TABLES

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**

TABLE 3-1

GEOMETRIC MEAN HYDRAULIC CONDUCTIVITIES - GREAT BASIN MODFLOW MODEL

Hydrogeologic Unit	Zones	Geometric Mean *K* (ft/day), un-weighted
Upper Basin-Fill Aquifer Unit	18	3.42
Lower Basin-fill Aquifer Unit	4	0.20
Volcanic Unit	15	0.06
Thrusted Lower Carbonate Aquifer Unit	2	0.01
Thrusted Non-Carbonate Confining Unit	3	0.03
Upper Carbonate Aquifer Unit	12	0.12
Upper Siliciclastic Confining Unit	3	0.01
Lower Carbonate Aquifer Unit	45	0.14
Non-Carbonate Confining Unit	23	0.01

APPENDIX A

(ZDON, DAVISSON & LOVE, 2015, IN PRESS

APPENDIX B

CATALOG OF SPRINGS – MIDDLE AMARGOSA RIVER BASIN

INDEX TO CATALOG OF SPRINGS

APPENDIX C

M.L. DAVISSON & ASSOCIATES REPORT – "CONSTRAINTS ON THE RECHARGE SOURCES, FLOWPATHS, AND AGES OF GROUNDWATER IN THE AMARGOSA RIVER VALLEY USING STABLE ISOTOPE, WATER QUALITY AND NOBLE GAS DATA"

APPENDIX D

CONCEPTUAL CROSS-SECTIONS – AMARGOSA RIVER

APPENDIX E

STEADY-STATE CARBONATE AQUIFER

MODEL SIMULATION RESULTS

Environmental Forensics, 0:1–12, 2015

ISSN: 1527-5922 print / 1527-5930 online
DOI: 10.1080/15275922.2015.1091406

Testing the Established Hydrogeologic Model of Source Water to the Amargosa River Basin, Inyo and San Bernardino Counties, California

Q1 Andy Zdon,[1] M. Lee Davisson,[2] and Adam H. Love[1]
[1]*Andy Zdon & Associates, Inc., Walnut Creek, California, USA*
Q2 [2]*ML Davisson & Associates, Inc., Livermore, California, USA*

The current conceptual hydrogeologic model established for source water to the Amargosa River was tested in order to help inform management decisions regarding the Amargosa River's Federal designation as Wild and Scenic through an Act of Congress. The limited availability of water in this region results in the critical need for effective management in the basin to maintain its Wild and Scenic attributes inclusive of habitat for several endangered and threatened species. The use of forensic tools and integration of multiple lines of geologic, hydrogeologic, geochemical, and stable isotopic evidence suggest that the simple historical model for primary groundwater transport through this region is incorrect and that a large supply of regional baseflow does not provide the hydrogeological foundation of the Amargosa River basin. Data collected is consistent with an alternative model requiring complex source mixing and shallow alluvial groundwater that supports river flow. This conclusion also suggests Wild and Scenic conditions in this basin are more precarious than previously understood.

Keywords: hydrogeology, source water, forensics, isotopes, regional flow model

Introduction

In 2009, the Amargosa River in California between Shoshone and the terminus of the Amargosa Canyon received Wild and Scenic status through an act of Congress. As a result, the U.S. Bureau of Land Management is charged with developing a management plan for the Wild and Scenic portion of the River. Given the limited availability of water in this region, maintenance of its Wild and Scenic attributes requires adequate water in the spring-fed River. Reduced groundwater elevations and associated reduced river flow could severely impact several endangered species, including Desert Pupfish and Amargosa Vole that are dependent on the river system. Therefore, it is essential that a comprehensive understanding of hydrogeologic conditions of the basin exist for the management plan development and implementation to avoid potentially irreversible negative impacts.

This article describes the investigation of the hydrogeology of the California portion of the Amargosa Basin, south of the Nevada state line (Figure 1). Detailed regional hydrogeologic investigations in the California portion of the basin have been virtually non-existent, whereas the Nevada portion of the Amargosa Basin are more thoroughly researched as a result of field investigations related to the Nevada Test Site and the proposed nuclear waste repository at Yucca Mountain, Nevada (e.g., Eakin, 1966; Winograd and Thordarson, 1975; Eaton 1982; Dettinger et al., 1995; Laczniak et al., 1996). Although multiple investigations have been conducted in the California portion of the basin for various specific reasons (for example solar facility siting), all hydrogeologic models of the California portion of the basin have been conceptual, and based on limited datasets. The local conceptualizations also have differed from the developed computer model simulations of southern Nevada regional groundwater (Belcher and Sweetkind, 2010).

Current Conceptual Model and Recent Studies

Given the lack of equivalent comprehensive data and simulation effort in the California portion, the prevailing conceptual model to date primarily extends the geological and hydrogeological features observed in Nevada. This results in generalizing a broad westward groundwater movement toward the Amargosa groundwater flow system as postulated in earlier works by the United States Geological Survey (e.g., Malmberg, 1967; Winograd and Thordarson, 1975; Eaton 1982; Dettinger et al., 1995), and in the absence of new information has continued to be generally accepted.

Q3 Address correspondence to Andy Zdon, Andy Zdon & Associates, Inc., 2121 North California Blvd., Suite 290, Walnut Creek, California, USA, 94596. E-mail: andy@andyzdon.net

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/uenf.

The regional groundwater flow system is considerably more extensive than the Amargosa River Basin (ARB) watershed since the watershed boundary is underlain in part by the carbonate rock aquifer that drains toward Death Valley, but its role in directing recharge towards the ARB is poorly understood. Regional carbonate groundwater recharges from snowmelt and rainfall accumulating at higher elevations in southern and central Nevada eventually reaches the ARB (Bedinger et al., 1989; Planert and Williams, 1995).

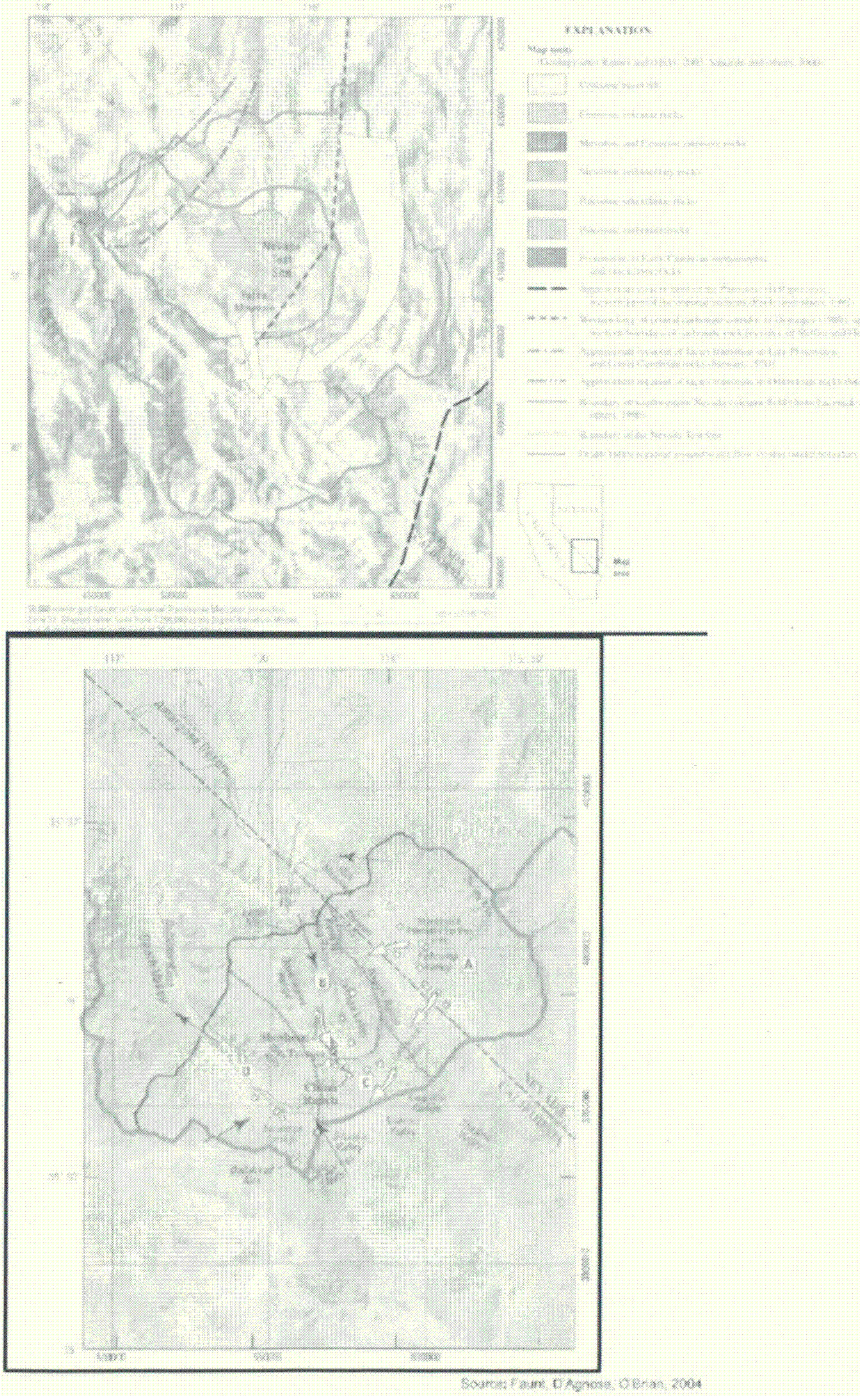


Figure 1. a) Surface geology and conceptualized regional groundwater flow in southern Nevada and southern California (after Sweetkind et al., 2004); b) Map of the Amargosa River Basin showing the Amargosa River Watershed, the location of the Spring Mountains, Pahrump Valley, Chicago Valley
Q4 and California Valley; c) Important topographic and geographic locations referred to in the text discussions throughout the Amargosa Basin.

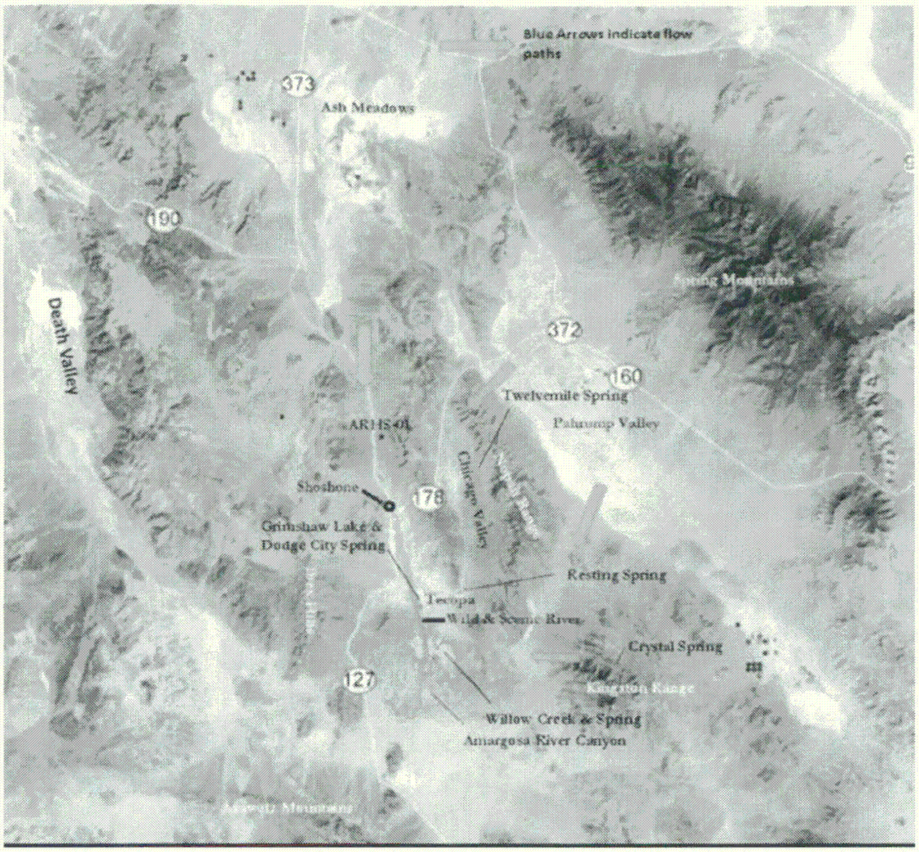


Figure 1. (Continued)

Within the Middle Amargosa River Basin (Figure 1b and 1c), it has been postulated that groundwater moves through the carbonate aquifer southwest from the Spring Mountains and beneath Pahrump Valley toward the Tecopa–Shoshone–Chicago Valley–California Valley areas (Faunt et al., 2004). A cross-section based on this concept is in Figure 2 (based on Planert and Williams, 1995) demonstrating flow paths that could be expected as groundwater moves from the Spring Mountains to the Shoshone-Tecopa area. As shown, a westward groundwater gradient across the region combined with contiguous lower Paleozoic carbonate rocks would be required for groundwater to pass continuously in a direct path beneath the drainage divides defined by topographic relief.

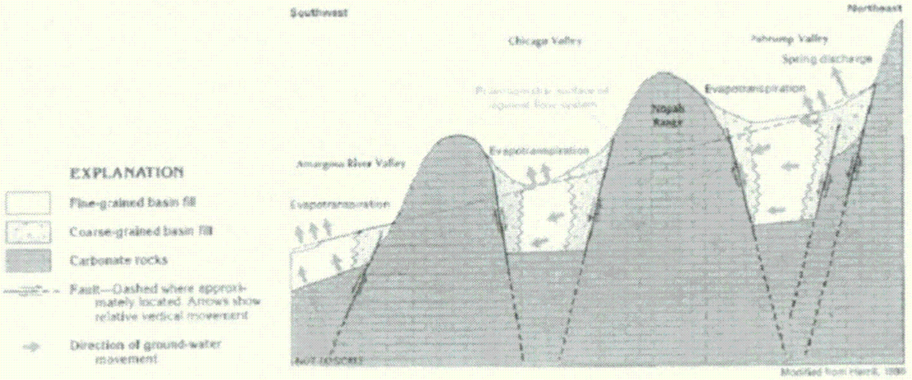


Figure 2. Conceptual cross-section of groundwater flow paths from the Spring Mountains to the Shoshone-Tecopa area.

Previous studies of the hydrogeology and chemistry of this region provide some initial bases for the evaluation. Winograd and Thordarson (1975) developed one of the early frameworks for groundwater flow in southern Nevada related to the Nevada Test Site, which included extensive discussion of the Ash Meadows springs discharge area. Based on earlier work, they also summarized types of groundwater hydrochemistry that showed calcium magnesium bicarbonate groundwater associated with both the carbonate rock of the Spring Mountains 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 (1975) 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% Spring Mountains recharge and 40% from Pahranagat Valley to the east.

Davisson et al. (1999) showed that stable isotopes of oxygen-18 and deuterium measured in southern Nevada regional groundwater had been previously evaporated during its original recharge as melted snow in central Nevada (Rose et al., 1999). Applying a methodology that removed the evaporative effects during recharge, the isotope abundances subsequently followed systematic decrease with increasing latitude and local elevation throughout southern Nevada consistent with underlying physical principals of fractionation.

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: 1) a Spring Mountains recharge source, 2) a deep regional groundwater derived from fracture flow of southern Nevada, and 3) groundwater derived from basin-filled groundwater of the Amargosa Desert.

Thomas et al. (2003) 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 in Nevada.

Hurst (2012) specifically focused on tritium, oxygen-18, deuterium, strontium isotopes, and uranium isotopes in regions along the California portion of 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 complex mixing along the entire length of the Amargosa River.

This article uses forensic techniques, utilizing new data along with compiled results from previous studies, to evaluate the source of water to the ARB and test the current conceptual model. The data and discussion that follows demonstrates that groundwater in the ARB is recharged from multiple sources and is inconsistent with a simple replenishment from regional carbonate groundwater derived solely from the easterly Spring Mountains.

Methods

Prior to this investigation, groundwater level and water quality information were sparse in the area of the Wild & Scenic River. Initially, this effort was focused on developing a basis for a Wild & Scenic River management plan. Since 2010 groundwater elevations have been measured in numerous existing wells in the Nevada portion of the basin, and four newly constructed monitoring wells in the California portion of the basin using a combination of hand-measured groundwater levels and those collected by transducer-data logger installations. In addition discharge was measured in springs and the Amargosa River (Figure 3). These flow measurements are noted here for context but are not discussed further in this report. Groundwater elevations were contoured to aid in the understanding of regional gradients and inferred groundwater flow directions in the basin fill.

In addition, ground and surface water samples were collected and measured for water quality and stable isotope analyses. Samples for water quality were collected in 1-pint glass bottles. The water quality samples were preserved with nitric acid (as appropriate), stored at 4°C, and analyzed for general anions, cations, and dissolved metals at Advanced Technology Laboratories, Inc., in Las Vegas, NV. Water samples were collected for oxygen-18 and deuterium stable isotopic analysis using laboratory-clean, airtight 60 milliliter glass bottles. Samples were analyzed at the University of Arizona (Tucson, AZ, USA) or the Isotech Laboratories (Champaign, IL, USA). Results are reported normalized to standard mean ocean water (SMOW) following conversion to standard δ ("del") notation:

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

where R is the isotope ratio of the sample and R_{std} is the ratio of the standard. In addition, stable isotope data were compiled from previous works for springs and groundwater wells within the Amargosa region (Thomas et al., 1996; Rose et al. 1997). The δD and $\delta^{18}O$ results are used to distinguish different water populations that imply different recharge areas or elevations.

Analyses

The geologic complexity of the ARB requires a multi-variant approach to analyzing the hydrogeologic framework and the

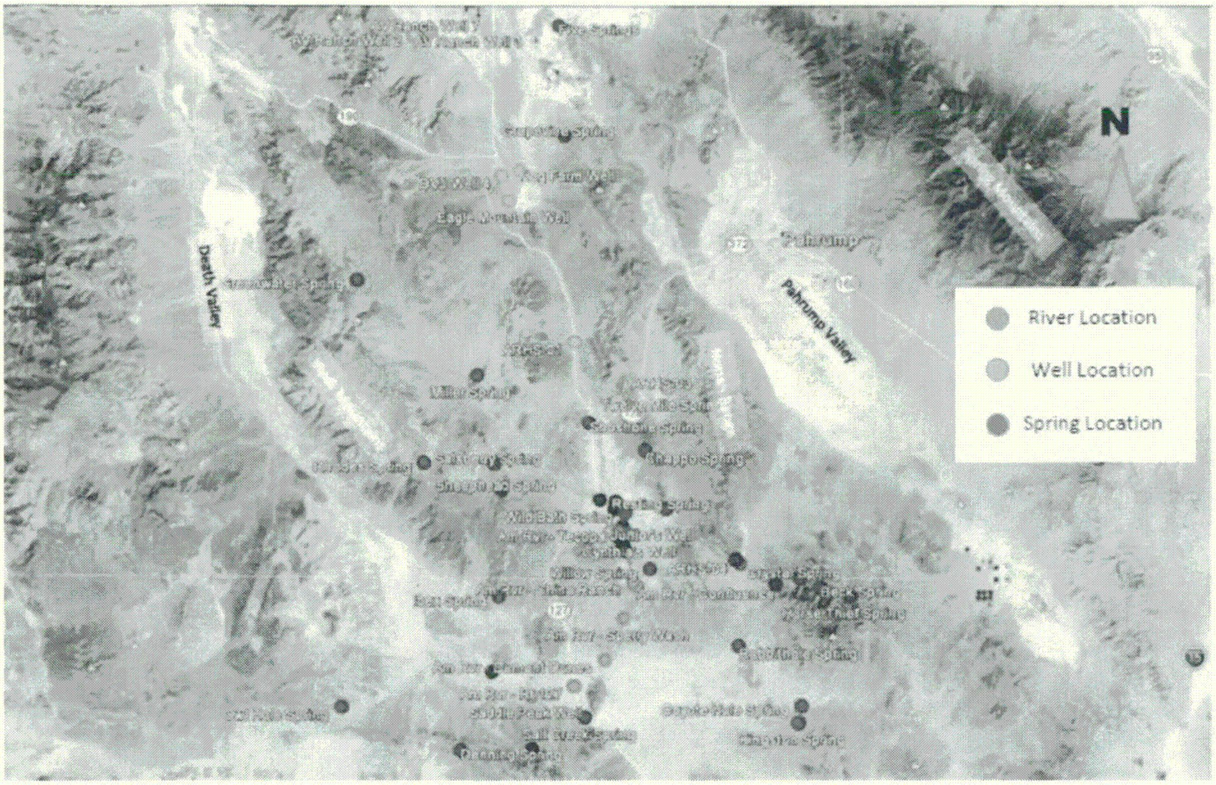


Figure 3. Groundwater and surface water sampling locations throughout the Amargosa Basin.

associated groundwater recharge areas and flowpaths that supply spring discharge in this area. Our approach has been to combine published geologic maps and cross-sections with measured groundwater levels both historical, and in new monitoring wells completed for a broader study. Furthermore, water quality chemistry and isotope data have been compiled from published sources along with new data to delineate recharge areas, inferred flowpaths, and geologic controls on water quality.

Geologic Framework

The ARB 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 ranges and flat arid valleys or basins. The ranges generally trend north-northwest parallel to the regional structural regime. The geologic units present in the ARB are very diverse ranging from Precambrian, Paleozoic and Mesozoic metamorphic and sedimentary rocks and Mesozoic-aged igneous rocks, to Tertiary and Quaternary-aged volcanic rocks, and playa, fluvial and alluvial deposits (Figure 4a).

In the ARB, the principal hydrogeologic units consist of unconsolidated basin fill materials, volcanic rocks (primarily in Nevada), the carbonate rocks that comprise the regional carbonate aquifer, and silicic bedrock units. 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). 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. Wells and boreholes that are completed in aquifer materials underlying these aquitards may exhibit artesian conditions such as at Borehole Spring and Borax Spring in the Shoshone-Tecopa area. Bedrock units of the Nopah and Resting Spring Ranges and portions of the Amargosa Range generally extend and underlie the alluvial valleys. The bedrock units consist of Precambrian to Mesozoic-aged metamorphic and sedimentary rocks, consisting of Paleozoic-age carbonate rocks (the carbonate rock aquifer), quartzite, and shale, which have been folded and faulted.

The valley areas are covered by coalescing alluvial fans forming broad slopes between the surrounding mountains and the valley floors. The regional topographic gradient of the Northern Amargosa River Basin is generally to the south-southeast with gradients that typically range from 5

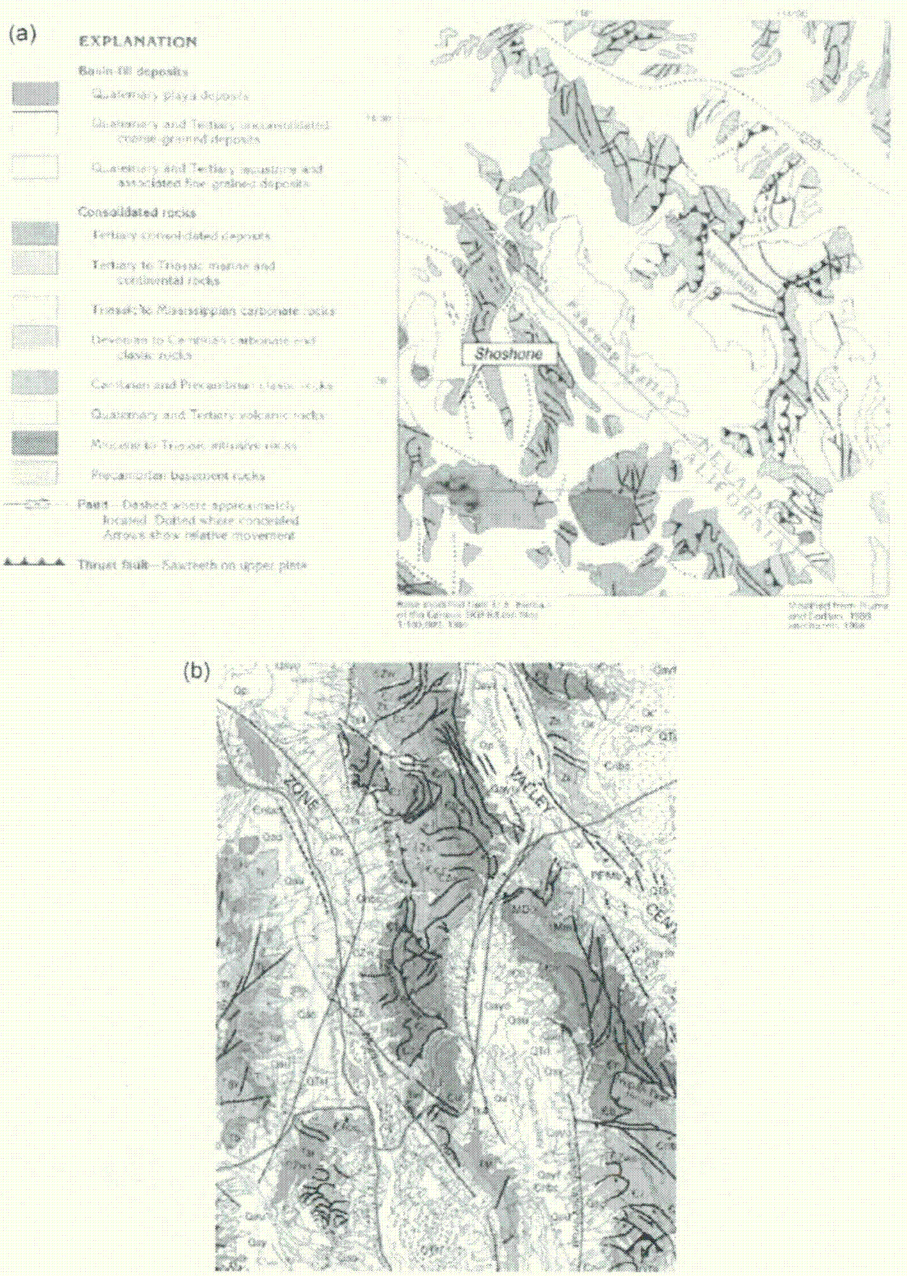


Figure 4. a) Geologic units present in the Amargosa Basin (from Planert and Williams, 1995) b) Detailed geologic map of the Middle Amagosa Basin indicating that Precambrian to Cambrian bedrock units underlying the carbonate rock units outcrop along the western base of the Resting Spring Range and the portion of the Nopah Range south of the Nopah Peak Thrust (from Workman, et al., 2002).

Q5

to 15 feet per mile. The basin fill deposits are interpreted to be underlain primarily by Paleozoic sediments although the central portions of the basin 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 (Figure 3).

Based on the results of more recent detailed mapping by the USGS (Workman, et al., 2002), it appears that in the Shoshone–Tecopa area, the carbonate rock aquifer as a conduit for groundwater to move directly from the Spring Mountains/ Pahrump Valley area toward the Shoshone–Tecopa area may be more complex than originally posited. Figure 4b shows a portion of the 2002 geologic map indicating that Precambrian to Cambrian bedrock units underlying the carbonate rock units and crop out 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 primarily comprise quartzite, shale, siltstone and dolomite of lesser permeability or porosity than would be expected of the Paleozoic-age carbonate rocks. Generally, bedrock units such as these produce little water except where they are fractured and faulted, providing pathways for groundwater movement. Therefore, flow paths from the Pahrump Valley area toward the Middle Amargosa Basin may require a more circuitous route. This suggests that groundwater moving toward the Amargosa River would likely have to enter the basin through carbonate rocks north of the Nopah Thrust, and south of the range.

Hydrogeology

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 generally south to the river's terminus at the playa in Death Valley. The only materials within the California portion of the ARB 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). 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. Except during runoff events from rainstorms, the perennial flow in the Wild and Scenic section of the river is completely derived from groundwater.

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 2010 groundwater levels is shown in Figure 5. Little change has been observed in levels south of Death Valley Junction since 2010.

Precipitation and snowmelt runoff from the mountains surrounding the Middle ARB recharges basin alluvium and flow towards the Amargosa River. Figure 5 shows the conceptualized flow paths implied by groundwater levels within the Middle ARB. North of Shoshone, groundwater flows south in the alluvium around Eagle Mountain.

In the California portion of the basin, the valley and the Amargosa River are additionally fed from sparse water runoff from the east slope of the Amargosa Range and the west slope of the Resting Spring Range (Figure 5). When runoff is present, 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. Sparse runoff 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, toward 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.

As stated earlier, the Amargosa River may receive some underflow into Chicago Valley by groundwater passing beneath and around the north of the Nopah Range (north of the Nopah Peak Thrust). Groundwater in Chicago Valley would encounter a barrier caused by the submerged non-carbonate bedrock units of the Resting Spring Range, and flow southward toward the Amargosa River. Resting Spring may be at least a partial result of this flow.

Based on the field reconnaissance activities, water temperature, and water quality chemistry 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 assumed deep circulation paths (such as Tecopa Hot Springs) to those with shallow and more local circulation paths (such as at Crystal Spring in the Kingston Range).

Other surface water bodies in this region are all spring-fed: 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 flow is utilized by vegetation, or it percolates back into the subsurface. Willow Creek is 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.

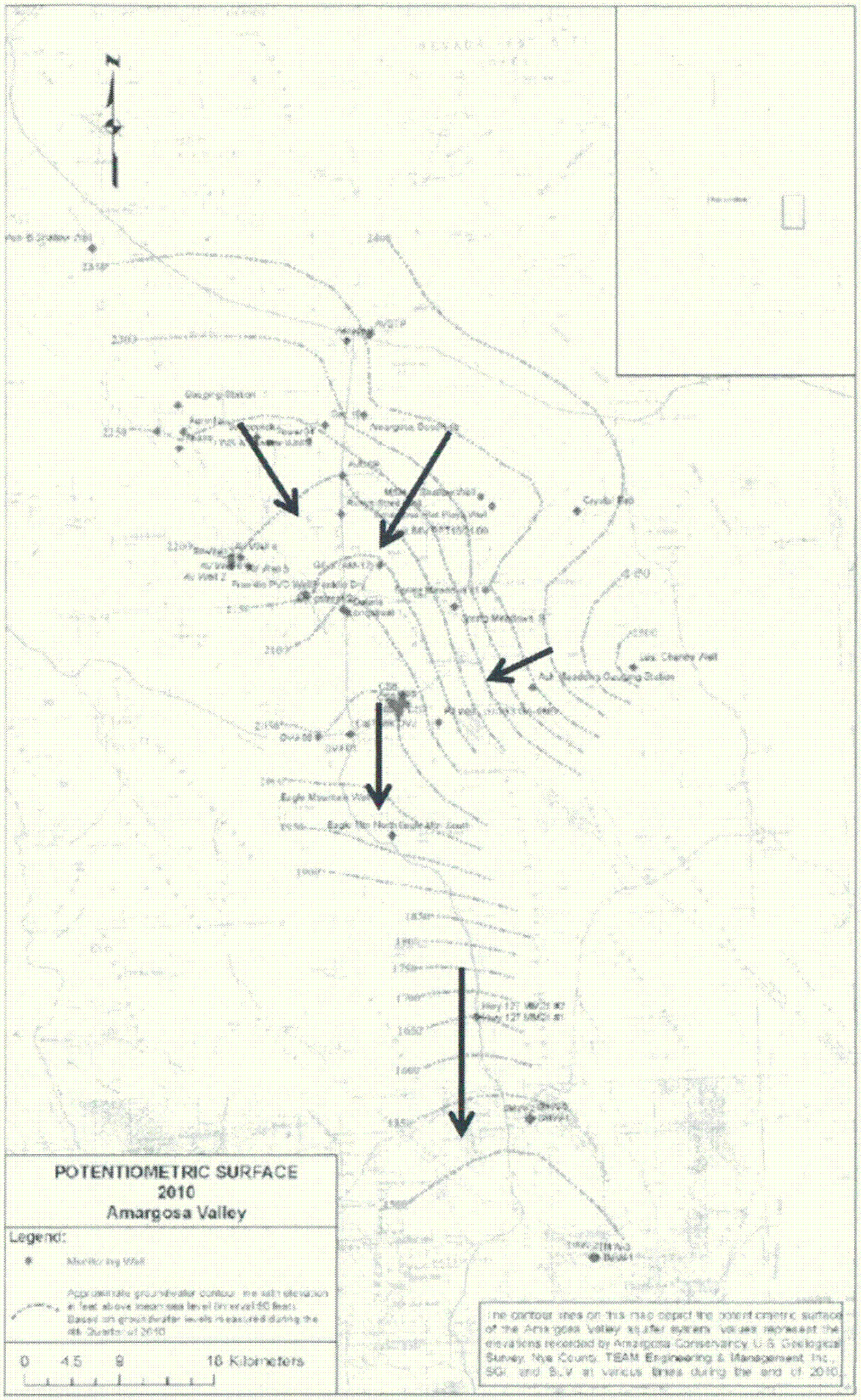


Figure 5. Generalized groundwater flow contour and gradient map for the middle Amargosa River Basin.

Table 1. *Groundwater quality summary for Southern Nevada and Southeastern California*

Region	WQ Type	TDS Range mg/L	$Cl + SO_4$ Range mg/L
Regional Carbonate Aquifer	$CaMgHCO_3$	200–000	10–500
Nevada Test Site	$NaKHCO_3$	90–1100	15–650
Ash Meadows	$CaMgNaKHCO_3$	400–500	140–200
Amargosa River Basin	$NaKHCO_3ClSO_4$	350–5100	100–3000

Chemical Signatures

Groundwater quality in the ARB tends toward high total dissolved solids contributed by appreciable levels of chloride and sulfate. In order to place this water quality in context, regional groundwater data were compiled from Rose et al. (1997) for the Nevada Test Site, Thomas et al. (1996) and Winograd and Thordarson (1975) for the regional carbonate aquifer, Ash Meadows, and parts of southeastern California, and those of Hurst (2012) for the ARB. A summary is tabulated in Table 1, and data are plotted and compared on a piper diagram in Figure 6. Note that between the regional carbonate aquifer and the ARB groundwater, water quality changes from Ca-Mg-HCO3 type toward Na-K-HCO3-Cl-SO4 type accompanied by increased salinity. The ARB groundwater is dominated by Na-K-HCO3 type water quality, but chloride and sulfate increase progressively downgradient along with total dissolved solids. Ash Meadows is a mixture of Spring Mountains and Nevada Test Site type water quality as noted by others (Winograd and Thordarson, 1975).

Two potential processes may influence the water quality in the Amargosa River Valley groundwater. One may be the ubiquitous Tecopa lakebed geologic deposits that uniquely occur in the Tecopa region. These lakebeds were accumulated during high stands of glacial ice in the Pleistocene period of Earth's history that caused large amounts of surface runoff that accumulated in closed basin lakes in Nevada and southeastern California. These lakes ultimately went through wet/dry cycles that accumulated precipitated salts (predominately chlorides and sulfates), similar as seen today in desert playas. Modern groundwater encountering the Tecopa lakebeds will undoubtedly dissolve soluble salts in the sediment, which will contribute to increasing salinity of the water.

The additional process that will contribute increased salinity in ARB groundwater is the elevated water temperature found in the Tecopa region. High heat flow (80–90 mW/m^2; Blackwell et al., 2011) has been measured throughout this region from the Spring Mountains in the east to the eastern edge of the Sierra Nevada. The heat flow is significantly lower northeast of Ash Meadows (50–60 mW/m^2), corresponding to the regional carbonate aquifer, but in contrast heat flow is high under the Nevada Test Site. Note groundwater temperatures can range up to 45°C in parts of the Nevada Test Site (Rose et al., 1997). Groundwater in the Tecopa region also has high temperatures up to 50°C. The regional carbonate aquifer groundwater temperature typically ranges between 20–30°C.

The increase in groundwater temperature can have significant impact on groundwater quality. For instance, dissolved silica increases with increasing temperature, and carbonate solubility is expected to simultaneously decrease. However, although silica is higher for thermal water in this area, alkalinity tends to be higher as well, suggesting other complexities. One possibility is that soluble salts liberated from Tecopa lakebed deposits may be the source of higher alkalinity, as well as the elevated chloride and sulfate in these waters. Note also that temperature should be considered a transient property, since water temperatures measured in spring discharge may be much cooler than its subsurface source depth and

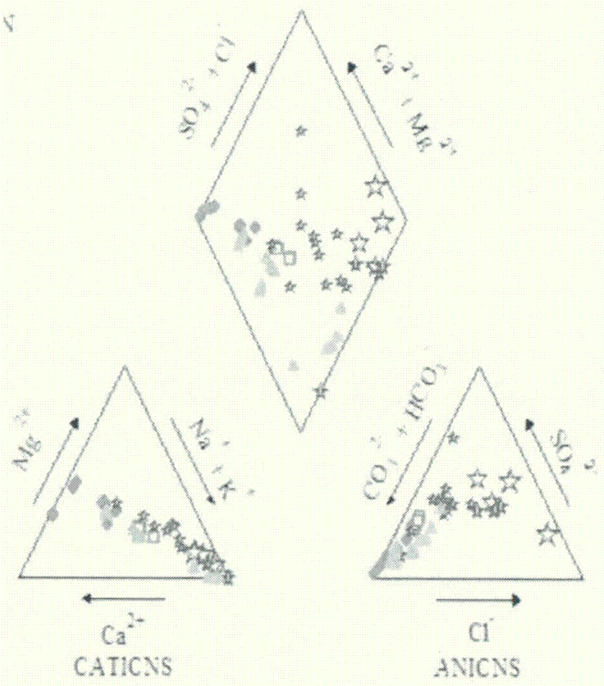


Figure 6. Piper plot comparing cation and anion relative concentrations in groundwater of the regional carbonate aquifer (red circles), Ash Meadows (open red squares), Nevada Test Site (green triangles), and Amargosa River Valley (open blue stars). The size of the symbol correlates to TDS. Note that between the regional carbonate aquifer and the Amargosa River Valley groundwater, water quality changes from Ca-Mg-HCO3 type toward Na-K-HCO3-Cl-SO4 type accompanied by increased salinity.

chemical modification could be imparted during migration to the surface and away from the discharge point. Nevertheless, there is a clear relationship between increased alkalinity and water pH in the ARB groundwater, and for the highest pH dissolved arsenic is elevated to hundreds to thousands of parts per billion. The source of the arsenic is unknown at this time.

Q6

Isotope Signatures

The $\delta^{18}O$ and δD abundances in precipitation systematically vary with increasing latitude and elevation. This results in lower $\delta^{18}O$ and δD isotope values in groundwater from north to south from central Nevada to southeastern California (Davisson et al., 1999). There is also a regional effect in the American Southwest where summer monsoonal precipitation occurs in areas directly north of the Gulf of California, causing substantial precipitation in some higher elevation areas of the desert. This summer monsoonal rain has higher isotope values than winter season equivalents because of warmer temperatures. For example, local high elevation areas such as the Spring Mountains, which support annual snow accumulation during the winter, has higher $\delta^{18}O$ and δD values than groundwater found in Oasis Valley on the south side of Pahute Mesa. The Spring Mountains receive some amount of precipitation annually from summer monsoons, whereas the Oasis Valley groundwater ultimately is derived from recharge further north of Pahute Mesa where isotopic values of mean precipitation are even lower and are predominately influenced by winter precipitation (Davisson et al., 1999). The orographic effect on stable isotopic signatures provides a means to use these differences to potentially derive recharge sources of groundwater sampled in the ARB. For example, Ash Meadows groundwater stable isotope signatures are consistent with a mixture between Spring Mountains and Oasis Valley and/or Pahranagat Valley (Winograd and Thordarson, 1975; Thomas et al., 1996).

Comparison of measured $\delta^{18}O$ and δD for groundwater and springs is shown in Figure 7 to illustrate differences among specific geographic groupings. A δD-$\delta^{18}O$ plot is illustrated and highlighted in color for each geographic grouping plotted on a shaded relief map (Figure 7). Note that Oasis Valley has the lowest isotopic values of all the groupings. In contrast, the Tecopa area springs and wells have the highest isotopic values. Accordingly, Oasis Valley as a sole source of Tecopa groundwater is not supported by the stable isotopic signatures. Note, monitoring well ARHS-1 ($\delta D = -91$ and $\delta^{18}O = -11.0$) above Shoshone, Twelve Mile Spring ($\delta D = -99$ and $\delta^{18}O = -13.6$) from the Chicago Valley, and Dodge City Spring ($\delta D = -95$ and $\delta^{18}O = -12.0$) were collected in and around the Tecopa area, but the isotopic ratios demonstrate their recharge sources are distinctly different.

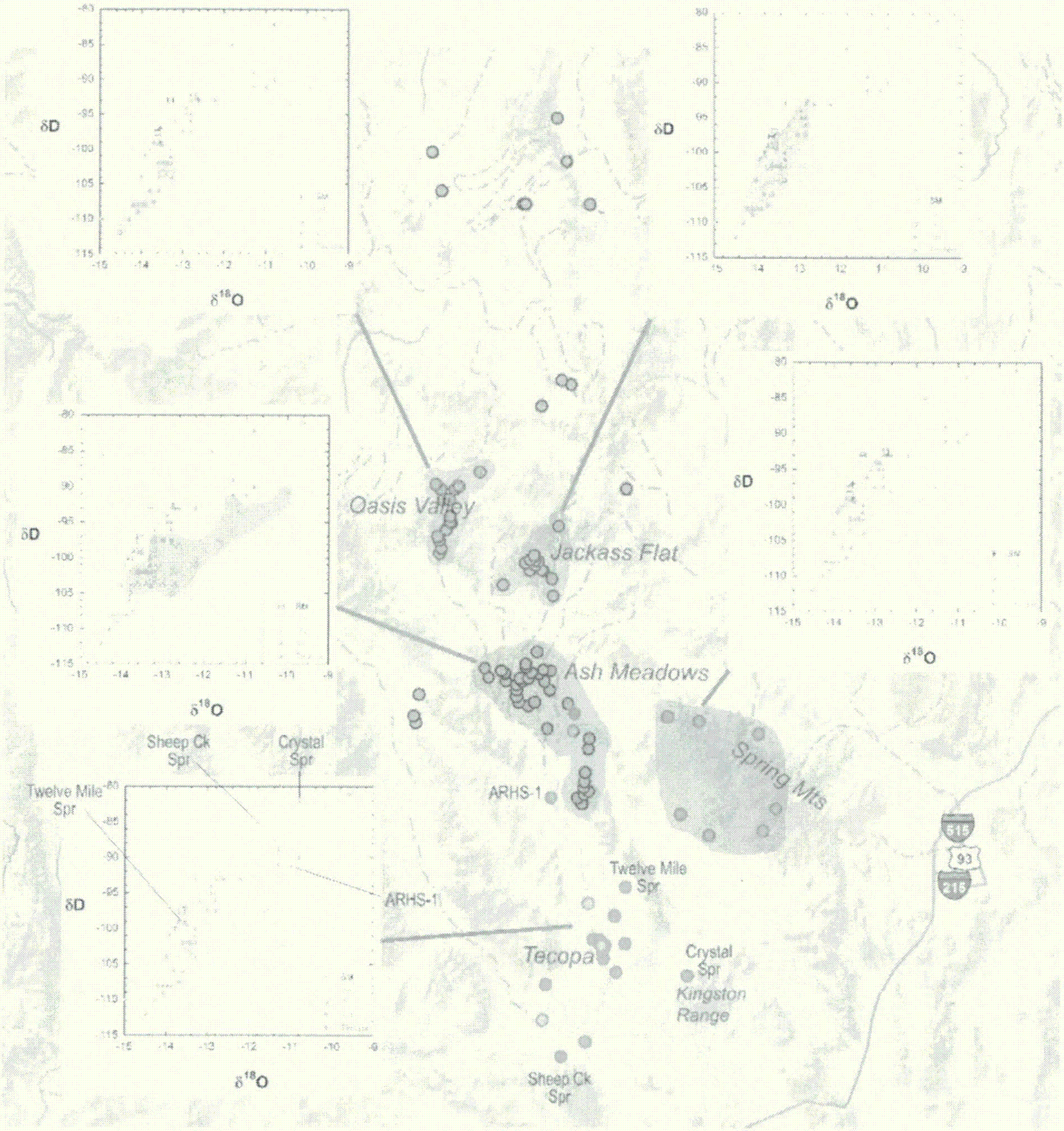
All these results are consistent with values measured in the Tecopa area. Note that the Spring Mountains isotope values are also elevated and form a fairly narrow range that conforms to the Global Meteoric Water Line (Figure 7). These result comparison among isotope values for Oasis Valley, Jackass Flats, and Springs Mountains with Ash Meadows indicate that Ash Meadows values overlap these groups and support recharge source as a mixture among them. Stable isotope signatures in the Tecopa grouping only have a moderate overlap with the Ash Meadows data and with Spring Mountains. The one Tecopa area groundwater that overlaps with Ash Meadows is Borax Spring (Figure 3 shows the location), which suggests Ash Meadows type groundwater as a potential recharge source. The remainder of the Tecopa groundwater is clearly influenced by a more Spring Mountains type recharge isotope value. However, recall that isotope values increase progressively toward the south, which suggests that additional recharge sources with similar isotope signatures, such as Spring Mountains be considered. We also know that the Kingston Range to the south has high isotope values, as seen for Crystal Spring which drains from those ranges, although it has undergone some evaporation, it overlaps with the Tecopa isotope grouping in Figure 7. Nevertheless, its recharge into the groundwater beneath Tecopa can influence the isotope signatures causing them to be higher than the Ash Meadows grouping. Note also that Sheep Creek Spring in the Avawatz Mountains has high isotope values that conform closely to the Global Meteoric Water Line, confirming that local precipitation does recharge in this area.

Implications for Basin Conceptualization

The data collected and analyzed in this paper are inconsistent with the current prevailing conceptual groundwater model that purports broad-based underflow from the regional carbonate aquifer solely from the east toward the ARB. Stable isotope and geochemical data support a refined conceptual model that accounts for multiple source contributors to groundwater within the Amargosa River basin, which includes a mixture of Ash Meadows, Spring Mountains and Kingston Range sources. The pathways for that groundwater to reach the area probably consist of one or a combination of:

- Water that moves through carbonate rocks beneath the northern portion of the Nopah Range into Chicago Valley, then toward the Amargosa River;
- Water that moves from Pahrump Valley through the low, faulted divide into California Valley then towards the river; and
- Water that moves southward from the Ash Meadows area (itself a mixture of waters from different sources).

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 likely to occur via deep-seated fracture flow, rather than within 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 lakebed deposits.



Q7

Figure 7. δD-$\delta^{18}O$ plots are compared as regional groupings in this map view. Note that the range in δD and $\delta^{18}O$ 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.

Additionally, regional subsurface heat flow increases groundwater temperature and contributes to increased dissolved silica, but its effect on increased pH and high arsenic concentrations (>400 ppb) observed in Tecopa water samples is unclear. Further work is needed to determine how much influence may be derived from soluble salts in the Tecopa lakebed deposits.

Groundwater from the deep carbonate rock aquifer is discharged to the basin fill north of the Shoshone-Tecopa area where it tends to move southward following the hydraulic gradient. Given the presence of lower permeability Tecopa lakebed deposits and bedrock of the Amargosa Canyon (and other constrictions in the area for instance at Resting Spring), groundwater is forced to the surface giving rise to the spring and perennially flowing portion of the Amargosa River. Given this scenario, the surface expression of flow likely represents a large fraction of the underflow that moves through this portion of the basin as opposed to the springs representing the surface expression of a large volume of underflow beneath those springs. Further, during drilling of monitoring well ARHS-01, despite its placement immediately next to a normally dry portion of the river (but where flow was thought to be moving along the subsurface along the river channel), drilling identified 40 feet of dry river gravel and 100 feet of dry lakebed deposits, prior to encountering a saturated gravel with water temperatures in excess of 30°C. This is also supportive of this concept of lesser underflow along the river channel than previously thought.

Additional investigation is necessary to confirm and refine this new conceptual model for the basin. One of those areas of investigation should include the installation of additional monitoring wells and associated geochemical sampling and analysis of groundwater (including trace metals and stable isotopes) to gain a greater understanding of flow paths. Second, further analysis of salts in the discharge area is recommended 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. Geophysical surveys in the vicinity of Tecopa to evaluate faulting in the vicinity of the thermal springs are recommended to evaluate the potential affect of subsurface geologic structures on groundwater flow and mixing.

Conclusions

Based on analysis and interpretation of the new data collected as part of this study within the geologic and hydrogeologic framework, the source water for the Amargosa River appears to be a complex mixture of deep geothermal and shallow alluvial groundwater sources are forced to the surface as springs at various locations throughout the basin as a result of underlying geologic structures. The conceptual model developed as part of this study suggests that although a deep underlying regional aquifer provides substantial volumes of water to the system, flow through the system is a more limited water supply that is more susceptible to regional and local water resource and climatic conditions. Future management of the Wild and Scenic status should consider the implications of this refined conceptual groundwater model for the basin in order to maintain its recognized Wild and Scenic attributes.

References

Bedinger, M. S., Sargent, K. A., and Langer, W. H. 1989. Studies of geology and hydrogeology in the Basin and Range Province, Southwestern United States, for isolation of high-level radioactive waste characterization of the Death Valley region, Nevada and California. *U.S. Geological Survey Professional Paper* 1307–F.

Belcher, W. R., and Sweetkind, D. S., eds. 2010. Death Valley regional groundwater flow system, Nevada and California—Hydrogeologic framework and transient groundwater flow model. *U.S. Geological Survey Professional Paper* 1711.

Blackwell, D., Richards, M., Frone, Z., Batir, J., Ruzo, A., Dingwall, R., and Williams, M. 2011. Temperature at depth maps for the conterminous US and geothermal resource estimates, *Geothermal Resources Council Transactions* 35:1545–1550. GRC Record 1029452.

Davisson, M. L., Smith, D. K., Keneally, J., and Rose, T. P. 1999. Isotope hydrology of southern Nevada groundwater: Stable isotopes and radiocarbon. *Water Resources Research* 35:279–294.

Dettinger, M. D., J. R. Harrill, D. L. Schmidt, and J. W. Hess. 1995. Distribution of carbonate-rock aquifers and the potential for their development, southern Nevada and adjacent parts of California, Arizona, and Utah. *U.S. Geological Survey Water-Resources Investigations Report* 91-4146, 100.

Eakin, T. E. 1966. A regional interbasin groundwater system in the White River area, southeastern Nevada. *Water Resources Research* 2:251–271.

Eaton, G. P. 1982. The Basin and Range province: Origin and tectonic significance. *Annual Review of Earth and Planetary Sciences* 10:409–440.

Faunt, C. C., Blainey, J. B., Hill, M. C., D'Agnese, F., and O'Brien, G. M. 2004. Transient numerical model. In *Death Valley regional groundwater flow system, Nevada and California—Hydrogeologic framework and transient ground-water flow model*. U.S. Geological Survey Scientific Investigations Report 2004–5205.

Hurst, R. W. 2012. *A multiple isotopic investigation of the Armargosa River: Inyo-San Bernardino Counties, CA and Nye County, NV.* Q8

Laczniak, R. J., Cole, J. C., Sawyer, D. A., and Trudeau, D. A. 1996. Summary of hydrogeologic controls on ground-water flow at the Nevada Test Site, Nye County, Nevada. *U.S. Geological Survey Water-Resources Investigations Reports* 96–4109, 59.

Larsen, D., Swihart, G. H., and Xiao, Y. 2001. Hydrochemistry and isotope composition of springs in the Tecopa basin, southeastern California, USA. *Chemical Geology* 179, 17–35.

Malmberg, G. T. 1967. Hydrology of the valley-fill and carbonate-rock reservoirs, Pahrump Valley, Nevada–California: U.S. Geological Survey Water–Supply Paper 1832.

Planert, M., and Williams, J. S. 1995. Ground water atlas of the United States—California, Nevada. U.S. Geological Survey Hydrologic Atlas HA 730–B.

Rose, T. P., Kenneally, J. M., Smith, D. K., Davisson, M. L., Hudson, G. B., and Rego, J. H. 1997. *Chemical and isotopic data for groundwater in Southern Nevada*. Lawrence Livermore National Laboratory UCRL-ID-128000.

Rose, T. P., Davisson, M. L., Criss, R. E., and Smith, D. K. 1999. Isotopic investigation of recharge to a regional groundwater flow system, Great Basin, Nevada, USA. In *Proceedings of the International Atomic Energy Agency Symposium on Isotope Hydrology in Water Resources Management*, May 1999m Vienna, Austria.

Thomas, J. M., Welch, A. H., and Dettinger M. D. 1996. Geochemistry and isotope hydrology of representative aquifers in the Great Basin region, Nevada, Utah, and adjacent states. *U.S. Geological Survey Professional Paper* 1409–C.

Thomas, J. M., F. C. Benedict, Jr., T. P. Rose, R. L Hershey, J. B. Paces, and Z. E. Peterman, et al. 2003. *Geochemical and Isotopic Interpretations of Groundwater Flow in Oasis Valley Flow System, Southern Nevada*. Department of Energy, Nevada Operations Office, DOE/NV/11508–56. Publ. No. 45190.

Walker, G. E., and Eakin, T. E. 1963. *Geology and ground water of Armargosa Desert, Nevada–California*. State of Nevada Department of Conservation and Natural Resources Ground–Water Reconnaissance Series Report 14.

Winograd, I. J., and Thordarson, W. 1975. Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada–California, with special reference to the Nevada Test Site. *U.S. Geological Survey Publications Professional Paper* 712–C.

Workman, J. B., Menges, C. M., Page, W. R., Taylor, E. M., Ekren, E. B., Rowley, P. D., et al. 2002. Geologic map of the Death Valley groundwater model area, Nevada and California. *U.S. Geological Survey Miscellaneous Field Studies* MF–2381.

AMARGOSA CANYON SPRINGS

Location: North end of Amargosa Canyon, south end of the town of Tecopa.
Directions: Walk due south along the river from the town of Tecopa post office parking lot approximately ¾ of a mile.

General Location of Amargosa Canyon spring system:

Latitude: N35.83937 (NAD83)
Longitude: W116.22399
Elevation: ~1,300 – 1,400ft

Location of Amargosa Canyon Spring #1:

Along east bank of Amargosa River approximately ¾ miles from Tecopa Post Office.
Latitude: N35.83937
Longitude: W116.22399
Elevation: 1,294 ft.

Location of Amargosa Canyon Spring #3:

By foot via the north end of the Amargosa Canyon and south of Amargosa Canyon #1.
Latitude: N35.82701
Longitude: W116.21942
Elevation: 1,262 ft.

Location of Amargosa Canyon Spring #4:

Gushet from cliff face on east bank of river canyon wall.
Latitude: N35.8348
Longitude: W116.2226
Elevation: 1,382 ft.

Location of Amargosa Canyon Spring #5 (Purple Notch Spring):

Gushet from cliff face on east bank of river canyon wall.
Latitude: N35.83602
Longitude: W116.22243
Elevation: 1,372 ft.

Background: It is likely that many of the springs were exposed during the construction of the railroad bed, which was carved out of the eastern wall of the Canyon. A photograph is available showing a Tonopah & Tidewater Railroad car (#4) stopped to take on water at "Red Cut" where a pipe was bored into the hillside tapping into the water from one of the springs (Serpico, 2013).

In the fall of 2010, Amargosa Canyon #1 spring was uncovered following a fire that burned much of the vegetation in the northern part of the Amargosa Canyon. As the vegetation grows back, access to the spring is becoming more difficult.

Description: Helocrene springs are present along the floor and wall of the eastern side of Amargosa Canyon along a 1.3-mile stretch of the Amargosa River. Vegetation at the mouth of the Canyon burned as the result of a fire that occurred around Labor Day weekend in 2010. A swampy area was revealed at the northern end of Amargosa Canyon within the burned zone, covering a small hillside. Water flowing downhill through the swampy area coalesces into larger and larger streams of water, and eventually into one large stream which forms a small waterfall (measured at approximately 38-gpm) before running into the Amargosa River (note, this spring is going to be rather inaccessible when the foliage grows back). South of this spring, additional springs were noted. Most of them are found along a former railroad bed. Flow at these springs range from less than 5-gpm to greater than 30-gpm. Total flow from all the springs in Amargosa Canyon remains unknown. Along the canyon wall carved out by the railroad, spring water seems to be emanating from the contact between an alluvial conglomerate which is situated above a mudstone formation. It is likely that the water is flowing in the permeable alluvium overlying the much less permeable mudstone below.

Amargosa Canyon #4 spring is a series of gushet (concentrated flow from a cliff face) springs located on the eastern bank of the Amargosa River, along the west-facing wall of the Amargosa Canyon. Water from this spring pours out of the canyon wall at the interface between a quartzite unit and the alluvium above. There is significant vegetation in the form of grasses that grow on the canyon wall. It is the only spring here, easily accessible without climbing gear. The combined spring discharge enters a railroad cut at the base of the canyon wall. A manmade ditch from the railroad cut directs the flow to the Amargosa River. The railroad cut is filled with tule, bulrush and tall grasses, which grade into willow and other trees further toward the river. This may be the "Red Cut" site described in the background section.

Mesquite are present at these spring along with arrow weed, willow, grapevine, and other plants (see data sheet). Tamarisk and phragmytes are also present. Disturbance at these springs is nonexistent to slight with only trail hiking being the only recreation type noted in the area.

Water Quality Parameters: taken from spring flow locations from north to south. No odor noted in any location. Parameters at Amargosa Canyon Spring #1 are obtained from the channelized flow just above the Amargosa River. Flow is measured at a point where water flows over a lip into a narrow pool. Depending on the changing conditions, flow is measured either with a bucket and stopwatch, or with a solid state flow meter. In May 2014, salinity at Amargosa Canyon #1, #3, and #5 was measured in lieu of TDS with salinity measured at 680 mg/L, 960 mg/L, and 920 mg/L, respectively. At Amargosa Canyon #4, parameters are obtained from the water pouring from the cliff face and measured with a bucket and stopwatch (for flow). The measurement point is quite narrow therefore the flow is difficult to measure accurately without modifications. The channel seems to combine all of the spring flow in the Amargosa Canyon #4 area, a direct it from the railroad cut to the Amargosa River. That flow was estimated at 30 gpm during April 2013.

Location ID	Date	Flow (gpm)	Temp (oC)	Spec Cond (µS/cmoC)	TDS (mg /L)	DO (mg/L)	pH
Am Cyn 1	11/17/2010	38	23.22	1053	685	7.42	7.93
Am Cyn 1	4/25/2011	--	22.46	1029	669	8.62	7.94
Am Cyn 1	5/11/2011	66.1	--	--	--	--	--
Am Cyn 1	9/21/2011	40.5	25.79	1076	700	7.74	8.12
Am Cyn 1	12/22/2011	78	18.73	1009	656	7.96	8.22
Am Cyn 1	1/12/2012	67.7	23.27	573	363		
Am Cyn 1	5/1/2012	80.2	21	1274	828		
Am Cyn 1	1/26/2013	83.4	22.44	1020	663	8.4	7.67
Am Cyn 1	5/6/2014	72.4	22.2	1278	--	7.15	8.17
Am Cyn 2	1/12/2011	NA	15.33	1271	826	8.69	8.16
Am Cyn 3	1/12/2011	30 (est)	16.74	1698	1,104	9.68	8.51
Am Cyn 3	4/25/2011	NA	21.1	1506	979	9.51	8.37
Am Cyn 3	9/21/2011	16	25.79	1597	1,035	8.57	8.26
Am Cyn 3	5/6/2014	9	20.9	1741	--	8.9	8.55
Am Cyn 4	1/12/2011	25 (est)	26.05	915	596	8.07	8.34
Am Cyn 4	4/25/2011	--	26.25	1240	809	8.63	8.13
Am Cyn 4	5/11/2011	7.7	--	--	--	--	--
Am Cyn 4	9/21/2011	8.1	28.2	1347	876	7.32	8.16
Am Cyn 4	12/22/2011	9.1	26.15	1273	828	7.34	8.33
Am Cyn 4	5/1/2012	7	26.11	1220	795	9.93	8.6
Am Cyn 4	1/26/2013	7.9	26.39	1537	999	9.42	8.31
Am Cyn 4	4/19/2013	7	26.64	1333	867	8.4	7.86
Am Cyn 5	1/12/2011	NA	18.88	1445	939	4.4	7.81
Am Cyn 5	5/6/2014	8-10	20.4	1647	--	8.32	8.49

Use: The springs are not in use, though have been used in the past as a source of water.

Access: These springs are on public land though are not accessible by vehicle due to land restrictions (private land to the north, wilderness to the south). On the north Jon Zellhoeffer grants permission to walk across his land from the Tecopa Post Office to access the canyon, but driving a vehicle across his property requires his permission.

Client Name: Amargosa Conservancy

Project: Amargosa Canyon Springs

Photograph 1: *Amargosa Canyon wall with spring water fed vegetation*

Photograph 2: *View of Amargosa Canyon*

Photograph 3: *Spring water emanating from canyon wall*

Photograph 4: *Amargosa River flowing within the canyon*

AMARGOSA RIVER 2

Location: The point where the Amargosa River crosses under California Route 127 near Dumont Dunes.

Directions: Travel south from the Shoshone approximately twenty five miles. Approximately two miles south past the turn off to the Dumont Dune Recreational Area is a small bridge which crosses over the Amargosa River.

Latitude: N35.66418 (NAD83) Longitude: W116.29722 Elevation: 433 ft amsl

Description: This is a measurement point for flow along the Amargosa River.

Water Quality Parameters: Flow measured by taking a velocity transect across the river using a solid state flow meter.

Location ID	Date	Flow (gpm)	Temp (°C)	Spec Cond (mS/cm°C)	TDS (mg/L)	DO (mg/L)	pH
Amargosa River 2	11/16/2010	256	21.4	4.295	2793	8.64	8.89
Amargosa River 2	4/29/2011	dry	--	--	--	--	--
Amargosa River 2	5/5/2011	dry	--	--	--	--	--
Amargosa River 2	9/23/2011	dry	--	--	--	--	--
Amargosa River 2	12/21/2011	dry	--	--	--	--	--
Amargosa River 2	5/4/2012	dry	--	--	--	--	--
Amargosa River 2	1/26/2013	dry	--	--	--	--	--
Amargosa River 2	4/18/2013	dry	--	--	--	--	--

Use: The riverbed at this location is managed by CalTrans.

Access: The riverbed is not fenced and is owned by the Bureau of Land Management.

AMARGOSA RIVER 2

Latitude: 35.6642 North Longitude: 116.2972 West Elevation: 443 feet
Location Description: Two miles south of the turnoff to Dumont Dune ORV Park on Route 127

Photo: 1

Date: November 2010

View of the Amargosa River flowing under Route 127, looking Southwest.

Photo: 2

Date: November 2010

View of the Amargosa River flowing under Route 127, looking Northeast.

AMARGOSA RIVER 2

Latitude: 35.6642 North Longitude: 116.2972 West Elevation: 443 feet

Location Description: Two miles south of the turnoff to Dumont Dune ORV Park on Route 127

Photo: 1

Date: November 2010

View of the Amargosa River flowing under Route 127, looking Southwest.

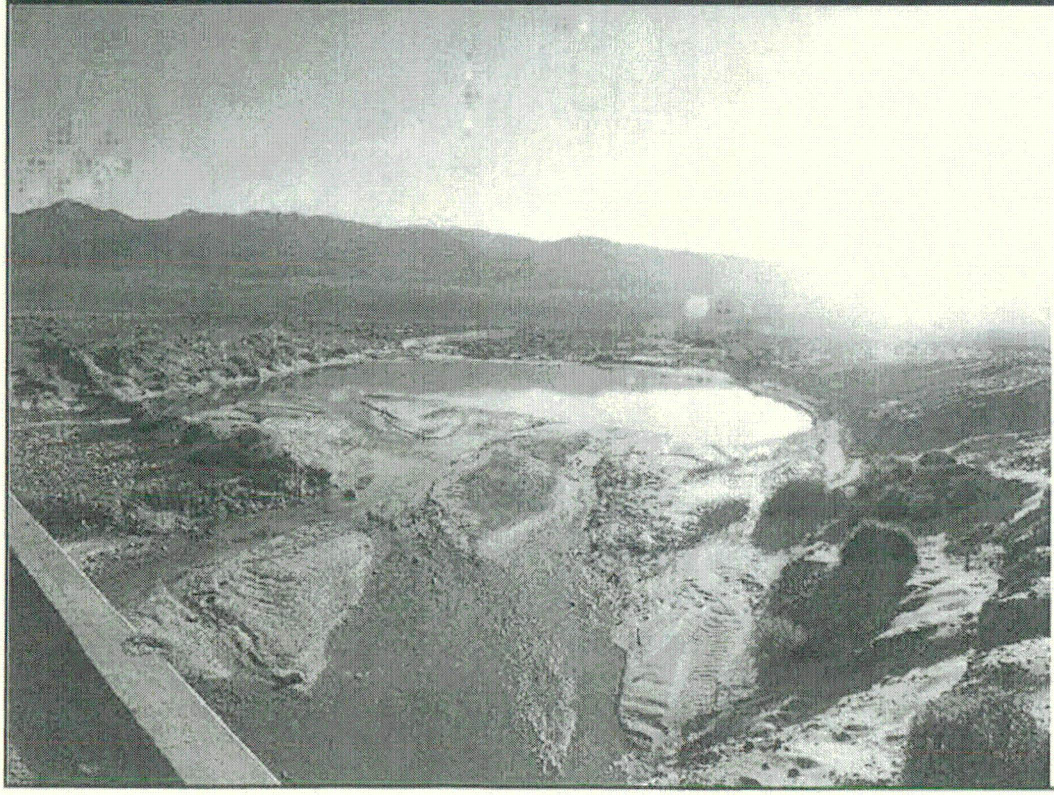


Photo: 2

Date: November 2010

View of the Amargosa River flowing under Route 127, looking Northeast.

AMARGOSA RIVER 3 (at Sperry Wash)

Location: Approximately five miles up Sperry Wash Road, at the intersection with Amargosa Canyon.

Directions: Travel south from the Shoshone approximately twenty five miles. Follow the access road east toward the Dumont Dunes ORV Park. Approximately three miles down the access road, turn left onto the ORV road leading up Sperry Wash. Approximately five miles up Sperry Wash road is the intersection with Amargosa Canyon. River measurements are collected at this location.

Latitude: N35.74639 (NAD83) **Longitude:** W116.22219 **Elevation:** 846 ft amsl

Description: This is a measurement point for flow along the Amargosa River.

Water Quality Parameters: Flow measured by taking a velocity transect across the river using a solid state flow meter.

Location ID	Date	Flow (gpm)	Temp (°C)	Spec Cond (mS/cm°C)	TDS (mg/L)	DO (mg/L)	pH
Amargosa River 3	11/16/2010	477	19.08	4.015	2,610	10.89	8.79
Amargosa River 3	4/29/2011	462	19.67	4.225	2,745	10.08	8.6
Amargosa River 3	5/5/2011	271	19.4	4.198	2,728	10.81	8.64
Amargosa River 3	9/20/2011	158	26.58	4.429	2,879	10.18	8.91
Amargosa River 3	9/23/2011	119	17	4.321	2,809	11.03	8.6
Amargosa River 3	12/21/2011	389	9.33	5.179	3,366	11.3	8.6
Amargosa River 3	5/4/2012	366	24.22	4.388	2,852	11.75	9.02
Amargosa River 3	1/26/2013	510	13.02	6.656	4,326	16.55	8.32
Amargosa River 3	4/18/2013	398	25.66	5.223	3,395	12.37	8.4

Access: The riverbed is not fenced and is owned by the Bureau of Land Management.

AMARGOSA RIVER 3

Latitude: 35.7464 North Longitude: 116.2222 West Elevation: 846 feet
Location Description: Five miles up Sperry Wash at intersection with Amargosa Canyon

Photo: 1

Date: November 2010

View of the Amargosa River at the southern end of Amargosa Canyon looking Southwest.

Photo: 2

Date: November 2010

View of the Amargosa River at the southern end of Amargosa Canyon looking Northeast.

AMARGOSA RIVER 3

Latitude: 35.7464 North Longitude: 116.2222 West Elevation: 846 feet
Location Description: Five miles up Sperry Wash at intersection with Amargosa Canyon

Photo: 3

Date: April 2013

View of the Amargosa River at the southern end of Amargosa Canyon looking Southwest.

Photo: 4

Date: April 2013

View of the Amargosa River at the southern end of Amargosa Canyon looking Northeast.

AMARGOSA RIVER 4

Location: The point where the Amargosa River crosses the road leading to the Dumont Dunes ORV Park.

Directions: Travel south from the Shoshone approximately twenty five miles. Follow the access road east toward the Dumont Dunes ORV Park. Approximately three miles down the access road, just after the turnoff to Sperry Wash, the Amargosa River intersects the road at a concrete lined depression.

Latitude: N35.69609 (NAD83) Longitude: W116.25082 Elevation: 649 ft amsl

Description: This is a measurement point for flow along the Amargosa River.

Water Quality Parameters: Flow measured by taking a velocity transect across the river using a solid state flow meter.

Location ID	Date	Flow (gpm)	Temp (°C)	Spec Cond (mS/cm°C)	TDS (mg/L)	DO (mg/L)	pH
Amargosa River 4	4/29/2011	70	15.67	4.472	2,904	11.88	8.93
Amargosa River 4	5/5/2011	dry	--	--	--	--	--
Amargosa River 4	9/23/2011	dry	--	--	--	--	--
Amargosa River 4	12/21/2011	136	3.79	4.727	3,073	12.35	8.6
Amargosa River 4	5/4/2012	44	27.23	4.617	3,003	9.07	9.22
Amargosa River 4	1/26/2013	171	12.06	6.025	3,916	15.34	8.49
Amargosa River 4	4/18/2013	dry	--	--	--	--	--

Access: The riverbed is not fenced and is owned by the Bureau of Land Management.

AMARGOSA RIVER 4

Latitude: 35.6961 North   Longitude: 116.2508 West   Elevation: 649 feet
Location Description: Three miles east of Route 127 on Dumont Dunes ORV Park access road

Photo: 1

Date: November 2010

View of the Amargosa River flowing across Dumont Dunes Road looking Northeast.

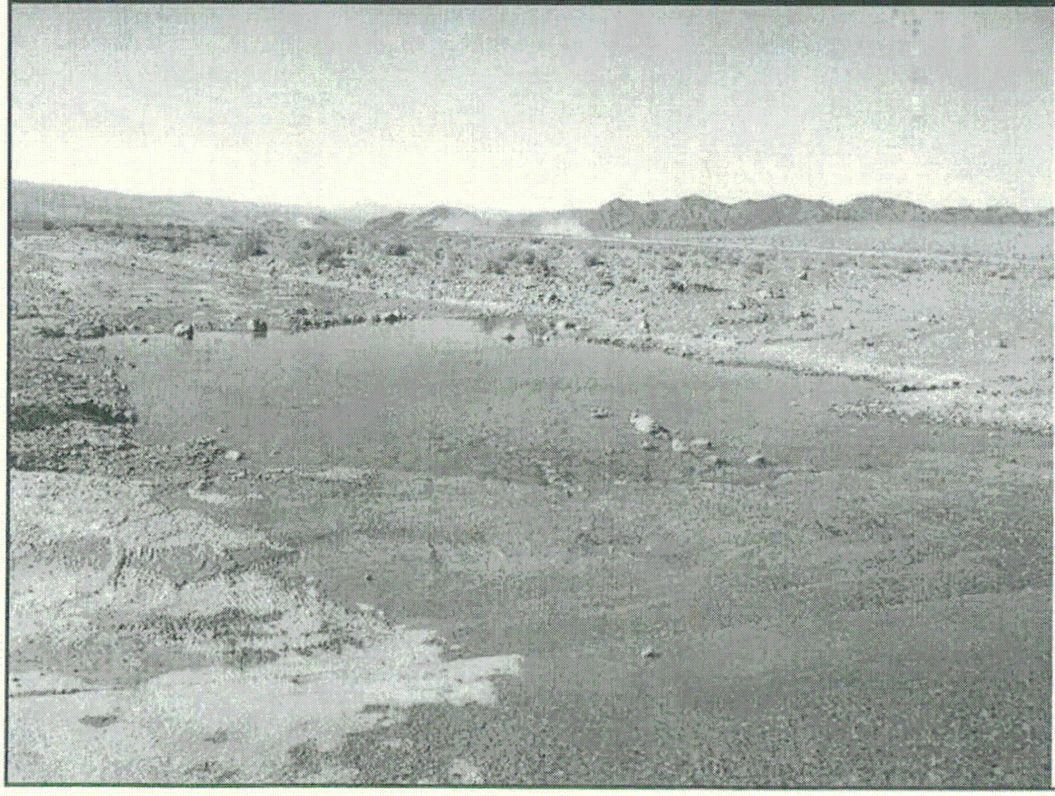


Photo: 2

Date: November 2010

View of the Amargosa River flowing across Dumont Dunes Road looking West.

AMARGOSA RIVER CONFLUENCE (USGS Gauge 2)

Location: The point of confluence between Willow Creek and the Amargosa River.

Directions: Follow the foot trail southwest from China Ranch approximately one and a half miles toward Amargosa Canyon. The trail to the Confluence measurement point is an additional half mile across the Amargosa River. It is best to consult a local guide before trying to find the trail.

Latitude: N35.7850 (NAD83)
Longitude: W116.2023
Elevation: 1,053 ft amsl
Description: This is a measurement point for flow along the Amargosa River.

Water Quality Parameters: Flow measured by taking a velocity transect across the river using a solid state flow meter.

Location ID	Date	Flow (gpm)	Temp (°C)	Spec Cond (mS/cm°C)	TDS (mg/L)	DO (mg/L)	pH
Confluence	4/29/2011	662	20.23	3.88	2,523	9.25	8.64
Confluence	9/22/2011	332	19.24	4.226	2,748	9.5	8.48
Confluence	12/22/2011	463	3.77	5.657	3,677	11.7	8.38
Confluence	5/3/2012	395	17.88	4.262	2,770	10.26	8.59
Confluence	1/27/2013	561	10.51	7.547	4,905	15.62	7.94
Confluence	4/20/2013	563	14.05	5.004	3,253	11.48	8.02

Access: The riverbed is not fenced and is owned by the Bureau of Land Management. This is within a wilderness area – foot traffic only.

AMARGOSA RIVER CONFLUENCE

Latitude: 35.7850 North   Longitude: 116.2023 West   Elevation: 1,053 feet
Location Description: Confluence of Willow Creek and the Amargosa River within Amargosa Canyon

Photo: 1

Date: April 2012

View of the Amargosa River measurement point immediately below the confluence with Willow Creek

Photo: 2

Date: April 2012

View of the Amargosa River looking South from the confluence with Willow Creek.

AMARGOSA RIVER CONFLUENCE

Latitude: 35.7850 North   Longitude: 116.2023 West   Elevation: 1,053 feet
Location Description: Confluence of Willow Creek and the Amargosa River within Amargosa Canyon

Photo: 3

Date: April 2013

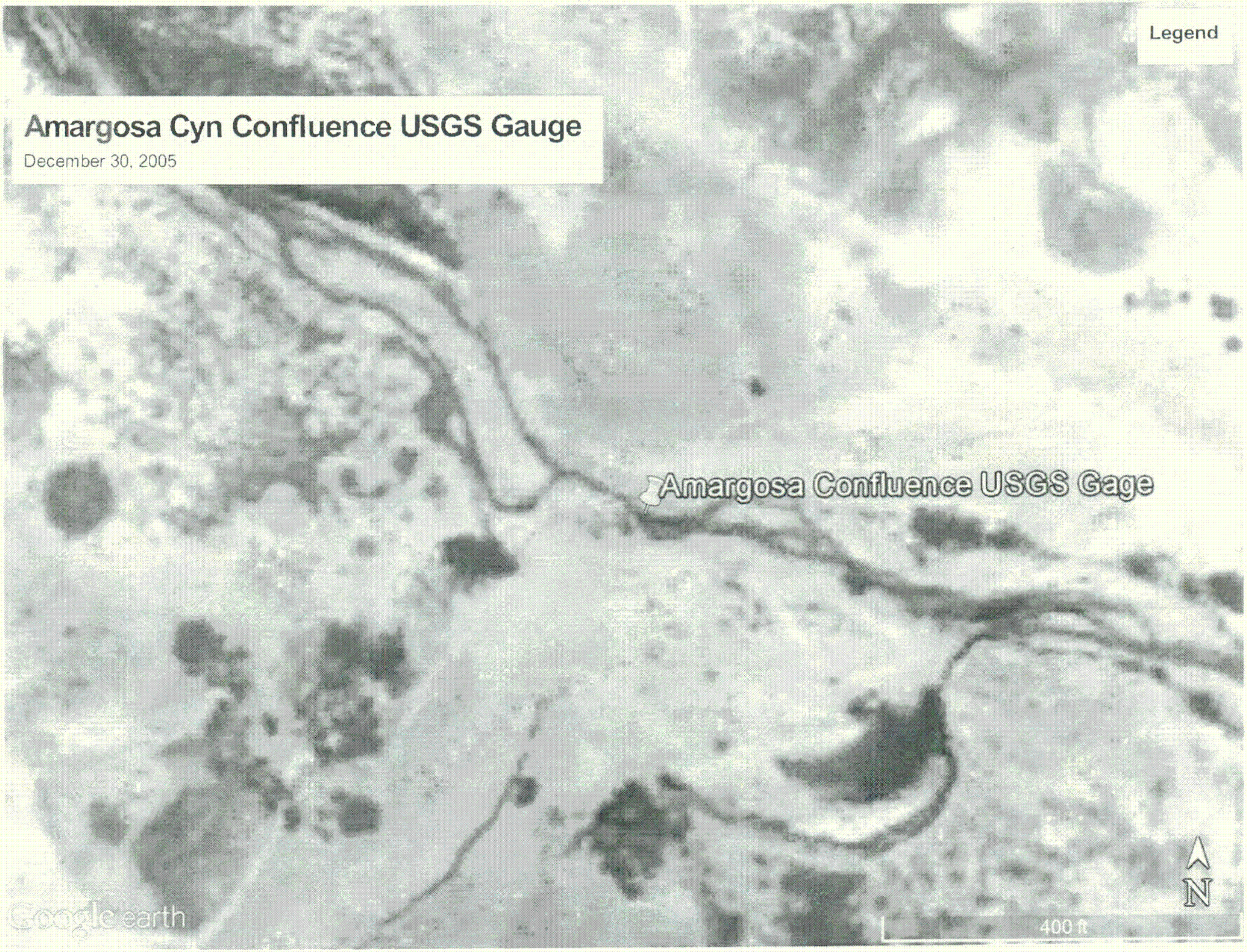
View of the Amargosa River measurement point immediately below the confluence with Willow Creek. Note the increased amount of vegetation relative to April 2012

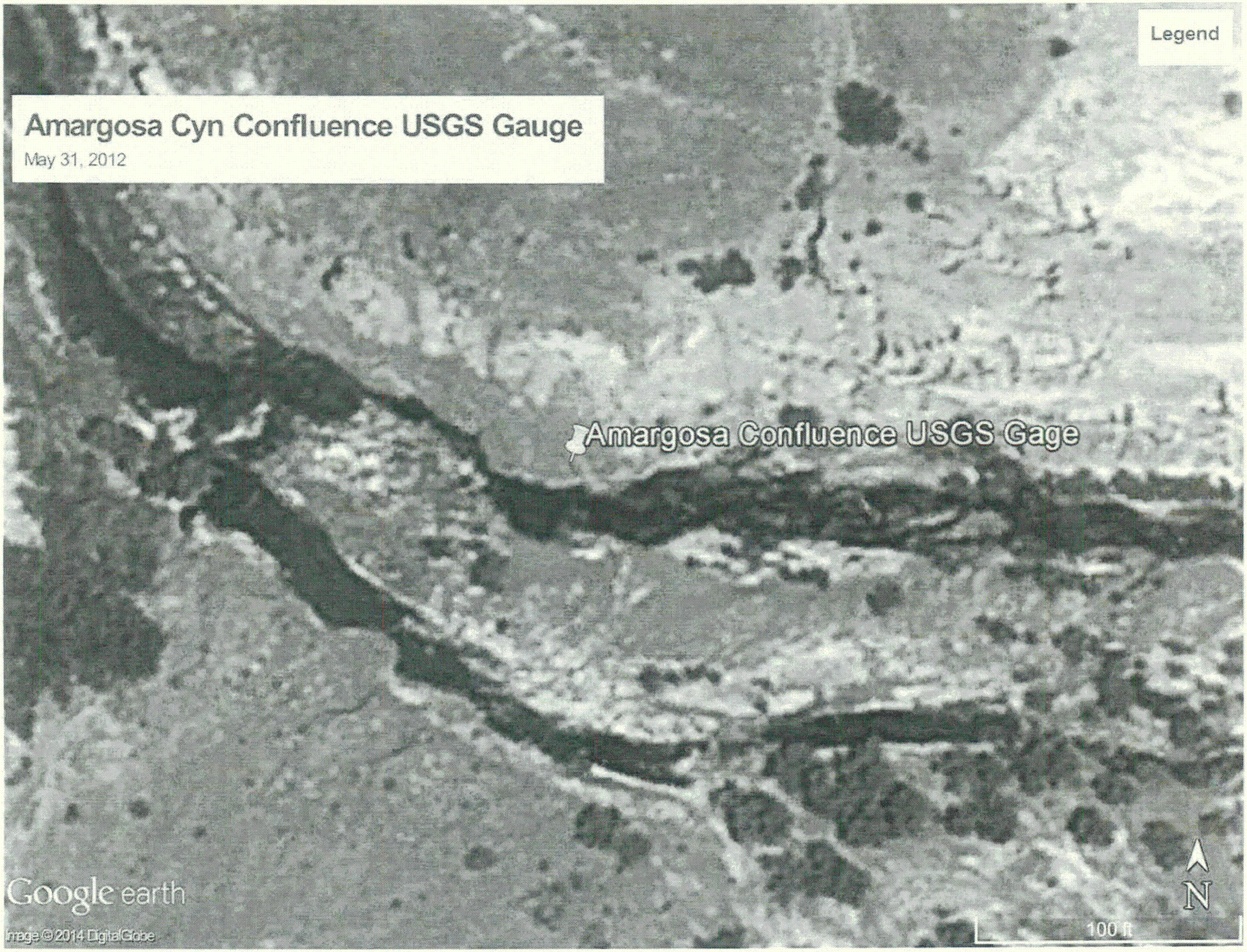
Photo: 4

Date: April 2013

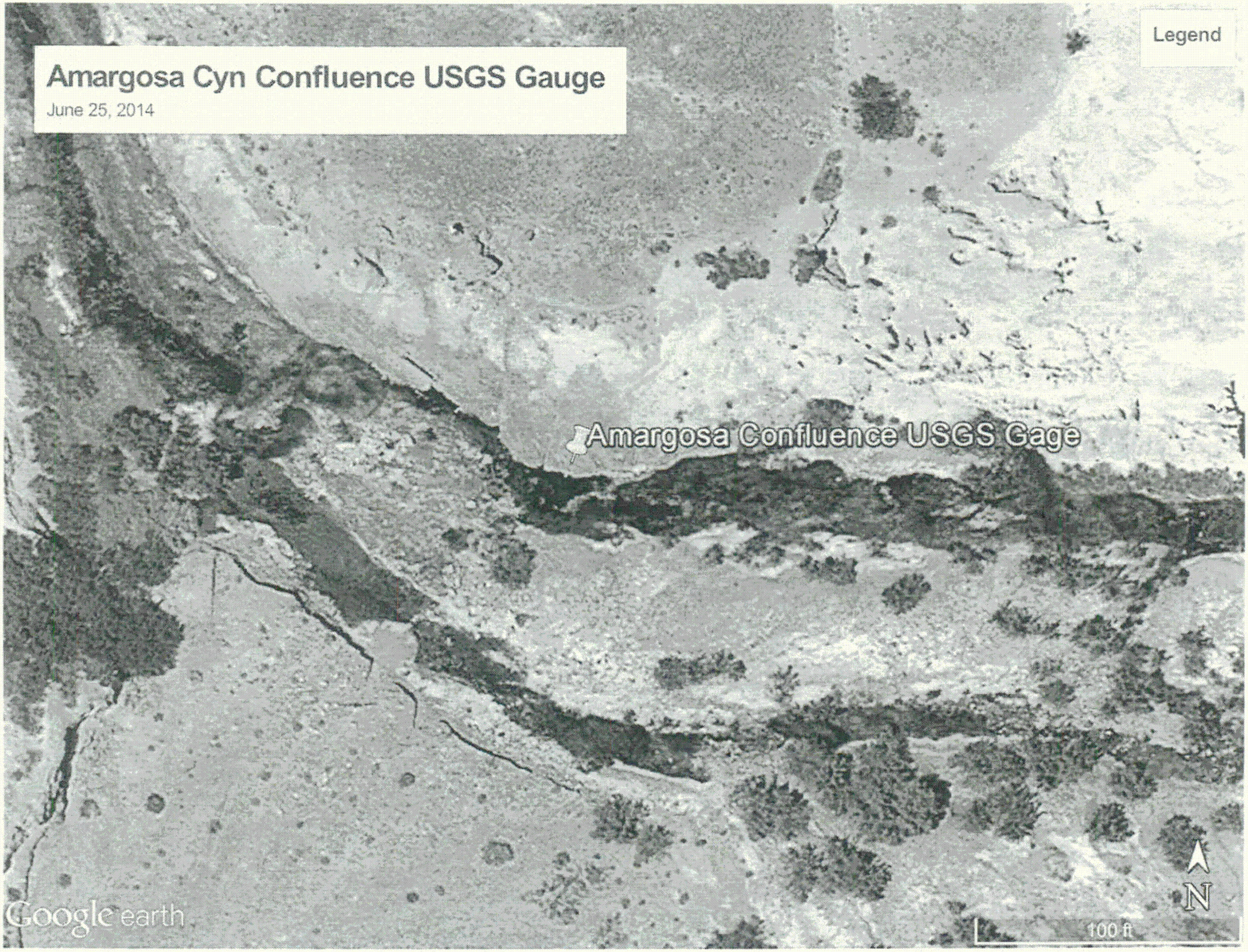
View of the Amargosa River looking Northeast from the confluence with Willow Creek.


Amargosa Cyn Confluence USGS Gauge
June 4, 1994
Legend
Amargosa Confluence USGS Gage
Google earth
Image U.S. Geological Survey
N
400 ft


Amargosa Cyn Confluence USGS Gauge
December 30, 2005
Legend
Amargosa Confluence USGS Gage
400 ft
N
Google earth



Legend
Amargosa Cyn Confluence USGS Gauge
May 31, 2012
Amargosa Confluence USGS Gage
Google earth
Image © 2014 DigitalGlobe
100 ft
N



Amargosa Cyn Confluence USGS Gauge
June 25, 2014
Legend
Amargosa Confluence USGS Gage
Google earth
N
100 ft

AMARGOSA RIVER USGS CHINA RANCH GAUGE

Location: The gauge is located approximately one mile southwest of China Ranch along the Amargosa RIver. The gauge itself is approximately ½ mile north of the confluence between China Ranch

Directions: Follow the trail southwest from China Ranch down China Ranch Wash. In approximately one mile, China Ranch Wash intersects with Amargosa Canyon. Walk an additional ½ mile northwest up Amargosa Canyon to get to the USGS China Ranch Gauge.

Latitude: N35.79042 (NAD83) Longitude: W116.20777 Elevation: 1,094 ft amsl

Description: This is a measurement point for flow along the Amargosa River.

Water Quality Parameters: Flow is measured by the USGS and by taking a velocity transect across the river using a solid state flow meter.

Location ID	Date	Flow (gpm)	Temp (°C)	Spec Cond (mS/cm°C)	TDS (mg/L)	DO (mg/L)	pH
Amargosa River/USGS 2	4/28/2011	558	18.13	3.876	2,520	12.65	8.52
Amargosa River/USGS 2	5/10/2011	656	15.9	3.481	2,263	11.45	8.46
Amargosa River/USGS 2	9/20/2011	*390*	23.05	3.658	2,378	10.22	8.53
Amargosa River/USGS 2	12/22/2011	*943*	--	--	--	--	--
Amargosa River/USGS 2	5/3/2012	488	19.07	3.899	2,534	12.03	8.69
Amargosa River/USGS 2	5/3/2012	*763*	--	--	--	--	--
Amargosa River/USGS 2	1/27/2013	914	11.33	10.56	6,863	15.83	8.57
Amargosa River/USGS 2	1/27/2013	*539*	--	--	--	--	--
Amargosa River/USGS 2	4/20/2013	399	15.96	4.634	3,012	14.04	8
Amargosa River/USGS 2	4/20/2013	*494*	--	--	--	--	--

Number indicates flow determined by USGS.
Number indicates flow determined by velocity transect and solid state flow meter.

Use:

Access: The riverbed is not fenced and is owned by the Bureau of Land Management.

AMARGOSA RIVER USGS CHINA RANCH GAUGE

Latitude: 35.7904 North Longitude: 116.2078 West Elevation: 1,094 feet
Location Description: ½ northwest of the confluence of China Ranch Wash and Amargosa Canyon

Photo: 1

Date: April 2012

View of the Amargosa River looking south down Amargosa Canyon toward the confluence with China Ranch Wash.

Photo: 2

Date: April 2012

View of the Amargosa River looking north up Amargosa Canyon.

AMARGOSA RIVER USGS CHINA RANCH GAUGE

Latitude: 35.7904 North Longitude: 116.2078 West Elevation: 1,094 feet
Location Description: ½ northwest of the confluence of China Ranch Wash and Amargosa Canyon

Photo: 3

Date: April 2013

View of the Amargosa River at the USGS measurement point. General perspective is looking south

Photo: 4

Date: April 2013

View from the USGS measurement point toward the west. Note additional river flow beneath the closest cut bank.

AMARGOSA RIVER USGS CHINA RANCH GAUGE

Latitude: 35.7904 North   Longitude: 116.2078 West   Elevation: 1,094 feet
Location Description: ½ northwest of the confluence of China Ranch Wash and Amargosa Canyon

Photo: 1

Date: April 2012

View of the Amargosa River looking south down Amargosa Canyon toward the confluence with China Ranch Wash.

Photo: 2

Date: April 2012

View of the Amargosa River looking north up Amargosa Canyon.

AMARGOSA RIVER USGS CHINA RANCH GAUGE

Latitude: 35.7904 North   Longitude: 116.2078 West   Elevation: 1,094 feet

Location Description: ½ northwest of the confluence of China Ranch Wash and Amargosa Canyon

Photo: 3

Date: April 2013

View of the Amargosa River at the USGS measurement point. General perspective is looking south

Photo: 4

Date: April 2013

View from the USGS measurement point toward the west. Note additional river flow beneath the closest cut bank.