows and from recharge in the Spring Mountains via various potential routes. Additional underflow from the south from the Silurian Valley area enters the system between the Amargosa River Canyon and Saratoga Springs (Faunt, D'Agnese and O'Brien, 2004).

With respect to the Middle Amargosa River Basin, the existing Death Valley Regional Flow System model could be used to evaluate the groundwater budgets for specific zones in this part of the groundwater system, therefore extracting underflow estimates for each of these areas. However, there would be significant uncertainty associated with them, as the model was developed without the benefit of the data collection effort that has been ongoing for the last three years. With the existing data and proposed data collection and analysis, refinement to that groundwater model, or a new groundwater flow model focused on the Middle Amargosa River Basin, will be an essential management tool and will likely provide additional insight into the dynamics of regional flow in the area.

3.4.4 Groundwater Basin Outflow Components

3.4.4.1 Spring Flow & Evapotranspiration

Spring flow and evapotranspiration have been combined as a basin outflow component in this basin as in this area as they are unavoidably linked. Groundwater-dependent vegetation (phreatophytes) are present along the Amargosa River and in spring areas. Springs discharge water from the groundwater system, but in nearly all cases within the basin, that flow either evaporates, is used by plants, or percolates back to the groundwater system within a relatively short distance. One of the few exceptions to this is Willow Creek south of Tecopa which rises from spring flow within China Ranch, and generally maintains surface flow to its confluence with the Amargosa River. In the Nevada portion of the basin, the discharge from spring flow and evapotranspiration has been estimated at 23,500 AFY (Walker & Eakin, 1963).

In the Shoshone - Tecopa - Chicago Valley - California Valley area, the combined spring flow and evapotranspiration has been estimated at approximately 8,900 AFY. In the Death Valley Basin, combined spring flow and evapotranspiration has been estimated at approximately 35,000 AFY (San Juan, Belcher, et.al, 2004).

Based on the field reconnaissance activities, it is clear that the springs in the California portion of the basin emanate from a variety of sources. These sources appear to range from those with deep circulation paths (such as Tecopa Hot Springs), and those with shallow and potentially more local circulation paths (such as at Willow Creek). With respect to specific spring flow (not including evapotranspiration or Amargosa River flow), AZI's total field estimated spring flow has typically been approximately 1.8 cfs during the spring reconnaissance activities (approximately 1,300 AFY).

3.4.4.2 Pumpage

Within the Amargosa River Basin, pumpage is primarily within the Northern Amargosa River Basin. This water is largely used for irrigation. Table 3-2 summarizes groundwater pumping from the Northern Amargosa River Basin since 1983 (NDWR, 2012a). This represents the most up to date pumping data available from the Nevada Division of Water Resources at the time of this report. Total pumping over time is also represented on Figure 3-9. Average annual pumping since 1983 has been 12,153 AFY. In 2012, a total of 17,622 AFY was pumped from the basin. As can be seen, over the 27 years of pumping records, the Northern Amargosa River Basin has seen a steady increase in pumping. For comparison purposes the annual duty for the Northern Amargosa River Basin is 27,336.86 AFY (includes certificate, permit, and ready for action) as of February 21, 2012 compared to the estimated annual perennial yield of the basin of 24,000 AFY (Walker and Eakin, 1963). This updated annual duty is a reduction of approximately 1,700 AFY since first reported in the 2011 SOBR (SGI, 2011).

In the Middle Amargosa River Basin and Death Valley Basin, water supplies are more reliant on spring flow, and groundwater pumping is relatively insignificant in comparison to the Nevada portion of the basin. Groundwater pumpage for domestic or public use is probably on the order of less than 100 AFY (San Juan, Belcher, et.al., in Belcher, 2004). Water used for irrigation of date palms is supplied by spring water. It is unlikely that water use in the Shoshone-Tecopa area has changed significantly since the last State of the Basin Report (SGI, 2012). Furthermore, any additional water usage resulting from the proposed new potable water supply for Tecopa will be insignificant to the overall water budget of the area.

Outside of the Amargosa River Basin, pumpage in the Pahrump Valley is of most significance to the Amargosa groundwater system. Pumping records available since 1959 (NDWR, 2012b) indicate that beginning with initial groundwater usage of 1,159 AFY in 1959, groundwater pumping in the Pahrump Valley rapidly increased to a maximum pumpage of 47,950 AFY in 1968 (Figure 3-10. During the period of 1964 through 1978, pumping in the Pahrump Valley averaged more than 37,000 AFY. Since that time, groundwater pumping in the Pahrump Valley has gradually decreased to the point that in 2011, total groundwater pumping in the Pahrump Valley was 13,352 AFY, the lowest pumpage since the initial record in 1959. The 2011 pumping rate (which also represents a 2739 AFY reduction in pumping since 2009) is likely attributable to economic conditions and may represent a temporary decrease from the 20,000 to 25,000 AFY of pumping that has been characteristic of the Pahrump Valley since 1980. In 2012, total pumping in Pahrump Valley was 14,136 AFY, an increase of 784 AFY from 2011.

Groundwater levels in the Pahrump Valley were noted to have declined steadily over the period of record, but of note is that impacts to springs in the Middle Amargosa Basin, particularly in the Shoshone – Tecopa area have not been reported. However, Thompson (1929) referred to a site called Yeoman Spring that had at the time an estimated flow of 90 gpm. Although there is no spring currently called Yeoman Spring, this appears to be the same spring now referred to as Chappo Spring. The only surface expression of flow at Chappo Spring is a "puddle" surrounded by trees (including non-native palms) and shrubs. Additionally, early reports indicated that Resting Springs had flows of substantially more than 200 gpm (up to 250 gpm). Both of these springs flow at rates lower than those reported in the first half of the 1900's. While this may be the result of spring modification and additional vegetation uptake, it is possible then, that spring flow in the Middle Amargosa Basin may have been effected by past pumping in the Nevada portion of the basin.

Recently, localized stabilization and recovery has been reported in selected areas of Pahrump Valley indicative of a basin beginning to come closer to balance with recently reduced pumping rates.

3.4.5 Groundwater Quality

Groundwater quality in the Amargosa River Basin is highly variable. In recharge areas, the concentrations of dissolved solids in groundwater are low. However dissolved solids will increase as the groundwater moves through the groundwater system and is in contact with the rock materials present. For example, in the area of Willow Creek, dissolved solids may be high due to the presence of gypsum deposits in the geologic materials through which groundwater in that area is flowing. In the Northern Amargosa River Basin where groundwater pumping is focused, much of the water present is suitable for irrigation (not all of which is suitable for domestic use), however water of medium to high salinity is locally present. Existing groundwater quality data along with those of new wells ARHS-01 through ARHS-04 (and associated well logs) are provided in Appendix G.

3.5 Groundwater in Storage

The volume of groundwater in storage within the basin fill is a function of the area of the aquifer material, a selected saturated thickness, and specific yield (ratio of the volume of water that the aquifer will yield due to gravity to the aquifer's volume) of aquifer material. For the purposes of this report, estimates of groundwater in storage are based on the existing literature. In the Amargosa Basin, the volume of groundwater in storage is orders of magnitude greater than the volume of recharge that occurs on an annual basis representing a groundwater accumulation over thousands of years. Storage calculations are rough estimates as the parameters described above are subject to significant variation.

In the Northern Amargosa River Basin, the volume of groundwater in storage for the Amargosa Desert has been estimated at 1.4 million acre-feet within the upper 100 feet of the saturated basin fill (Walker & Eakin, 1963). Estimates of the volume of groundwater in storage within the Middle Amargosa and Death Valley Basins have not been developed by the State of California.

3.6 Groundwater Levels and Discussion of Inflow and Outflow Components

The volume of groundwater in storage is an important aspect of the groundwater system. Changes in storage are identified in the field by changes in groundwater levels. A fundamental groundwater equation and the basis for evaluations of groundwater budgets (inflow vs. outflow estimates) is:

Inflow – Outflow = Change in Storage

When outflow exceeds inflow, there is a negative change in groundwater in storage and groundwater levels can be expected to decline. When inflow exceeds outflow, the reverse is true. When the system is in equilibrium, water levels will generally remain relatively constant despite short-term fluctuations. Long-term groundwater level declines are a clear indication that outflow has been exceeding inflow for an extended period of time. It should also be noted that in many areas, the recovery of groundwater levels due to groundwater being removed from storage can take longer than the period to remove it depending on the volume removed from storage, precipitation trends and the geology of the basin.

Taking this one step further, under predevelopment conditions, a groundwater system is in equilibrium, a condition where inflow equals outflow. Groundwater pumping causes a disruption in this equilibrium, and recharge amounts and patterns can change. More often, discharge amounts and patterns are impacted. This includes the loss of phreatophytic vegetation (vegetation whose water requirements are met by roots tapping groundwater such as in the area of springs) and reduction or elimination of spring flow. All pumped water must be supplied by one or more of the following:

- Decreases in groundwater storage;
- Increased or induced recharge; and
- Decreased discharge either in the form of reduced subsurface outflow or decreases in natural forms of discharge such as evapotranspiration, spring flow or river base flow.

Regardless of the amount of groundwater pumped, there will always be groundwater drawdown (and the removal of water from storage) in the vicinity of pumping wells, a necessity to induce the flow of groundwater to said wells. For most groundwater systems, the change in storage in response to pumping is a transient phenomenon that occurs as the system readjusts to the pumping stress. The relative contributions of changes in storage, increases in recharge, and decreases in natural discharges evolve over time. As an example, upward leakage from the carbonate rock aquifer to the basin fill aquifer has been postulated as early as the 1960's (Walker & Eakin, 1963). Elevated pumping in the basin fill aquifer could induce greater upward leakage from the carbonate rock aquifer that correspondingly could result in reduced spring flow from those carbonate rocks.

If the system can come to a new equilibrium (i.e., a combination of increased recharge and/or decreased discharge), the storage decreases will stop, and inflow will again equal outflow. The amount of groundwater "available" for a future groundwater development project is therefore dependent on what these long-term changes are, and how these changes affect the environmental resources of the area. Numerical models are ideal tools to evaluate these issues in that the complexities of the groundwater system can be evaluated in detail, and assumptions of how the groundwater system works can be tested for internal consistency. Further, with advances in software available to the groundwater professional, the efficiency and associated costs of groundwater modeling have significantly decreased over the last two decades.

Groundwater inflow, outflow and storage estimates were provided where available in the previous sections. Based on a review of limited shallow groundwater levels in the Shoshone – Tecopa area, the groundwater system in the Shoshone and Tecopa area appears stable.

3.7 Future Groundwater Use and Discussion of Groundwater Availability

As shown in Table 3-2 and Figure 3-9, there has been an increased use of groundwater in the Nevada portion of the Amargosa Basin over the past 25 years. The potential for future development will be limited by both quantity and quality of water. However, as can be seen by the active duty for the Northern Amargosa River Basin, there is significant potential for pumping to increase considerably should water rights holders fully exercise their water rights. Given the over-allocated nature of the Northern Amargosa River Basin, significant impacts to the groundwater resource could result if that condition occurred. These uses are anticipated to increase due to future population growth, and the likely future addition of groundwater usage for solar energy development. Although wet cooling solar projects are not anticipated, groundwater usage for processes such as mirror washing will still be needed.

The incremental increase of solar projects within the region could result in a significant steepening of the increased trend in groundwater usage. The competing demands for renewable energy and protection of the Amargosa River point to the need for increased knowledge and baseline hydrologic data in the Middle Amargosa River Basin. Recommendations for future investigations are provided in Section 4.0 of this report.

4.0 RECOMMENDATIONS FOR WILD & SCENIC RIVER MANAGEMENT

Given the regional nature of the groundwater source that feeds the Wild and Scenic Amargosa River, it is clear that an effective monitoring program for the WSR will include sites well away from the River. Although the management plan will be for a specific water course, the unique hydrology and the expansive area that contributes to the river through complex groundwater flowpaths would make purely river-centric monitoring of limited value. Based on the results of current and past work, decreases in groundwater level and associated underflow in the northern Amargosa basin and Pahrump Valley (both in Nevada) could affect springs in the Middle Amargosa Basin and the Amargosa River fed by those springs.

The Amargosa River Basin, which spans two states, three counties and one National Park, exists as one of the most important desert waterways in the southwestern United States. Both the groundwater and surface water in the basin support a unique and diverse ecosystem, while also supporting human needs through domestic, agricultural, wildlife, stock-watering, mining and other industrial uses. As the river is a groundwater-fed surface water body, relatively small variations in the groundwater surface elevation can have considerable effects on the ability for the river to maintain surface flow. While the Nevada portion of the basin has been well-studied, primarily as a result of hydrologic studies centered on the Nevada Test Site and the Yucca Mountain Project, until recently the California portion of the basin has seen little in the way of regional hydrogeologic investigations. Therefore, it is essential that a monitoring program be incorporated into management of the WSR that identifies changes in the groundwater system, prior to the Amargosa River being impacted.

In the Northern Amargosa River Basin groundwater is already over-allocated. Although pumping does not currently take place at the full amount entitled to by water rights holders, considerable impacts to the groundwater reservoir and associated springs could occur should those holders eventually fully exercise their water rights. Groundwater usage within the Northern Amargosa River Basin has steadily increased over the past 25 years, and the addition of a new industry to the area (solar) will likely provide additional pressure on the groundwater resource. Also as groundwater usage increases in the Northern Amargosa River Basin, it is conceivable then that groundwater flow into the Middle Amargosa River Basin could decrease. Given the importance of the alluvial aquifer to many of the springs in the Middle Amargosa River Basin, this issue is of key importance to sustaining the Amargosa River.

In 2009, the Amargosa River between Shoshone and the terminus of the Amargosa Canyon received Wild and Scenic status through an act of Congress. As a result, the BLM is charged with developing a management plan for the Wild and Scenic portion of the River. It is essential that hydrogeologic characterization of the California portion of the basin continue to take place in order for that management plan, and its associated management recommendations, to have a firm basis, and to assure that monitoring is conducted in a meaningful way to identify potential impacts to the river and its feeder springs before irreversible impacts from future groundwater development occur. Based on the results of the current and past hydrologic work along the Amargosa River, the following sections highlight technical needs that should be incorporated into a management plan for the Amargosa WSR.

4.1 Monitoring

Monitoring forms the basis for any water management activities in that it is impossible to manage any resource without a basis for what that resource comprises. The recommendations provided below contain provisions for both automated monitoring techniques and regular field monitoring. In desert areas where river channel or spring conditions can radically change as the result of one summer thunderstorm, having regular field observations taking place is key to not only monitor the resource, but to assure that automated data collection devices are working correctly (and to perform maintenance) and that physical conditions on the ground have not changed to the extent that automated data collection is compromised (e.g. river changing course and stream gage station no longer accurately measuring flow).

As described in Section 3.0, flow along the Amargosa River will be highly sensitive to changes in groundwater level. Generally, water rises to the surface of the river channel where constrictions are encountered forcing water to the surface. Groundwater monitoring will therefore be an essential component to river management. Additionally, infestation of non-native vegetation such as tamarisk will also have a negative effect on river flow and spring flow where it is present at spring discharge points. Visual monitoring of vegetation, particularly for the presence of tamarisk or other water-using, non-native vegetation will be a key component of river management.

AZI makes the following monitoring recommendations:

- **Spring Discharge, Water Level, Precipitation and Seepage Run Monitoring** - Flow discharge and groundwater elevation measurements should continue and be collected on a regular basis from the existing suite of springs and wells being monitored in addition to new wells. Seepage run monitoring should continue to be conducted periodically (at least three times per year) on the stretch of River from Tecopa to the Dumont Dunes area and should continue to consist of the existing five distinct monitoring locations (including the two USGS gauges, and three manual monitoring points). Basic field water quality data should be collected at all discharge, elevation and seepage run monitoring points.
- **Groundwater Level Measurements** should be collected regularly, preferably with pressure transducer/data logger installations at all existing (currently in place) and future monitoring wells. The existing monitoring wells (ARHS-01 through ARSH-04) should continue to be monitored as part of the Wild and Scenic Monitoring Program for the following reasons:
    - ARHS-01- North of Shoshone – identification of changes in groundwater level north of Shoshone Spring area resulting from pumping in northern part of basin;
    - ARHS-02- Willow Creek – identification of changes in groundwater level that may affect the most important tributary to the Wild and Scenic Amargosa River;

- ARHS-03 – Twelvemile Spring – Identification of changes in groundwater level that may indicate reduced movement of groundwater from Pahrump Valley beneath northern portion of Nopah Range; and,
- ARHS-04 – "Married Man's Camp" - identification of changes in groundwater level that may affect Willow Creek above the Willow Creek station.

Other wells to be monitored will include those new wells listed for future installation in Section 4.2.

- **Visual Monitoring** – Photographic and video (where applicable) documentation should be collected from specific locations to identify noticeable changes in the spring and river environments. This will assist in identification of tamarisk or other non-native vegetation encroachment that could affect river and spring flows. Additionally, periodic cross-checking with aerial imagery should be conducted to identify changes to areas not specific to monitoring sites.
- **Groundwater Usage** – Monitoring existing and proposed groundwater usage throughout the basin both in Nevada and California will be a key monitoring component protective of the WSR.

4.2 Additional Investigation

Currently, there is insufficient information to develop a groundwater budget for the Middle Amargosa River Basin or for that matter to specifically identify recharge locations for specific springs. Attempting to evaluate groundwater recharge and groundwater underflow into the basin will be difficult both from a technical standpoint and in funding what would be a major investigative endeavor. Therefore, the most logical means to evaluate the groundwater budget for the Middle Amargosa River Basin will be to develop a firm understanding of the various groundwater discharge components including evapotranspiration (including spring flow), subsurface underflow beyond Salt Creek and analyzing associated groundwater level trends. The recommendations for additional investigations are based on AZI's experience in the Amargosa Basin and elsewhere, from M.L. Davisson & Associates, Inc., and from the USGS (2013, 2014).

Based in the results of current investigative work, and in order to accomplish the larger goals of the project, the following lines of investigation to refine the conceptual model for the Middle Amargosa Basin should be considered fall into three categories including; 1) monitoring well installation to improve our understanding of the system and provide protective monitoring points; 2) additional investigation for sourcing of springs and the river; and 3) additional investigations to better understand the overall system.

- **Additional Piezometer/Monitoring Well Installation** – Up to 13 piezometers/monitoring wells (wells) should be installed to further evaluate the conceptual model of this part of the Amargosa Basin with an emphasis on understanding groundwater flow paths; and for supplemental monitoring to evaluate baseline groundwater conditions and identification of impacts to groundwater levels in the future should they occur. AZI anticipates the wells would consist of both shallow (assumed depth of 25 feet below ground surface (ft bgs)) and deep (assumed depth of up to 200 ft bgs) wells. We anticipate wells in the following general locations:

- One deep well in the alluvial aquifer between Eagle Mountain and Shoshone (anticipated depth to groundwater in this area is approximately 200 ft bgs);
- Two shallow wells along the Amargosa River between Shoshone and Tecopa;
- Two monitoring wells along the Amargosa River south of the Amargosa River Canyon (one near the site of Sperry and the other at the end of the graded dirt road north of Dumont Dunes);
- One shallow well along the Amargosa River near Tecopa and the USGS Amargosa River gaging station there;
- Four deep wells in the area northeast, east and southeast of Tecopa to evaluate flow coming from Chicago Valley and the Kingston Range, and,
- Up to three monitoring wells in California Valley / Southwest Pahrump Valley to evaluate connectivity between the two valleys.

Deep monitoring wells in the carbonate rock aquifer would be particularly helpful in evaluating flow paths and refining the conceptual model. However, they would also be costly. At this time, as it is anticipated that most future groundwater production will occur in the basin fill aquifer, a focus on monitoring wells in the basin fill is recommended here. Should sufficient funding become available for the installation of deep monitoring wells that could penetrate the carbonate rock aquifer in a meaningful way, locations that should be considered would be at Twelvemile Spring; ARHS-01 north of Shoshone, and in the Death Valley Junction/Eagle Mountain area.

- **Geochemical Sampling of New Piezometers/Monitoring Wells** - Water samples should be collected from new wells and analyzed for a specific suite of constituents, including field parameters, general chemistry, anions, cations, a comprehensive suite of trace metals, and selected stable/non-stable isotopes as presently being conducted with the exception of tritium which would no longer be analyzed.
- **Low-levels Metals Analysis** – Although metals analysis has been conducted at springs in the Middle Amargosa Basin, many of the metals are not detectable at standard laboratory detection limits. Metals suites can be quite informative to understanding the relationship between waters, so this would entail specialized analysis to obtain metals concentration information at substantially lower detection limits than typically conducted.
- **Radiocarbon Dating and Chlorofluorocarbons (CFCs) Analysis** – Carbon-13 and Carbon-14 analysis along with CFCs to age date waters, particularly in light of the results of the current analysis. Measuring radiocarbon abundance of spring water in the Amargosa River Valley with

the lowest helium ratios would indicate either high flux along faults or whether waters are very old.

- **Measure additional $^3He/^4He$ ratios –** Between Ash Meadows and Tecopa area to provide a continuum of ratios with downgradient distance and would facilitate the development of a groundwater age model.
- **Analysis of Salts in Discharge Areas** – To identify elements in discharge areas that may be introduced into spring waters at specific discharge points and their solubilities that may alter the chemical makeup of waters. This would provide comparative data to spring water containing high concentrations of total dissolved solids to determine if this is a viable mechanism to explain spring water compositions.
- **Geophysical Investigations** – Geophysical surveys in the vicinity of Tecopa to evaluate faulting in the vicinity of the thermal springs. Additional surveys north of ARHS-01 to evaluate the geologic connectivity between the northern portion of the basin and the area south of Eagle Mountain. This would also help inform our understanding of monitoring results in that area.
- **Installation of Four Precipitation Stations** – To evaluate areal and elevation variations in precipitation in the area (for greater understanding of the water budget of the area and to provide information useful in distributing recharge in the numerical groundwater flow model) and to refine our understanding of recharge sources and the effects of precipitation events on groundwater-level fluctuations, four precipitation stations should be installed at the following locations:
  - The south flank of Eagle Mountain;
  - Twelvemile Spring;
  - Saratoga Spring; and
  - Horsethief Spring (in the Kingston Range).

Precipitation samples could be collected from these stations (particularly the Kingston Range station) to evaluate recharge sources. These precipitation stations would also provide key data for any future investigations on effects of climate change on the Amargosa River and its feeder springs. These locations (along with the existing station in Tecopa) provide good areal coverage and spanning a wide elevation range (from approximately 200 ft msl to 4,600 ft msl). Permitting would be required by the BLM and Death Valley National Park (for Saratoga Spring). At this time, it is planned that data downloading would be accomplished during quarterly events as part of the hydrologic monitoring. It is anticipated that NOAA-II precipitation gages would be installed, manually serviced, and fitted with data loggers and flash memory data collection modules. The stations would be able to account for snow water content which would be of particular importance at the Kingston Range location (Horsethief Spring area). Precipitation stations would be secured by fencing.

4.3 Development of River Management Tool

The development of a refined numerical groundwater flow model for the Middle Amargosa Basin area should be developed as a management tool upon which to base future water management decisions. Ideally, the model would be created using the industry standard program MODFLOW originally developed by the USGS. The model should be developed in a means (e.g., using standard format files) that allows such a tool to be used efficiently and cost-effectively by groundwater professionals fluent in groundwater flow modeling representing governmental, non-profit and for profit private sector constituents and stakeholders. This will enable all future projects to be evaluated using the same tool which is useable in a timely, cost effective manner.

4.4 Periodic Updating of Technical Requirements

Best Management Practices (BMPs) for future groundwater development projects in the Amargosa River region should be established that are focused on protection of the Wild and Scenic Amargosa River. The monitoring proposed is a starting point. With additional monitoring wells as listed in Section 4.2 and additional investigations being conducted, the monitoring program will likely need to adapt to meet our growing knowledge of how the Amargosa River system works. The Wild & Scenic management plan then will need to be a dynamic plan, able to guide the management of the river with our ever growing knowledge of how it works and sustains its fragile ecology.

5.0 CONDITIONS AND LIMITATIONS

This report has been prepared according to generally accepted standards of hydrogeologic practice in California at the time this report was prepared. Findings, conclusions, and recommendations contained in this report represent our professional opinion and are based, in part, on information developed by other individuals, corporations, and government agencies. The opinions presented herein are based on currently available information and developed according to the accepted standards of hydrogeologic practice in California. Other than this, no warranty is implied or intended.

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FIGURES

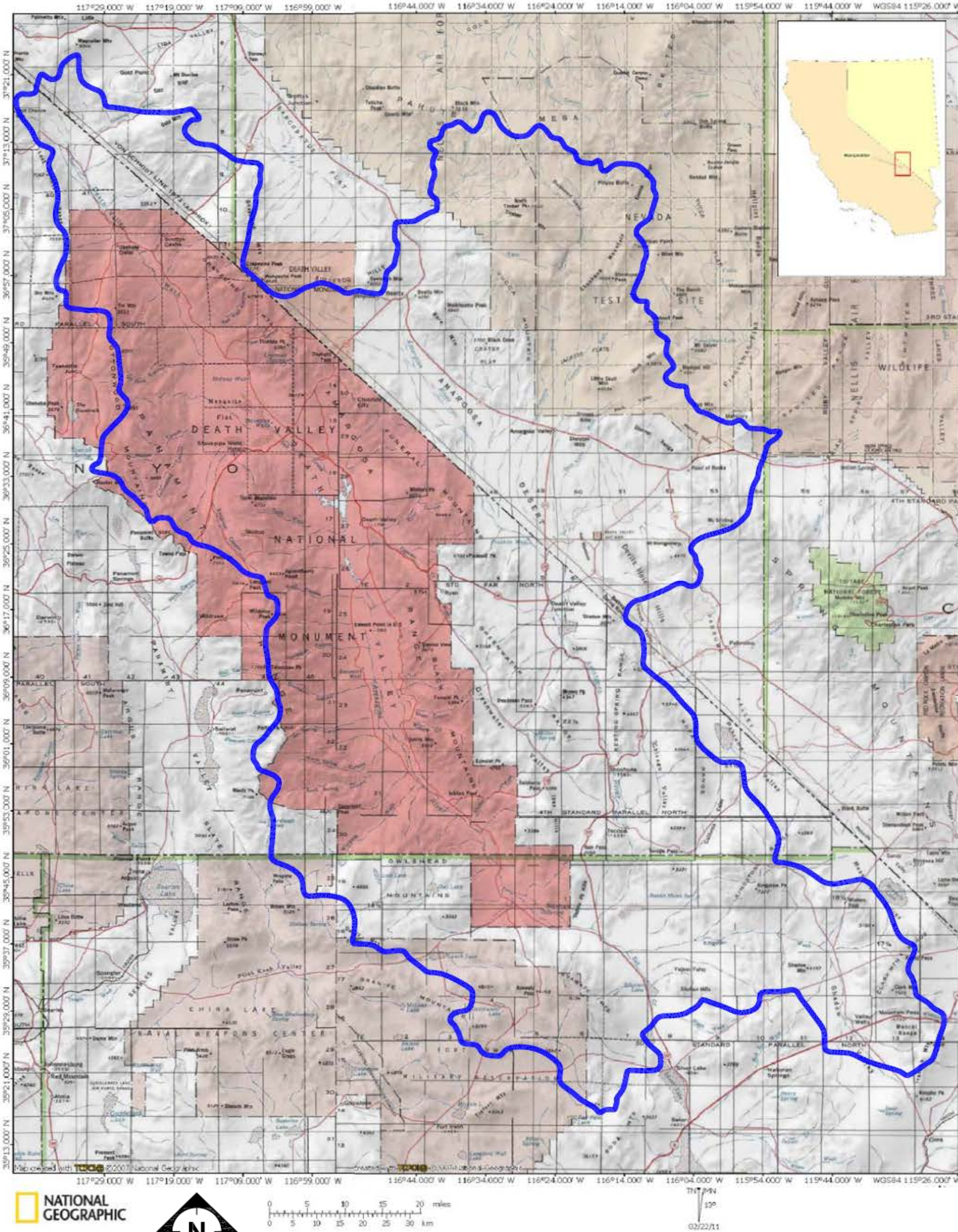

Figure 1-1. Location of Amargosa River Drainage Basin

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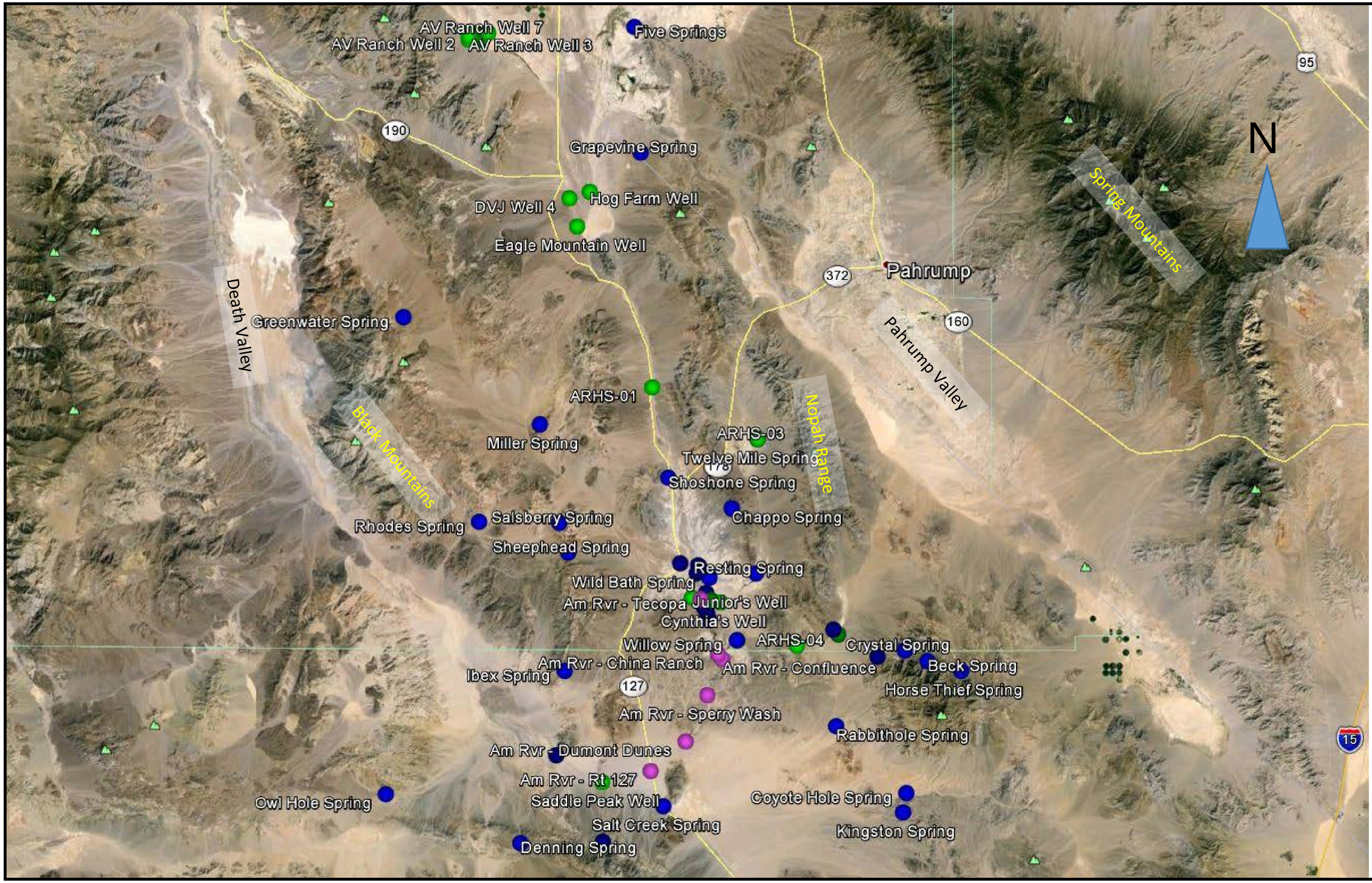

Figure 2-1

Data Collection Locations Map

Legend

- River Location
- Well Location
- Spring Location

Scale: 1" = ~10 miles

Date: June 10, 2014
Project: TNC – Amargosa
Image Source: Google Earth

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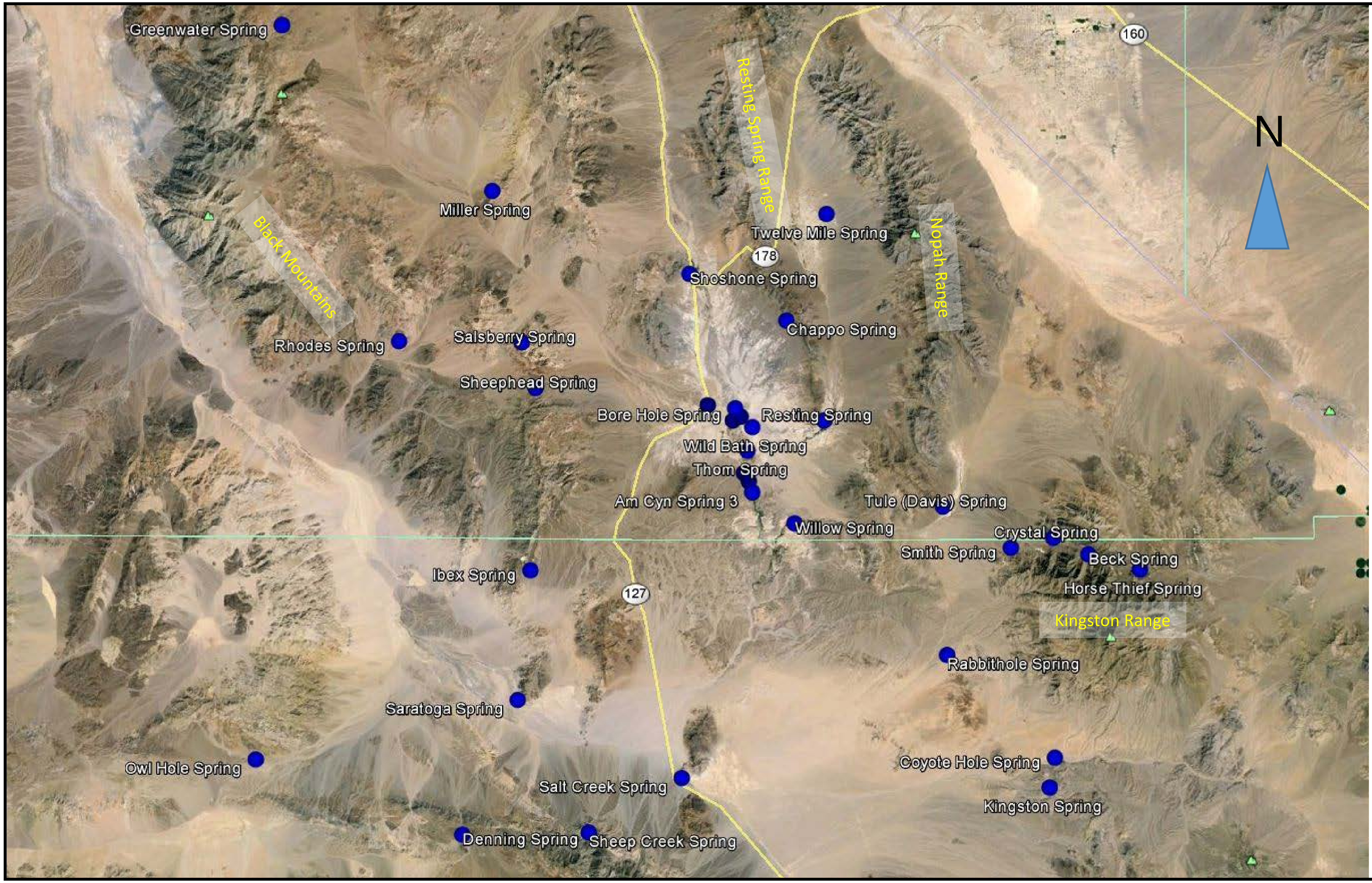

Figure 2-2

Spring Location Map

Legend

Spring Location

Scale: 1" = ~6 miles

Date: June 3, 2014
Project: TNC – Amargosa
Image Source: Google Earth

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Figure 2-3

River and Well Location Map

Legend

- River Location
- Well Location

Scale: 1" = ~6 miles

Date: June 3, 2014
Project: TNC – Amargosa
Image Source: Google Earth

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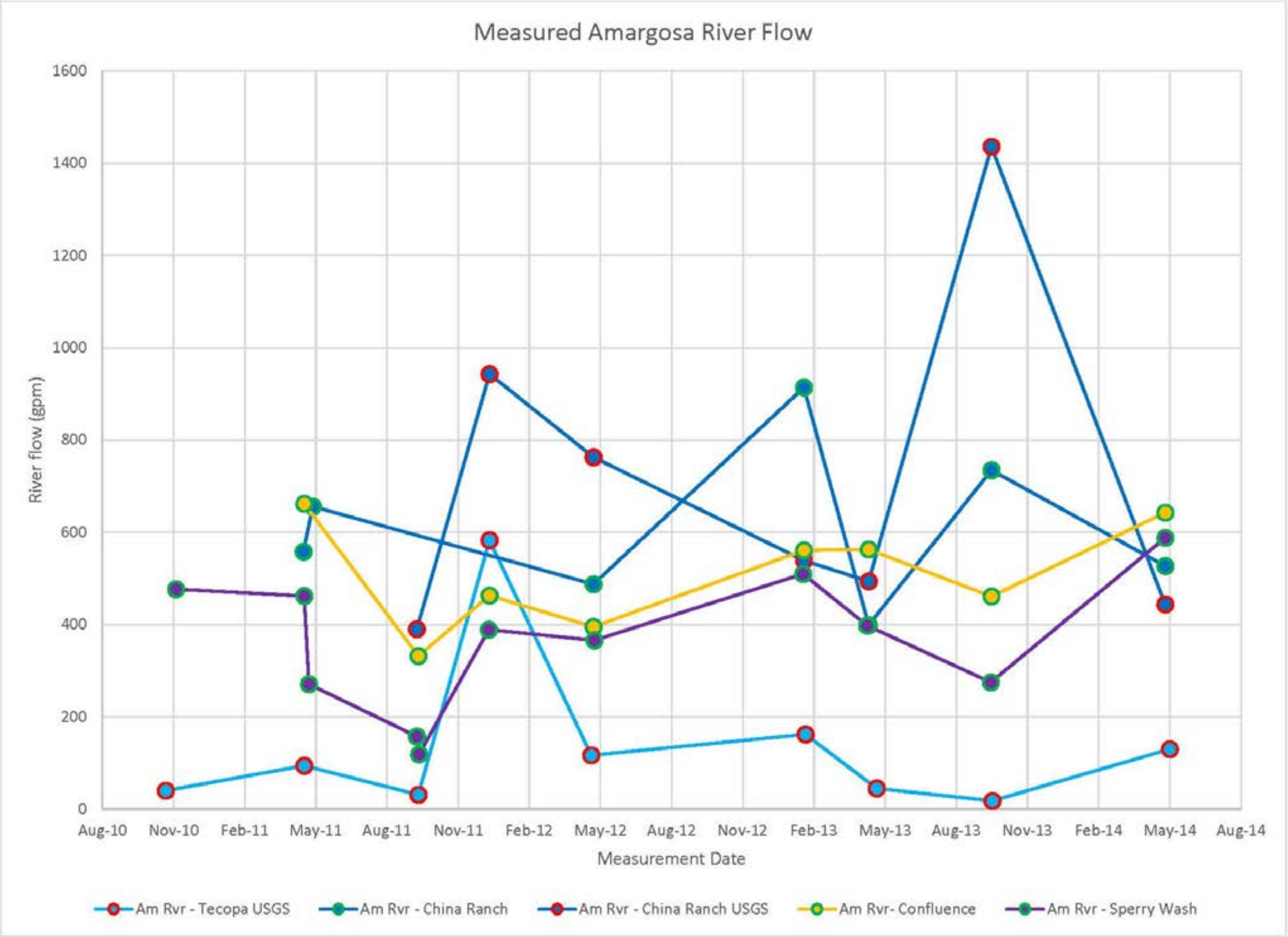

Figure 2-4

Amargosa River Hydrographs Periodic Monitoring Data

Date: June 23, 2014
Project: TNC – Amargosa

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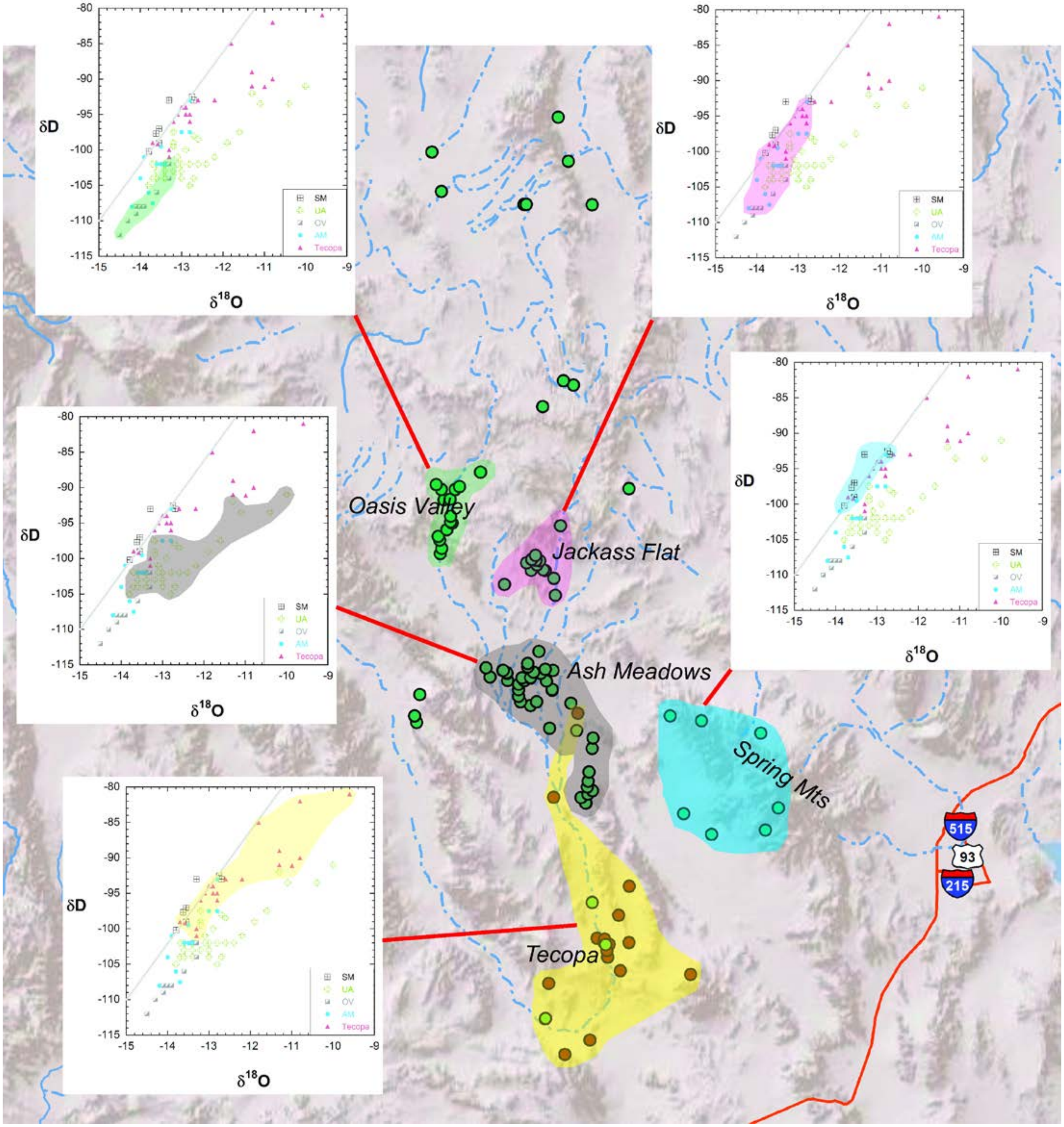
Figure 2-5 Passive Diffusion Sampler
Used for Noble Gas Sampling



δD-δ18O plots are compared as regional groupings in this map view. Note that the range in δD and δ18O values decreases in general from north to south and that the Tecopa region groundwater overlaps most with Spring Mts. and Ash Meadows. This suggests that either are potential sources for Tecopa groundwater, although for the latter mixing with Spring Mts. or possibly Kingston Range recharge would be required.

Figure 2-6 Regional Stable Isotope Groupings

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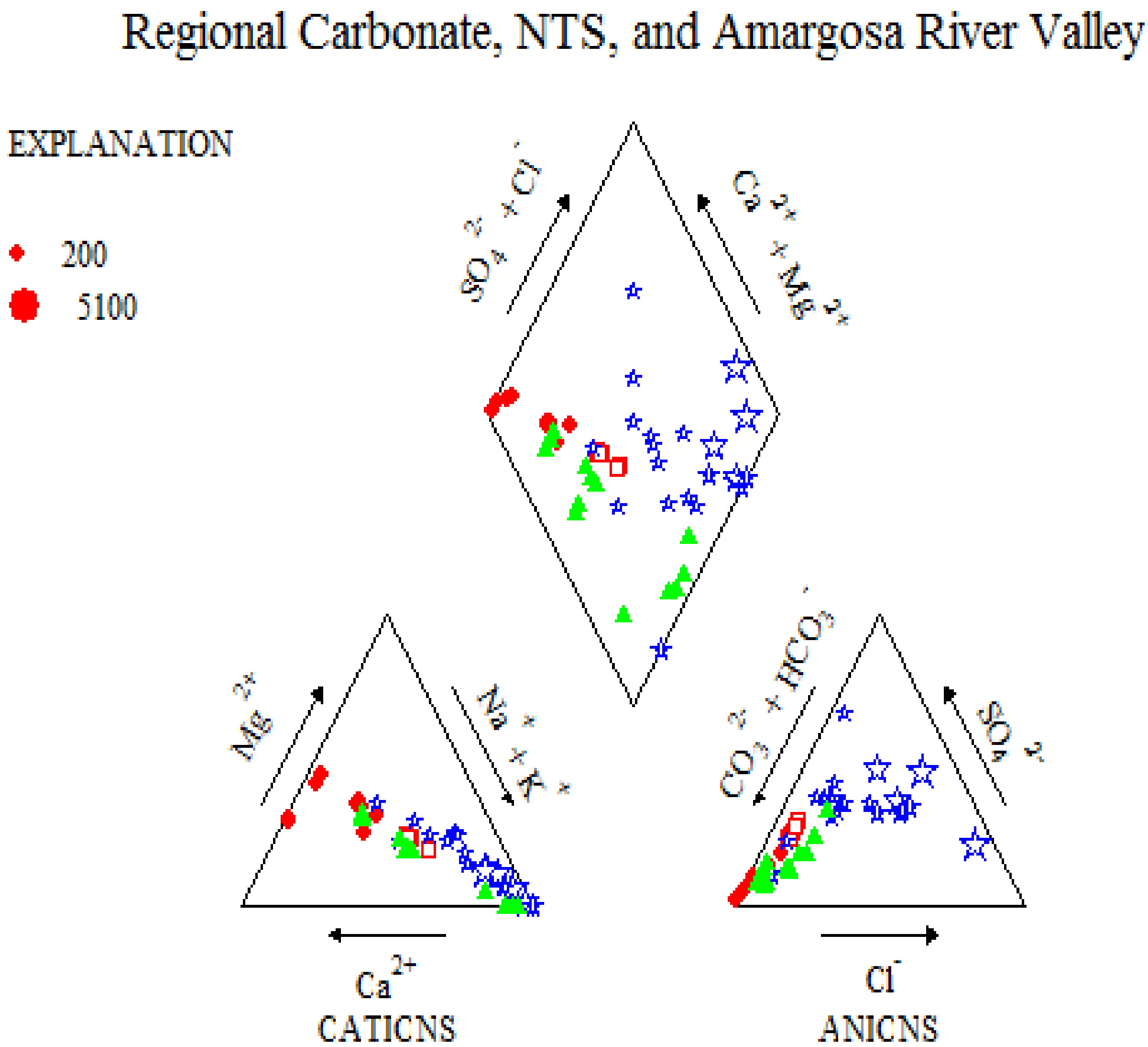

Piper plot comparing cation and anion relative concentrations in groundwater of the regional carbonate aquifer (red circles), Ash Meadows (open red squares), Nevada Test Site (green triangles), and Amargosa River Valley (open blue stars). Note that between the regional carbonate aquifer and the Amargosa River Valley groundwater, water quality changes from Ca-Mg-HCO_3 type toward Na-K-HCO_3-Cl-SO_4 type accompanied by increased salinity.

Figure 2-7 Piper Plot for Amargosa Region Waters

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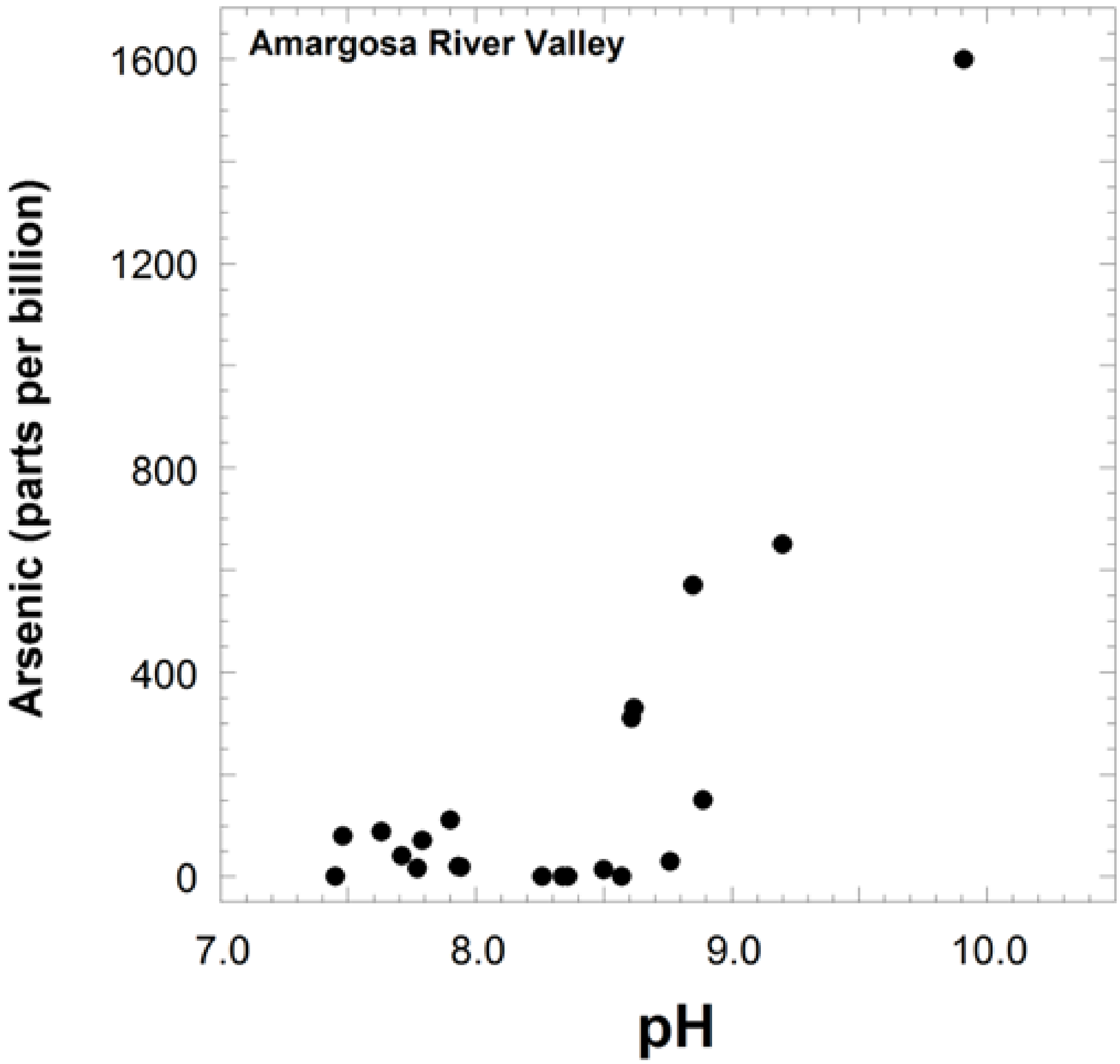

Arsenic solubility increases with increasing pH as illustrated by groundwater in the Amargosa River Valley region. The ultimate source of arsenic is not known but could be associated with the Tecopa lake beds deposits.

Figure 2-8 Arsenic and pH Relationships, Middle Amargosa Waters

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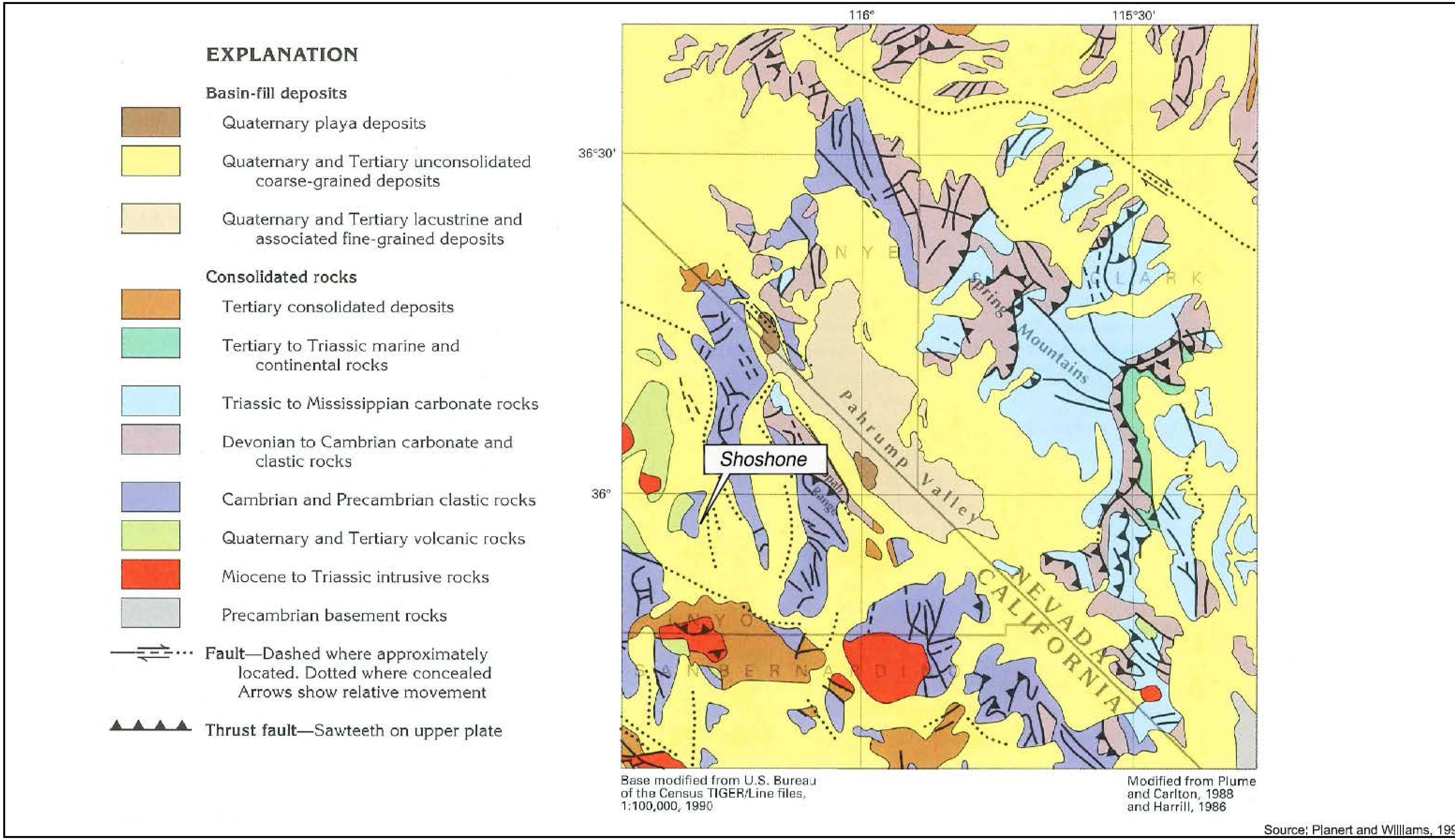
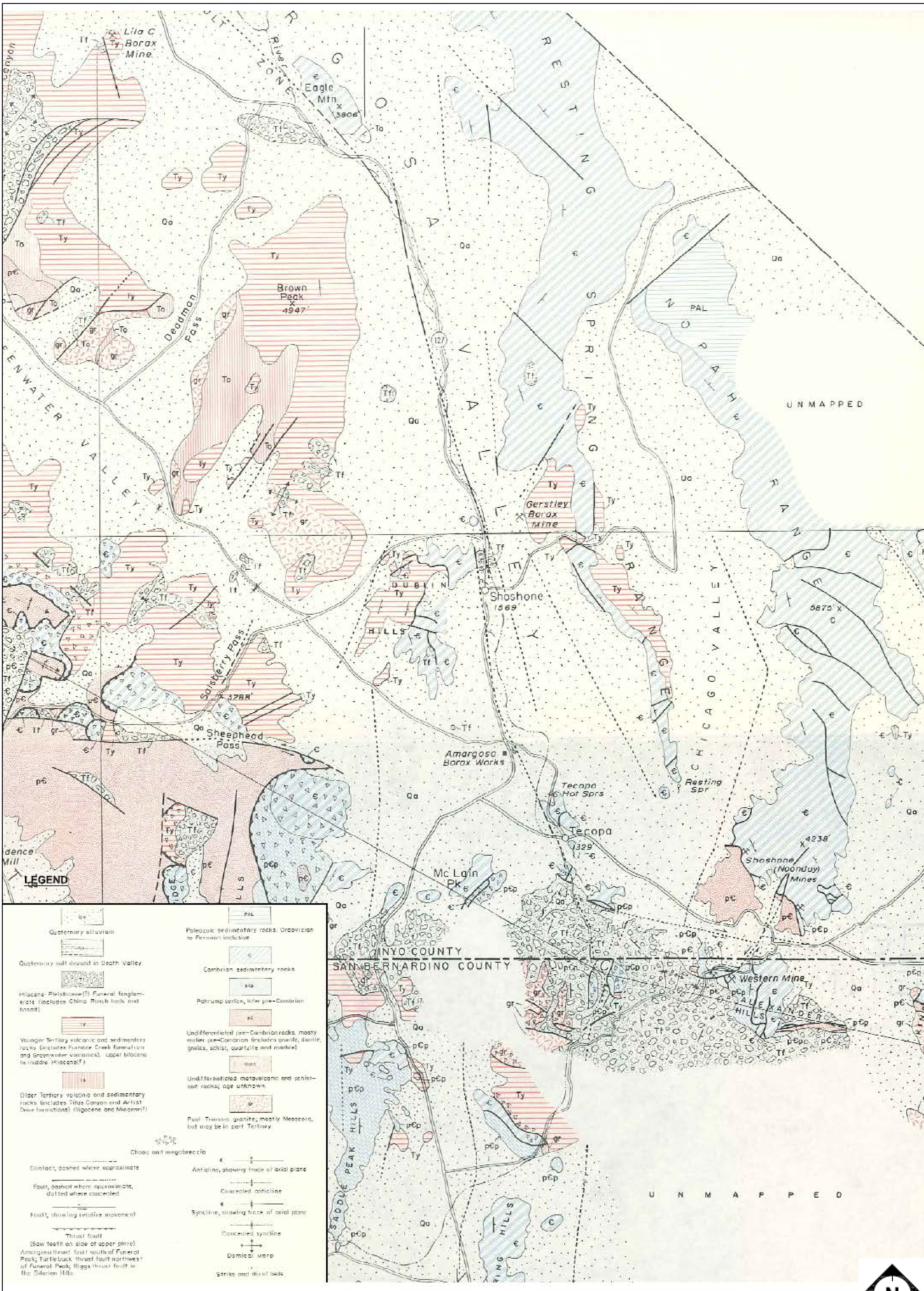


Figure 3-1. Regional Geologic Map



SOURCE:
STATE DEPARTMENT OF CALIFORNIA, DEPARTMENT OF NATURAL RESOURCES, DIVISION OF MINES, BULLETIN 170, CHAPTER II, CONTRIBUTION 10, PLATE 7, 1954.

Figure 3-2. Geology of the Shoshone-Tecopa Area

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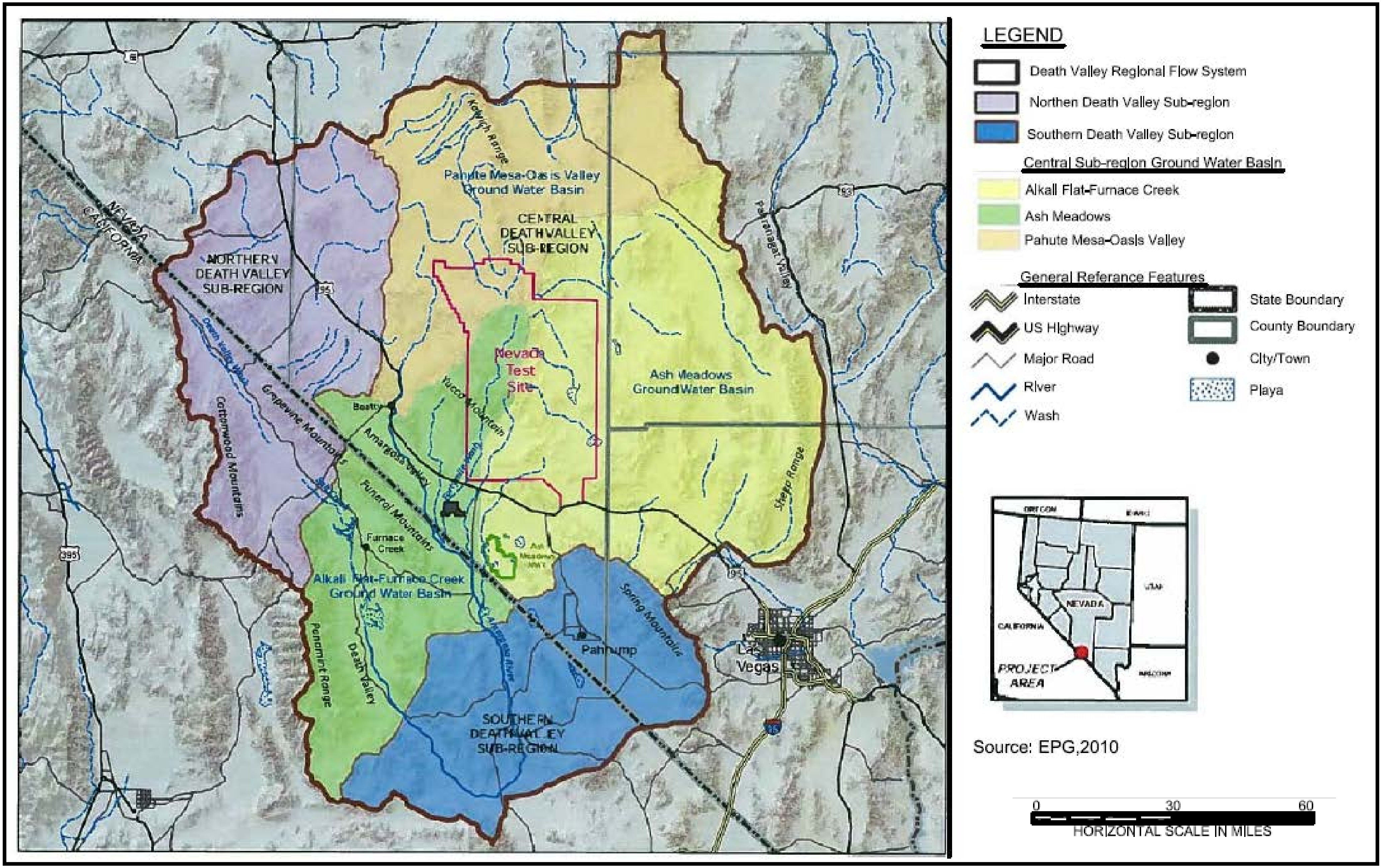

Figure 3-3. Extent of the Death Valley Regional Flow System

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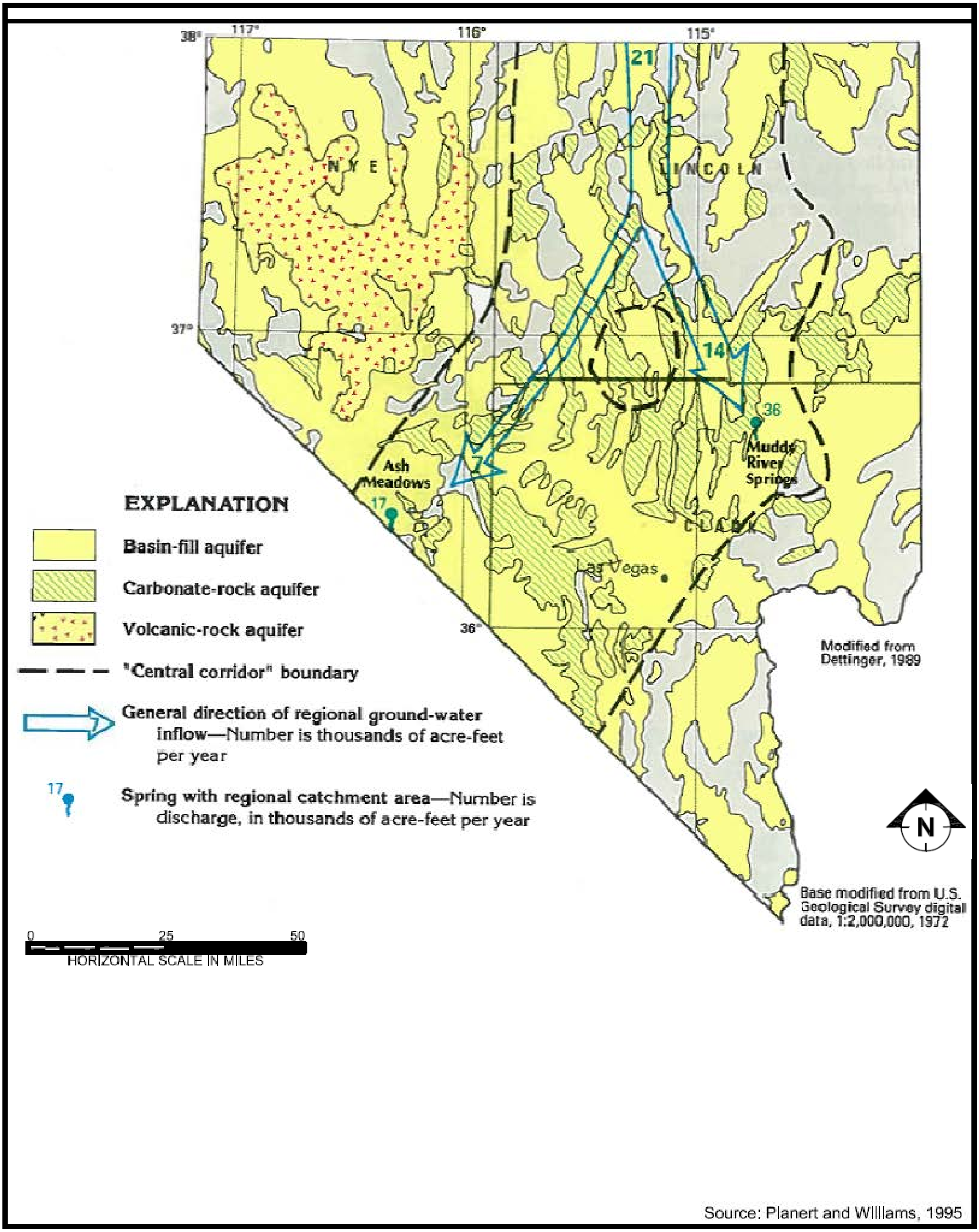

Figure 3-4. Paths for Regional Groundwater Flow – Nevada Portion of Basin

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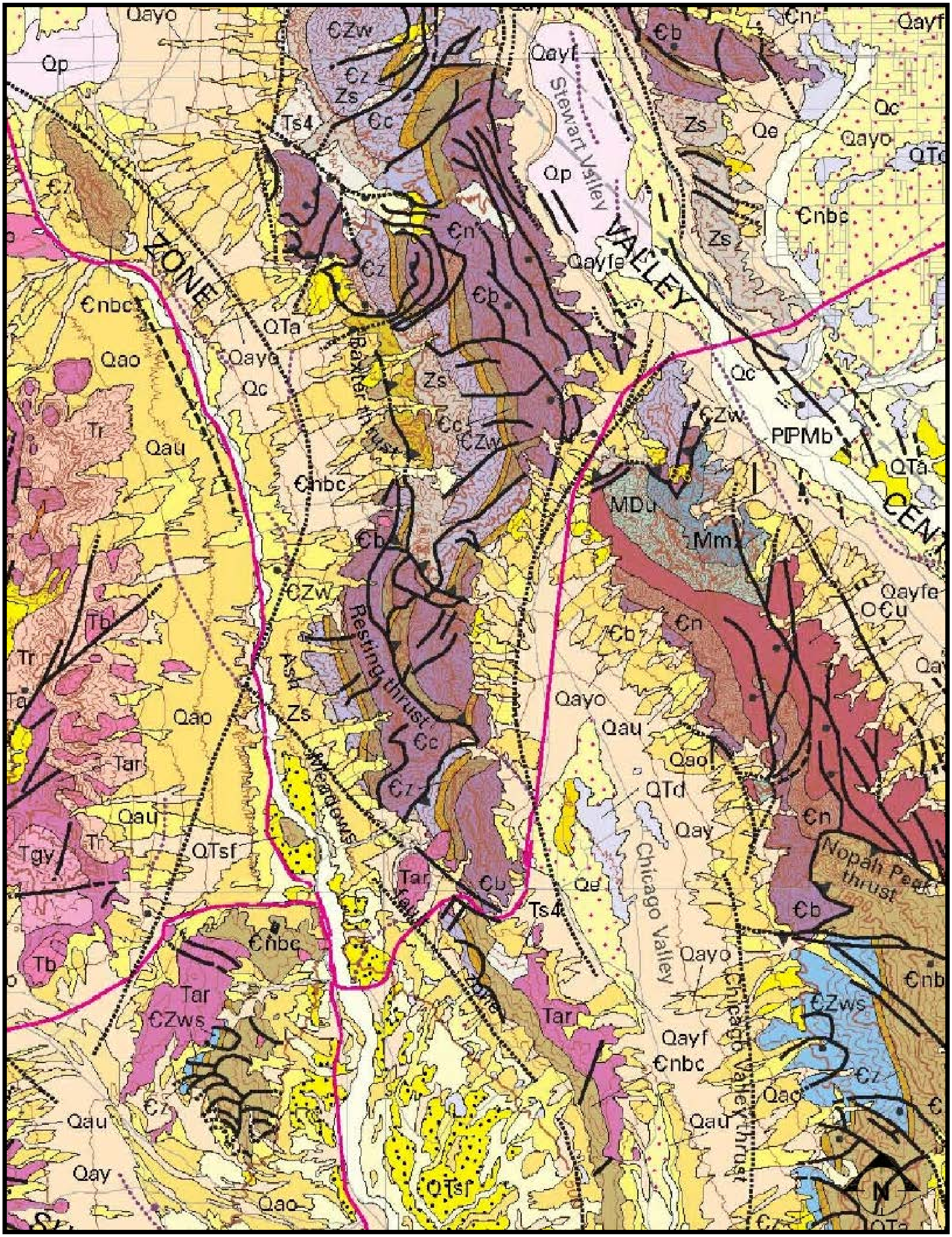

Figure 3-5. Geology of Chicago Valley Area (Workman 2002)

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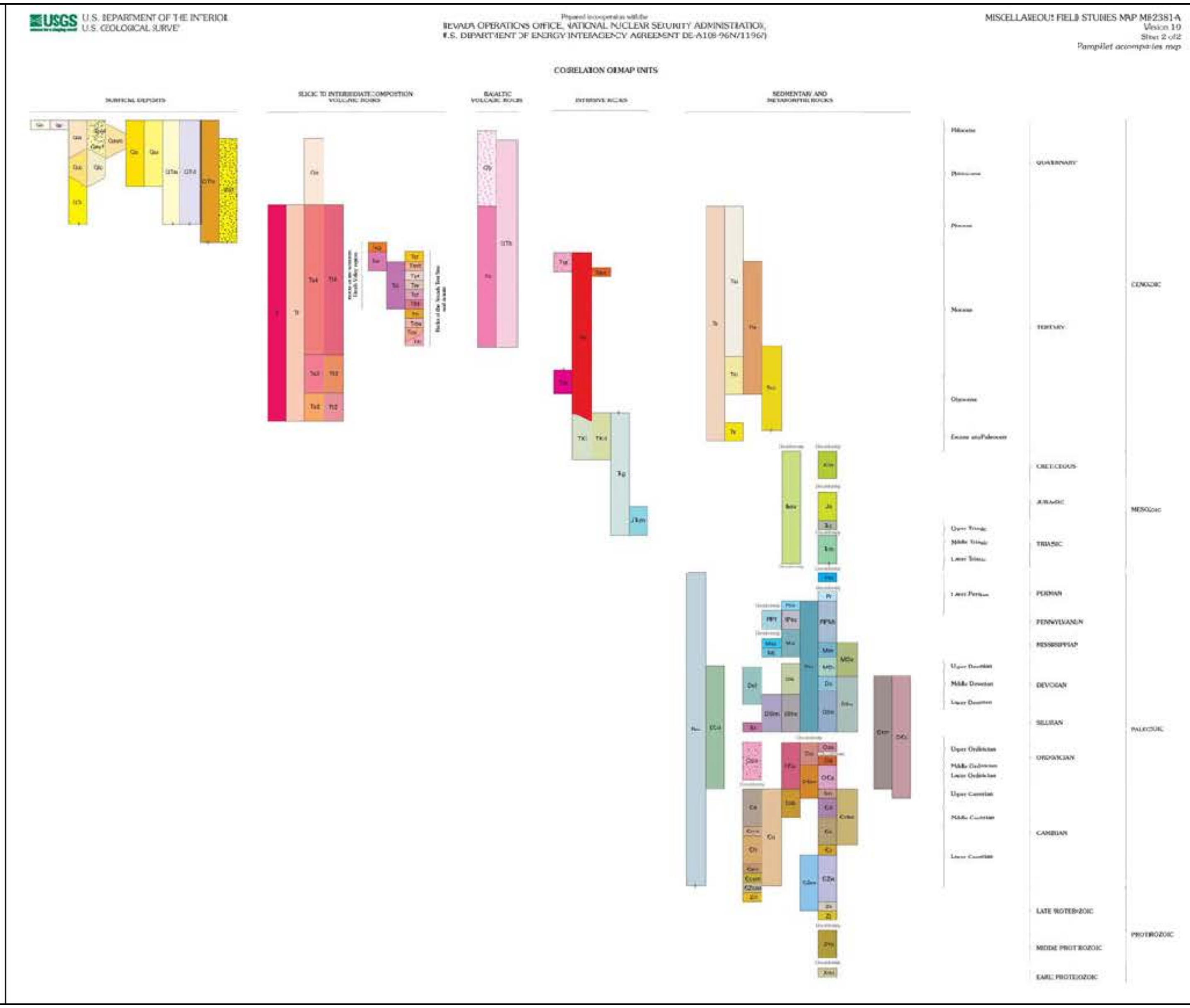

Figure 3-5A. Geology of Chicago Valley Area, Stratigraphy Section (Workman 2002)

LIST OF MAP UNITS

SURFICIAL DEPOSITS

- Qc — Channel aluvium (Holocene)
- Qp — Playa and (or) salt pan deposits (Holocene)
- Qay — Young alluvium (Holocene to latest Pleistocene?)
- Qayf — Young finegrained alluvium (Holocene to latest Pleisocene?)
- Qayе — Evaporite surface crust of salts and (or) carbonate (Holocene to latest Pleistocene?)
- Qayc — Intermediate-age alluvium (middle Holocene to latest Pleistocene?)
- Qe — Eolian deposits (Holocene to middle Pleistocene)
- Qau — Undifferentiated alluvium (Holocene to Pleistocene)
- QTau — Undifferentiated older alluvium (Holocene to latest Tertiary)
- QTd — Deposits associated with modern or past ground-water discharge (Holocene to late Tertiary)
- QTls — Landslide block (Holocene to late Tertiary)
- QTsl — Old alluvial, paludal, or lacustrine sediments (Pleistocene to late Tertiary)
- Qao — Old alluvium (late to middle Pleistocene)
- Qlc — Old lacustrine deposits (late to middle Pleistocene)
- QTa — Oldest alluvium (middle Pleistocene to late Tertiary)

BEDROCK UNITS

SILICIC TO INTERMEDIATE-COMPOSITION VOLCANIC ROCKS

- Qa — Young intermediate-composition lava flows, undivided (Pleistocene)
- Tv — Volcanic rocks, undivided (Pliocene to Oligocene)
- Tr — Felsic-composition lava flows, undivided (Pliocene to Oligocene)
- Ta4 — Intermediate-composition lava flows, unit 4 (Pliocene and Miocene)
- Tt4 — Ash-flow tuffs and interbedded air-fall tuffs, unit 4 (Pliocene and Miocene)

Rocks of the southern Death Valley region (Miocene)

- Tvg — Greenwater Volcanics
- Tcr — Intermediate- to felsic-composition lava flows of the central Death Valley volcanic field
- Tss — Intermediate- to felsic-composition lava flows of the southern Death Valley-Kingston Range volcanic belt

Rocks of the Nevada Test Site and vicinity (Miocene)

- Tst — Stonewall Flat Tuff and tuffs of the Thirsty Canyon Group, undivided
- Tmt — Tuffs of the Timber Mountain Group
- Tpt — Tuffs of the Paintbrush Group
- Tw — Wahmonie and Salyer Formations, undivided
- Tct — Tuffs of the Crater Flat Group
- Tbt — Tuffs of the Belted Range Group
- Tlt — Lithic Ridge Tuff, rhyolite of Picture Rock, Tunnel Formation, and comendite of Quartet Dome, undivided
- Tqv — Volcanic rocks of Quartz Mountain
- Tuv — Older ash-flow tuffs and lava sequences, undivided
- Tkv — Lava flows of the Belted Range
- Ta3 — Intermediate-composition lava flows, unit 3 (Miocene and Oligocene)
- Tt3 — Ash-flow tuffs and interbedded air-fall tuffs, unit 3 (Miocene and Oligocene)
- Ta2 — Intermediate-composition lava flows, unit 2 (Oligocene)
- Tt2 — Ash-flow tuffs and interbedded air-fall tuffs, unit 2 (Oligocene)

BASALTIC VOLCANIC ROCKS

- Qb — Young basaltic lava flows (Holocene to Pleistocene)
- QTb — Basaltic lava flows, undivided (Pleistocene to Miocene)
- Tb — Old basaltic lava flows (Pliocene to Miocene)

INTRUSIVE ROCKS

- Tgy — Young granitic intrusive rocks (Miocene)
- Tei — Younger intermediate-composition intrusive rocks (Miocene to Oligocene)
- Tws — Gabbro to diorite intrusive rocks of Willow Springs (Miocene)
- Tgo — Older granitic intrusive rocks (Miocene? to Oligocene)
- TKi — Older intermediate-composition intrusive rocks (Oligocene to Cretaceous)
- TKd — Mafic intrusive rocks (Oligocene to Cretaceous)
- TRg — Oldest granitic intrusive rocks (Tertiary? to Triassic)
- JTRqm — Avawatz Mountains quartz monzodiorite, undivided (Early Jurassic to Late Triassic)

SEDIMENTARY AND METAMORPHIC ROCKS

- Ts — Sedimentary rocks, undivided (Pliocene to Eocene)
- Ts4 — Sedimentary rocks, unit 4 (Pliocene and Miocene)
- Tls — Landslide and mega-breccia deposits (Miocene to Oligocene)
- Tso — Sedimentary rocks older than the rocks of the Nevada Test Site and vicinity (Miocene to Eocene?)
- Ts3 — Sedimentary rocks, unit 3 (Miocene and Oligocene)
- Ts1 — Sedimentary rocks, unit 1 (Eocene and Paleocene)
- Msv — Sedimentary and volcanic rocks, undivided (Mesozoic)
- Klw — Lavinia Wash sequence (Upper and Lower Cretaceous)
- Ja — Aztec Sandstone (Jurassic)
- TRc — Chinle Formation (Upper Triassic)
- TRm — Moenkopi Formation (Middle? and Lower Triassic)
- Pzu — Sedimentary rocks, undivided (Paleozoic)
- Pkt — Kaibab and Toroweap Formations, undivided (Lower Permian)
- Pr — Redbeds (Lower Permian)
- Pov — Owens Valley Group (Lower Permian)
- PSu — Sedimentary rocks, undivided (Permian to Silurian)
- PPMb — Bird Spring (Lower Permian and Pennsylvanian) and Indian Springs Formations (Upper Mississippian)
- PPt — Tippipah Limestone (Lower Permian and Pennsylvanian)
- PPkc — Keeler Canyon Formation (Lower Permian to Middle Pennsylvanian)
- Mu — Sedimentary rocks, undivided (Upper and Lower Mississippian)
- Msc — Scotty Wash Quartzite (Upper Mississippian) and Chainman Shale (Upper and Lower Mississippian), undivided
- Mm — Monte Cristo Group (Upper and Lower Mississippian)
- MDe — Eleana Formation (Mississippian and Upper Devonian)
- Mj — Joana Limestone (Lower Mississippian)
- MDu — Sedimentary rocks, undivided (Lower Mississippian and Upper and Middle Devonian)
- Dlb — Lost Burro Formation (Upper and Middle Devonian)
- DCd — Dolomite and limestone, undifferentiated (Devonian to Upper Cambrian)
- Dsl — Slope-facies carbonate rocks (Upper to Lower Devonian)
- Ds — Simonson Dolomite (Middle Devonian)
- DSu — Sedimentary rocks, undivided (Devonian and Silurian)
- DЄm — Mountain Springs Formation (Middle Devonian, Lower Ordovician, and Upper Cambrian)
- DЄu — Mountain Springs (Middle Devonian, Lower Ordovician, and Upper Cambrian) and Nopah Formations (Upper Cambrian), undivided
- DSsl — Sevy (Middle and Lower Devonian) and Laketown (Upper and Middle Silurian) Dolomites, undivided
- DSlm — Lone Mountain Dolomite (Lower Devonian and Silurian)
- DShv — Hidden Valley Dolomite (Lower Devonian and Silurian)
- Sr — Roberts Mountains Formation (Silurian)
- Opk — Palmetto Formation (Upper, Middle, and Lower Ordovician)
- OЄu — Sedimentary rocks, undivided (Ordovician and Upper Cambrian)
- Oeo — Ely Springs Dolomite (Upper Ordovician) and Eureka Quartzite (Upper and Middle Ordovician), undivided
- Oes — Ely Springs Dolomite (Upper Ordovician)
- Oe — Eureka Quartzite (Upper and Middle Ordovician)
- OЄpn — Pogonip Group (Middle and Lower Ordovician and Upper Cambrian) and Nopah Formation (Upper Cambrian), undivided
- OЄp — Pogonip Group (Middle and Lower Ordovician and Upper Cambrian)
- Єe — Emigrant Formation (Upper and Middle Cambrian)
- Єu — Sedimentary rocks, undivided (Upper to Lower Cambrian)
- Єnb — Nopah (Upper Cambrian) and Bonanza King Formations (Upper and Middle Cambrian), undivided
- Єn — Nopah Formation (Upper Cambrian)
- Єnbc — Nopah (Upper Cambrian), Bonanza King (Upper and Middle Cambrian), and Carrara Formations (Middle and Lower Cambrian), undivided
- Єb — Bonanza King Formation (Upper and Middle Cambrian)
- Єc — Carrara Formation (Middle and Lower Cambrian)
- Єms — Mule Spring Limestone (Lower Cambrian)
- Єh — Harkless Formation (Lower Cambrian)
- Єz — Zabriskie Quartzite (Lower Cambrian)
- ЄZws — Wood Canyon Formation (Lower Cambrian and Late Proterozoic) and Stirling Quartzite (Late Proterozoic), undivided
- ЄZw — Wood Canyon Formation (Lower Cambrian and Late Proterozoic)
- Єpo — Poleta Formation (Lower Cambrian)

Campito Formation (Lower Cambrian and Late Proterozoic)

- Єcam — Montenegro Member (Lower Cambrian)
- ЄZcaa — Andrews Mountain Member (Lower Cambrian and Late Proterozoic)
- Zd — Deep Spring Formation (Late Proterozoic)
- Zs — Stirling Quartzite and Reed Dolomite, undivided (Late Proterozoic)
- Zj — Johnnie and Wyman Formations, undivided (Late Proterozoic)
- ZYp — Pahrump Group (Late and Middle Proterozoic)
- Xmi — Metamorphic and igneous rocks, undifferentiated (Early Proterozoic)

Figure 3-5B. Geology of Chicago Valley Area, Map Key

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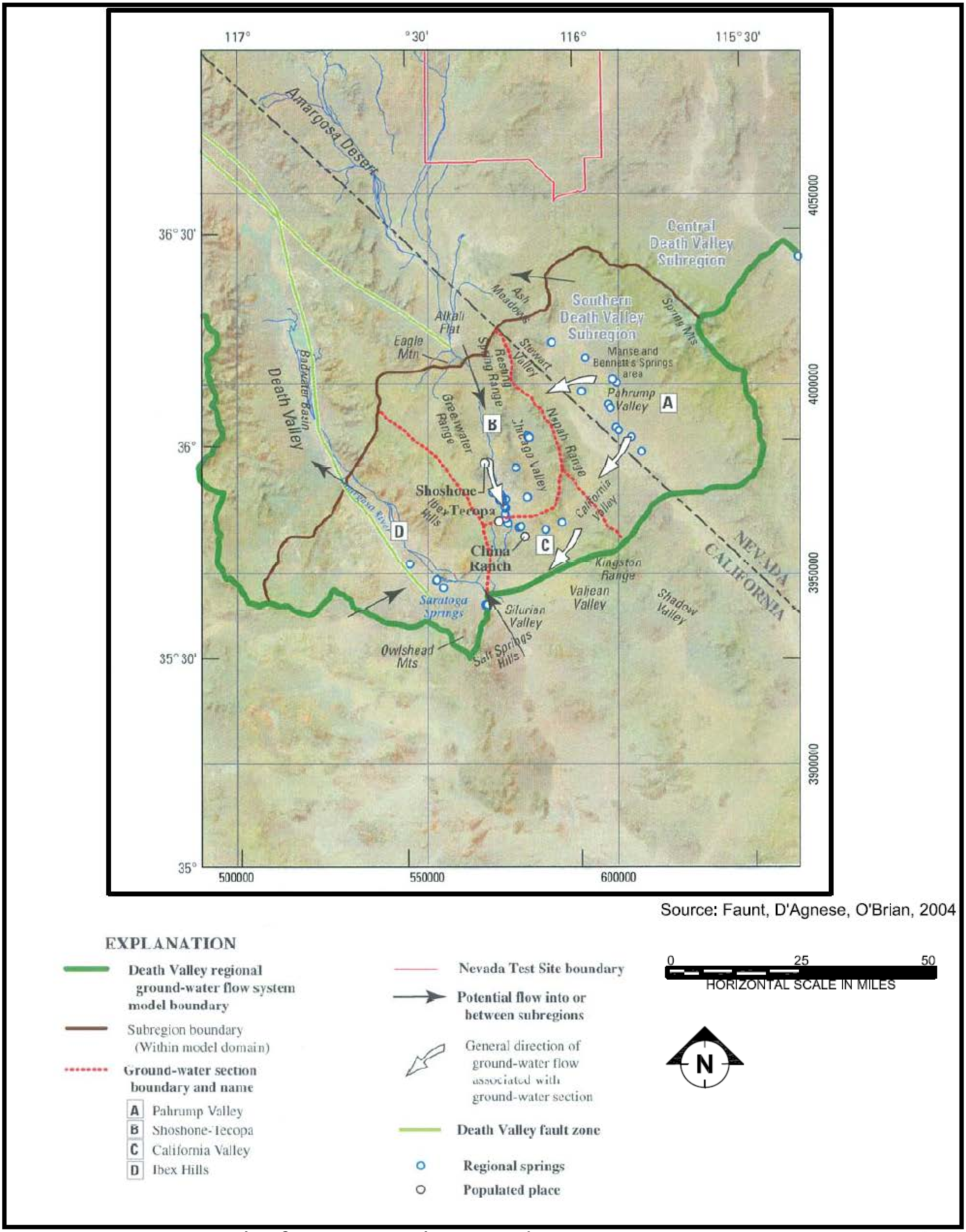

Source: Faunt, D'Agnese, O'Brian, 2004

Figure 3-6. Paths for Regional Groundwater Flow – Middle Amargosa River and Death Valley Basins

ANDY ZDON & ASSOCIATES, INC.

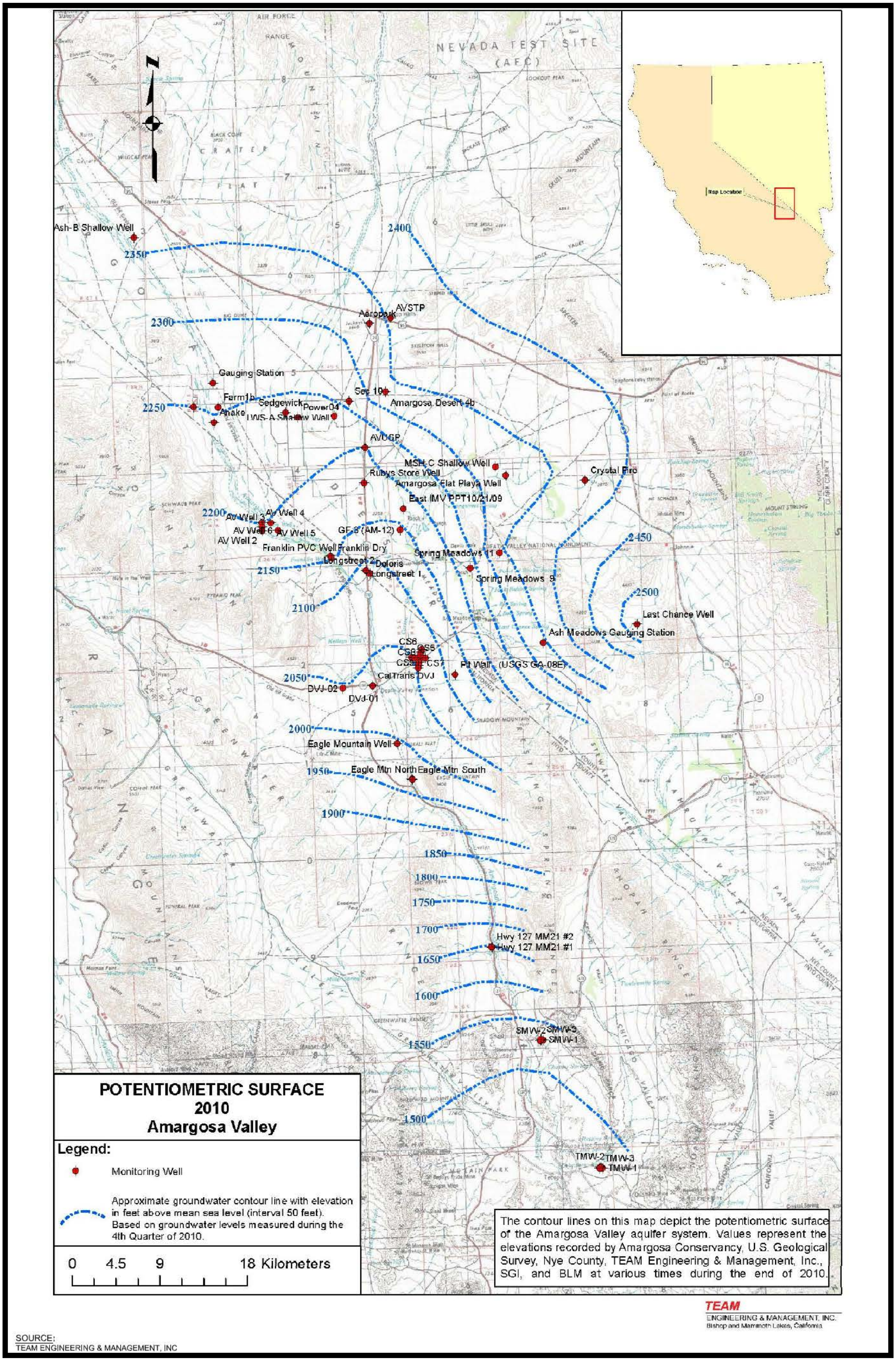

Figure 3-7. Potentiometric Surface Map – 4th Quarter 2010

ANDY ZDON & ASSOCIATES, INC.

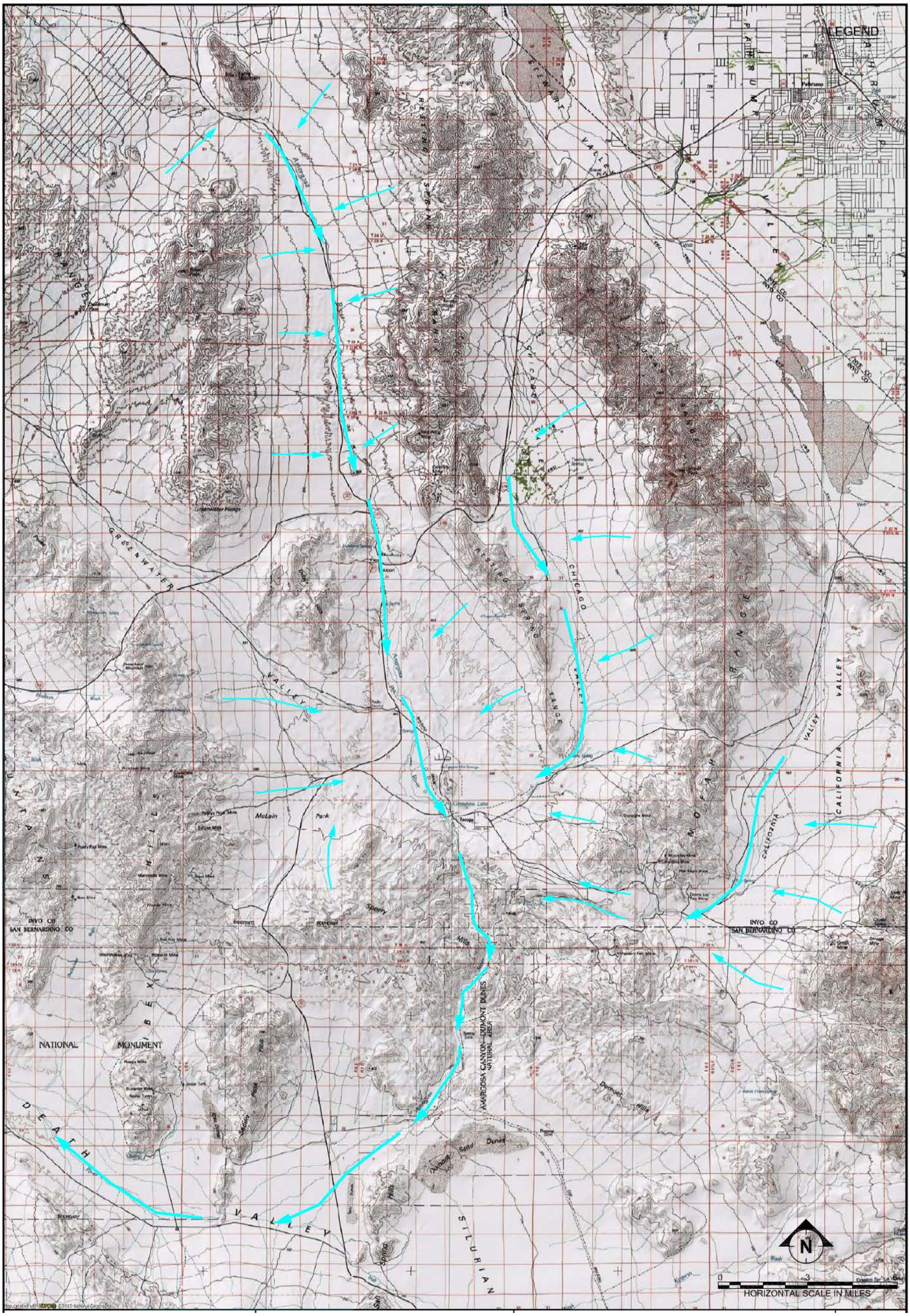

Figure 3-8. Conceptual Shallow Alluvium Flow Paths Within the Middle Amargosa River Basin

ANDY ZDON & ASSOCIATES, INC.

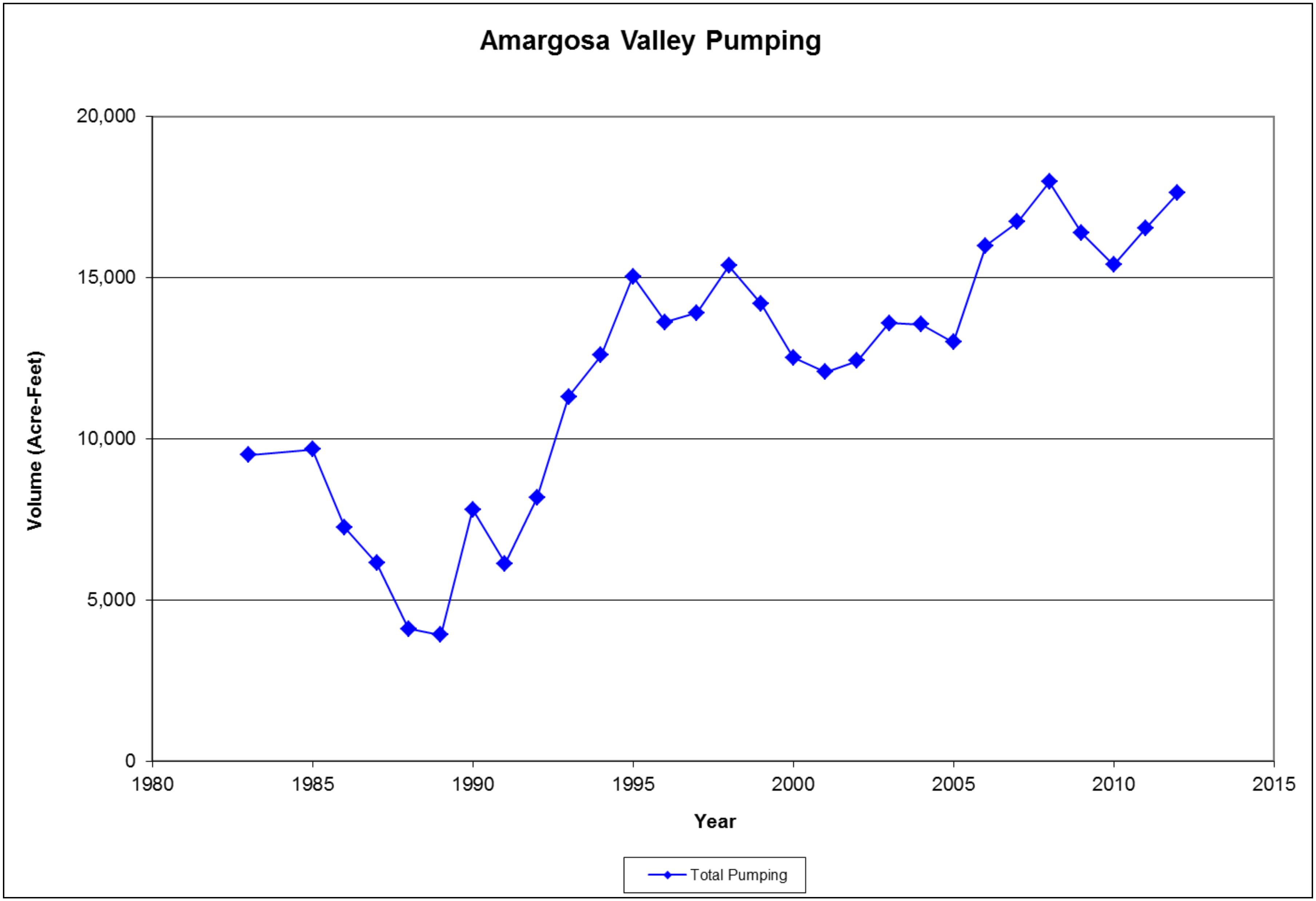

Figure 3-9. Pumping vs. Time, Amargosa Desert Area, Nevada

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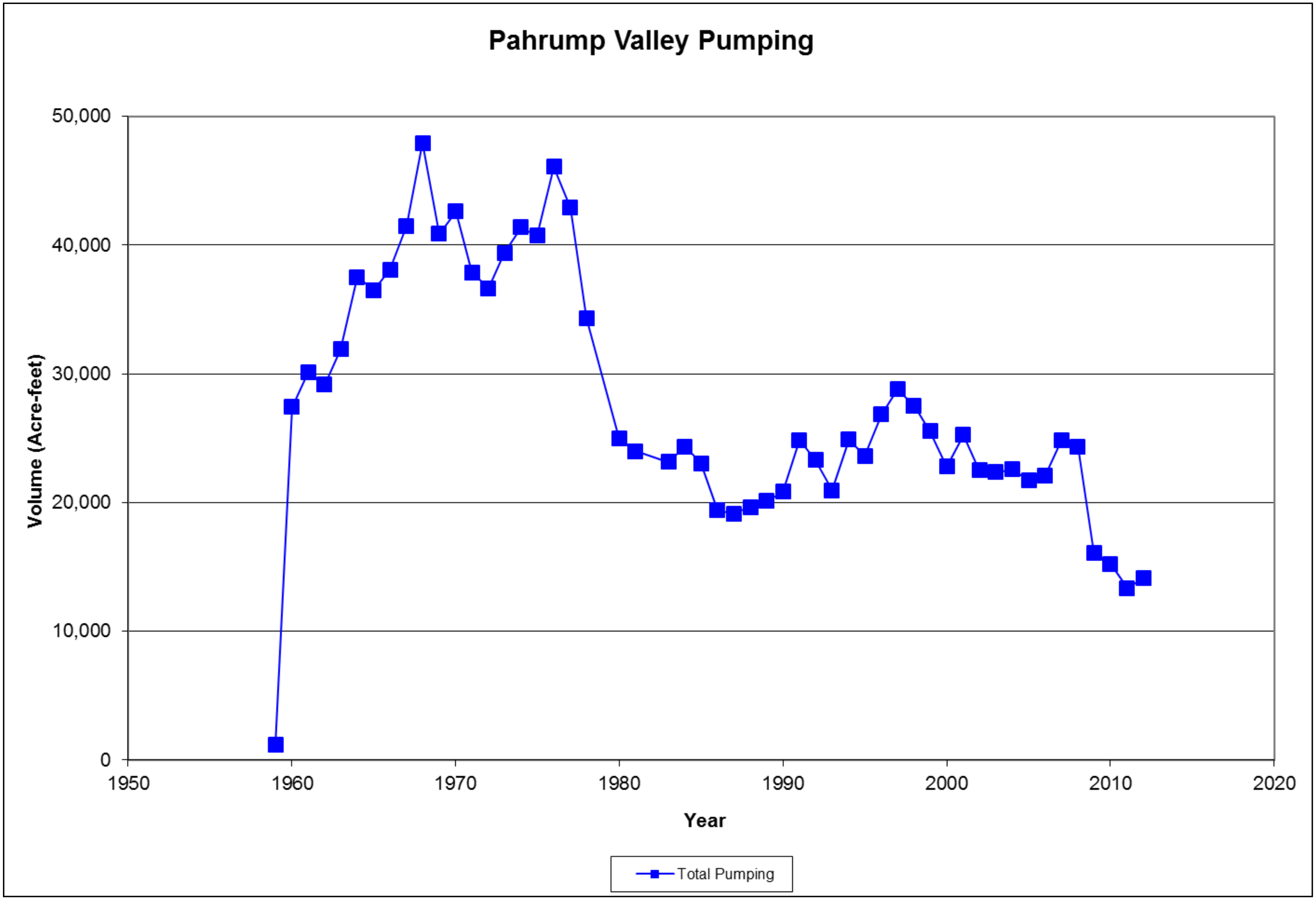

Figure 3-10. Pumping vs. Time, Pahrump Valley, Nevada

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TABLES

Table 2-1
Field Reconnaissance Data Summary
Amargosa Basin
California/Nevada

Name	Date of Visit	Latitude	Longitude	Elevation (ft amsl)	Flow (gpm)	Flow Measurement Method*	Temp. (deg C)	Spec. Cond. (mS/cm-deg C)	TDS (mg/L)	DO (mg/L)	pH	ORP (mV)	Notes
Springs													
Amargosa Canyon Spring 1	11/17/2010	35.83937	116.22399	1,294	38	meter	23.22	1.053	685	7.42	7.93	105.3	North end of Amargosa Canyon in burned area
Amargosa Canyon Spring 1	4/25/2011	35.83937	116.22399	1,294	--	--	22.46	1.029	669	8.62	7.94	253.5	North end of Amargosa Canyon in burned area
Amargosa Canyon Spring 1	5/11/2011	35.83937	116.22399	1,294	66.1	bucket	--	--	--	--	--	--	North end of Amargosa Canyon in burned area
Amargosa Canyon Spring 1	9/21/2011	35.83937	116.22399	1,294	40.5	bucket	25.79	1.076	700	7.74	8.12	-42.4	North end of Amargosa Canyon in burned area
Amargosa Canyon Spring 1	12/22/2011	35.83937	116.22399	1,294	78	meter	18.73	1.009	656	7.96	8.22	77.4	North end of Amargosa Canyon in burned area
Amargosa Canyon Spring 1	5/1/2012	35.83937	116.22399	1,294	67.7	bucket	23.27	0.573	363	9.28	8.33	18.7	North end of Amargosa Canyon in burned area
Amargosa Canyon Spring 1	1/26/2013	35.83937	116.22399	1,294	80.2	bucket	21	1.274	828	12.32	8	61.7	North end of Amargosa Canyon in burned area
Amargosa Canyon Spring 1	4/19/2013	35.83937	116.22399	1,294	83.4	bucket	22.44	1.02	663	8.4	7.67	-106.5	North end of Amargosa Canyon in burned area
Amargosa Canyon Spring 1	9/25/2013	35.83937	116.22399	1,294	61	bucket	23.74	0.886	576	5.09	7.85	-180.4	North end of Amargosa Canyon in burned area
Amargosa Canyon Spring 1	5/6/2014	35.83937	116.22399	1,294	72.4	bucket	22.3	1.348	878	7.29	8.17	68.2	North end of Amargosa Canyon in burned area
Amargosa Canyon Spring 3	1/12/2011	35.82701	116.21942	1,262	30	visual	16.74	1.698	1104	9.68	8.51	186.4	Southern most Amargosa Canyon spring
Amargosa Canyon Spring 3	4/25/2011	35.82701	116.21942	1,262	25-30	visual	21.1	1.506	979	9.51	8.37	261.8	Southern most Amargosa Canyon spring
Amargosa Canyon Spring 3	9/21/2011	35.82701	116.21942	1,262	16	meter	25.79	1.597	1035	8.57	8.26	-17.8	Southern most Amargosa Canyon spring
Amargosa Canyon Spring 3	5/6/2014	35.82701	116.21942	1,262	10.4	bucket	20.9	1.861	1229	8.88	8.55	58.5	Southern most Amargosa Canyon spring
Amargosa Canyon Spring 4	1/12/2011	35.8348	116.2226	1,382	25	visual	26.05	0.915	596	8.07	8.34	182.2	Amargosa Canyon spring eminating from east canyon wall
Amargosa Canyon Spring 4	4/25/2011	35.8348	116.2226	1,382	--	--	26.25	1.24	809	8.63	8.13	242.1	Amargosa Canyon spring eminating from east canyon wall
Amargosa Canyon Spring 4	5/11/2011	35.8348	116.2226	1,382	7.7	bucket	--	--	--	--	--	--	Amargosa Canyon spring eminating from east canyon wall
Amargosa Canyon Spring 4	9/21/2011	35.8348	116.2226	1,382	8.1	bucket	28.2	1.347	876	7.32	8.16	-18	Amargosa Canyon spring eminating from east canyon wall
Amargosa Canyon Spring 4	12/22/2011	35.8348	116.2226	1,382	9.1	bucket	26.15	1.273	828	7.34	8.33	111.3	Amargosa Canyon spring eminating from east canyon wall
Amargosa Canyon Spring 4	5/1/2012	35.8348	116.2226	1,382	7	bucket	26.11	1.22	795	9.93	8.6	28.4	Amargosa Canyon spring eminating from east canyon wall
Amargosa Canyon Spring 4	1/26/2013	35.8348	116.2226	1,382	7.9	bucket	26.39	1.537	999	9.42	8.31	55.2	Amargosa Canyon spring eminating from east canyon wall
Amargosa Canyon Spring 4	4/19/2013	35.8348	116.2226	1,382	7	bucket	26.64	1.333	867	8.4	7.86	-106.1	Amargosa Canyon spring eminating from east canyon wall
Amargosa Canyon Spring 4	9/25/2013	35.8348	116.2226	1,382	7	bucket	27.73	1.1	714	5.44	8.16	-168.5	Amargosa Canyon spring eminating from east canyon wall
Amargosa Canyon Spring 4	5/6/2014	35.8348	116.2226	1,382	~10	visual	26.4	1.64	1066	7.04	8.52	38.1	Amargosa Canyon spring eminating from east canyon wall
Beck Spring	11/19/2010	35.78359	115.9322	4,439	5	visual	17.91	0.54	351	3.97	7.14	161.6	Located in the Kingston Range
Borax Spring	1/12/2011	35.88804	116.25789	1,342	6.8	bucket	30.53	3.019	1963	0.61	9.91	-296.7	
Borax Spring	5/5/2011	35.88804	116.25789	1,342	6.9	bucket	--	--	--	--	--	--	
Borax Spring	9/21/2011	35.88804	116.25789	1,342	5.9	bucket	30.51	2.981	1938	1.71	10.14	-404.7	
Borax Spring	4/30/2012	35.88804	116.25789	1,342	5.7	bucket	30.52	2.74	1781	3.2	10.31	-217.1	pipe cracked on casing
Borax Spring	1/28/2013	35.88804	116.25789	1,342	5.8	bucket	30.02	3.451	2242	0.99	10.08	-107.5	pipe cracked on casing
Borax Spring	4/18/2013	35.88804	116.25789	1,342	6.1	bucket	30.44	2.985	1940	0.49	9.45	-307.2	pipe cracked on casing
Borax Spring	9/23/2013	35.88804	116.25789	1,342	6.1	bucket	30.14	2.498	1624	0.07	9.74	-324.8	pipe cracked on casing
Borax Spring	5/12/2014	35.88804	116.25789	1,342	8.1	bucket	29.8	3.234	2100	0.27	10.02	-260.2	pipe cracked on casing
Bore Hole Spring	11/11/2010	35.88608	116.23416	1,356	20	visual	47.77	4.156	2704	2.28	8.62	141.4	Likely part of Tecopa Hot Spring system
Bore Hole Spring	5/2/2011	35.88608	116.23416	1,356	20	visual	43.98	4.176	2711	1.95	8.71	109.5	Likely part of Tecopa Hot Spring system
Bore Hole Spring	9/21/2011	35.88608	116.23416	1,356	26.2	meter	47.48	4.202	2731	1.31	8.68	-74.6	Likely part of Tecopa Hot Spring system
Bore Hole Spring	4/30/2012	35.88608	116.23416	1,356	90	bucket	47.68	3.89	2529	0.16	8.93	-13.3	Likely part of Tecopa Hot Spring system
Bore Hole Spring	1/25/2013	35.88608	116.23416	1,356	105	meter/visual	46.83	4.852	3157	1.62	8.85	29.6	Likely part of Tecopa Hot Spring system
Bore Hole Spring	4/18/2013	35.88608	116.23416	1,356	81	meter/visual	47.75	4.202	2731	0.35	8.47	-143.3	Likely part of Tecopa Hot Spring system
Bore Hole Spring	9/24/2013	35.88608	116.23416	1,356	105.2	meter	46.59	3.571	2323	0.46	8.48	-240	Likely part of Tecopa Hot Spring system
Bore Hole Spring	5/10/2014	35.88608	116.23416	1,356	148	USGS[+]	46.3	4.453	2899	1.1	8.71	44.5	Likely part of Tecopa Hot Spring system
Chappo Spring	11/12/2010	35.94723	116.18992	1,989	<5	visual	24.52	0.782	508	0.92	7.48	48.9	
Chappo Spring	5/1/2011	35.94723	116.18992	1,989	<5	visual	23.23	0.755	491	3.81	7.81	82.6	
Chappo Spring	5/9/2014	35.94723	116.18992	1,989	<5	visual	26.6	0.996	650	0.83	7.47	82.7	
Crystal Spring	11/19/2010	35.79503	115.96176	3,808	5	visual	21.09	0.632	411	4.23	7.45	165.6	Located in the Kingston Range
Crystal Spring	4/26/2011	35.79503	115.96176	3,808	13.5	bucket	21.18	0.61	397	5.73	7.52	257.5	Located in the Kingston Range
Crystal Spring	9/22/2011	35.79503	115.96176	3,808	9.5	bucket	21.38	0.637	414	5.12	7.29	-0.4	Located in the Kingston Range
Crystal Spring	12/22/2011	35.79503	115.96176	3,808	8.3	bucket	21.3	0.607	395	4.26	7.45	153.1	Located in the Kingston Range
Crystal Spring	4/30/2012	35.79503	115.96176	3,808	5.9	bucket	21.19	0.586	381	6.06	7.61	34.2	Located in the Kingston Range
Crystal Spring	1/25/2013	35.79503	115.96176	3,808	6.8	bucket	20.86	0.732	476	5.68	7.43	50.1	Located in the Kingston Range
Crystal Spring	4/21/2013	35.79503	115.96176	3,808	5.4	bucket	21.19	0.638	415	5.26	6.93	-100.5	Located in the Kingston Range

Table 2-1
Field Reconnaissance Data Summary
Amargosa Basin
California/Nevada

Name	Date of Visit	Latitude	Longitude	Elevation (ft amsl)	Flow (gpm)	Flow Measurement Method*	Temp. (deg C)	Spec. Cond. (mS/cm-deg C)	TDS (mg/L)	DO (mg/L)	pH	ORP (mV)	Notes
Crystal Spring	9/24/2013	35.79503	115.96176	3,808	7.1	bucket	21.52	0.538	349	3.51	7.3	-192.7	Located in the Kingston Range
Crystal Spring	5/4/2014	35.79503	115.96176	3,808	4.3	bucket	21.2	0.949	--	3.54	7.43	--	Located in the Kingston Range
Dodge City Spring	5/4/2014	35.88018	116.22955	1,387	~20	visual	23	4.302	2795	8.2	8.79	80.4	Located near Tecopa Hot Springs
Five Springs	1/18/2011	36.46457	116.3193	2,349	30	bucket	34.44	0.523	336	3.96	7.77	107.1	Located in Ash Meadows
Five Springs	5/1/2011	36.46457	116.3193	2,349	28.6	bucket	34.24	0.693	454	4.44	7.6	179.3	Located in Ash Meadows
Five Springs	5/4/2012	36.46457	116.3193	2,349	22.1	bucket	34.52	0.664	432	5.26	7.68	30.1	Located in Ash Meadows
Five Springs	1/24/2013	36.46457	116.3193	2,349	23.8	bucket	34.18	0.826	536	4.68	7.69	38.6	Located in Ash Meadows
Five Springs	4/24/2013	36.46457	116.3193	2,349	23.8	bucket	34.41	0.718	467	4.18	7.25	-105.3	Located in Ash Meadows
Five Springs	9/23/2013	36.46457	116.3193	2,349	21	bucket	34.55	0.607	395	2.83	7.31	-195.6	Located in Ash Meadows
Five Springs	5/5/2014	36.46457	116.3193	2,349	23.5	bucket	34.3	0.873	566	3.83	7.59	97.3	Located in Ash Meadows
Horse Thief Spring	11/19/2010	35.77294	115.88824	4,637	5	visual	16.04	0.444	288	2.86	6.94	158.1	Located in the Kingston Range
Horse Thief Spring	4/26/2011	35.77294	115.88824	4,637	10.1	bucket	15.31	0.436	284	6.91	7.37	269	Located in the Kingston Range
Horse Thief Spring	9/22/2011	35.77294	115.88824	4,637	7.9	bucket	17.61	0.473	308	2.26	7.04	22.8	Located in the Kingston Range
Horse Thief Spring	12/22/2011	35.77294	115.88824	4,637	8	bucket	17.26	0.441	287	3.53	6.96	124.6	Located in the Kingston Range
Horse Thief Spring	4/30/2012	35.77294	115.88824	4,637	8.8	bucket	16.72	0.429	279	3.96	7.2	62	Located in the Kingston Range
Horse Thief Spring	1/25/2013	35.77294	115.88824	4,637	--	--	16.71	0.54	351	<4	6.7	60	Located in the Kingston Range
Horse Thief Spring	4/18/2013	35.77294	115.88824	4,637	--	--	16.64	0.5	326	2.54	6.47	-108.6	Located in the Kingston Range
Horse Thief Spring	9/24/2013	35.77294	115.88824	4,637	--	--	17.86	0.401	261	1.69	6.84	-218.4	Located in the Kingston Range
Horse Thief Spring	5/4/2013	35.77294	115.88824	4,637	10	visual	16.8	0.573	--	1.7	6.95	--	Located in the Kingston Range
Ibex Spring	11/4/2010	35.77211	116.4111	1,133	no flow	visual	18.78	2.486	1617	0.98	8.76	30.5	
Ibex Spring	4/24/2011	35.77211	116.4111	1,133	no flow	visual	16.35	2.234	1452	2.99	7.98	114.4	
Ibex Spring	5/11/2014	35.77211	116.4111	1,133	no flow	visual	16.7	2.327	1515	2.4	8.44	108.3	
Owl Hole Spring	11/16/2010	35.63931	116.64766	1,911	no flow	visual	17.01	4.098	2664	0.29	6.86	-73	
Owl Hole Spring	5/11/2014	35.63931	116.64766	1,911	no flow	visual	13.7	7.543	4901	1.06	7.49	116.2	
Resting Spring	1/23/2011	35.87728	116.15757	1,767	150	bucket	26.84	0.923	600	5.62	8.36	157.8	
Salsberry Spring	1/10/2011	35.93162	116.4182	3,410	5	visual	2.35	0.595	386	13.01	8.24	181.8	Spring water mixed with runoff from melting snow and ice
Salt Spring	11/5/2010	35.62622	116.28041	550	<5	visual	20.48	6.514	4235	0.74	7.94	-176.9	
Salt Spring	5/10/2011	35.62622	116.28041	550	<5	visual	19.46	8.944	5814	5.79	7.7	196.2	
Salt Spring	5/11/2014	35.62622	116.28041	550	<5	visual	26.3	10.429	6793	8.34	8.3	124.5	
Saratoga Spring	11/4/2010	35.6809	116.42254	207	unknown	visual	28.8	4.73	3075	2.49	7.71	259.1	
Sheep Creek Spring	11/5/2010	35.58863	116.36047	1,719	5	visual	23.1	0.614	400	8.57	9.02	62.5	
Sheep Creek Spring	4/24/2011	35.58863	116.36047	1,719	5	visual	21.4	1.216	789	7.67	7.78	188.2	
Sheephead Spring	1/17/2011	35.89979	116.40629	3,253	2	visual	11.58	0.818	531	8.59	8.22	169.8	
Shoshone Spring	1/23/2011	35.98056	116.27384	1,611	250+	meter	33.54	1.624	1056	3.75	7.79	162.7	This is from the Shoshone Spring source
Shoshone Spring	4/27/2011	35.98056	116.27384	1,611	250+	meter	--	--	--	--	--	--	This is from the Shoshone Spring source
Shoshone Spring	5/1/2012	35.98056	116.27384	1,611	104***	bucket	33.51	1.477	960	6.77	7.68	16.7	This is from the Shoshone Spring source
Shoshone Spring	1/29/2013	35.98056	116.27384	1,611	--	--	33.31	1.847	1201	5.85	7.66	30.7	This is from the Shoshone Spring source
Shoshone Spring	5/2/2013	35.98056	116.27384	1,611	--	--	33.47	1.601	1040	4.5	7.41	-97.1	This is from the Shoshone Spring source
Shoshone Spring	9/25/2013	35.98056	116.27384	1,611	--	--	33.62	1.35	878	2.55	7.23	-182.1	This is from the Shoshone Spring source
Shoshone Spring	5/12/2014	35.98056	116.27384	1,611	--	--	32.3	1.831	1190	2.99	7.51	149.4	This is from the Shoshone Spring source
Smith Spring	11/19/2010	35.78814	115.99752	3,066	~1	visual	21.41	0.451	293	5.36	7.81	86.9	Data from flow out of spring box
Smith Spring	4/26/2011	35.78814	115.99752	3,066	2-3	visual	--	--	--	--	--	--	Data from flow out of spring box
Smith Spring	5/9/2014	35.78814	115.99752	3,066	dry	visual	--	--	--	--	--	--	Data from flow out of spring box
Tecopa Hot Spring	11/11/2010	35.8789	116.23812	1,332	6**	bucket	40.76	4.306	2799	0.84	8.61	120.7	Sample from Amargosa Conservancy Trailer spring outlet
Tecopa Hot Spring	9/21/2011	35.8789	116.23812	1,332	5.1**	bucket	38.85	6.4	4100	2.74	9.18	-71.1	Sample from Amargosa Conservancy Trailer spring outlet
Tecopa Hot Spring	4/30/2012	35.8789	116.23812	1,332	4.9**	bucket	41.2	3.525	2311	3.54	8.96	20	Sample from Amargosa Conservancy Trailer spring outlet
Tecopa Hot Spring	1/29/2013	35.8789	116.23812	1,332	5.4**	bucket	38.02	5	3250	3.48	8.87	32.9	Sample from Amargosa Conservancy Trailer spring outlet
Tecopa Hot Spring	9/23/2013	35.8789	116.23812	1,332	5.3**	bucket	41.38	3.675	2389	1.7	8.43	-237.4	Sample from Amargosa Conservancy Trailer spring outlet
Tecopa Hot Spring	5/10/2014	35.8789	116.23812	1,332	~5	visual	40.6	4.598	2990	0.23	8.71	60.7	Sample from Amargosa Conservancy Trailer spring outlet
Thom Spring	11/11/2010	35.85661	116.22677	1,408	5	visual	24.81	1.571	1021	2.77	7.63	148.3	Data from flowing water within the vegetation
Thom Spring	4/30/2012	35.85661	116.22677	1,408	~2	visual	24.9	1.478	960	3.66	6.79	74.9	Data from flowing water within the vegetation
Thom Spring	1/28/2013	35.85661	116.22677	1,408	<5	visual	28.63	1.819	1182	2.8	7.73	32.9	Data obtained near modified outflow

Table 2-1
Field Reconnaissance Data Summary
Amargosa Basin
California/Nevada

Name	Date of Visit	Latitude	Longitude	Elevation (ft amsl)	Flow (gpm)	Flow Measurement Method*	Temp. (deg C)	Spec. Cond. (mS/cm-deg C)	TDS (mg/L)	DO (mg/L)	pH	ORP (mV)	Notes
Thom Spring	4/30/2013	35.85661	116.22677	1,408	<5	visual	27.96	1.601	1.04	1.83	7.2	-141.5	Data obtained near modified outflow
Thom Spring	9/25/2013	35.85661	116.22677	1,408	<5	visual	29.09	1.34	871	1.13	7.35	-209.9	Data obtained near modified outflow
Thom Spring	5/5/2014	35.85661	116.22677	1,408	<5	visual	27.8	1.889	1229	0.93	7.55	83	Data obtained near modified outflow
Twelvemile Spring	11/14/2010	36.02172	116.15531	2,240	no flow	visual	19.23	0.8	520	1.38	7.66	-141	Data from shallow puddle
Wild Bath Spring	11/11/2010	35.87277	116.21932	1,424	1.7	bucket	29.88	1.642	1067	4.69	7.9	165.5	Tub located off Furnace Creek Road behind Tecopa Hot Springs
Wild Bath Spring	9/21/2011	35.87277	116.21932	1,424	1.9	bucket	37.99	1.664	1083	5.59	7.83	-2.2	Tub located off Furnace Creek Road behind Tecopa Hot Springs
Wild Bath Spring	5/5/2012	35.87277	116.21932	1,424	1.3	bucket	34.89	1.559	1012	5.64	8.37	16.2	Tub located off Furnace Creek Road behind Tecopa Hot Springs
Wild Bath Spring	1/25/2013	35.87277	116.21932	1,424	<2	visual	36.53	1.906	1024	4.52	7.94	52.8	Tub covered with plastic tarp
Wild Bath Spring	5/4/2013	35.87277	116.21932	1,424	<2	visual	33.83	1.633	1061	3.97	7.81	-99.8	Tub located off Furnace Creek Road behind Tecopa Hot Springs
Wild Bath Spring	9/25/2013	35.87277	116.21932	1,424	<2	visual	30.76	1.403	911	5	8.07	-178.5	Tub located off Furnace Creek Road behind Tecopa Hot Springs
Wild Bath Spring	5/10/2014	35.87277	116.21932	1,424	<2	visual	35.5	1.872	1216	3.85	8.2	85.5	Tub located off Furnace Creek Road behind Tecopa Hot Springs
China Ranch Cyn Spring 1	1/13/2011	35.80335	116.14099	1,770	10	visual	13.94	1.215	789	9.34	8.5	44.5	a.k.a. Willow Canyon 1 spring
China Ranch Cyn Spring 2	1/13/2011	35.80445	116.14235	1,767	20+	visual	21.28	0.931	606	6.22	8.17	46.6	a.k.a. Willow Canyon 3 spring
Willow Spring 1	11/3/2010	35.80556	116.18284	1,420	28	bucket	23.73	1.502	958	5.72	8.26	3.4	Junction of spring water capture piping (above pond)
Willow Spring 1	4/26/2011	35.80556	116.18284	1,420	--	--	21.92	1.141	737	6.21	7.29	93.1	Junction of spring water capture piping (above pond)
Willow Spring 1	9/23/2011	35.80556	116.18284	1,420	20	bucket	--	--	--	--	--	--	Combined pond outflow and spring box
Willow Spring 2	1/18/2011	35.80098	116.19449	1,235	120-130	meter	17.98	1.91	1241	8.34	8.18	-31.1	Measurement taken at culvert
Willow Spring 2	9/23/2011	35.80098	116.19449	1,235	52.9	meter	24.16	1.028	668	8.08	8.14	-29.2	Measurement taken at culvert
Willow Spring 2	5/1/2012	35.80098	116.19449	1,235	--	--	22.33	1.164	756	8.95	8.09	16.2	Measurement taken at culvert
Willow Spring 2	4/30/2013	35.80098	116.19449	1,235	--	--	22.99	1.154	750	7.12	7.24	-116.8	Measurement taken at culvert
Willow Spring 2	9/25/20123	35.80098	116.19449	1,235	37	meter	23.64	0.837	544	5.6	8	-169.4	Measurement taken at culvert
Willow Spring 2	9/25/20123	35.80098	116.19449	1,235	4.5	USGS	--	--	--	--	--	--	Measurement taken at culvert
Amargosa River													
Amargosa River/USGS 1	11/3/2010	35.84954	116.23081	1,325	40	USGS	--	--	--	--	--	--	At the Tecopa USGS flow station
Amargosa River/USGS 1	4/29/2011	35.84954	116.23081	1,325	94	USGS	--	--	--	--	--	--	At the Tecopa USGS flow station
Amargosa River/USGS 1	9/22/2011	35.84954	116.23081	1,325	31	USGS	--	--	--	--	--	--	At the Tecopa USGS flow station
Amargosa River/USGS 1	12/22/2011	35.84954	116.23081	1,325	583	USGS	--	--	--	--	--	--	At the Tecopa USGS flow station
Amargosa River/USGS 1	4/30/2012	35.84954	116.23081	1,325	117	USGS	17.97	10.806	7024	10.28	9.36	36.3	At the Tecopa USGS flow station
Amargosa River/USGS 1	1/29/2013	35.84954	116.23081	1,325	162	USGS	5.99	14.25	9264	17.48	8.71	57.4	At the Tecopa USGS flow station
Amargosa River/USGS 1	4/30/2013	35.84954	116.23081	1,325	45	USGS	17.52	9.69	6303	10.14	8.34	-172.8	At the Tecopa USGS flow station
Amargosa River/USGS 1	9/25/2013	35.84954	116.23081	1,325	18	USGS	19.4	5.659	3681	5.4	8.58	-207	At the Tecopa USGS flow station
Amargosa River/USGS 1	5/10/2014	35.84954	116.23081	1,325	130	USGS	19.5	9.499	6142	7.98	9.2	23.5	At the Tecopa USGS flow station
Amargosa River/USGS 2	4/28/2011	35.79042	116.20777	1,094	558	meter	18.13	3.876	2520	12.65	8.52	152	At China Ranch USGS flow station
Amargosa River/USGS 2	5/10/2011	35.79042	116.20777	1,094	656	meter	15.9	3.481	2263	11.45	8.46	189.6	At China Ranch USGS flow station
Amargosa River/USGS 2	9/20/2011	35.79042	116.20777	1,094	390	USGS	23.05	3.658	2378	10.22	8.53	-33.4	At China Ranch USGS flow station
Amargosa River/USGS 2	12/22/2011	35.79042	116.20777	1,094	943	USGS	--	--	--	--	--	--	At China Ranch USGS flow station
Amargosa River/USGS 2	5/3/2012	35.79042	116.20777	1,094	487.9	meter	19.07	3.899	2534	12.03	8.69	51.8	At China Ranch USGS flow station
Amargosa River/USGS 2	5/3/2012	35.79042	116.20777	1,094	763	USGS	--	--	--	--	--	--	At China Ranch USGS flow station
Amargosa River/USGS 2	1/27/2013	35.79042	116.20777	1,094	914	meter	11.33	10.56	6863	15.83	8.57	86	At China Ranch USGS flow station
Amargosa River/USGS 2	1/27/2013	35.79042	116.20777	1,094	539	USGS	--	--	--	--	--	--	At China Ranch USGS flow station
Amargosa River/USGS 2	4/20/2013	35.79042	116.20777	1,094	399	meter	15.96	4.634	3012	14.04	8	-104.8	At China Ranch USGS flow station
Amargosa River/USGS 2	4/20/2013	35.79042	116.20777	1,094	494	USGS	--	--	--	--	--	--	At China Ranch USGS flow station
Amargosa River/USGS 2	9/24/2013	35.79042	116.20777	1,094	735	meter	15.1	3.263	2121	6.95	8.32	-184.4	At China Ranch USGS flow station
Amargosa River/USGS 2	9/24/2013	35.79042	116.20777	1,094	1436	USGS	--	--	--	--	--	--	At China Ranch USGS flow station
Amargosa River/USGS 2	5/4/2014	35.79042	116.20777	1,094	527	meter	17.8	4.443	2886	9.83	8.61	84.4	At China Ranch USGS flow station
Amargosa River/USGS 2	5/4/2014	35.79042	116.20777	1,094	444	USGS	--	--	--	--	--	--	At China Ranch USGS flow station
Willow Creek	4/29/2011	35.78757	116.20039	1,107	42.9	bucket	20.75	1.474	954	9.4	8.42	190.6	Above confluence with Amargosa River
Willow Creek	12/22/2011	35.78757	116.20039	1,107	dry	bucket	--	--	--	--	--	--	Above confluence with Amargosa River
Willow Creek	5/3/2012	35.78757	116.20039	1,107	37.7	bucket	20.53	1.357	882	10.89	8.8	25.4	Above confluence with Amargosa River
Willow Creek	1/27/2013	35.78757	116.20039	1,107	33	meter/visual	14.28	1.651	1073	15.49	8.38	69.3	Above confluence with Amargosa River
Willow Creek	4/20/2013	35.78757	116.20039	1,107	47	meter	27.07	1.414	919	9.28	8.15	-107.1	Above confluence with Amargosa River
Willow Creek	9/24/2013	35.78757	116.20039	1,107	dry	visual	--	--	--	--	--	--	Above confluence with Amargosa River

Table 2-1
Field Reconnaissance Data Summary
Amargosa Basin
California/Nevada

Name	Date of Visit	Latitude	Longitude	Elevation (ft amsl)	Flow (gpm)	Flow Measurement Method*	Temp. (deg C)	Spec. Cond. (mS/cm-deg C)	TDS (mg/L)	DO (mg/L)	pH	ORP (mV)	Notes
Willow Creek	5/4/2014	35.78757	116.20039	1,107	25	meter/visual	18.1	1.421	923	10.1	8.61	106.1	Above confluence with Amargosa River
Amargosa River Confluence	4/29/2011	35.785	116.2023	1,053	662	meter	20.23	3.88	2523	9.25	8.64	205	Confluence with Willow Creek
Amargosa River Confluence	9/22/2011	35.785	116.2023	1,053	332	meter	19.24	4.226	2748	9.5	8.48	-7.2	Confluence with Willow Creek
Amargosa River Confluence	12/22/2011	35.785	116.2023	1,053	463	meter	3.77	5.657	3677	11.7	8.38	63.6	Confluence with Willow Creek
Amargosa River Confluence	5/3/2012	35.785	116.2023	1,053	395	meter	17.88	4.262	2770	10.26	8.59	32.2	Confluence with Willow Creek
Amargosa River Confluence	1/27/2013	35.785	116.2023	1,053	561	meter	10.51	7.547	4905	15.62	7.94	89.9	Confluence with Willow Creek
Amargosa River Confluence	4/20/2013	35.785	116.2023	1,053	563	meter	14.05	5.004	3253	11.48	8.02	-111.9	Confluence with Willow Creek
Amargosa River Confluence	9/24/2013	35.785	116.2023	1,053	461	meter	14.61	3.54	2301	7.04	8.43	-147.5	Confluence with Willow Creek
Amargosa River Confluence	5/4/2014	35.785	116.2023	1,053	643	meter	17.3	4.786	3114	9.21	8.63	111.4	Confluence with Willow Creek
Amargosa River 3	11/16/2010	35.74637	116.22219	846	477	meter	19.08	4.015	2610	10.89	8.79	172.1	At Sperry Wash
Amargosa River 3	4/29/2011	35.74637	116.22219	846	462	meter	19.67	4.225	2745	10.08	8.6	202.3	At Sperry Wash
Amargosa River 3	5/5/2011	35.74637	116.22219	846	271	meter	19.4	4.198	2728	10.81	8.64	190.4	At Sperry Wash
Amargosa River 3	9/20/2011	35.74637	116.22219	846	158	meter	26.58	4.429	2879	10.18	8.91	-11.8	At Sperry Wash
Amargosa River 3	9/23/2011	35.74637	116.22219	846	119	meter	17	4.321	2809	11.03	8.6	-10.5	At Sperry Wash
Amargosa River 3	12/21/2011	35.74637	116.22219	846	389	meter	9.33	5.179	3366	11.3	8.6	130.7	At Sperry Wash
Amargosa River 3	5/4/2012	35.74637	116.22219	846	366	meter	24.22	4.388	2852	11.75	9.02	22.4	At Sperry Wash
Amargosa River 3	1/26/2013	35.74637	116.22219	846	510	meter	13.02	6.656	4326	16.55	8.32	76.2	At Sperry Wash
Amargosa River 3	4/18/2013	35.74637	116.22219	846	398	meter	25.66	5.223	3395	12.37	8.4	-102	At Sperry Wash
Amargosa River 3	9/23/2013	35.74637	116.22219	846	275	meter	22.71	4.171	2711	8.34	8.69	-157.7	At Sperry Wash
Amargosa River 3	5/4/2014	35.74637	116.22219	846	588	meter	26.2	4.831	3140	12.72	8.93	29.8	At Sperry Wash
Amargosa River 4	4/29/2011	35.69609	116.25082	649	70	meter	15.67	4.472	2904	11.88	8.93	206.3	At crossing of Dumont Dunes Road
Amargosa River 4	5/5/2011	35.69609	116.25082	649	dry	meter	--	--	--	--	--	--	At crossing of Dumont Dunes Road
Amargosa River 4	9/23/2011	35.69609	116.25082	649	dry	meter	--	--	--	--	--	--	At crossing of Dumont Dunes Road
Amargosa River 4	12/21/2011	35.69609	116.25082	649	136	meter	3.79	4.727	3073	12.35	8.6	214.1	At crossing of Dumont Dunes Road
Amargosa River 4	5/4/2012	35.69609	116.25082	649	44	meter	27.23	4.617	3003	9.07	9.22	22.5	At crossing of Dumont Dunes Road
Amargosa River 4	1/26/2013	35.69609	116.25082	649	171	meter	12.06	6.025	3916	15.34	8.49	76.4	At crossing of Dumont Dunes Road
Amargosa River 4	4/18/2013	35.69609	116.25082	649	dry	meter	--	--	--	--	--	--	At crossing of Dumont Dunes Road
Amargosa River 4	9/23/2013	35.69609	116.25082	649	<50	visual	16.54	5.134	3338	6.8	8.95	-195.2	At crossing of Dumont Dunes Road
Amargosa River 4	5/4/2014	35.69609	116.25082	649	<50	visual	25.4	5.926	3854	7.9	9.15	79.1	At crossing of Dumont Dunes Road
Amargosa River 2	11/16/2010	35.66418	116.29722	443	256	meter	21.4	4.295	2793	8.64	8.89	126.7	At rt 127 crossing south of Dumont Dunes
Amargosa River 2	4/29/2011	35.66418	116.29722	443	dry	visual	--	--	--	--	--	--	At rt 127 crossing south of Dumont Dunes
Amargosa River 2	5/5/2011	35.66418	116.29722	443	dry	visual	--	--	--	--	--	--	At rt 127 crossing south of Dumont Dunes
Amargosa River 2	9/23/2011	35.66418	116.29722	443	dry	visual	--	--	--	--	--	--	At rt 127 crossing south of Dumont Dunes
Amargosa River 2	12/21/2011	35.66418	116.29722	443	dry	visual	--	--	--	--	--	--	At rt 127 crossing south of Dumont Dunes
Amargosa River 2	5/4/2012	35.66418	116.29722	443	dry	visual	--	--	--	--	--	--	At rt 127 crossing south of Dumont Dunes
Amargosa River 2	1/26/2013	35.66418	116.29722	443	dry	visual	--	--	--	--	--	--	At rt 127 crossing south of Dumont Dunes
Amargosa River 2	4/18/2013	35.66418	116.29722	443	dry	visual	--	--	--	--	--	--	At rt 127 crossing south of Dumont Dunes
Amargosa River 2	9/23/2013	35.66418	116.29722	443	dry	visual	--	--	--	--	--	--	At rt 127 crossing south of Dumont Dunes
Amargosa River 2	5/4/2013	35.66418	116.29722	443	<50	visual	--	--	--	--	--	--	At rt 127 crossing south of Dumont Dunes

Table 2-1
Field Reconnaissance Data Summary
Amargosa Basin
California/Nevada

Name	Date of Visit	Latitude	Longitude	Elevation (ft amsl)	Flow (gpm)	Flow Measurement Method*	Temp. (deg C)	Spec. Cond. (mS/cm-deg C)	TDS (mg/L)	DO (mg/L)	pH	ORP (mV)	Notes
Wells					Depth to Water (ft from top of casing)								
ARHS-1	5/25/2012	36.0773	116.2953	1,780	111.72	dtw meter	35	2.941	1910	2.04	8.26	107.3	At rt 127, 6 miles north of Shoshone, CA
ARHS-1	4/24/2013	36.0773	116.2953	1,780	111.88	dtw meter	--	--	--	--	--	--	At rt 127, 6 miles north of Shoshone, CA
ARHS-2	5/25/2012	35.8054	116.1825	1,430	5.79	dtw meter	24.36	0.912	593	4.2	7.54	129.8	At China Ranch
ARHS-2	1/25/2013	35.8054	116.1825	1,430	5.94	dtw meter	23.73	1.095	714	5.52	7.6	36.9	At China Ranch
ARHS-2	4/30/2013	35.8054	116.1825	1,430	6.83	dtw meter	--	--	--	--	--	--	At China Ranch
ARHS-2	9/24/2013	35.8054	116.1825	1,430	6.39	dtw meter	25.73	0.798	519	3.41	7.25	-178.8	At China Ranch
ARHS-2	5/9/2014	35.8054	116.1825	1,430	5.69	dtw meter	24.5	1.27	826	3.86	7.46	178.4	At China Ranch
ARHS-3	4/24/2013	36.0216	116.1554	2,205	18.64	dtw meter	24.6	0.77	500	5.48	6.86	-101.2	Located adjacent to 12 Mile Spring
ARHS-3	9/24/2013	36.0216	116.1554	2,205	19.34	dtw meter	24.63	0.647	421	3.72	7.42	-182.7	Located adjacent to 12 Mile Spring
ARHS-3	5/5/2014	36.0216	116.1554	2,205	19.13	dtw meter	24.3	1.087	709	5.5	7.68	81.1	Located adjacent to 12 Mile Spring
ARHS-4	9/24/2013	35.7999	116.1035	2,072	12.5	dtw meter	24.08	0.656	427	4.1	7.5	-171.6	Located adjacent to Married Man's Camp
ARHS-4	5/9/2014	35.7999	116.1035	2,072	11.94	dtw meter	22.6	1.106	722	4.96	7.52	149.6	Located adjacent to Married Man's Camp
Cynthia's Well	1/16/2011	35.8461	116.20478	1,447	38.87	dtw meter	20.61	0.898	584	7.1	8.5	110.4	Located in Tecopa Heights
Cynthia's Well	5/12/2011	35.8461	116.20478	1,447	40.51	dtw meter	--	--	--	--	--	--	Located in Tecopa Heights
Cynthia's Well	9/23/2011	35.8461	116.20478	1,447	42.75	dtw meter	--	--	--	--	--	--	Located in Tecopa Heights
Cynthia's Well	5/5/2012	35.8461	116.20478	1,447	40.22	dtw meter	22.31	1.163	756	3	8.36	33.9	Located in Tecopa Heights
Cynthia's Well	1/27/2013	35.8461	116.20478	1,447	39	dtw meter	--	--	--	--	--	--	Located in Tecopa Heights
Cynthia's Well	4/25/2013	35.8461	116.20478	1,447	40.95	dtw meter	23.06	1.251	813	2.75	7.36	-113.8	Located in Tecopa Heights
Cynthia's Well	5/12/2014	35.8461	116.20478	1,447	41.16	dtw meter	23.8	1.151	748	6.2	7.86	76	Located in Tecopa Heights
Eagle Mountain Well	11/4/2010	36.24987	116.3953	2,007	14.82	dtw meter	22.76	3.35	2177	4.25	8.85	54.4	Located west of Eagle Mountain
Eagle Mountain Well	5/1/2011	36.24987	116.3953	2,007	14.78	dtw meter	--	--	--	--	--	--	Located west of Eagle Mountain
Eagle Mountain Well	9/21/2011	36.24987	116.3953	2,007	14.77	dtw meter	--	--	--	--	--	--	Located west of Eagle Mountain
Eagle Mountain Well	4/30/2012	36.24987	116.3953	2,007	14.94	dtw meter	19.79	3.251	2112	7.39	8.42	36.5	Located west of Eagle Mountain
Eagle Mountain Well	1/24/2013	36.24987	116.3953	2,007	15	dtw meter	21.23	4.043	2628	7.98	8.45	41.1	Located west of Eagle Mountain
Eagle Mountain Well	4/24/2013	36.24987	116.3953	2,007	14.97	dtw meter	20.08	3.487	2267	7.05	7.93	-112.4	Located west of Eagle Mountain
Eagle Mountain Well	9/23/2013	36.24987	116.3953	2,007	14.75	dtw meter	22.8	2.984	1938	5.9	8.09	-181.4	Located west of Eagle Mountain
Eagle Mountain Well	5/9/2014	36.24987	116.3953	2,007	14.92	dtw meter	20	3.864	--	6.6	8.56	--	Located west of Eagle Mountain
Married Man's Well	11/19/2011	35.80038	116.10177	2,096	25.82	dtw meter	--	--	--	--	--	--	Locate at head of Willow Creek Wash
Married Man's Well	4/30/2012	35.80038	116.10177	2,096	25.49	dtw meter	23.96	1.255	816	3.61	7.59	-114.5	Locate at head of Willow Creek Wash
Married Man's Well	1/25/2013	35.80038	116.10177	2,096	25.51	dtw meter	--	--	--	--	--	--	Locate at head of Willow Creek Wash
Junior's Well	1/16/2011	35.8512	116.24252	1,346	NA	NA	24.29	2.04	1326	6.63	8.33	69	Located west of Amargosa River (opposite of Tecopa)
Hog Farm Well	1/28/2013	36.28748	116.37854	2,017	<5	visual	21.17	1.653	1074	0.97	8.66	39.9	Located southeast of Death Valley Junction
Hog Farm Well	4/24/2013	36.28748	116.37854	2,017	<5	visual	21.56	1.432	930	<1	7.67	-180.7	Located southeast of Death Valley Junction
Hog Farm Well	9/23/2013	36.28748	116.37854	2,017	<5	visual	21.94	1.219	792	0.4	8.48	-258	Located southeast of Death Valley Junction
Hog Farm Well	5/5/2014	36.28748	116.37854	2,017	<5	visual	21.6	1.74	1131	0.14	8.74	31.3	Located southeast of Death Valley Junction
Tecopa School Well	11/11/2010	35.84854	116.21743	1,372	NA	NA	20.06	1.372	892	4.59	7.6	161.2	Sample from spigot adjacent to well head
Tule Spring Well	11/13/2010	35.81178	116.04909	1,989	10.4	dtw meter	18.85	0.855	556	0.23	7.42	-54.8	Data from well. Strong odor of decay
Tule Spring Well	4/30/2012	35.81178	116.04909	1,989	10.01	dtw meter	19.37	0.827	537	1.76	7.87	26.8	Data from well. No smell from well.
Tule Spring Well	1/25/2013	35.81178	116.04909	1,989	10	dtw meter	17.44	0.981	638	<2.5	7.35	66.5	Data from well. No smell from well.
Tule Spring Well	4/21/2013	35.81178	116.04909	1,989	9.83	dtw meter	17.38	0.91	591	1.35	6.9	-160.6	Data from well. Moderate odor of decay
Tule Spring Well	9/24/2013	35.81178	116.04909	1,989	10.8	dtw meter	20.91	0.728	473	0.37	7.42	-272.3	Data from well. Moderate odor of decay
Tule Spring Well	5/9/2014	35.81178	116.04909	1,989	9.98	dtw meter	19.2	1.234	800	0.5	7.4	59.9	Data from well. Moderate odor of decay

Notes:
ft amsl = feet above mean sea level
gpm = gallons per minute
Temp. = temperature
deg C = degrees Celcius
mS/cm-deg C = milliSiemans per centimeter degrees Celcius
Spec. Cond. = specific conductivity

Table 2-1
Field Reconnaissance Data Summary
Amargosa Basin
California/Nevada

Name	Date of Visit	Latitude	Longitude	Elevation (ft amsl)	Flow (gpm)	Flow Measurement Method*	Temp. (deg C)	Spec. Cond. (mS/cm-deg C)	TDS (mg/L)	DO (mg/L)	pH	ORP (mV)	Notes

TDS = total dissolved solids
mg/L = milligrams per liter
DO = dissolved oxygen
ORP = oxidation-reduction potential
mV = millivolts

*Flow Measurement Method = spring and river flow were measured either directly with a solid state meter (meter), indirectly using time to fill a 5-gallon bucket (bucket), or using visual estimation techniques (visual).

Table 3-1
Mean Annual Flow
Amargosa River
California/Nevada

Year	Discharge (cfs)				
	Station 1	Station 2	Station 3	Station 4	Station 5
1962	ND	1.04	ND	ND	ND
1963	ND	2.54	ND	ND	ND
1964	ND	0.786	ND	ND	0.011
1965	ND	1.03	ND	ND	0.019
1966	ND	7.67	ND	ND	0.000
1967	ND	0.736	ND	ND	0.776
1968	ND	1.68	ND	ND	0.249
1969	ND	9.19	ND	ND	ND
1970	ND	1.36	ND	ND	ND
1971	ND	0.648	ND	ND	ND
1972	ND	0.626	ND	ND	ND
1973	ND	ND	ND	ND	ND
1974	ND	0.596	ND	ND	ND
1975	ND	0.722	ND	ND	ND
1976	ND	9.93	ND	ND	ND
1977	ND	8.80	ND	ND	ND
1978	ND	8.59	ND	ND	ND
1979	ND	0.567	ND	ND	ND
1980	ND	4.86	ND	ND	ND
1981	ND	1.06	ND	ND	ND
1982	ND	0.948	ND	ND	ND
1983	ND	14.9	ND	ND	ND
1984	ND	ND	ND	ND	ND
1985	ND	ND	ND	ND	ND
1986	ND	ND	ND	ND	ND
1987	ND	ND	ND	ND	ND
1988	ND	ND	ND	ND	ND
1989	ND	ND	ND	ND	ND
1990	ND	ND	ND	ND	ND
1991	ND	ND	ND	ND	ND
1992	ND	3.38	ND	0.046	ND
1993	ND	11.70	ND	0.095	ND
1994	ND	0.222	0.014	0.000	ND
1995	ND	6.36	0.220	1.72	ND
1996	ND	ND	ND	ND	ND
1997	ND	ND	ND	ND	ND
1998	ND	ND	ND	ND	ND
1999	ND	ND	ND	ND	ND
2000	1.82	0.726	ND	ND	ND
2001	1.14	0.864	ND	ND	ND
2002	ND	0.724	ND	ND	ND
2003	ND	5.23	ND	ND	ND
2004	ND	1.26	ND	ND	ND
2005	ND	11.1	ND	ND	ND

Table 3-1
Mean Annual Flow
Amargosa River
California/Nevada

Year	Discharge (cfs)				
	Station 1	Station 2	Station 3	Station 4	Station 5
2006	ND	0.629	ND	ND	ND
2007	ND	4.89	ND	ND	ND
2008	ND	0.512	ND	ND	ND
2009	ND	0.531	ND	ND	ND
2010	ND	1.52	ND	ND	ND
2011	ND	5.04	ND	ND	ND
2012	ND	0.370	ND	ND	ND
2013	ND	0.688	ND	ND	ND

Notes:

Station 1 = USGS 10251375 Amargosa River at Dumont Dunes near Death Valley, San Bernardino County, California (Latitude 35º41'45", Longitude 116º15'02" NAD27).

Station 2 = USGS 10251300 Amargosa River at Tecopa, Inyo County, California (Latitude 35º50'45", Longitude 116º13'45" NAD27).

Station 3 = USGS 10251259 Amargosa River at Hwy 127 near Nevada State Line, Inyo County, California (Latitude 36º23'12", Longitude 116º25'22" NAD27).

Station 4 = USGS 10251218 Amargosa River at Hwy 95 below Beatty, Nevada, Nye County, Nevada (Latitude 36º52'52", Longitude 116º45'04" NAD27).

Station 5 = USGS 10251220 Amargosa River near Beatty, Nevada, Nye County, Nevada (Latitude 36º52'01.76", Longitude 116º45'37.53" NAD83).

ND = No Data

Complete Annual Data Sets Only.

Table 3-2
Summary of Pumping
Amargosa Desert
Nevada

Year	**Pumping** (AFY)					
	Irrigation	**Mining**	**Commercial**	**Quasi Municipal & Domestic**	**Other**	**Total Pumping**
1983	9,105	125	20	250	NA	**9,500**
1985	8,472	950	20	230	NA	**9,672**
1986	6,553	550	10	125	NA	**7,238**
1987	5,700	302	10	125	NA	**6,137**
1988	2,978	996	10	125	NA	**4,109**
1989	1,566	2,220	10	125	NA	**3,921**
1990	4,953	2,720	10	125	NA	**7,807**
1991	4,942	1,070	10	100	NA	**6,122**
1992	5,761	2,293	10	100	NA	**8,164**
1993	8,709	2,481	10	100	NA	**11,300**
1994	9,977	2,508	10	100	NA	**12,595**
1995	12,354	2,571	10	100	NA	**15,035**
1996	11,043	2,285	205	50	30	**13,613**
1997	10,454	2,506	576	366	0	**13,902**
1998	12,040	2,417	537	382	0	**15,376**
1999	10,835	2,389	593	364	0	**14,181**
2000	9,711	1,366	1,057	378	10	**12,522**
2001	9,407	1,187	1,067	396	10	**12,067**
2002	9,576	1,302	1,128	415	0	**12,421**
2003	10,471	1,356	1,324	437	0	**13,588**
2004	10,603	1,169	1,319	453	0	**13,544**
2005	10,764	438	1,332	466	4	**13,004**
2006	13,124	527	1,844	491	2	**15,988**
2007	14,059	377	1,793	505	2	**16,736**
2008	12,356	1,108	3,984	517	2	**17,967**
2009	11,477	510	3,905	487	1	**16,380**
2010	9,898	313	4,683	498	1	**15,393**
2011	11,258	321	4,458	499	0	**16,536**
2012	13,190	174	3,756	502	0	**17,622**