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INYO/LA Geochemical Cooperative Study

Final Report

Department of Water and Power

MWH

County of Inyo California

GTC
Geochemical Technologies Corporation

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Al	Aluminum
AOI	Area of Interest
Aqueduct	Los Angeles Aqueduct
B	Boron
$BaSO_4$	Barite
$H_3BO_3^o$	Boric Acid
C	Celsius
Ca	Calcium
$CaCO_3$	Calcite
CaF_2	Fluorite
$CaMg(CO_3)_2$	Dolomite
$CaSO_42H_2O$	Gypsum
Cd	Cadmium
Cl	Chloride
Cr	Chromium
Cu	Copper
EC	Electrical Conductivity
EPA	Environmental Protection Agency
Fe	Iron
FEIR	Final Environmental Impact Report
GTC	Geochemical Technologies Corporation
H	Hydrogen
HCO_3	Alkalinity
ICWD	Inyo County Water Department
Tech Group	Inyo/Los Angeles Technical Group
K	Potassium
K_{ap}	Activity Product for a Mineral
K_{eq}	Equilibrium Constant
LADWP	Los Angeles Department of Water and Power
Mg	Magnesium
MWH	Montgomery Watson Harza
MWL	Meteoric Water Line
n	Neutrons
Na	Sodium
na	Not Analyzed
O	Oxygen
p	Protons
RPD	Reported Percent Difference
S	Sulfur
Se	Selenium
SI	Saturation Index
SiO_2	Silica
SO_4	Sulfate
TDS	Total Dissolved Solids
TIMS	VG Thermal Ionization Mass Spectrometer

TU	Tritium Units
$UO_2CO_3^o$	Neutral Uranium Carbonate Complex
USGS	United States Geological Survey
VSMOW	Vienna Standard Mean Ocean Water
Zn	Zinc
^3H	Tritium
$\delta^{11}B$	Boron Stable Isotope
$\delta^{34}S$	Sulfur Stable Isotope
$\delta^{18}O$	Oxygen Stable Isotope
δD	Hydrogen Stable Isotope
δ	Delta Notation
‰	Permil Notation

Executive Summary

Executive Summary

Under Agreement 47026 between the Los Angeles Department of Water and Power (LADWP) and MWH, MWH conducted Task 3.1.8 entitled "Geochemical Study – Preparation of Final Report." Per Task Order 3.1.8, the Final Report:

- Reviews and documents the results of groundwater sampling at Thibaut and Reinhackle Springs AOIS in April 2003.
- Includes existing lithologic cross-sections prepared for the Taboose-Thibaut Wellfield and Reinhackle Spring studies.
- Includes boring logs for sampling program wells as an appendix to the report.
- Includes a summary table that includes well construction details for wells included in the sampling program.
- Provides short descriptions of the local geology and hydrology at each area of interest. In addition, it presents potentiometric surface maps developed for the area of interests.
- Incorporates written comments on Technical Memorandum No. 2 (MWH/GTC, January 14, 2003).
- Includes tables and figures to summarize the analytical data.

The purpose of this report, which represents the deliverable for Task 3.1.8, is to summarize the results of the Geochemical Cooperative Study.

INTRODUCTION

MWH and Geochemical Technologies Corporation (GTC) have supported the LADWP and the Inyo County Water Department (ICWD) in the completion of this study. Together, this group is referred to as the Cooperative Study Team.

The purpose of this study is to examine the geochemical signatures of selected springs and seeps and to compare these signatures to shallow and deep groundwater samples to identify the source of spring/seep water. These results may be useful for linking spring and seep flows to particular aquifers. Understanding this linkage will improve groundwater models necessary to assess potential pumping effects.

The Cooperative Study Team, through a series of conference calls and e-mail, developed specific key questions for each AOI. These key questions and preliminary answers were documented in Technical Memorandum No. 2 dated January 14, 2003 (MWH/GTC, January 14, 2003). These key questions were discussed and finalized at a Cooperative Study Team meeting on March 4, 2003. Discussion related to the key questions was documented in the meeting minutes dated March 7, 2003. Geochemical modeling and additional sampling were focused on developing answers to these key questions.

The seven spring areas of interest (AOI) as listed below:

- Baker Springs,
- Wilkerson Springs,
- Seeley Springs,
- Thibaut Springs,
- Fault Scarp Springs (IND 102),
- Reinhackle Spring, and
- Fault Scarp Springs (DWP 9).

DISCUSSION BY AREA OF INVESTIGATION

This geochemical investigation of seeps and springs in Owens Valley is comprised of seven Areas of Interest (AOIs). Provided herein is an overview of key questions and associated findings by AOI.

Baker Springs

- *Question No. 1 - What is the source for the spring water (recharge from nearby creeks, shallow groundwater, or upwelling from the deeper aquifer along faults)?*

Finding(s)

1. The Baker Springs Complex contains numerous seeps, springs, and an attendant wetland. The sample collected for this complex is from the down slope end and has significant flow emerging from the bedrock and alluvium contact, but no evidence of ponding, evaporation, or stagnation. The sample collected appears to be representative of the groundwater at this point and was used to represent the chemical composition of the complex.
2. Two shallow wells upgradient from Baker Spring were sampled. Mass transfer modeling and inspection of isotopic data indicate that the water emerging from the spring could be shallow groundwater modified by a very small extent of reaction with aquifer minerals. However, chloride and bromide do not fit the mass balance calculations well enough to state confidently that all of the water emerging from the spring is derived from shallow groundwater.
3. The modeling scenarios are not unique because other minerals could be used, and well W341 has a mixed water composition. Based on chemistry and location, the spring complex appears to be the terminus of a shallow and local flow system exhibiting minor mixing with deeper-sourced water and minimal reaction with minerals in the aquifer matrix.
4. The deeper aquifer was sampled from well W341. Unfortunately, the screened interval for this well is sufficiently shallow that the produced water is commingled shallow and deep groundwater as evidenced by the presence of tritium. If it is assumed that deeper water, upgradient from the spring has essentially the composition of well W341, then a mixture of 7% well W341 with 93% shallow well T844 with a small contribution from mineral reactions results in a composition essentially the same as the Baker Spring complex. The isotopic data support the modeling results. Because the fault is known to

transect the area, and plausibly could be diverting deeper water upward, this scenario seems plausible for the data available.

- *Question No. 2 - Is there a difference in composition across the faulted area?*

Finding(s)

1. The only sampled well immediately downgradient and on the east side of the Quaternary fault bounding the spring complex was well V013N. This well is located on the Valley floor and is dissimilar to other groundwater samples in the Baker Springs area. It is assumed to be influenced by local recharge of dilute surface water or inflow from the north. As a result, the data collected in this study is not sufficient to answer this question.

Wilkerson Springs

- *Question No. 1 - Is the composition of Wilkerson Springs distinctive because it is located in a different geologic regime on the east side of the Owens River?*

Finding(s)

1. Chemical composition of both Wilkerson Springs and Mule Spring are derived from chemical weathering of Paleozoic carbonate rocks of the White and Inyo Mountains and is distinctive because of its location in a different geologic regime on the east side of the Owens River. The sulfur isotopes indicate that Wilkerson Springs derives some of the chemical and isotopic composition from non-carbonate erosional debris, perhaps of lacustrine or granitic origin.
2. The springs, located on the east side of the Valley, have significantly different composition from virtually all other wells or springs within the flow field of the alluvial fans draping the west side of Owens Valley. This circumstance derives from the difference in geology on either side of the Valley and could probably be used to determine the influence of eastern sources to wells on the Valley floor. Furthermore, these two springs are very different from one another.

- *Question No. 2 - Is the chemical and isotopic composition of Wilkerson Springs correlative with the composition of downgradient wells?*

Finding(s)

1. The pumping wells sampled (W378 and W375) have the same enriched δ^{34}S value as Mule Spring (23.4 – 27.5 ‰), and the implication is that water produced from these two deeper wells is at least influenced by recharge from the east side of the Valley. Comparatively, the δ^{34}S value for Wilkerson Springs (9.4 ‰) is significantly less than that for W378 and W375 (27.5 ‰ and 27.4 ‰, respectively), thereby indicating that it is neither correlative with these somewhat distant wells nor correlative with Mule Spring.
2. The boron isotopes support a source of solute derived from marine deposits in the deep wells, and δD and δ^{18}O suggest the water to be from a colder and wetter paleoclimate. It is not known if this deeper water is from much earlier recharge (e.g. Pleistocene) dammed up against the Poverty Hills fault, or simply represents rapid and significant groundwater movement down the Waucoba Canyon alluvial fan derived from snowmelt and rainfall.

- *Question No. 3 - Can the shallow and deep aquifers be differentiated by the analytical data?*

Finding(s)

1. The analytical data demonstrate that the shallow and deep aquifer chemistries can be differentiated. There is chemical similarity between the composition of shallow wells (T469 and V011N) and the deep wells, but the isotopes are different, indicating a different source for the water. Well T469 has modern tritium levels (V011N does not), and both shallow wells have expected levels for δD and $\delta^{18}O$, and depleted levels of $\delta^{11}B$ and $\delta^{34}S$, whereas the deep wells do not have tritium and have enriched levels of $\delta^{11}B$ and $\delta^{34}S$. The isotopic data indicate that the source of shallow groundwater may be derived from upgradient flow or flow from the west. The deeper wells have marine signatures of $\delta^{34}S$ and $\delta^{11}B$, no detectable tritium, and δD and $\delta^{18}O$ indicate that the source is from colder climate or snowmelt.

Seeley Springs

- *Question No. 1 - What is the source for the water in production well W349?*

Finding(s)

1. Five wells and one mountain-front spring on the west side of the Owens River were sampled. The composition of the shallow wells (T669, T846), the pumping well (W349), and one deep well (V362) all have similar composition to each other and to the Owens River/Aqueduct samples. As such, the data demonstrates that the source of water for well W349 is similar to other sampled shallow and deep wells, with the exception of well V364. Well V364 is located on the east side of both the Owens River and 1872 fault line and has a different chemical and isotopic composition. The chemical composition for well V364 is consistent with what would be expected from weathering of volcanic rocks such as those adjacent to and east of the well.
2. The five wells of similar composition have sample depths that range from 41 to 231 feet, thereby indicating that the shallow aquifer system is well mixed in this area. Furthermore, the tritium content at all wells is detectable and indicates that the portion of the aquifer that is affected by recent recharge is a significant proportion of the produced water.

- *Question No. 2 - Is it possible to determine a mixing percentage between shallow and deep aquifer contribution to the production well?*

Finding(s)

1. It was not possible to determine mixing percentages between the shallow and deep aquifer contributions to the production well because there was not a clear picture of either end member.

Additional findings from investigation at this AOI include:

1. The sampled mountain front spring DWP35 has a dilute solute, a distinct boron isotopic value, and the groundwater source for the spring does not appear to be influencing the composition of the sampled downgradient wells.

2. The cluster of isotopic data for sulfur and boron coupled with the inclusion of the Aqueduct isotopic values that are also similar supports the argument that recharge from the Owens River is influencing the aquifer composition in this area.

Thibaut Springs

- *Question No. 1 - Water emerges from Thibaut Springs even during seasonal pumping periods. Is the flow topographically controlled or is a component of this discharge from the deeper aquifer diverted to the surface by a facies change or fault?*

Finding(s)

1. It could not be determined definitively what controls the flow at Thibaut Springs. West of Thibaut Springs, the separation between the shallow and deep aquifer is not pronounced and mixing could easily occur. In the vicinity of the spring the combination of a break in the slope of the land surface and the emergence of aquitards could divert the mixed water into shallower zones yielding the discharge at Thibaut Springs. However, it is probable that the spring is composed predominantly of deeper water such as that represented by wells V055 or W382.

- *Question No. 2 - Is there an observable component of the spring water composition in the nearby production well W382 that would indicate a common groundwater source?*

Finding(s)

1. Thibaut Springs has chemical characteristics similar to both shallow and deep wells in the vicinity of the spring (including well W382), with the exception of wells F053 and T655. The flowing well F053 is suspected of influencing the composition of the nearby shallow well T655. However, this water is clearly different from and unrelated to the discharge from Thibaut Springs.
2. A new shallow well, T864, was constructed upgradient to Thibaut Springs following the field sampling of 2002. Consequently, this well was sampled in 2003 for comparison to the spring composition. Computations indicate that the composition of the deeper wells more closely compare to the spring than do the shallow wells. A mixture of 90% V055 and 10% T864 with ion exchange and mineral dissolution, would yield the observed composition of Thibaut Springs.

- *Question No. 3 - Although the Aqueduct is downgradient, is there geochemical evidence that recharge from the Aqueduct is contributing to flow?*

Finding(s)

1. Thibaut Springs discharges onto the alluvial slopes above the Aqueduct and is not affected by Aqueduct recharge. Geochemical evidence shows that the spring water is compositionally different from the Aqueduct water and suggests a deep groundwater source for Thibaut Springs.

Fault Scarp Springs (IND 102)

- *Question No. 1 - What is the source of the spring water, and is there an Aqueduct component?*

Finding(s)

1. The Aqueduct composition is not considered contributory to the composition observed for the wells in the IND102 vicinity. The Aqueduct is almost two miles away, separated by a low potentiometric gradient, and the intermediate groundwater would be impacted by creek recharge.
2. The chemical and isotopic compositions of the spring and the nearby shallow wells are similar in water type, general composition, and for the most part, similar isotopic composition, suggesting a shallow groundwater source for the spring.

- *Question No. 2 - Is there an observable difference in water composition across the fault?*

Finding(s)

1. The IND102 spring complex appears related to the 1872 fault lineament and surface ponding, seeps, and springs are aligned with the fault trace. The potentiometric gradient across the fault in the vicinity of IND102 indicates that there is an impact on groundwater flow.
2. Shallow well V007G has a more dilute TDS value, detectable levels of tritium, and has a depleted $\delta^{34}S$ value than the wells along the fault. The most obvious and consistent explanation for these anomalous values is that this groundwater is affected by recharge from the nearby Independence Creek and does not represent a difference from the wells near the fault due to the presence of the fault.
3. Overall, there is not an observable difference in water composition across the fault.

- *Question No. 3 - Does the spring or any of the downgradient wells have a correlative composition to the mountain front springs?*

Finding(s)

1. Coyote Springs has a chemical and isotopic composition, except for $\delta^{34}S$, that is typical of water derived from the Paleozoic carbonates of the Inyo Mountains. The $\delta^{34}S$ is depleted and may represent a sulfate source that was fractionated during marine deposition. There is no evidence that the groundwater source of Coyote Spring has any influence on the composition of IND102 or the wells in the vicinity of the IND102 complex. The important conclusion is that the chemical and isotopic composition of Coyote Springs is local and not observed in any of the wells or springs elsewhere in this AOI.

Reinhackle Spring

- *Question No. 1 - Does the chemical or isotopic composition of the spring indicate that recharge from the Aqueduct is a component of spring flow?*

Finding(s)

1. Reinhackle Spring is similar in both chemical and isotopic composition to the sampled Aqueduct water, thereby suggesting that recharge from the Aqueduct is a component of spring flow.
2. Although the composition of Reinhackle Spring is virtually identical to the Aqueduct, the conclusion that the spring exists because of the Aqueduct recharge cannot be made with chemical data alone. The Aqueduct is recharging water to the shallow groundwater and may not be elevating the potentiometric surface to any significant amount beyond a recharge mound below the Aqueduct. The assessment that the groundwater composition is the same as the Aqueduct does not imply that the elevation of the groundwater and thus the discharge rate of the spring are significantly altered because of the Aqueduct. Rather, this assessment primarily establishes a link in flow path between the Aqueduct and the spring.

- *Question No. 2 - Can the composition of surrounding shallow or deep wells be correlated to the spring composition?*

Finding(s)

1. The compositions of the surrounding shallow wells and the Aqueduct samples are correlative with Reinhackle Spring's composition. The three samples from the Aqueduct, the shallow well T597, and Reinhackle Spring all have similar chemical compositions. In all five samples, the concentrations of the more chemically conservative elements such as chloride, boron, and bromide are almost identical. In contrast to these five samples, the concentrations of the same conservative elements for the deep wells ranged from two to ten times less.
2. The deep wells should not contain measurable tritium; therefore, the amounts of tritium detected in deep wells create a scientific dilemma. The presence of tritium is not likely a result of sampling error. Furthermore, travel times documented by Danskin (1998) indicate that rapid recharge and transport to the deep aquifer is probably not the cause of measurable tritium. Consideration of surface water recharge from nearby creeks, leakage from the shallow groundwater aquifer, and access to the upper-screened sections of wells does provide an explanation for elevated tritium in the sampled deep wells. The source for the tritium detected in three wells that sample the deeper aquifer is still unverified, but the probable origin is shallow groundwater.

Fault Scarp Spring (DWP 9)

- *Question No. 1 - Is the spring water composition similar to other fault scarp springs and does the composition indicate a source for the water?*

Finding(s)

1. The fault scarp spring composition is unique and easily differentiated from the deeper aquifer. The composition is not consistent with a granitoid host rock and is dissimilar from any other spring on the west side of the Valley. The water emerging from the fault scarp is from a source deeper than the local groundwater and different from the more regional

groundwater upgradient to the north. The shallow wells downgradient are being influenced by the fault scarp discharge, and in the absence of this source, the shallow groundwater would have the more commonly observed sodium-calcium –bicarbonate characteristics.

2. This spring is an example of a fault-controlled spring in that the flow may actually be emerging at the surface because of the fault. Other springs emerge at the surface in areas where faults exist as partial barriers to flow diverting local groundwater to the surface, and in such cases (e.g., Baker Springs) the nearby groundwater is similar to and the origin of the spring water. In this spring circumstance, the water composition is enigmatic. The fault may be a conduit, and the groundwater similarity is only with downgradient groundwater that is a mixture of the spring water and local upgradient groundwater.
3. The spring temperature and solute load is elevated anomalously. Interpretations would seem to require that the spring is related to the fault, and may in fact represent some upwelling of water derived from hot springs, or perhaps more deeply circulating groundwater that is heated slightly and allowed to react more vigorously with the host rock.

CONCLUSION

To conclude, the purpose of this study was to examine the geochemical signatures of selected springs and seeps and to compare these signatures to shallow and deep groundwater samples to identify the source of spring/seep water. As such, the Inyo/Los Angeles Technical Group and extended Geochemical Cooperative Study Team was successful in meeting the objectives of the study.

Section 1

Introduction

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Introduction

Under Agreement 47026 between the Los Angeles Department of Water and Power (LADWP) and MWH, MWH conducted Task 3.1.8 entitled "Geochemical Study – Preparation of Final Report." Per Task Order 3.1.8, the Final Report will:

- Review and document the results of groundwater sampling at Thibaut and Reinhackle Springs AOIS in April 2003.
- Include existing lithologic cross-sections prepared for the Taboose-Thibaut Wellfield and Reinhackle Spring studies.
- Include boring logs for sampling program wells as an appendix to the report.
- Prepare summary table that includes well construction details for wells included in the sampling program.
- Develop short descriptions of the local geology and hydrology at each area of interest. In addition, the report presents potentiometric surface maps developed for the area of interests.
- Incorporate written comments on TM-2 (MWH/GTC, January 14, 2003)
- Prepare tables and figures to summarize the analytical data.

The purpose of this report, which represents the deliverable for Task 3.1.8, is to summarize the results of the Geochemical Cooperative Study.

GEOCHEMICAL COOPERATIVE STUDY TEAM

The Geochemical Cooperative Study is one of eight cooperative studies being developed or conducted by the Inyo/Los Angeles Technical Group (Tech Group). MWH and Geochemical Technologies Corporation (GTC) have supported the Inyo County Water Department (ICWD) and the Los Angeles Department of Water and Power (LADWP) in the completion of this study. Together, this group is referred to as the Cooperative Study Team. Team roles and responsibilities are summarized below:

- LADWP provided funding for the MWH/GTC contract, assisted with the selection of seeps and springs for the study, supported the field sample collection effort, and reviewed all documentation prepared for the study.
- ICWD assisted in the selection of seeps and springs for study, provided field support during sample collection, and reviewed all documentation prepared for the study.
- MWH/GTC organized and documented project meetings, provided field support during sample collection, took the lead in analyzing and interpreting investigation results, prepared all project documentation, evaluated technical feasibility of sampling the desired seeps and springs, and developed field sampling protocols.
- ICWD wrote a literature review of geochemical investigations pertinent to the study.

BACKGROUND

The Tech Group is required by the Inyo/LA Water Agreement (1991) and the Final Environmental Impact Report (FEIR, 1991) to manage groundwater pumping from existing and new wells in order to avoid reductions in spring flows that would cause significant decreases or changes in spring associated vegetation. The Green Book (1991) states that the Tech Group will identify and monitor areas of vegetation dependent upon springs and flowing wells. The FEIR (1991) expands this monitoring commitment to include seeps as well as springs. The FEIR (1991) also outlines management options to remedy potential impacts. One option for pumping management to meet the water supply and vegetation protection goals of the Inyo/LA Water Agreement (1991) is to pump from wells sealed to the deep aquifer in preference to wells constructed in both the shallow and deep aquifers.

Several tests have demonstrated that the timing and magnitude of drawdown in the shallow aquifer due to pumping from the deep aquifer is buffered by the less permeable confining layers separating them (Harrington, 1998; Jackson, 1997). For this reason, developing appropriate management measures for deep-aquifer pumping requires assessment of the potential sensitivity of critical springs and seeps.

Ecosystems Science compiled the initial list of springs to be considered for this investigation for LADWP in 1999. Subsequently, ICWD recommended a subset of key springs for the Geochemical Cooperative Study. The final selections agreed upon by LADWP and ICWD are the springs sampled and evaluated in this report. Spring areas are defined as “Areas of Interest” (AOI) in the Owens Valley. Each of the seven AOIs addressed, along with corresponding springs, wells, and/or surface water sampled, is listed in **Table 1-1**. A summary well construction table showing well construction information for wells sampled as well as available boring logs is provided in **Appendix A** for reference purposes. In addition, the Los Angeles Aqueduct (Aqueduct) was sampled at the following three locations:

- Mazourka Canyon Road,
- Georges Bridge, and
- Above Alabama Gates.

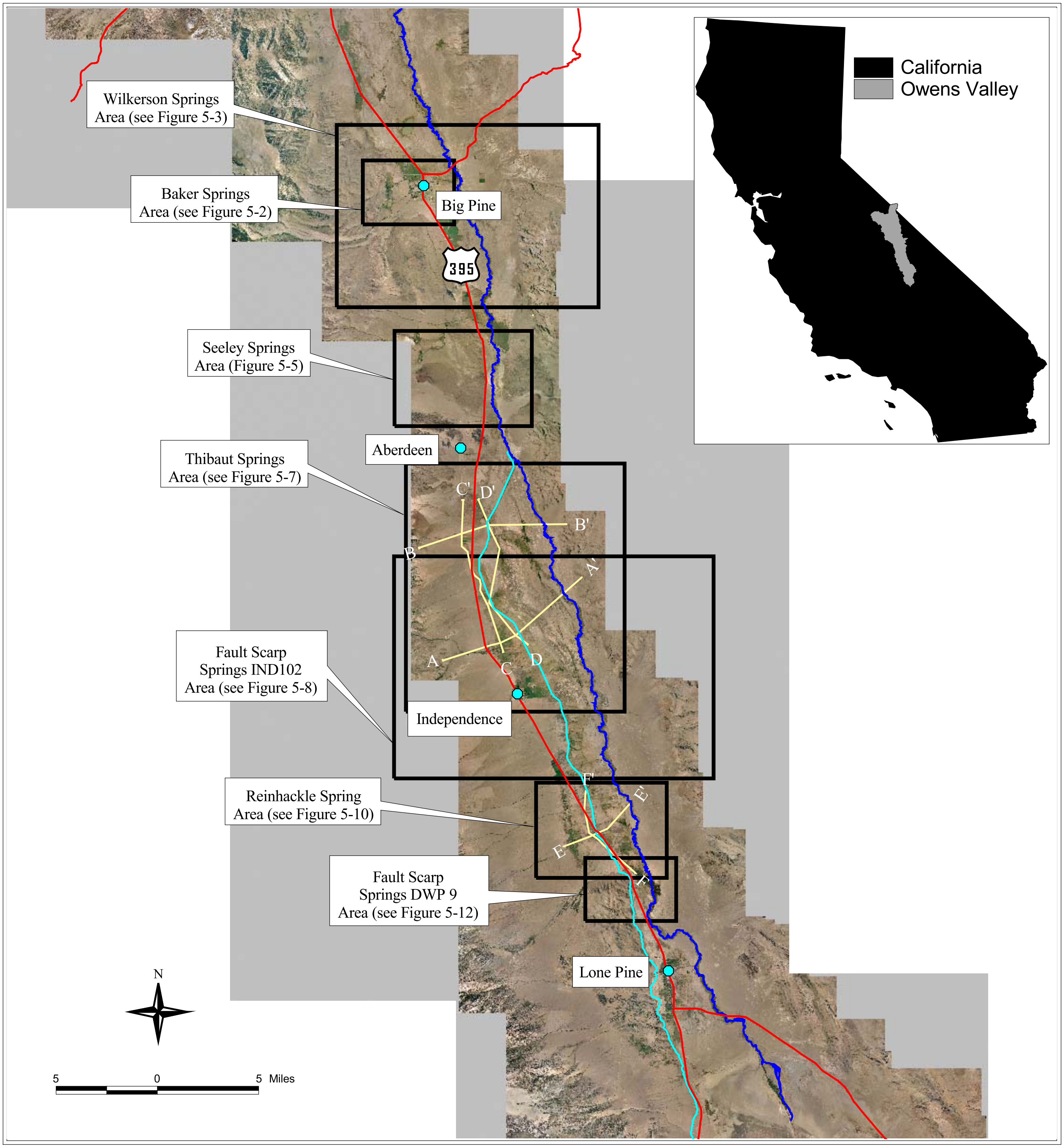
AOIs are shown on the overview map presented as **Figure 1-1**. This figure also shows the locations of cross sections discussed and presented in Section 5

During the 2002 field season, it was the intention of the project personnel to sample each spring as well as nearby shallow, deep, and pumping wells, and to collect salient hydrologic data. However, the flow at Thibaut Springs AOI is currently diffuse and is better defined as a seep. The valley-floor springs of Big and Little Seeley, IND56 and IND215, were dry during the period of the project and could not be sampled.

Table 1-1
Summary of Area of Investigations for the Geochemical Study

Area of Interest	**Sampling Points**	
	Springs	Wells/Surface Water
Baker Springs (DWP 26)	• Baker Springs (DWP 26)	• T844 • T845 • W341 • V013N • Baker Creek • Giroux Ditch
Wilkerson Springs (DWP 22)	• Wilkerson Spring (DWP 22) • Mule Spring	• W375 • W378 • T469 • V011N
Seeley Springs (DWP 16 & 17)	• Fault-controlled mountain front spring (DWP 35)	• W349 • V362 • V364 • T669 • T846
Thibaut Springs (DWP 11)	• Thibuat Springs (DWP 11) • Grover Anton Spring (DWP 13)	• T676 • V055 • W382 • F053 • T655 • T863 • T864
Fault Scarp Springs (IND 102)	• Boron Spring (DWP 12) • Coyote Spring • IND 102	• F029 • V327 • V007G • T450 • T375
Reinhackle Spring (DWP 7)	• Reinhackle Spring (DWP 7)	• T652 • T597 • W348 • V012 • W403 • F082
Fault Scarp Spring (DWP 9)	• Fault Scarp Spring (DWP 9)	• T394 • T446 • V013 • V258

NOTES
Spring identification numbers shown in ()'s.



Legend

□ Spring

● Town

Cross Section

Owens River

Los Angeles Aqueduct

□ Area of Interest

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Figure 1-1
Site Overview

STUDY OBJECTIVES

The purpose of this study is to examine the geochemical signatures of selected springs and seeps and to compare these signatures to shallow and deep groundwater samples to assist in the identification of the source of spring/seep water. These results may be useful for linking spring and seep flows to particular aquifers. Understanding this linkage will improve groundwater models necessary to assess potential pumping effects. However, it must be noted that geochemical signatures alone are not typically adequate to provide definitive identification of water sources. Rather, they provide additional information that must be interpreted along with and in the context of more traditional hydrogeologic data.

The Cooperative Study Team, through a series of conference calls and e-mail, developed specific key questions for each AOI. These key questions and preliminary answers were documented in Technical Memorandum No. 2 dated January 14, 2003 (MWH/GTC, January 14, 2003). These key questions were discussed and finalized at a Cooperative Study Team meeting on March 4, 2003. Discussion related to the key questions was documented in the meeting minutes dated March 7, 2003. Geochemical modeling and additional sampling were focused on developing answers to these key questions.

PREVIOUS GEOCHEMICAL INVESTIGATIONS

Geochemical characterization of spring/seep and well water is a common technique applied to lend insight into the hydrogeology of springs and groundwater flow systems (Hem, 1985; Garrels and MacKenzie, 1967). In a classic study conducted by Garrels and MacKenzie (1967), spring water chemistry, source water chemistry (snow), and clay mineralogy in the Sierra Nevada of California were used successfully to reconstitute the weathering of the surrounding parent rocks. They demonstrated conclusively that hydrochemical analysis is a powerful tool to reconstruct likely flow paths, determine sources of spring water, or evaluate groundwater mixing in groundwater systems. The level of detail of that analysis is beyond the scope of this study, but several examples exist of studies conducted near the Owens Valley that relied on geochemistry to evaluate hydrology of closed basins.

Hardie (1968) and Jones (1965) used geochemistry to evaluate the relationship of hydrology and controls on groundwater and soil salinity development in Saline and Deep Springs Valley, respectively. Similarly, Smith and Drever (1976) studied spring water chemistry at Teels Marsh, Nevada to assess processes affecting groundwater. Recently, Bredehoeft and King (1999) and Farnham et al. (1999) used chemistry of springs in the Death Valley area to assess groundwater source and the possibility of impacts from construction of nuclear waste storage facilities at Yucca Mountain, Nevada. Studies similar in scope and objectives to this proposal have been conducted on Owens Lake to better understand the potential groundwater flow paths between sampled wells and sources of spring water (Font, 1995; Lopes, 1998). Additionally, in an ongoing study at the Owens Lake, the source water for springs has been identified as an important unknown in the existing groundwater model. Because springs represent sensitive and valuable habitats, the consultants recommended that the data gap must be addressed to assess accurately potential impacts of proposed pumping before rational groundwater management plans could be developed (CDM, 1999).

Relying on geochemical analyses to investigate the hydrogeology of an area is less intrusive and usually less expensive than extensive drilling programs. Interpretation of the geochemical data, however, is rarely straightforward, and such studies commonly rely on modeling of the solid and aqueous phase interactions, groundwater mixing, and evolution of groundwater geochemistry along likely flow paths (Back, 1966; Hardie and Eugster, 1970). For example, locally, Font (1995) relied heavily on geochemical models to investigate the complicated groundwater relationships on Owens Lake. Models have primarily been of two types. Geochemical speciation and chemical mass balance models have been used to evaluate spatial and temporal changes along groundwater flowpaths (McCutcheon et. al., 1992). Several models have been developed and are widely applied.

REPORT ORGANIZATION

This report is organized into seven sections as listed below:

Section 1 – Introduction
Section 2 – Hydrogeology
Section 3 – Methods and Results
Section 4 – Geochemical and Isotopic Methods of Interpretation
Section 5 – Discussion by Area of Interest
Section 6 – Broader Conclusions for the Study
Section 7 – References

Section 2

Hydrogeology

Section 2
Hydrogeology

GEOLOGIC SETTING

The geology and water resources of the Owens Valley have been studied extensively since the late 1800s. In 1991, the United States Geological Survey (USGS) published a comprehensive report on the geology and water resources of the Owens Valley that summarized previous work conducted by the USGS since the 1980s (Hollett et. al., 1991). This report formed the basis for the conceptual model of the valley-wide groundwater flow model later published by Danskin (1998).

The Owens Valley is generally divided into two structural regimes, the Bishop Basin to the north, and the Owens Lake Basin to the South (Hollett et. al., 1991). These basins are each defined by grabens filled with erosional debris from the White/Inyo Mountains to the east, and the Sierra Nevada to the west. Well-defined structural or volcanic features separate the basins, and examples include:

- Northwest-southeast trending normal faults creating a subsurface bedrock high,
- The Poverty Hills, which is an exposed horst block of bedrock, and
- The Big Pine basalt flow of Quaternary age.

Through recent geologic time, the lower portion of the Bishop Basin contained a lake with a southern boundary that may have been in the approximate location of Tinemaha Reservoir. As the Bishop Basin filled with detritus from the surrounding hillsides, lacustrine sediments mixed with fluvial sediments, forming alternating layers of relatively coarse alluvial material mixed with fluvial sediments and lacustrine clays.

Coincident with this mixed fluvial/lacustrine environment was volcanic eruptions during Pleistocene time, emanating from vents along the faults on the west side of the Owens Valley. These flows commingled with fluvial and lacustrine deposits, becoming partially buried east of Highway 395. The flows have high hydraulic conductivity from the presence of clinker zones, breccia, lava tubes, and cracks, as well as fracturing resulting from recent faulting.

STRUCTURAL GEOLOGY

The Owens Valley as a whole is tectonically active and is dominated by relatively recent faulting and associated volcanism. Fluvial and lacustrine sediments have filled a graben formed by normal faulting of the White Mountain Fault Zone to the east, and strike-slip faulting on the Owens Valley Fault Zone to the west. As their name implies, these faults are not discrete ruptures, but rather a series of splays and en echelon scarps on both sides of the Owens Valley.

The Owens Valley Fault Zone in the area of Big Pine is particularly active, with estimated slip rates of approximately 2 millimeters per year. Surface displacement associated with the 1872 earthquake is well documented between the Poverty Hills, Crater Mountain, and north in between Klondike Lake and Warren Lake (Beanland and Clark, 1987). The 1872 rupture is particularly well preserved along the east side of Crater Mountain.

Of particular interest in groundwater modeling is the effect that faults have on groundwater flow. Faulting can have the effect of either increasing or decreasing the transmissivity of individual aquifers. In the valley-fill sediments, faulting would be expected to produce a barrier to groundwater flow, due to fault gouge, or the fact that permeable layers are displaced. The opposite effect can occur in olivine basalts, such as those found in the Crater Mountain area. In this case, faulting of the basalts would be expected to produce fracture zones that would greatly increase the secondary permeability of the volcanic rocks.

In the Big Pine area, there is little evidence as to the potential conduit or barrier effects of faulting in the volcanic rocks because all wells are located east of the fault as it crosses Crater Mountain. The groundwater gradient across the fault cannot be determined, thereby preventing the detection of either a barrier or transmissive zone.

There is evidence that faulting results in a barrier to groundwater flow in the unconsolidated deposits of the Big Pine Creek alluvial fan. Shallow groundwater exists upgradient to and within the Baker Springs complex west of Big Pine. West of the fault that bounds the spring complex on the east, groundwater is shallow, as evidenced by phreatophytic vegetation. Two test holes (T844 and T845) drilled in 2001 near Baker Creek exhibit shallow or flowing groundwater. East of the faults, groundwater is relatively deep, such as measured in well W341 (80 feet below ground surface). This change in water levels across the fault suggests that, at least locally, the fault is a barrier to groundwater flow.

SUMMARY OF KEY HYDROGEOLOGIC FACTORS

Danskin (1998) summarizes the substantial prior work for the Owens Valley and presents a hydrogeologic model of the Valley's groundwater flow system. In addition, LADWP and ICWD routinely measure water levels in monitoring wells, record flow in the Aqueduct and reservoir system, gauge flow in mountain front streams, canals, and ditches, and record production data from the pumping wells.

For this study, piezometric surface maps were created for each AOI. These maps represent lines of equal potential or potentiometric surface and were constructed with water level measurements (feet above mean sea level) from wells screened in the shallow unconfined aquifer. In order to interpolate between points of known value, the kriging technique was used. Kriging is a gridding method that uses the best linear unbiased estimation method applied to intrinsic functions. Where estimated values were clearly inaccurate from kriging, a significant change in hydraulic conductivity, or the presence of a water body, then contour lines were estimated manually.

The following is a brief list of key hydrogeologic factors derived from aforementioned published material supplemented by observations made in the course of this study.

- The predominant source of groundwater supply to the Owens Valley is recharge derived from rainfall and snowmelt in the Sierra Nevada. A much smaller percentage of recharge is

attributable to precipitation in the Inyo and White Mountains. Direct recharge on the valley floor from rainfall is not a significant percent of the water balance for the Owens Valley.
- Virtually all of the recoverable groundwater resides in the unconsolidated material, e.g. alluvial material, volcanic flows, and pyroclastics.
- Groundwater movement follows the steep gradients into the Valley from the Sierra Nevada on the west and the Inyo and White Mountains on the east. Near the valley floor, the gradients turn abruptly down the Valley towards Owens Lake. Potentiometric surfaces as presented by Danskin (1998) are used here as guidelines; however, detailed potentiometric surfaces were developed for each AOI using only measured values from monitored wells (see Section 5).
- The alluvial fans and valley fill were divided by Danskin (1998), essentially separating the hydrologic system into a shallow water table aquifer and a deeper confined aquifer.
- Steep groundwater gradients result in relatively high groundwater flow rates in this geologic setting. Danskin (1998) computes rates of horizontal flow of from 50 to 200 ft/yr based on hydraulic properties.

On a regional scale, the division by Danskin (1998) is a practical division. However, on the local scale of the spring and seep AOIs, this division is complicated by the presence of fine-grained sediments of limited lateral extent that still allow for mixing of shallow and deep aquifers or by the absence of aquitards altogether down to the total depths of the wells of interest. Mixing may also occur between aquifer zones prior to arrival of groundwater to the specific spring, at which point the aquifer may separate into water table and confined systems. Mixing of shallow and recently recharged groundwater with water from deeper zones in the aquifer is generally confirmed by the presence of tritium; however, a persistent complication to interpretation is the large screened interval of deep wells that produce from both shallow and deeper zones in the aquifer.

An investigation was done for this project of the seasonal variation in the potentiometric surface at each of the spring areas to determine if the fluctuation in water level was significant enough to affect the direction of groundwater flow and affect any of the conclusions. Averaging the two or three closest wells to each spring yielded a seasonal fluctuation on the order of less than five feet for the period of record for shallow wells. Data for some wells extend back to the 1970s. No evidence was seen for seasonal groundwater fluctuations that would change the direction of flow significantly enough to alter the interpretations made in this report.

The effect of faults on groundwater flow and related seeps and springs is a continuous area of inquiry for hydrogeologists working in the Owens Valley, and for the present, there are no uniformly applicable rules of interpretation for fault effects in Owens Valley. For example, the following general observations can be made, although they may only apply on a local scale.

- Faults and fractures in the unconsolidated material probably do not impact groundwater flow.
- Bedrock faulted to a position adjacent to unconsolidated material forms a barrier and restricts flow or diverts flow upward if the bedrock is on the downgradient side.
- Bedrock faults can also create conduits and serve as pathways for fluid movement.
- Faults juxtaposing bedrock alluvium may alter groundwater flow.
- High anisotropic permeability may exist along faults.

Section 3

Methods and Results

Section 3
Methods and Results

SAMPLE COLLECTION AND FIELD MEASUREMENTS

Collection of samples was completed in three field excursions over a fourteen-month period, from March 2002 to April 2003. All pre-selected wells, springs, and seeps were sampled in March 2002. The Aqueduct was sampled at three locations in April 2002. Confirmation sampling of two new shallow wells and two deep wells was done in April 2003. Field activities included:

- Measuring water levels,
- Purging wells,
- Collecting samples using existing pumping wells, peristaltic pumps in shallow wells and springs, and submersible pumps in deep observation wells,
- Preserving samples for laboratory chemical and isotopic analyses, and
- Measuring the unstable parameters pH, temperature, dissolved oxygen (DO), and oxidation-reduction potential (Eh) in the field.

All procedures and field instrumentation were agreed upon by the entire Cooperative Study Team prior to the field work. The methods employed were consistent with professionally-accepted practices as specified by agencies such as the USGS or the Environmental Protection Agency (EPA). These methods were document in Technical Memorandum No. 1 entitled, "Owens Valley Geochemistry Cooperative Study Sampling and Analysis Plan" (MWH, January 15, 2002).

Field measurements for dissolved oxygen and oxidation/reduction potential were less reliable than anticipated, in part because of malfunctioning equipment. There were no detrimental consequences because it is now believed that these parameters would not serve as discriminators for the needed spring and seep-source interpretations.

ANALYTICAL METHODS

Chemical analyses were performed at MWH Laboratories in Pasadena, California. Analytical results are summarized in this section. Analyses were performed using standard accepted procedures. Protocol for sample handling and analytical methods is provided in **Appendix B**. Similarity in analyses should be evaluated in the context of the expected analytical error for the methods employed. The MWH laboratory protocol requires the analysis of a matrix standard with each batch of samples. The following list represents three standard deviations (3σ) in reported percent difference (RPD) between the actual value and the measured value for the major analytes of interest as analyzed in the matrix standards used in this project.

Analyte	RPD (3σ)
Sodium (Na)	5.40
Potassium (K)	4.73
Calcium (Ca)	5.42
Magnesium (Mg)	6.39
Alkalinity (HCO_3)	5.36
Chloride (Cl)	1.66
Sulfate (SO_4)	2.35

A pre-approved list of isotopic species guided sampling, and the selection of samples for measurements depended on the set of questions posed for a specific AOI. The isotopic investigation was comprised of the radioactive isotope tritium and the stable isotopic ratios for boron, hydrogen, oxygen, and sulfur. All stable isotopic measurements except boron were made in the Department of Geosciences Isotope Geochemistry Laboratory at the University of Arizona. The following stable isotopic analyses were performed on a Finnigan Delta mass spectrometer: hydrogen (δD, 0.9 ‰), oxygen ($\delta^{18}O$, 0.08 ‰), and sulfur ($\delta^{34}S$, 0.2 ‰), whereby ‰ is the standard permil notation . [Note: the expected precision of each to 1-sigma in permil notation is included in parentheses.] The analyses for enriched tritium (^3H) were done by beta counting with a detection limit of approximately 0.5 tritium units (TU). Tritium measurements were also performed in the Isotope Geochemistry Laboratory of the Department of Geosciences, University of Arizona.

The stable isotopic measurement for boron ($\delta^{11}B$) with a 1-sigma precision of 0.5 ‰ was performed on a VG Thermal Ionization Mass Spectrometer (TIMS) under the direction of Geochemical Technologies Corporation in the Isotope Laboratory of the Department of Hydrology and Water Resources, University of Arizona.

RESULTS

Summaries of the chemical and isotopic data are provided in **Table 3-1** through **Table 3-8** and are arranged by AOI, oriented from north to south in the Owens Valley. In addition, tri-linear diagrams for each AOI are provided in **Appendix C**. Five analytes were found to be below their detection limit for almost all samples. As such, these analytes were deemed to be unimportant to this investigation and were consequently omitted from the tables. These five analytes, along with their detection limit based on the method used for analysis, are listed below:

- Aluminum (25 μg/l),
- Cadmium (0.5 μg/l),
- Chromium (1.0 μg/l),
- Copper (μg/l), and
- Selenium (5.0 μg/l).

The following notes pertain to the table entries for each AOI:

- Alkalinity represents the result of a titration for total alkalinity reported as bicarbonate,
- The pH value is a field measurement,
- Silica is reported as SiO_2,

- Screened intervals are not available for some wells,
- The stable isotopic values are given in the standard permil notation (‰), and
- Tritium values are given in Tritium Units rather than picocuries per liter.

Table 3-1
Analysis of Water Samples Collected from the Los Angeles Aqueduct

ANALYTE	UNIT	Mazourka Canyon Road	George Creek Bridge	Above Alabama Gates
Sample Date	--	4/11/02	4/11/02	4/11/02
Temperature	^{o}C	17.8	18.5	18.6
pH	std. units	8.04	7.94	7.99
Well Depth	ft	N/A (surface)	N/A (surface)	N/A (surface)
Alkalinity (HCO_3)	mg/l	129	156	156
Arsenic	µg/l	26	25	25
Barium	µg/l	16	16	16
Boron	µg/l	470	460	440
Bromide	µg/l	38	34	36
Calcium	mg/l	28	28	27
Chloride	mg/l	15	15	15
Fluoride	mg/l	0.68	0.68	0.67
Iron	mg/l	<0.02	<0.02	<0.02
Magnesium	mg/l	7.3	7.2	7.1
Manganese	µg/l	3	<2.0	<2.0
Total Nitrate as N	mg/l	0.045	0.039	0.036
Potassium	mg/l	4.8	4.7	4.7
Silica	mg/l	40	36	37
Sodium	mg/l	38	38	38
EC	µmho/cm	347	341	334
Sulfate	mg/l	28	27	27
TDS	mg/l	230	220	220
Uranium	µg/l	7.4	7.2	7.3
Vanadium	µg/l	7.6	7.4	7.6
Zinc	µg/l	<5.0	<5.0	<5.0
δD	‰	na	-121	-120
$\delta^{18}O$	‰	na	-16.0	-15.8
^{3}H	TU	na	5.1	4.7
$\delta^{34}S$	‰	na	7.5	7.6
$\delta^{11}B$	‰	na	5.2	4.2

NOTES
na = not analyzed
N/A = not applicable
ND = not detected
< = Less than the detection limit

Table 3-2
Analysis of Water Samples Collected from the Baker Springs (DWP 26) AOI

ANALYTE	UNIT	Giroux Ditch	DWP 26	T845	T844	Baker Creek	W341	V013N
Source Type	--	stream	spring	sw	sw	creek	pw	dw
Sample Date	--	3/14/02	3/20/02	3/13/02	3/13/02	3/15/02	3/14/02	3/15/02
Temperature	°C	4.9	15.6	15.1	13.3	na	17.2	13.3
pH	Std. units	7.74	7.16	7.55	7.26	7.40	7.62	6.31
Well depth	ft	N/A (surface)	N/A (surface)	31.6	39.08	N/A (surface)	754	120
Screened Interval	ft	N/A	N/A	unknown	unknown	N/A	65-750	unknown
Alkalinity (HCO_3)	mg/l	45	159	107	151	39	98	56
Arsenic	µg/l	<1.0	1.2	2.6	1.4	<1.0	1.8	<1.0
Barium	µg/l	5.6	27	5.1	29	3.8	16	15
Boron	µg/l	5	26	18	20	9	15	20
Bromide	µg/l	<5.0	21	12	17	<5.0	39	6.6
Calcium	mg/l	11	34	24	34	7.3	26	12
Chloride	mg/l	2.2	4.9	3.1	3.2	<1.0	23	1.4
Fluoride	mg/l	0.08	0.40	0.22	0.35	0.06	0.15	0.13
Iron	mg/l	<0.02	<0.02	<0.02	<0.02	0.12	<0.02	<0.02
Magnesium	mg/l	1.6	5.9	2.5	4.5	1.2	4.3	2.4
Manganese	µg/l	<2.0	<2.0	<2.0	400	4.5	<2.0	<2.0
Total Nitrate as N	mg/l	0.045	0.14	0.24	0.025	<.025	0.202	0.52
Potassium	mg/l	1.2	3.1	2	2.3	<1.0	2.3	1.3
Silica	mg/l	12	20	40	36	21	30	33
Sodium	mg/l	5.6	22	16	18	5	22	6.2
EC	µmho/cm	90	292	198	261	64	253	100
Sulfate	mg/l	5.9	19	9.5	11	2.6	12	3.5
TDS	mg/l	55	200	130	210	51	160	83
Uranium	µg/l	3.0	7.2	2.0	4.1	1.4	2.9	<1.0
Vanadium	µg/l	<3.0	4.2	3	4.9	<3.0	7.6	<3.0
Zinc	µg/l	<5.0	<5.0	<5.0	5.9	<5.0	<5.0	<5.0
δD	‰	-126	-127	-124	-122	-133	-126	-127
$\delta^{18}O$	‰	-17.5	-17.6	-17.4	-17.1	-18	-17.6	-17.3
^{3}H	TU	5.3	3	4.5	7.9	7.3	2.7	6.4
$\delta^{34}S$	‰	6.7	14	12.1	5.6	13	8.3	3.5
$\delta^{11}B$	‰	15.8	8.5	0.9	4.9	12.8	17.6	8.4

NOTES
na = not analyzed
N/A = not applicable
ND = not detected
< = Less than the detection limit
dw = deep well; sw = shallow well; pw = pumping well

Table 3-3
Analysis of Water Samples Collected from the Wilkerson Spring (DWP 22) AOI

ANALYTE	UNIT	W378	T469	V011N	W375	DWP 22	Mule Spring
Source Type	--	pw	sw	sw	pw	spring	spring
Sample Date	--	3/14/02	3/15/02	3/14/02	3/14/02	3/20/02	3/19/02
Temperature	°C	15.08	15.71	16.44	8.5	14.8	22.9
pH	Std. units	7.4	6.9	7.7	7.7	7.0	7.6
Well depth	ft	430	41.67	78.4	470	N/A (surface)	N/A (surface)
Screened Interval	ft	200-400	unknown	unknown	260-440	N/A	N/A
Alkalinity (HCO_3)	mg/l	128	115	255	224	122	246
Arsenic	μg/l	<1.0	<1.0	3.5	5.9	5	<1.0
Barium	μg/l	21	9.9	48	44	43	16
Boron	μg/l	74	190	730	390	100	89
Bromide	μg/l	39	22	84	46	72	76
Calcium	mg/l	18	18	25	33	17	60
Chloride	mg/l	20	5	55	19	8.5	10
Fluoride	mg/l	0.31	0.14	2.3	0.75	0.43	0.30
Iron	mg/l	0.58	0.61	0.43	0.53	0.1	0.028
Magnesium	mg/l	5.2	3.4	5.6	8.1	7.3	49
Manganese	μg/l	290	4.1	98	94	<2.0	<2.0
Total Nitrate as N	mg/l	<0.025	<0.025	<0.025	<0.025	<0.025	0.13
Potassium	mg/l	2.6	2	5.2	5.1	3.2	3.3
Silica	mg/l	65	25	69	57	8.6	9.4
Sodium	mg/l	34	23	93	57	58	42
EC	μmho/cm	273	208	562	434	387	763
Sulfate	mg/l	5.9	8.4	<2.0	20	85	220
TDS	mg/l	180	140	350	280	250	530
Uranium	μg/l	<1.0	<1.0	<1.0	1.7	1.4	3.4
Vanadium	μg/l	<3.0	3.5	<3.0	4.6	6.2	<3.0
Zinc	μg/l	<5.0	2300	7.7	<5.0	<5.0	<5.0
δD	‰	-130	-124	-130	-127	-123	-122
δ^{18}O	‰	-18	-16.6	-18	-17.5	-16.7	-16.6
^{3}H	TU	<0.8	5.2	<0.5	<0.4	<0.5	<0.5
δ^{34}S	‰	27.5	4.8	ND	27.4	9.4	23.4
δ^{11}B	‰	17.3	-2.2	-0.3	7.4	8.5	15.3

NOTES
na = not analyzed
N/A = not applicable
ND = not detected
< = Less than the detection limit
dw = deep well; sw = shallow well; pw = pumping well

Table 3-4
Analysis of Water Samples Collected from the Seeley Springs AOI

ANALYTE	UNIT	DWP 35	V362	T669	W349	V364	T846
Source Type	--	spring	dw	sw	pw	sw	sw
Sample Date	--	3/21/02	3/13/02	3/13/02	3/11/02	3/12/02	3/12/02
Temperature	°C	10.9	17.2	17.8	18.1	17.5	16.7
pH	Std. units	7.71	7.28	6.80	6.90	7.52	7.38
Well depth	ft	N/A (surface)	218	52	231	70.15	41.2
Screened Interval	ft	N/A	unknown	42-52	unknown	unknown	unknown
Alkalinity (HCO_3)	mg/l	78	174	296	292	532	262
Arsenic	μg/l	<1.0	3.5	4.8	7.6	0.065	3.5
Barium	μg/l	<2.0	6.8	57	30	70	20
Boron	μg/l	20	480	1100	1000	2600	960
Bromide	μg/l	10	29	69	67	130	58
Calcium	mg/l	17	21	43	36	30	34
Chloride	mg/l	4.4	11	38	36	70	25
Fluoride	mg/l	0.16	0.77	0.59	0.5	0.89	0.98
Iron	mg/l	0.068	<0.02	0.62	na	<0.02	<0.02
Magnesium	mg/l	3.9	9.2	20	25	55	15
Manganese	μg/l	<2.0	<2.0	86	13	<2.0	<2.0
Total Nitrate as N	mg/l	0.039	0.25	<.025	0.29	0.039	0.11
Potassium	mg/l	2.7	6	8.8	8.3	18	6.5
Silica	mg/l	52	54	69	61	83	53
Sodium	mg/l	9.6	42	68	56	120	63
EC	μmho/cm	157	341	608	558	1000	526
Sulfate	mg/l	9.5	15	31	19	48	26
TDS	mg/l	130	230	380	370	690	370
Uranium	μg/l	<1.0	16	5.8	19	20	9.4
Vanadium	μg/l	6.2	21	6.4	26	21	21
Zinc	μg/l	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
δD	‰	-124	-123	-124	-124	-118	-118
$\delta^{18}O$	‰	-17.5	-17.2	-17.1	-17.2	-15.9	-15.9
^{3}H	TU	10.9	5.3	3.8	3.2	5.7	5.8
$\delta^{34}S$	‰	8.1	8.9	10.0	7.9	1.2	10.8
$\delta^{11}B$	‰	26.3	1.1	0.9	2.0	-0.9	0.4

NOTES
na = not analyzed
N/A = not applicable
ND = not detected
< = Less than the detection limit
dw = deep well; sw = shallow well; pw = pumping well

Table 3-5
Analysis of Water Samples Collected from the Thibaut Springs (DWP 11) AOI

ANALYTE	UNIT	Grover Anton Spring (DWP 13)	F053	T655	T863	T864	V055	DWP 11	W382	T676
Source Type	--	spring	dw	sw	sw	sw	dw	spring	pw	sw
Sample Date	--	3/13/02	3/07/02	3/12/02	4/17/03	4/17/03	3/07/02	3/19/02	3/13/02	3/15/02
Temperature	ºC	15.1	20.9	19.4	18.6	19.8	16.5	17.8	19.0	15.6
pH	Std. units	7.46	7.30	7.37	7.44	7.7	7.30	7.37	8.45	7.64
Well Depth	ft	N/A (surface)	159	21	41.4	41.5	183	N/A (surface)	635	21
Screened Interval	ft	N/A	60-152	11-21	30-40	30-40	51-183	N/A	275-615	11-21
Alkalinity (HCO_3)	mg/l	135	296	394	157	163	71	89	89	200
Arsenic	µg/l	16	3.3	16	<1	58	2.2	1.5	3.8	5.5
Barium	µg/l	3.2	42	48	42	7	19	6	20	34
Boron	µg/l	250	2600	2700	110	340	28	46	240	79
Bromide	µg/l	18	110	130	20	50	17	16	14	19
Calcium	mg/l	44	19	50	37	21	21	28	11	46
Chloride	mg/l	13	140	160	6.7	13	2.3	3.1	3.7	3.2
Fluoride	mg/l	0.15	1.9	1.6	0.18	0.76	0.16	0.20	1.1	0.83
Iron	mg/l	<0.02	0.59	<0.02	0.43	1.00	0.84	0.028	<0.02	<0.02
Magnesium	mg/l	3.3	13	11	9.0	9.3	1.4	6.7	0.85	11
Manganese	µg/l	<2.0	270	7.8	24	23	620	2.1	5.2	6
Total Nitrate as N	mg/l	0.33	<0.025	<0.025	<0.1	0.65	0.17	0.21	<0.025	<0.025
Potassium	mg/l	3	3.7	2.2	3	6.8	1.6	3.1	1.6	4.3
Silica	mg/l	30	36	40	40	38	18	26	20	65
Sodium	mg/l	16	180	200	11	37	12	13	34	19
EC	µmho/cm	303	990	997	300	356	171	239	202	358
Sulfate	mg/l	23	64	68	22	30	23	42	21	28
TDS	mg/l	200	610	730	200	240	120	170	140	270
Uranium	µg/l	13	4.4	11	<1.0	2.2	7.7	4.9	<1.0	2.7
Vanadium	µg/l	<3.0	7	28	na	na	9	10	21	18
Zinc	µg/l	<5.0	<5.0	<5.0	<5.0	6.3	24	<5.0	<5.0	6.2
δD	‰	-117	-130	-126	-117	-121	-124	-123	-126	-123
$\delta^{18}O$	‰	-16.3	-17.5	-17.5	-16.0	-16.4	-17.3	-17.4	-17.6	-17.3
^{3}H	TU	5.2	<0.5	<0.5	1.2	<0.7	<0.4	<0.8	<0.4	<0.5
$\delta^{34}S$	‰	6.7	9.6	9.8	8.7	3.2	6.4	-1.2	5.8	4.9
$\delta^{11}B$	‰	2.7	-4.0	-0.1	6.0	3.1	-9.1	11.8	-12.3	-0.8

NOTES
na = not analyzed
N/A = not applicable
ND = not detected
< = Less than the detection limit
dw = deep well; sw = shallow well; pw = pumping well

Table 3-6
Analysis of Water Samples Collected from the Fault Scarp Springs (IND 102) AOI

ANALYTE	UNIT	Boron Spring (DWP 12)	F029	VOO7G	T450	IND 102	T375	V327	Coyote Spring
Source Type	--	spring	dw	sw	sw	spring	sw	dw	spring
Sample Date	--	3/19/02	3/07/02	3/07/02	3/7/02	3/18/02	3/11/02	3/11/02	3/12/02
Temperature	°C	17.0	14.9	16.3	16.6	16.0	17.47	18.4	18.5
pH	Std. units	7.66	7.70	7.72	7.17	7.44	8.21	7.96	7.38
Well Depth	ft	N/A (surface)	360	22.3	20.0	N/A (surface)	51.72	159.7	N/A (surface)
Screened Interval	ft	N/A	unknown	unknown	unknown	N/A	unknown	146-174	N/A
Alkalinity (HCO_3)	mg/l	120	67	92	73	102	84	188	163
Arsenic	µg/l	<1.0	4.6	4.7	<1.0	5	9.8	4.2	1.3
Barium	µg/l	12	8.1	11	4.9	11	8.1	60	18
Boron	µg/l	270	28	87	210	230	57	190	180
Bromide	µg/l	24	5.3	8.2	18	18	6.1	23	130
Calcium	mg/l	29	17	23	13	22	14	20	81
Chloride	mg/l	11	1.3	4.9	9.5	10	1.3	12	20
Fluoride	mg/l	0.11	0.12	0.10	0.20	0.21	0.4	0.53	0.71
Iron	mg/l	0.069	<0.02	<0.02	2.7	0.032	<0.02	0.19	<0.02
Magnesium	mg/l	4.9	3.5	3.4	0.75	2	1	4.5	21
Manganese	µg/l	<2.0	<2.0	<2.0	37	17	<2.0	81	<2.0
Total Nitrate as N	mg/l	0.56	0.22	0.090	0.16	0.16	0.03	<.025	0.83
Potassium	mg/l	2.8	1.3	1.5	1.4	1.8	1.7	4.3	2.1
Silica	mg/l	26	33	26	29	27	45	70	32
Sodium	mg/l	26	7.7	15	29	29	21	46	54
EC	µmho/cm	276	144	197	202	240	162	316	730
Sulfate	mg/l	23	14	17	22	21	15	<2.0	220
TDS	mg/l	180	110	150	140	160	130	240	560
Uranium	µg/l	15	3.2	5.3	3.5	5.8	<1.0	<1.0	11
Vanadium	µg/l	6.1	5.9	5.4	3.6	13	8.2	3.7	3.6
Zinc	µg/l	<5.0	<5.0	7.9	1200	<5.0	660	<5.0	36
δD	‰	-122	-122	-122	-127	-126	na	-124	-111
$\delta^{18}O$	‰	-16.9	-17.2	-16.9	-17.2	-17.2	na	-17.2	-14.9
^{3}H	TU	<0.4	14.3	2.8	<0.5	<0.5	na	<0.9*	<0.6
$\delta^{34}S$	‰	8.4	7.1	0.1	9.0	9.4	na	ND	3.7
$\delta^{11}B$	‰	6.8	na	-0.9	2.7	2.1	0.7	0.7	17.0

NOTES
na = not analyzed
N/A = not applicable
ND = not detected
< = Less than the detection limit
dw = deep well; sw = shallow well; pw = pumping well

Table 3-7
Analysis of Water Samples Collected from the Reinhackle Spring (DWP 7) AOI

ANALYTE	UNIT	T652	F082	W348	W403	T597	V012	DWP 7
Source Type	--	sw	dw	pw	pw	sw	dw	spring
Sample Date	--	3/11/02	4/17/03	3/11/02	4/17/03	3/8/02	3/12/02	3/15/02
Temperature	ºC	18.8	16.3	18.4	19.4	13.2	16.3	17.4
pH	Std. units	7.10	6.99	7.38	?	7.80	7.38	7.48
Well depth	ft	36.82	266	488	560	20.91	485	N/A (surface)
Screened Interval	ft	unknown	98-194	70-460	250-550	unknown	unknown	N/A
Alkalinity (HCO$_3$)	mg/l	176	67	126	77	137	127	160
Arsenic	µg/l	1.1	<1.0	<1.0	8.6	9.8	<1.0	15
Barium	µg/l	17	4.3	8.9	<2.0	28	9.1	24
Boron	µg/l	120	<50	100	<50	390	55	550
Bromide	µg/l	24	8.1	26	8.6	30	32	38
Calcium	mg/l	24	12	17	1.2	25	27	29
Chloride	mg/l	2.4	1.6	3.7	2.6	14	5.3	15
Fluoride	mg/l	0.43	0.09	0.23	0.46	0.59	0.10	0.62
Iron	mg/l	<0.02	0.14	<0.02	<0.1	<0.02	<0.02	<0.02
Magnesium	mg/l	4.5	2.9	3.4	<0.1	5.9	6.3	5.3
Manganese	µg/l	<2.0	13	<2.0	<2.0	<2.0	<2.0	<2.0
Total Nitrate as N	mg/l	<.025	0.16	0.17	0.17	0.12	0.21	0.15
Potassium	mg/l	3.7	1.1	1.8	<1.0	3.9	1.4	4.3
Silica	mg/l	41	32	40	20	29	39	35
Sodium	mg/l	37	10	29	32	35	16	36
EC	µmho/cm	275	113	224	137	308	238	332
Sulfate	mg/l	8.1	4	10	4	25	12	18
TDS	mg/l	190	110	160	105	190	180	220
Uranium	µg/l	11	2.5	9.0	1.8	4.6	19	8.2
Vanadium	µg/l	10	na	11	na	7.7	9	12
Zinc	µg/l	<5.0	<5.0	<5.0	<5.0	210	7.3	<5.0
δD	‰	-121	-119	-123	-127	-121	-122	-120
δ^{18}O	‰	-16.8	-16.2	-17.2	-17.1	-16.2	-17.1	-15.6
^{3}H	TU	7.7	5.5	3	2.1	4.5	2.7	5.8
δ^{34}S	‰	5.4	6.1	6.4	6.2	6.7	7.6	8.2
δ^{11}B	‰	6.7	13.9	10.0	11.8	6.4	25.2	2.3

NOTES
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Table 3-8
Analysis of Water Samples Collected from the Fault Scarp Spring (DWP 9) AOI

ANALYTE	UNIT	DWP 9	T394	V013	T446	V258
Source Type	--	spring	sw	dw	sw	dw
Sample Date	--	3/18/02	3/08/02	3/08/02	3/08/02	3/08/02
Temperature	^{o}C	23.2	27.5	19.0	16.4	19.8
pH	Std. units	7.52	7.42	7.37	7.60	7.30
Well Depth	ft	N/A (surface)	60.8	339	21	200
Screened Interval	ft	N/A	unknown	55-310	unknown	70-187
Alkalinity (HCO_3)	mg/l	126	95	101	101	188
Arsenic	µg/l	20	19	1.3	33	6
Barium	µg/l	6.2	8.8	7.9	50	25
Boron	µg/l	1600	2100	22	3600	300
Bromide	µg/l	170	230	21	320	28
Calcium	mg/l	34	38	14	47	17
Chloride	mg/l	190	280	3.9	420	10
Fluoride	mg/l	2.5	3.2	0.22	4.1	1.3
Iron	mg/l	<0.02	0.38	<0.02	1.6	11
Magnesium	mg/l	2.3	1.6	3.2	4.8	4.1
Manganese	µg/l	<2.0	38	4.7	87	290
Total Nitrate as N	mg/l	<0.025	<0.025	0.078	<0.025	<0.025
Potassium	mg/l	3.9	5.1	1.7	7.4	7.7
Silica	mg/l	18	37	36	57	80
Sodium	mg/l	150	190	24	260	38
EC	µmho/cm	889	1180	186	1640	329
Sulfate	mg/l	53	75	7.9	120	<2.0
TDS	mg/l	530	680	130	970	230
Uranium	µg/l	17	1.7	13	<1.0	<1.0
Vanadium	µg/l	5.4	<3.0	8.6	<3.0	<3.0
Zinc	µg/l	21	9.3	<5.0	860	8.7
δD	‰	-127	-131	-124	-130	-125
$\delta^{18}O$	‰	-16.9	-17.3	-17.3	-17.2	-17.3
^{3}H	TU	4.0	0.9	1.8	<0.6	<0.4
$\delta^{34}S$	‰	12.1	13.0	9.5	11.0	no SO_4
$\delta^{11}B$	‰	10.7	10.9	12.6	13.5	-12.7

NOTES
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N/A = not applicable
ND = not detected
< = Less than the detection limit
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Section 4

Geochemical and Isotopic Methods of Interpretation

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GEOCHEMICAL MODELING

Evaluation and interpretation of chemical data relied on three types of geochemical modeling:

- Reaction state,
- Chemical and isotopic mixing, and
- Mass transfer with inverse calculations.

The definitions and examples of each modeling type, as well as additional discussion of modeling approaches, are described in Bassett (1997). The applications of each of these modeling types to the circumstances of the Owens Valley project are described below.

Reaction State Modeling

The outcome of "reaction state modeling" is a computation of the thermodynamic activity for the aqueous species in each water sample and the determination of "saturation state," or closeness to equilibrium with respect to minerals the water may encounter. The reaction state computations for this report were done with SOLMINEQ88 and PHREEQC, both of which are computer codes written and supplied by the USGS. The only available documentation for SOLMINEQ88 is the original manual published in 1988, and even though the code has subsequently been modified, most modifications are noted in the comments section of the current version of the code itself (Kharaka et al., 1988). PHREEQC is available from the USGS at their Internet site (www.usgs.gov).

As an example for the computation of thermodynamic activity of aqueous species, consider the analysis from Grover Anton Spring (**Appendix D**). For Grover Anton Spring, there are analytical results for 20 elements, including pH. However, after computing the distribution of the element mass as it is represented in solution, the model output indicates that there are actually at least 284 aqueous ions and complexes present in solution (**Appendix D**). This computed distribution of species allows one to determine several attributes useful in geochemical simulations.

- First, the charge of each of the species is useful in ion exchange and adsorption calculations because these reactions are charge dependent. Species distribution changes with alteration to the solution composition, pH, temperature, and consequently the proportion and identity of the charged species must be recalculated for the circumstance of each water sample.
- Secondly, the distribution of the element mass among species will define the dominant species and assist in explaining mobility or transport efficiency. As an example, the output for uranium in Grover Anton Spring (**Appendix D**) indicates uranium forms 16 aqueous species, but the dominant complex in this environment is the neutral uranium carbonate

complex, ($UO_2CO_3^o$), which accounts for its lack of sorption and explains the mobility of uranium in oxidizing and carbonate rich environments.
- Finally, the distribution of species calculation also yields the thermodynamic activity of each ion. This activity is listed in column nine of the output (**Appendix D**) and differs from concentration by the effect of the activity coefficient. The thermodynamic activity is the "effective concentration," and it is that value that is required in the computation closeness to equilibrium with respect to minerals of interest.

The closeness to equilibrium is generally referred to as the saturation state of the water. In order to define the saturation state of the water with respect to any mineral of interest, the activity product for a mineral (K_{ap}) is compared to the equilibrium constant (K_{eq}) to determine if the water:

- Is in equilibrium with a particular mineral or gas phase,
- Has the potential to dissolve specific minerals, or
- Will precipitate specific phases.

The activity product is simply the product of the computed activity of every element that comprises the mineral adjusted for the stoichiometry of the elements in the mineral. For example, for dolomite ($CaMg(CO_3)_2$) the dissolution reaction is as follows:

$$CaMg(CO_3)_{2(Solid)} \leftrightarrow Ca^{2+} + Mg^{2+} + 2(CO_3^{2-}).$$

The activity product is then written as:

$$(K_{ap}) = \{Ca^{2+}\}\{Mg^{2+}\}\{CO_3^{2-})^2.$$

The braces indicate aqueous thermodynamic activity.

The saturation state, or saturation index (SI) as it is often termed, is the comparison of the activity product for a given solution to the equilibrium constant for the mineral of interest.

$$SI = K_{ap}/K_{eq}$$

This expression is defined as the saturation state equation and can be used to assess equilibrium.

For example, water recharged into alluvial fans along the mountain front may initially be undersaturated with respect to specific soluble phases. Given sufficient time, these phases may react with the water by dissolution and alter the water composition. By determining the reaction state of the water, it is possible to identify which minerals have possibly reacted and which minerals still have the potential to react with the water. This information may then be used to interpret the compositional differences and "reaction potential" along the flow path between sampled locations.

A typical list of minerals that might be considered for such an analysis is included in **Appendix E**. This table of mineral data lists the mineral name with columns for: the computed activity product (K_{ap}), the equilibrium constant for the dissolution of the mineral at the temperature of the sample (K_{eq}), and the saturation state ($\log K_{ap}/K_{eq}$). The numerical designation of the degree of saturation for each water sample is simply the logarithm of the activity product divided by the equilibrium constant. A value of near zero indicates nearness to equilibrium, while positive values indicate supersaturation and negative values indicate undersaturation. Interpretation of these values is improved by knowledge of kinetic behavior. For example, the model typically computes that quartz is significantly undersaturated in groundwater. In other words, the potential to dissolve quartz is high, but because the rate of dissolution at these temperatures is too slow to be significant, groundwater almost never reaches equilibrium with respect to quartz.

For each AOI, the discussion regarding saturation state will be included in a subsection titled “Geochemical Modeling.” In Owens Valley, the granitic geologic terrain provides a rather small number of phases that could dissolve at a rate sufficient for the groundwater to reach equilibrium with respect to that mineral. For example, calcite is present in minor quantities but is abundant enough and sufficiently soluble that it is common for both surface and groundwater to reach equilibrium. In such instances, the concentration (or more precisely the thermodynamic activity) of some components such as calcium and bicarbonate will be constrained by this solubility control. If more calcium is added from another source, then calcite may precipitate, and if mixing occurs with a more dilute water, then additional calcite may dissolve. This behavior is defined as a solubility constraint and is governed by the thermodynamic state of the water.

The saturation state assessment provides an evaluation of which minerals are to be considered in defining the causes of water compositional changes. Minerals that are alkaline earth salts of carbonate, sulfate, and fluoride are relatively soluble, and if present equilibrium could constrain groundwater compositions. For example, at Grover Anton Spring, sulfate minerals like gypsum and anhydrite are two orders of magnitude (two log units) below saturation and barite is 1.5 log units below saturation. These minerals would readily dissolve if present, and the fact that these springs are so far out of equilibrium indicates their absence. In contrast, the saturation state for calcite is -0.3, which is 0.3 log units from equilibrium. This saturation state is actually close enough to assume that the water is at saturation with respect to calcite and clearly supports the assertion that calcite is present and available for reaction with groundwater.

Clay minerals are often found as the byproduct of the weathering of igneous rocks such as those found in the Sierra Nevada. There are many possible reaction pathways that can result in the weathering process producing clay byproducts. Aluminum is a structural component of all the clay minerals present in significant amounts in this region, but aluminum concentrations in groundwater were typically below detection limit. Therefore, computation of clay mineral activity products could often not be made without including aluminum in the equation. Well V258 is the only well in which aluminum was present above the detection limit at 60 micrograms per liter. It is interesting to note that in this case saturation states can be computed, and in the computer output for well V258, the common clay minerals of kaolinite and smectite are about nine orders of magnitude supersaturated (**Appendix E**). This information supports a general conclusion often made about weathering reactions in igneous environments, which is that when the aluminum concentration is sufficiently high for nucleation of new mineral phases, or for mineral transformation to initiate, that thermodynamically the clay minerals have a high thermodynamic potential to form. In other words, the weathering of igneous rocks and the formation of clay minerals is energetically favored and will proceed. Unfortunately, the saturation state is not easily computed because one key component, aluminum, is not present at a concentration easily quantified.

Many minerals are not present in sufficient quantity, or dissolve too slowly, to reach equilibrium in this aquifer setting. A mineral such as gypsum, which is common in the western United States, is not present here in sufficient quantity, even in the marine rock of the ranges east of the Owens River, to reach equilibrium with the water in the local aquifers. In contrast, the carbonate minerals, which are less soluble, do indicate equilibrium in many samples evaluated.

Solubility Overview

The geochemical model SOLMINEQ88 was used to compute the distribution of aqueous species and the saturation state with respect to key minerals. Surface water and groundwater compositions in the study area are rather dilute, with total dissolved solids generally in the 200 to 300 mg/l range. The geochemical model indicates that equilibrium has typically not been attained with the sulfates, fluorides, chlorides, and many oxide salts typically found in similar geologic provinces, further supporting the assumption that these mineral phases are either not present or are not in contact with the groundwater in sufficient quantities to constrain compositions. Calcite may be the only phase present in abundance that is in equilibrium with the groundwater.

Trace Metals

Although samples were collected for trace metal analysis, few metals were found to be present above the detection limit. For example, of the 41 samples analyzed:

- None contained measurable amounts of cadmium or selenium,
- Only one sample contained detectable aluminum,
- Three had detectable chromium values,
- Four measured copper, and
- Less than half yielded detectable iron, manganese, and zinc.

It is interesting to note that most samples yielded detectable quantities of arsenic, uranium, and vanadium, due in part to the igneous source rocks, but principally due to the fact that as the computer model indicates, in this dilute, neutral pH, and oxidizing environment, these three metals migrate as oxyanions. Oxyanions are negatively charged aqueous molecules. Since the majority of the mineral surfaces in this geological environment, under these pH conditions, are also negatively charged these ions are not retarded by sorption and move freely, essentially with the velocity of the groundwater.

Geochemical Mixing Simulations and Inverse Modeling

Mixing calculations were performed to determine if the chemical composition of a target spring could be simulated by combining the compositions of upgradient sources (e.g., a shallow and deep aquifer well, or a surface water and shallow well) in any possible percentage of mixing. In several of the mixing calculations the model indicted that there was no combination of percentages of any of the wells considered that would yield the observed chemical composition of the spring or seep being considered. The computer model PHREEQC allows the user to include variability to the analysis so that an allowance can be made for the expected error in the chemical analysis or error resulting from spatial and temporal variability in the composition of water samples. The magnitude of this error should be compatible with the known uncertainty associated with historical data or laboratory tests of standards and matrix spikes. In most cases, simple mixing scenarios did not match the spring composition satisfactorily. In general, this error suggests additional elemental mass is needed from another source, which is an indication that mass transfer must be considered (e.g., minerals have dissolved or precipitated, or ion exchange has occurred).

Reaction Path Modeling

Reaction path modeling is a term used to describe the evolution of a water composition as chemical reactions proceed. For example, the path can be the sequence of chemical changes that occur as minerals dissolve or precipitate, or as gases enter or leave the groundwater, even if no transport is considered. This path is a change in composition of a specified unit volume of water, such as in an aquifer as one considers compositions at several locations in the direction of groundwater movement. A path can be numerically simulated by considering the transfer of mass between solid phases and the water. This set of reactions must be governed by thermodynamics and known kinetic constraints, and may be evaluated with or without coupling the chemical reactions to the flow equations.

If the flow pathway is known, then inverse modeling can be done to determine if the composition of an upgradient well could be altered in a plausible manner by mineral dissolution or precipitation, or ion exchange reactions, in order to yield the composition of a downgradient well or a target spring. Mineral compositions must be defined, and assumptions must be made as to the likelihood of these phases being present in the aquifer. Consequently, an understanding of the local geology is required in order to carry out these calculations accurately.

The mixing and inverse calculations were performed using the USGS geochemical model PHREEQC (Parkhurst, 1995). The key equations and definitions used in inverse modeling are discussed in Bassett (1997) and Bassett et al. (1992).

ISOTOPIC THEORY

The water that comprises spring discharge in Owens Valley is in many cases derived from several sources. Isotopic measurements were in the monitoring program because of their unique capabilities for tracing and differentiating solute sources. As Owens Valley groundwater moves from mountain front to valley floor, it bifurcates into shallow unconfined and deeper confined zones separated by layered beds of low permeability fan and lacustrine deposits. Recharge of surface runoff from streams, creeks, ponds, etc., and recharge from the Aqueduct all represent potential sources for the springs of interest in this study. These sources are not easily differentiated using chemical composition alone.

Isotopic data provide a different interpretive approach from that obtained by using only chemical data. For example, when stable isotopes are employed, the isotopic ratio of the solute provides a “label” for the solute. This ratio remains unaltered even as solute concentration changes, because the measurement relies on the ratio of nuclides of the same element. If the source of the solute has a unique ratio, then this characteristic signature is often maintained during migration or mixing, allowing for tracing the solute pathway and for determination of mixing percentages. The theoretical considerations are discussed below, with a discussion of how the use of isotopic data increases the probability of interpreting the source of chemical constituents detected in groundwater. In addition to the stable isotopes, one radioactive isotope, tritium (^{3}H) is discussed. Tritium is the radioactive nuclide of hydrogen and the concentration of tritium was measured in the project to provide a relative indication of "age" of the water. The "age" is a general indication of how recently the water was isolated from the atmosphere, ostensibly during recharge.

Four stable isotopic systems were tested: hydrogen, oxygen, sulfur, and boron. Each system contributes different information (e.g., the hydrogen/oxygen stable isotopic ratio identifies processes that affect the water itself whereas the, other two stable isotopes are solute specific). The following discussion provides general theoretical information about the isotopic systems. Later in Section 5 is a discussion of the use of the data in interpreting the hydrogeology and geochemistry at the AOIs.

Environmental Isotopes of Hydrogen and Oxygen (δD and δ^{18}O)

Oxygen has three naturally occurring stable isotopes, hydrogen has two, and the average natural abundance is given below:

^{1}H	99.9844 %
^{2}H	0.0156 %
^{16}O	99.7621 %
^{17}O	0.0379 %
^{18}O	0.2000 %

The ratio of the stable isotopes of both oxygen (^{18}O/^{16}O) and hydrogen (^{2}H/^{1}H or D/H for deuterium/hydrogen) atoms in groundwater historically has provided information about climatic history, recharge environment, and even anthropogenic contribution. Isotopic fractionation of these two elements is most commonly related to atmospheric conditions. Both ^{18}O/^{16}O and D/H have large enough mass differences between the two isotopes that a depletion of the heavier isotope occurs as a result of physical processes such as evaporation, adsorption, or diffusion. The reaction rates of these physical processes are mass dependent, and consequently the ratio of the two isotopes in a population changes as these processes proceed. For example, in the evaporation of water, the vapor is depleted in deuterium by as much as 1 percent under equilibrium conditions, leaving an enriched residual liquid. The vapor/liquid fractionation is reversible, so that as a mass of atmospheric vapor loses part of the vapor mass to condensation and rainfall, the liquid water is enriched (increased in the amount of the isotope with the greater mass, deuterium), and if loss of vapor mass from the atmosphere occurs by precipitation, then the enriched liquid water is removed from the residual vapor mass. The simplified explanation of the net result of this process is that vapor is progressively depleted (increased in the proportion of the isotope with the lighter mass) as the vapor mass moves across the continent.

Stable isotopic data are conventionally reported as a delta (δ) notation, which is a comparison between a sample and a standard using the ratio of the two most abundant isotopes. The δ notation converts the ratios to a linear representation and provides a method of depicting very small changes in the isotopic ratio. For example, using D/H as the illustration, the measured

D/H ratio of a sample (spl) is compared to the accepted D/H ratio for the hydrogen standard (std). A delta notation for D/H is then written as δD, computed as shown in the equation below, with units of per thousand or "per mil," symbolized as " ‰."

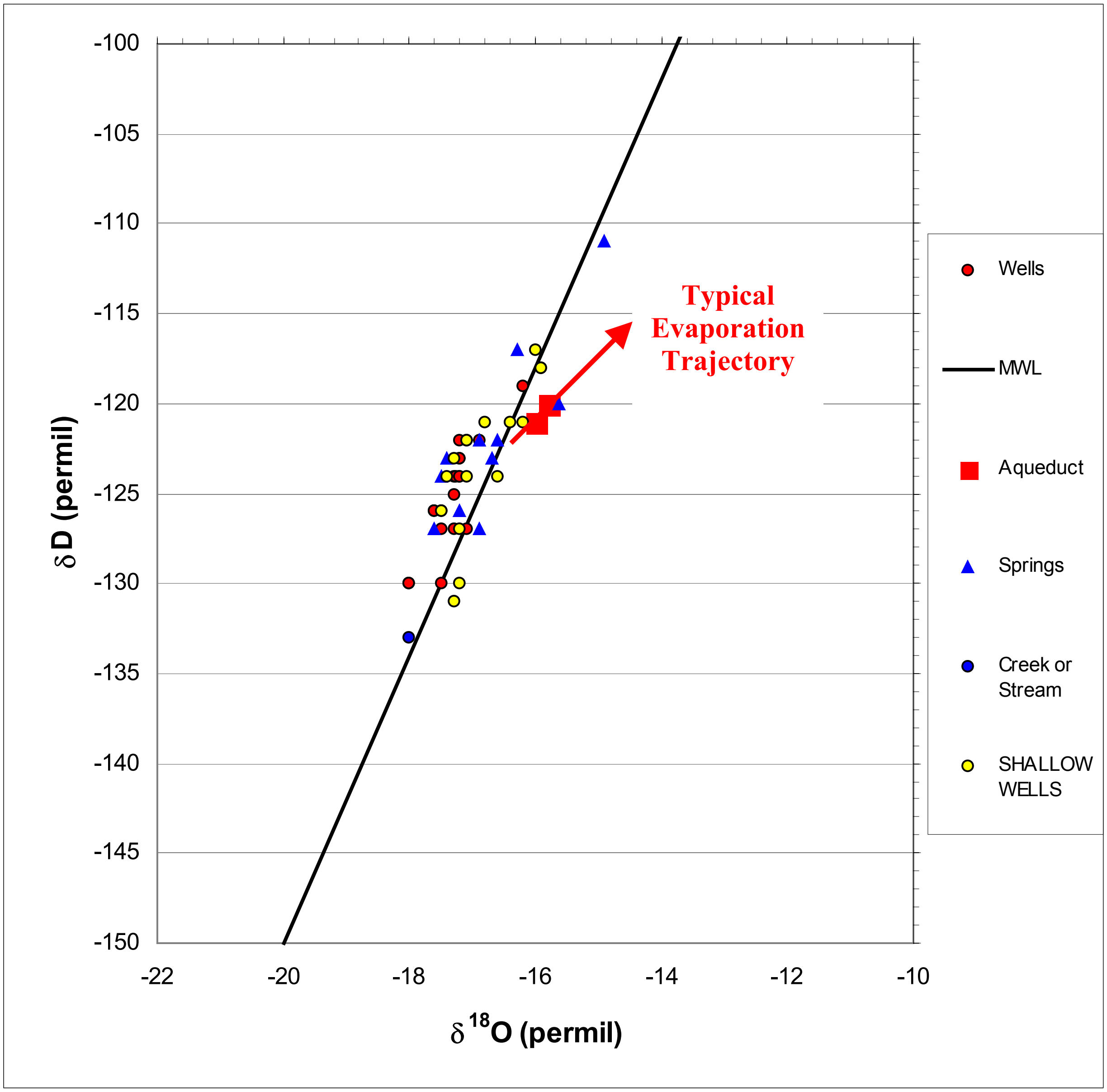
$$\delta D \text{ ‰}_{spl} = \left[\frac{(D/H)_{spl} - (D/H)_{std}}{(D/H)_{std}} \right] \times 10^3$$

Note that if the D/H ratio of the sample is a smaller value than the D/H ratio of the standard, then the computed δD will be a negative value. Conversely, samples with larger ratios than the standard will be positive numbers. In a comparison of data, a sample that has a more negative ratio than another, is termed "depleted" in the isotope with greater mass, and a more positive ratio is "enriched." Colloquial terms are often used such as "lighter" or "heavier" values for depleted and enriched values respectively. By international agreement, the accepted standard for both D/H and $^{18}O/^{16}O$ is synthetic seawater known as the Vienna Standard Mean Ocean Water (VSMOW).

The hydrologic cycle is often described as beginning with evaporation of seawater to create the atmospheric masses of moisture that cover the continents, the evaporation process causes the simultaneous alteration of both the hydrogen and oxygen isotopic ratios. This change in the isotopic ratios is termed fractionation, and the consequence is a progressive enrichment of the heavier isotope in residual water and depletion in evaporated water, which is clearly seen in a cross plot of these two isotopes. This plot is known as the Global Meteoric Water Line (MWL) and is comprised of precipitation (meteoric water) data collected worldwide. Using the δD and $\delta^{18}O$ data from all samples collected to date in the Owens Valley, a comparison can be made to the MWL (**Figure 4-1**).

This cross plot illustrates the geographic and climatic signature that rain or snowfall may have prior to recharge, remembering that the MWL applies to the water in the atmosphere and does not apply to surface water or groundwater. Consequently, the local precipitation has an "isotopic signature" that is somewhat unique to specific regions, elevations, and climates, because of the fractionation that particular area experiences. Groundwater and surface water isotopic values are often compared to the MWL to assess the alterations that may have occurred as the water accumulates on the land surface, enters the subsurface and becomes groundwater, or evaporates on the land surface. The deuterium and oxygen isotopic data for Owens Valley predominantly cluster near the MWL and, except for a few locations, this indicates little fractionation from evaporation has occurred (**Figure 4-1**).

Figure 4-1
Owens Valley Hydrogen and Oxygen Isotopic Data Plotted against the Meteoric Water Line



Radioactive Isotope of Hydrogen (^{3}H tritium)

Tritium is generated by cosmogenic mechanisms, similar to that of radiocarbon, only the collisions are with neutrons (n) or protons (p) of slightly different energies, as cosmic radiation; reactions with nitrogen as the parent molecule represents the predominant reaction:

$$^{14}N + n \rightarrow {}^{3}H + {}^{12}C$$
$$^{16}O + p \rightarrow {}^{3}H + {}^{14}O$$
$$^{16}O + p \rightarrow {}^{3}H = {}^{17}F$$

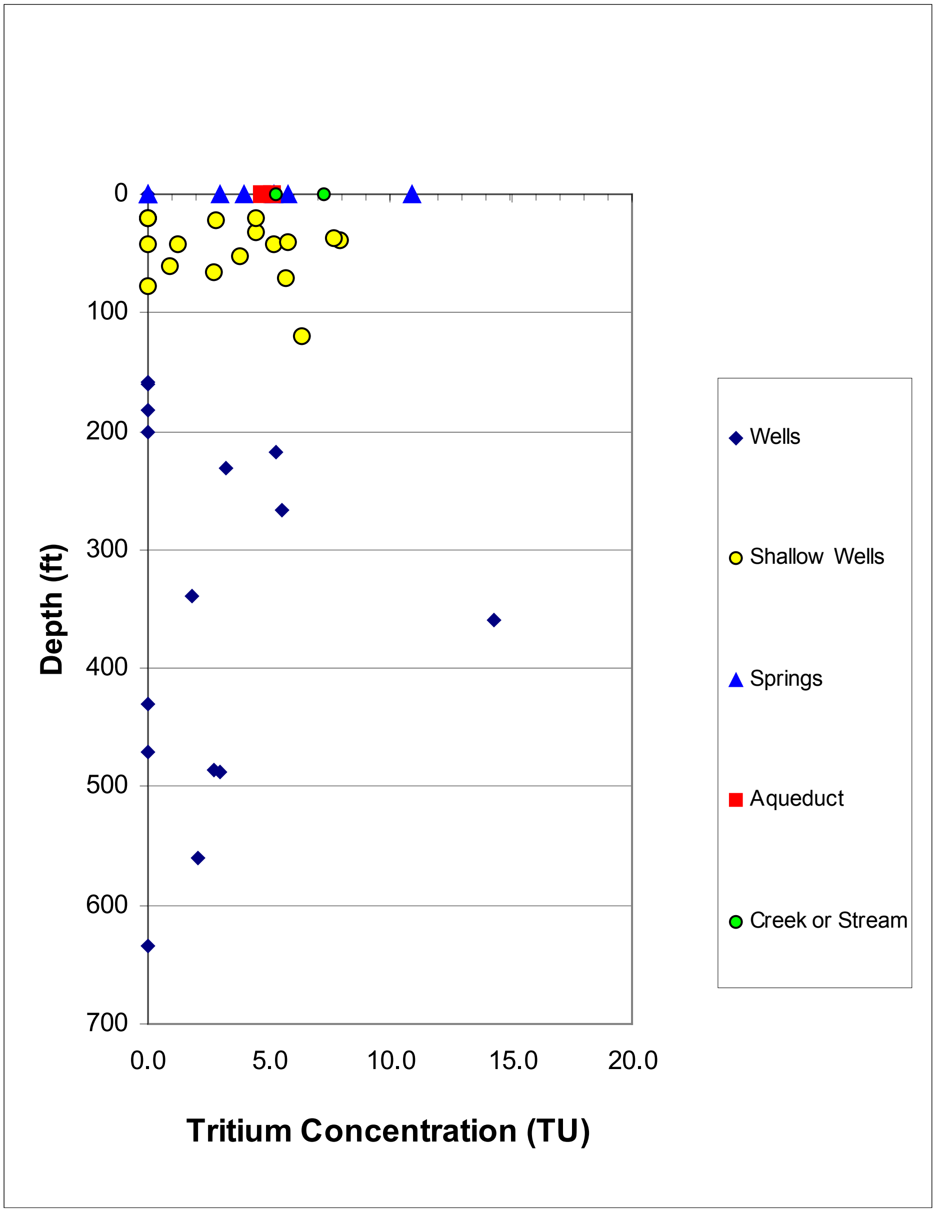
The background natural concentration of ^{3}H in the atmosphere is about 5 Tritium Units (TU) where 1 TU = 1 atom of ^{3}H in 10^{18} atoms of H. In terms of radioactivity 1 TU is 0.12 Becquerel (Bq) per liter of water and 1 Bq = 1.000 disintegration per second. After about 7 half-lives, an isotope will have an activity of less than 1 percent of its original value and is below the detection limits for most instruments. Consequently, since the half-life of ^{3}H is 12.43 years, the natural background value of surface water will be undetectable without significant enrichment during analysis in about 50 years. Obviously the use of natural tritium for dating groundwater is limited to “young” water.

^{3}H was also contributed to the atmosphere by nuclear weapons testing. ^{3}H concentrations in the atmosphere exceeded 10,000 TU in the early 1960s and have declined rapidly since that time, essentially back to near natural background levels. ^{3}H values in groundwater that are greater than 5 TU are almost certainly evidence of water recharged during the post-bomb testing time period or later than the 1960’s. The exact age cannot be determined because the atmospheric concentration of ^{3}H was highly variable depending on the intensity of bomb testing.

Obviously if there is no measurable ^{3}H in groundwater then it could be assumed that the water has been isolated from atmospheric ^{3}H for more than about 100 years. Conversely, water containing tritium above a detection limit of about 0.5 TU, assuming no mixing with older water devoid of tritium, is probably younger than about 50 years. Younger would be defined as having been recharged and isolated from the atmosphere less than 50 years before present. Water recharged in the 1950s with a tritium content of several hundreds of tritium units would still have a content of from 10 to 30 TU.

None of the samples collected in the Owens Valley are greater than 15 TU (flowing well F029 at 14.3 TU) and many are below detection limit (**Figure 4-2**). Except for F029, surface waters, as would be expected, have the largest tritium values and some of the deeper wells also have measurable tritium (see Section 5 discussion).

Figure 4-2
Display of Tritium Content with Depth for Owens Valley Samples



Boron Stable Isotopic Composition ($\delta^{11}B$)

The element boron (B) has two isotopes ^{11}B and ^{10}B, and the ratio of the two is measured routinely in a solid source mass spectrometer. The value of B as a tracer derives from three unique characteristics:

- B is present in virtually all surface water, groundwater and reservoir waters,
- B is chemically conservative, and
- B has two stable isotopes whose ratio is naturally variable over a large range.

The ubiquity of B is the consequence of its high solubility. The predominant dissolved B species that occurs in intermediate to acidic pH water is undissociated boric acid, $H_3BO_3^o$, a Lewis acid which has a pK_a of 9.2. Because the predominant aqueous species is the neutral boric acid, ion exchange is insignificant, and adsorption is important only in regimes of high surface area minerals at elevated pH values. B is not naturally affected by reducing environments and therefore the B oxyanion is stable and unaffected by changing redox conditions. Finally, because the solubility of most B salts is high, B is not lost to precipitation of salts except in environments of high evaporation such as playas. B does co-precipitate with carbonates, sulfates, and oxyhydroxides of Al and Fe in small amounts.

The two stable isotopes of boron, ^{11}B and ^{10}B, are present naturally in a ratio of approximately 4:1. The delta notation for boron is written as the $\delta^{11}B$ ‰ and is compared to the National Institute of Standard Technology (NIST951) with a ratio of 4.04362.

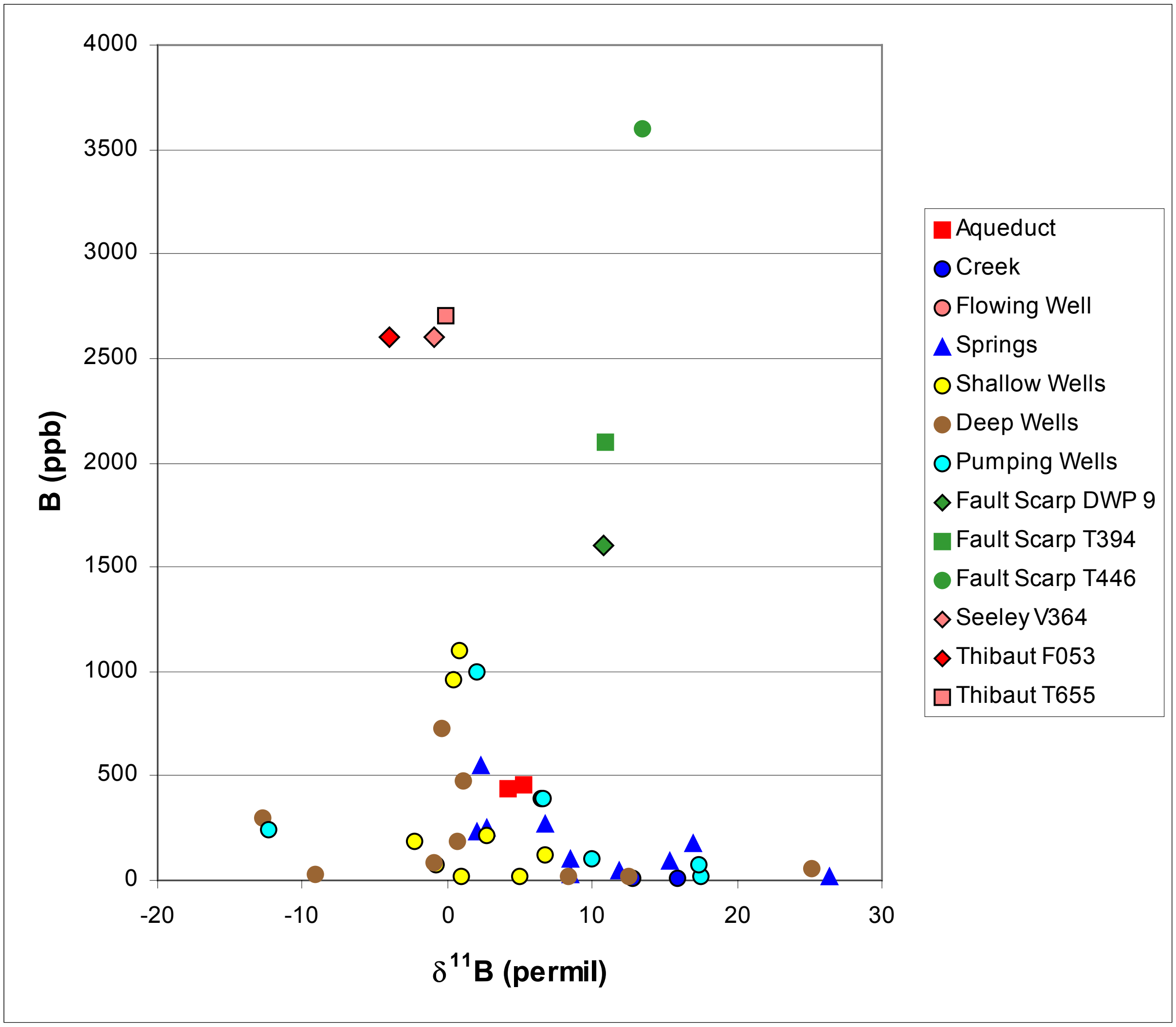
$$\delta^{11}B\ ‰_{spl} = \left[\frac{(^{11}B/^{10}B)_{spl} - (^{11}B/^{10}B)_{std}}{(^{11}B/^{10}B)_{std}}\right] \times 10^3$$

The natural variation of the stable isotopic composition of rocks, minerals, and natural waters is quite large, ranging over more that 70 per mil. In general, the evaporite materials, especially continental evaporites, are depleted in ^{11}B. Marine related rocks and seawater are among the most enriched materials in ^{11}B.

It has been shown in numerous studies that the boron isotopic signature is useful in hydrogeologic investigations because it is frequently related to the source of the water. Because boron is chemically conservative, it can generally be assumed that the boron signature does not change along the flowpath as a result of reaction. Even if the groundwater represents a mixture of sources, the boron from each end-member can be used to determine the mixing percentage of the source waters if the end-members are known (Davidson and Bassett, 1993; Bassett et al., 1995; Leenhouts et al., 1998; Carty et al., 2002).

All boron concentrations for which the boron isotopic ratios were measured for the Owens Valley are displayed in **Figure 4-3**. The boron data are especially useful because of the large range of values. The isotopic data scatter over more than 40 permil, and, similarly, the boron concentration ranges by than three orders of magnitude.

Figure 4-3
Boron Isotopic Data for Owens Valley Samples



Sulfur Stable Isotopic Composition ($\delta^{34}S$)

Sulfur occurs naturally as four stable isotopes with ^{34}S and ^{32}S being most abundant. Consequently, the $^{34}S/^{32}S$ isotopic ratio is most commonly used.

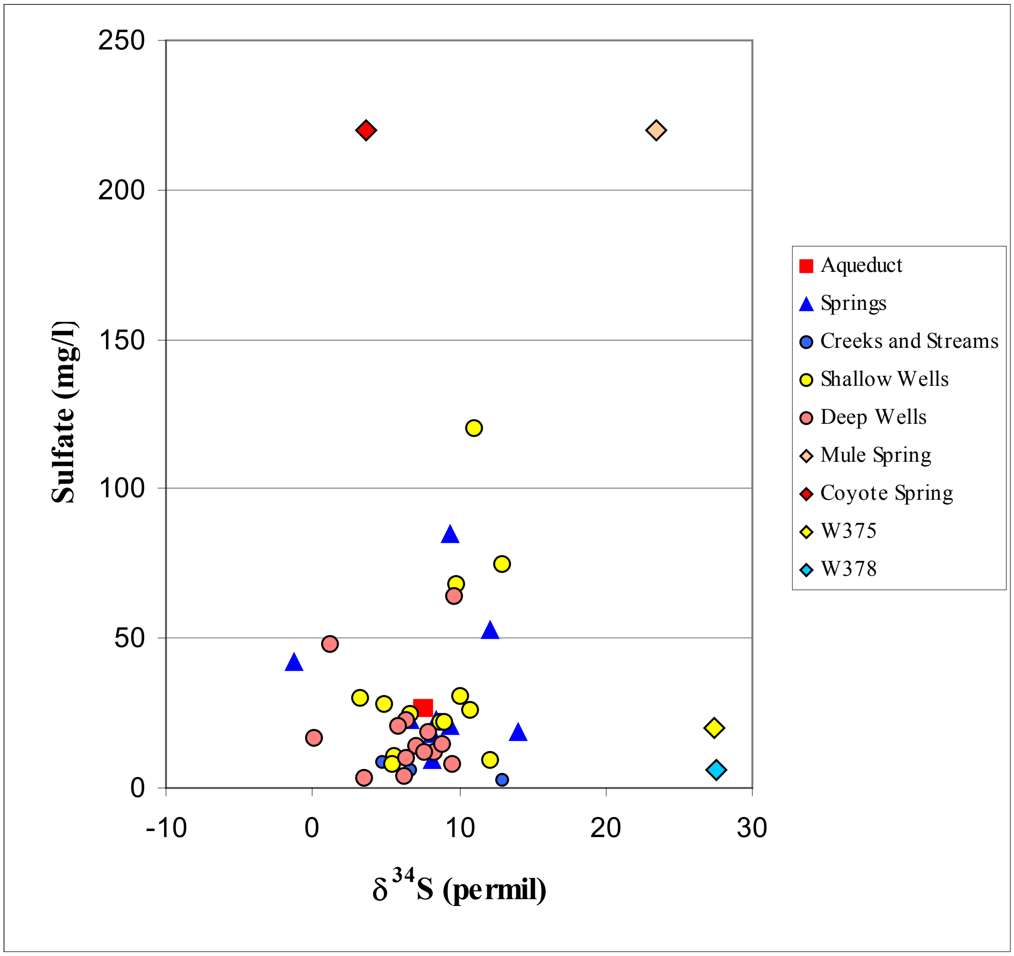
The two most abundant stable isotopes of sulfur are conventionally reported using the delta (δ) notation. The delta notation for sulfur is written as $\delta^{34}S$ with units of per mil; the standard used for comparison is sulfur from the Canyon Diablo meteorite.

$$\delta^{34}S\ ‰_{\text{spl}} = \left[\frac{(^{34}S/^{32}S)_{\text{spl}} - (^{34}S/^{32}S)_{\text{std}}}{(^{34}S/^{32}S)_{\text{std}}} \right] \text{ x } 10^{3}$$

The natural variation of the sulfur stable isotopic composition of rocks, minerals and natural waters is quite large, ranging over more that 100 per mil (Hoefs, 1997; Coplen et al., 2002). In general, the evaporate materials, especially continental evaporites, and seawater, are enriched in ^{34}S, and sedimentary rocks can range across the entire scale. As the result of chemical and microbiological processes, the isotopic ratio can change, and it is this value that serves as an indicator of the environment from which the sulfur originated.

The range of values for samples from the Owens Valley area is large, approximately 30 permil, and is indicative of a variety of sources for the sulfate (**Figure 4-4**). Note that two springs (Coyote and Mule) and two deep wells (W375 and W378) are inconsistent with the cluster of the rest of the data. These locations will be discussed in the context of the other data by AOI in Section 5.

Figure 4-4
Distribution of Sulfur Isotopic Values by Water Type for Owens Valley Samples



Section 5

Discussion by Area of Interest

Section 5

Discussion by Area of Interest

The geochemical investigation of seeps and springs in Owens Valley is comprised of seven AOIs, each with specific objectives for the sampling conducted. In this section, each AOI is discussed separately from north to south (see **Table 1-1**), and summary comments are provided at the end of each AOI. The discussion of AOIs is preceded by an initial discussion of the Aqueduct. Broader conclusions for the whole study are presented in Section 6.

LOS ANGELES AQUEDUCT

The Los Angeles Aqueduct intake is approximately five miles south of Tinemaha Reservoir and is subsequently unlined for a 25-mile reach to the diversion structure known as Alabama Gates, just north of Lone Pine. Three samples were collected in April 2002 from the last 12.5 miles of the unlined Aqueduct as follows and shown on **Figures 5-8** and **5-12**:

- Mazourka Canyon Road,
- Georges Bridge, and
- Above Alabama Gates.

The analytical results (**Table 3-1**) are identical within the expected analytical error as discussed in Section 3. Whether these three analyses can be considered representative of the historical composition of water in the Aqueduct is an open question. Historical data provided by LADWP for the seasonal and annual variation in chemical composition of Aqueduct water at specific monitoring points were examined. Inspection of chemical analyses for samples collected at the release point below Tinemaha Reservoir for 1995-2000 support the assumption that the samples collected in 2002 are reasonably representative of the annual mean compositions. The large seasonal changes in temperature, chloride, and boron are illustrated in **Figure 5-1** as examples of the expected Aqueduct composition. The mean, minimum, and maximum values for the Aqueduct over the 1995-2000 period are presented in **Table 5-1** for comparison with the samples collected during the March-April 2002 sampling event. Note that the values of the samples collected during this project are close to the means, but large variation could be expected over time. Furthermore, the mean value for chloride for the period of Runoff years 1974-1985 (13 mg/l) is provided in Hollett and others (1991). This value closely matches the 5-year mean of 13.7 calculated for this study.

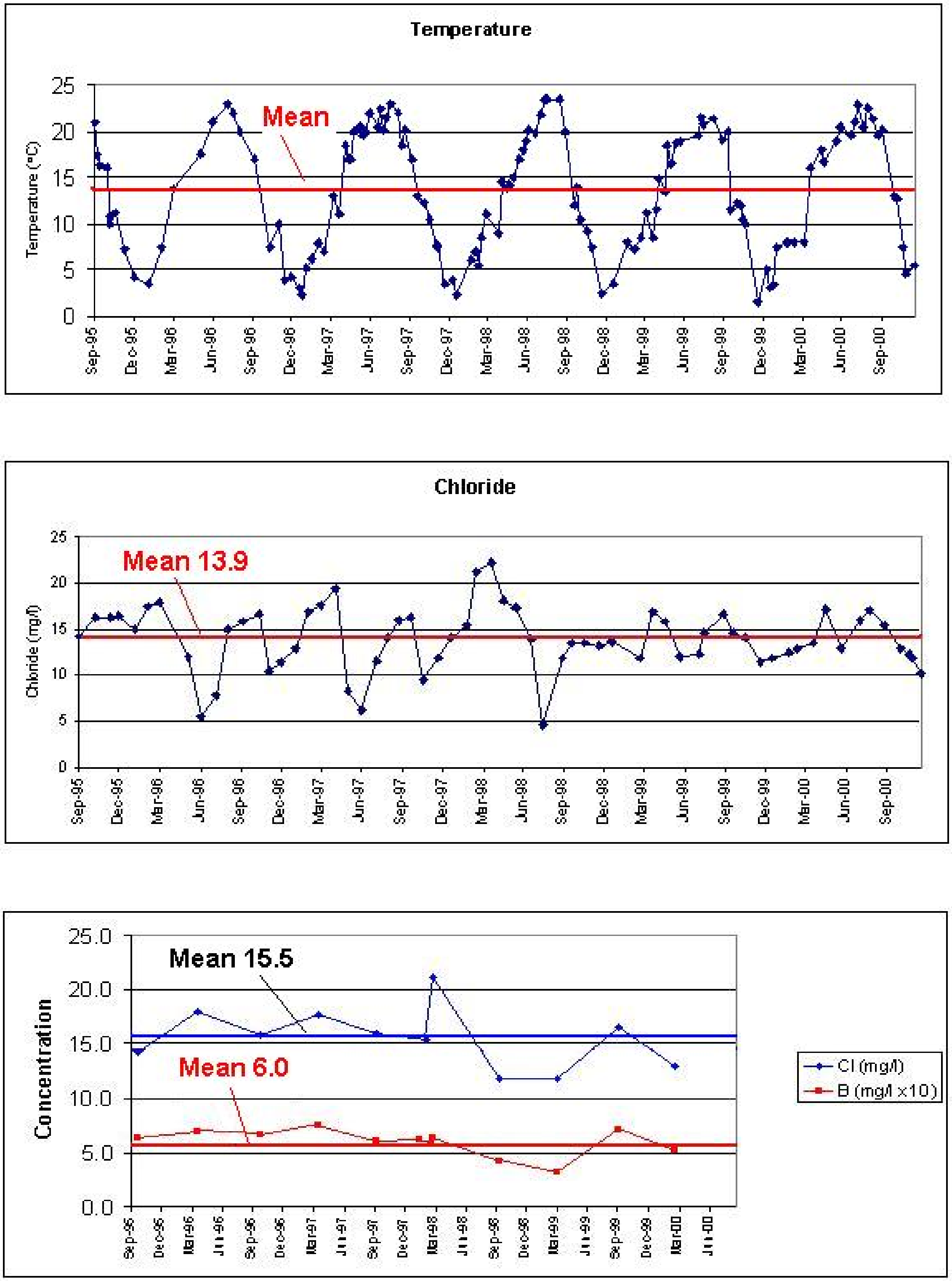


Figure 5-1
Historical Data (1995-2000)for Aqueduct Samples from Below Tinemaha Reservoir

Table 5-1
Historical Aqueduct Data Compared with Samples Collected in March 2002

Samples Collected 1995-2000	**Temperature**	**Chloride (Cl)**	**Boron (B)**	**Cl/B**
Aqueduct at Tinemaha	**^oC**	**mg/l**	**mg/l**	**unitless**
Mean	13.7	14	0.60	26.37
Maximum	23.5	22	0.76	36.88
Minimum	2.2	5	0.32	15.6
Standard Deviation (1σ)	6.4	3.7	0.12	4.6
Samples Collected in 2002				
Mazourka	17.8	15	0.47	31.9
George Creek Bridge	18.5	15	0.46	32.6
Above Alabama Gates	18.6	15	0.44	34.1

Due to seasonal variation in elemental concentration, as well as the tendency for these variations to be attenuated in groundwater as the recharged water is mixed, the most useful analysis for determining the percentage of Aqueduct contribution to the aquifer may be the mean of reported historical concentrations. These data must be used with caution because of the small sample size and the nonuniform frequency of sampling, both of which impact not only the detail of the seasonal variation but also the mean value. Chloride samples were collected on a monthly schedule, while the samples collected for the boron analysis were on a biannual schedule. For comparison purposes, the chloride data were plotted along with the boron results using only the biannual chloride data in order to illustrate the effect on both the trend and the mean value (see bottom graph on **Figure 5-1**). As a result, seasonal cycles were abbreviated, and mean values were adjusted.

The Tinemaha data representing a five-year period of record, corroborated by the isotopic constituent data collected for this study, are used to gauge the contribution of the Aqueduct to the aquifer. The evaluation of Aqueduct contribution to the local groundwater is explored in greater detail in the discussion of the Reinhackle Spring AOI.

Evaluation of reaction state for the Aqueduct was limited to the samples collected in this study. The Aqueduct samples are relatively diluted, with a total dissolved solids (TDS) of slightly greater that 200 mg/l. The minerals that are most likely to constrain the composition of the Aqueduct water are carbonates such as calcite ($CaCO_3$), sulfates such as gypsum ($CaSO_4.2H_2O$), barite ($BaSO_4$), fluorides such as fluorite (CaF_2), and/or silica minerals like cristobalite. The modeling computes that gypsum, barite, and fluorite are all significantly undersaturated, meaning that the water has significant potential to dissolve these phases if encountered. However, the elements that are contained in these phases are not constrained by equilibrium conditions with these minerals. It does appear that calcite is at equilibrium with the Aqueduct water and, if the water evaporated or were diluted slightly, calcite would precipitate or dissolve, respectively. The Aqueduct is close to equilibrium with respect to cristobalite, but the modeling did not reveal any additional minerals that could be restricting the composition of Aqueduct water.

Reaction state modeling also allows for the determination of the dominant aqueous species that are exhibited by each element. The trace metal content was generally low (e.g. Al, Cd, Cr, Fe, Se, and Zn were all below detection limit). Uranium is predominantly bound as an uncharged or neutral carbonate complex (UO_2CO_{3aq}) and consequently should be highly mobile.

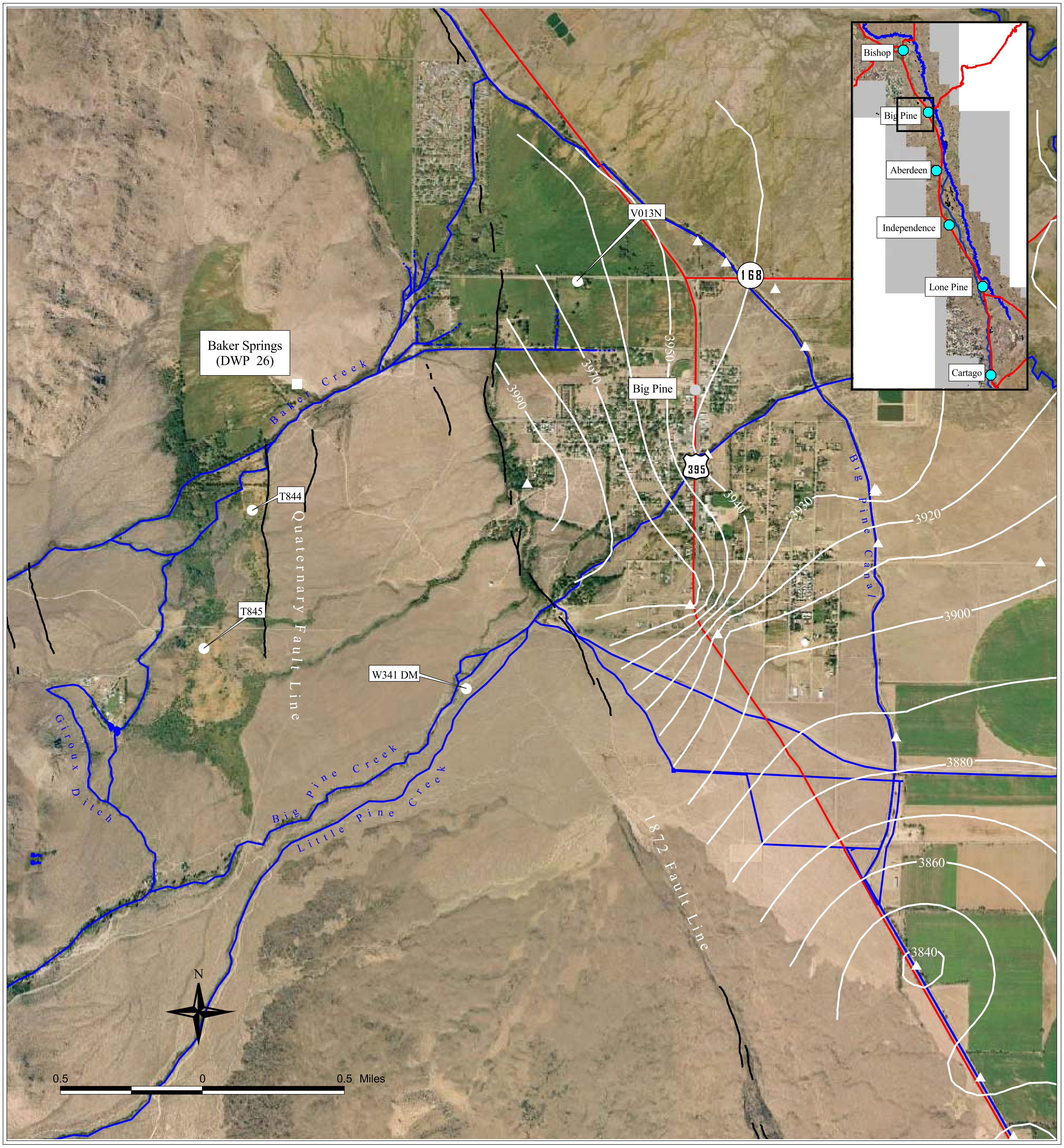
The arsenic concentration in the three Aqueduct samples averaged 25 ppb, which is below the 50 ppb drinking water standard, but does exceed the new Environmental Protection Agency standard of 10 ppb to be implemented by 2006. Arsenic was measured in concentrations above the detection limit of 1.0 ppb in 13 of the locations sampled to a maximum value of 58 ppb in Well T864, but was below detection at all other locations. Evaluation of water quality was not an objective of this study. The principal study objectives focused on source and flow path. The distribution of arsenic concentration did not provide a clear capability for tracing source.

Note that the isotopic data for the Aqueduct are consistent between the three samples analyzed, indicating very little difference between these two portions of the Aqueduct and confirming reproducibility for the isotopic analyses as well. The tritium values were near 5 TU, which is common for surface water. The δD and $\delta^{18}O$ values show evidence of some evaporation, as indicated by data plots aligning with the evaporation line rather than the MWL (**Figure 4-1**). Comparison between the $\delta^{34}S$ and $\delta^{11}B$ of Aqueduct water to other wells will be addressed below by AOI as appropriate.

BAKER SPRINGS

The Baker Springs (DWP 26) AOI and its associated features, including sampling locations, (**Table 1-1**) are shown on **Figure 5-2**. In addition, the piezometric surface for April 2002 is shown on this map. The Baker Springs complex is assumed to be a fault-controlled system located on the alluvial fan approximately 1.5 miles west of Big Pine. The 1872 fault line is the most visible fault structure in the vicinity; however, minor faults have been mapped and inference to other faults can be seen in the linear features parallel and sub-parallel to the major structural elements (**Figure 5-2**). Numerous seeps and small springs comprise the Baker Springs complex. Water emerges over a large area creating a rush-sedge wet meadow. The location sampled is a small spring emerging at the contact of bedrock and alluvium on the downslope edge of the spring complex. The sampled location is in the immediate vicinity of a Quaternary fault line and approximately 0.5 miles to the west of the 1872 fault scarp. The large wetland area was unsuitable for sample collection because the discharge was small and diffuse. As such, there was no obvious collection or discharge point where it could be reasonably assumed that the groundwater had minimal time to react with the atmosphere, wetland sediments, or decaying vegetation. The actual location sampled was chosen because it had relatively high flow from a distinct discharge point.

Surface water samples were collected from a spring in the Baker Springs complex, Baker Creek, and Giroux Ditch. Groundwater was collected from two shallow wells upgradient from the sampled spring (T844 and T845), the nearest pumping well (W341), and a deep well (V013N) downgradient from the spring complex.



Legend

□ Spring

△ Shallow Aquifer Data Point Used to Construct Piezometric Surface

○ Sampled Well

Fault

River

Inyo/LA Geochemical Cooperative Study Final Report

Figure 5-2
Piezometric Surface Map for
Baker Springs Area of Interest
(DWP 26)(April 2002)

The objective of sampling at this AOI was to answer the following key questions:

- Question No. 1 - What is the source for the spring water (recharge from nearby creeks, shallow groundwater, or upwelling from the deeper aquifer along faults)?
- Question No. 2 - Is there a difference in composition across the faulted area?

Analytical Data Discussion

The general water type for each sample is illustrated by means of a Stiff Diagram for visual comparison between sampled locations (**Appendix F**), and detailed chemical and isotopic compositions for samples from this location are reported in **Table 3-2**.

All seven samples are relatively dilute, with TDS of 210 mg/l or less, and all are Ca-Na-HCO_3 type waters. Furthermore, all samples (wells and surface water) had tritium suggesting recent recharge. It would be reasonable to assume that the water composition from each of these locations is derived from snowmelt that has reacted with the soil and aquifer minerals. Variations in chemical composition among these samples could be caused by several factors. Three of the most plausible factors are listed below:

- Mineral reactions (e.g., variable extent of reaction of groundwater with minerals as a result of contact time, pH, temperature, or surface area, and spatial variability in rock type, and differences in reaction rates as a result of factors such as contact time, pH, temperature),
- Vegetation (e.g., nutrient consumption and decay products), and
- Anthropogenic contributions (e.g., agriculture, ranching, and residential). With the exception of well V013N, contribution to the chemical composition from anthropogenic sources is likely minimal because of the location on the slopes, lack of cultivation, and absence of residences in the immediate area at present.

Mass balance simulations are a widely used practice for granitic terrains, similar to those in the vicinity of the Baker Springs complex, in order to define the evolution of the chemical composition of groundwater. The groundwater chemical composition definition process can be summarized as:

- Snowmelt water reacting principally with feldspars, biotite, hornblende, calcite, and soil CO_2,
- Precipitating clay minerals and oxyhydroxides of iron, aluminum, and silica, and
- Exchanging major cations with clay minerals, generating a typical groundwater composition dominated by sodium, calcium, and bicarbonate.

Furthermore, because virtually all the waters in this AOI are of the same water type, the difference between the water compositions among the sampled wells can be explained as variations of the same reactions, but to different extents, with the added factor of mixing between the shallow and deep aquifer, and recharge of surface water.

Geochemical Modeling

Geochemical modeling for the Baker Springs area was done only on a limited scale to understand the compositional changes and to identify the processes that govern the groundwater geochemistry. Presently there are no data available for snowmelt water chemical composition in this region. Snowmelt generally represents the most significant source for the observed chloride, sulfate, and other minor cations that originate from air fall and marine derived atmospheric precipitation. Recent work by Pretti and Stewart (2002) for the Owens Valley confirms snowmelt as the source for atmospheric precipitants in streams draining from the Sierra Nevada into the valley.

The modeling focus for this AOI was on the plausibility of the conceptual model to determine the origin of the spring composition and develop an understanding of the spring's water source.

Reaction State Modeling

The reaction state geochemical modeling for the Baker Spring complex AOI included the springs, two surface waters, and four wells. In all seven samples, the water was undersaturated with respect to gypsum, barite, and fluorite. The aluminum concentration was found to be below the 25 µg/l limit of detection in all samples. At that level, feldspars, biotite and hornblende are all undersaturated, and will have the potential to dissolve. The surface waters of Giroux Ditch and Baker Creek are not at equilibrium with calcite, but the four wells and Baker Spring computed close enough to saturation that equilibrium with calcite is probable. This computation indicates that calcite was a source mineral and sufficient calcite and sufficient silicate hydrolysis producing bicarbonate has occurred to bring the water to equilibrium.

Saturation with respect to clay minerals was not computed using the reported analytical data because the aluminum concentration was below the detection limit. Aluminum is a key element in the composition of all clay minerals that might be of consideration in this geological environment (kaolinite, illite, and smectite), and aluminum activity must be defined to compute the thermodynamic saturation state. For the sake of interpretation, we can assume that the aluminum concentration is near 25 µg/l detection limit, in which case the clay minerals of kaolinite, illite, and smectite are supersaturated by several orders of magnitude. The same supersaturated circumstance will be true if we arbitrarily lower the aluminum concentration a few micrograms per liter in the calculation to what the actual concentration of Al may be. As such, these waters have the thermodynamic potential to react with the aquifer host rock. The water should dissolve the local feldspars, biotite, hornblende, etc. and will subsequently precipitate clay minerals. This precipitation will in turn yield a rather small prescribed set of elements to solution; all of which are consistent with the observed composition of the water in the Baker Creek area. This process is generally accepted as a silicate-weathering scenario and is corroborated by numerous other studies in similar environments.

Trace metals (Al, Cd, Cr, Cu, Fe, Se, and Zn) are all below detection limit in all samples except for the zinc result at well T844, where the measured concentration was 5.9 µg/l. Zinc is often a constituent introduced from the well casing or pump hardware. Owing to the absence of zinc in other samples, its presence could easily be related to well corrosion. Uranium is present as a mobile carbonate complex.

Geochemical Mixing Calculations

The Baker Springs complex discharges onto the alluvial slopes above and to the west of Big Pine. Well control near the spring is sparse; consequently, the hydrogeology is not well understood. As an alternative, geochemical modeling is relied upon to estimate the contribution of shallow and deep groundwater sources to the spring composition. The following detailed discussion of the mixing assessment illustrates a useful approach to defining the water source and illustrates the corroboration between the isotopic and chemical data when the most probable scenarios are identified.

The shallow wells T844 and T845 are located approximately 0.5 and 1 mile respectively upgradient from the sampled spring location. Samples were collected from both wells for analysis. There are no deep wells upgradient from the spring, but well W341 located south of the springs, is assumed to be representative of mixed shallow and deep water in the vicinity of the Baker Springs complex and downgradient of the fault block. This well was also sampled for analysis. Because of the elevated location of these three wells on the alluvial slopes, it is reasonable to assume that the origin of the groundwater pumped from these wells is from recharge of snowmelt. Furthermore, the chemical composition can also be assumed to have been derived from snowmelt with its intrinsic solute, dry fall, and vegetative contents, plus the addition of solute obtained from reaction with soil and the granitic host rock. Other work has demonstrated that in granitic environments, especially for rocks with similar mineral content to that found in the Sierras, that the chemical evolutionary process can be satisfactorily defined with mass transfer modeling (Bassett et al., 1992; Drever and Hurcomb; 1986; Drever and Zobrist, 1992; Mast et al., 1990; and Pretti and Stewart, 2002). The minerals required to account for the observed chemical composition of these three wells are readily available and are sufficiently reactive to yield the observed groundwater compositions. Thus, it can be concluded without conducting the mass transfer modeling for this portion of the system that snowmelt plus mineral reactions, evolves to the composition of the two shallow wells and the deep groundwater well samples.

The use of inverse modeling was required to explain the change in composition between these three upgradient wells and the spring composition. The Baker Spring water chemical composition is different from either the shallow or the deep well samples; consequently, the spring source water is most probably a mixture of water composition represented by these wells alone or a mixture of groundwater sources with additional solute from reaction with the aquifer minerals.

The inverse modeling process initially solves all the possible combinations of mixing between groundwater sources and then further evaluates mixing with inclusion of possible dissolution and precipitation reactions using specified minerals. The outcome of this analysis was two scenarios that were identified as reasonable explanations for the spring source water:

- Scenario No. 1 - Shallow groundwater with the composition of well T844, plus additional reaction with the aquifer material will approximately yield the composition of Baker Springs, and
- Scenario No. 2 - Groundwater (well T844) mixed with deep-aquifer water (well W341) plus additional reaction with the aquifer material yields the composition of Baker Springs.

Scenario No. 1

100% T844 + Additional mineral reaction = Baker Spring Composition
Dissolve additional chloride 0.044 mmoles
Dissolve 0.08 mmoles calcite
Dissolve 0.020 mmoles K-feldspar
Dissolve 0.042 mmoles of pyrite
Precipitate 0.055 mmoles of $Fe(OH)_{3am}$
Precipitate 0.020 mmoles of $Al(OH)_{3am}$
Precipitate 0.328 mmoles of SiO_{2am}
Ion Exchange Ca^{+2} 0.120 mmoles
Ion Exchange Na^{+1} 0.126 mmoles
Ion Exchange Mg^{+2} 0.058 mmoles

Isotopic Check

Isotope	T844	Process of Mineral Source	Final Water	Baker Spring
δD (‰)	-122	local seasonal range	-122. to -133	-127
$\delta^{18}O$ (‰)	-17.1	local seasonal range	-17.1 to -18	-17.6
$\delta^{11}B$ (‰)	4.9	silicates add (0.0006 mmoles @22 ‰)	8.5	8.5
$\delta^{34}S$ (‰)	5.6	pyrite (0.042 mmoles @ 25.5 ‰)	14	14
^{3}H (TU)	7.9	decay 17 years (0.5 mi @ 150 ft/yr)	3	3

Scenario No. 1 confirms that when water with the chemical composition of well T844 is modified by minimal additional reaction with the aquifer minerals, it will yield a water chemical composition, for most of the major constituents, that is virtually identical to that observed for the Baker Spring complex. The exception is that neither the chloride nor bromide values fit the chemical profile of the Baker Spring complex, and this difference makes this solution less preferred. An additional mass of both chloride and bromide is needed to equal the Baker Spring composition, and neither element would likely be derived from mineral dissolution alone. One could assume that the Cl and Br values for well T844 are variable over the season and that this measured value is lower than that normally observed.

Scenario No. 2

92.6% T844 + 7.4% W341 + Additional Mineral Reactions = Baker Spring Composition
Dissolve 0.019 mmoles of calcite
Dissolve 0.108 mmoles of plagioclase
Dissolve 0.020 mmoles of K-feldspar
Dissolve 0.047 mmoles of pyrite
Precipitate 0.062 mmoles of $Fe(OH)_3$
Precipitate 0.603 mmoles of SiO_2 (am)
Precipitate 0.169 mmoles of $Al(OH)_3$ (am)
Ion Exchange Ca^{+2} 0.051 mmoles
Ion Exchange Mg^{+2} 0.051 mmoles

Isotopic Check

Isotope	T844	W341	Process of Mineral Source	Final Water	Baker Spring
δD (‰)	-122	-126	local seasonal range	-122. to -133	-127
$\delta^{18}O$ (‰)	-17.1	-17.6	local seasonal range	-17.1 to -18	-17.6
$\delta^{11}B$ (‰)	4.9	17.6	silicates add (0.0006 mmoles @17.3 ‰)	8.5	8.5
$\delta^{34}S$ (‰)	5.6	8.3	pyrite (0.042 mmoles @ 25.5 ‰)	14	14
^{3}H (TU)	7.9	2.7	decay 17 years (0.5 mi @ 150 ft/yr)	3	3

An alternate solution would be to mix well T844 with a groundwater such as well W341, which has significantly higher concentrations of both Cl and Br and accounts for the difference between Scenario No. 1 and the measured composition of Baker Spring. The isotopic data also indicates that Scenario No. 2 is plausible. The environmental isotopes, δD and $\delta^{18}O$, are subject to seasonal variation. This variation is indicated by the range of values observed for the seven sampled locations all of which have undoubtedly derived the δD and $\delta^{18}O$ content from the same snowmelt source of water, but perhaps at different times. The sampled δD and $\delta^{18}O$ values from theses locations vary over a range that encompasses the values observed for Baker Spring.

The sulfur isotopic value could not result from groundwater mixing alone. A small amount of sulfate must be added to the water, probably from dissolution of pyrite, and if the $\delta^{34}S$ of the pyrite were near 25 ‰ then the mixed water would have the same $\delta^{34}S$ value as Baker Creek. The $\delta^{34}S$ values for pyrite in the Sierra Nevada were not measured for this study; however, a value of 25 ‰ or greater was observed for sulfate in the pumping wells W375 and W378, and this sulfate was most likely derived from oxidation of pyrite. The deeper aquifer should represent longer reaction times with the aquifer matrix, perhaps supporting the plausibility of pyrite derived $\delta^{34}S$ of 25 ‰ in the Baker Springs area as well.

Discussion of Scenarios

Modeling confirms that by mixing 93% of groundwater with the composition of well T844, 7% of groundwater from the deeper aquifer (well W341), and a minimal additional reaction with the aquifer matrix, a chemical composition virtually identical, for most of the major constituents, to that observed for the Baker Spring sample would result. The isotopic data indicate that this scenario is plausible. It should be noted that in this scenario, the chloride and bromide data are similar to the measured values within the analytical error. Regarding tritium, it should be assumed that the tritium value would decay to below detection limit before it emerges at the spring.

Both of these modeled scenarios successfully matched the target spring composition to the extent that the results were plausible, except for the Cl and Br difference in Scenario No. 2. If the modeling is constrained by the following three guidelines, then Scenario No. 2 fits the field situation better:

- The conservative elements of Cl and Br in the initial waters must yield a computed water composition that matches the target composition within a narrow percent (e.g. 10 percent),
- In mixing simulations for which the calculated mass of any specific element was deficient relative to the elemental concentration in the well being simulated, minerals were allowed to react with the water, as long as the water was undersaturated with respect to the mineral.
- The isotopic concentrations were mixed, and the results simply compared by inspection.

It should be stressed that mineral reactions are not unique, and that many other combinations are possible if one can justify using different mineral compositions. Furthermore, one could also allow more substantial silicate reactions involving the precipitation of clay minerals that would greatly increase the number of scenarios. Reliance on the precipitation of clay minerals to yield the observed water composition for this location and for these fast groundwater flow rates was deemed improbable, because it is unlikely that sufficient time existed for nucleation and precipitation of clay minerals in the travel time between the shallow well T844 and the spring.

Samples collected from the deep wells W341 and V013N contain tritium, which indicates that some of the produced water is derived from the shallow groundwater, because only shallow water would have been recently exposed to atmospheric tritium. Well W341 is a pumping well with a total depth of 754 feet. One would not expect it to produce “recent” water (i.e., water recharged within the past 50 years). However, the well screen in well W341 is from 65 – 750 feet below ground surface. As a result, the shallower groundwater exposed to atmospheric tritium could reasonably be expected to extend deeply enough to be produced from the upper section of the screened interval. Thus, the tritium content in the deep wells is consistent with the well construction if the screened intervals are considered. In summary, all wells could be producing some water affected by recent recharge that would contain tritium derived from nuclear weapons testing over the past 50 years.

The large screened interval of the pumping well reveals the mixed nature of the produced water and emphasizes the fact that the specific chemical and isotopic composition of the deep aquifer is still not well defined.

Fault Effects

The presence of a barrier fault could affect the spring’s composition if groundwater mixes at the barrier or changes direction of flow. For instance, unmixed water could enters laterally, or from depth, or be fed by specific zones in the aquifer and be able to penetrate the fault barrier. No such effects on chemical composition are discernable with the current database. All wells and springs with the exception of well V013N are upgradient of the mapped faults, and well V013N is sufficiently different in composition that it is probable that it is affected by valley-floor recharge and inflow from further north.

Faulting does seem to impact the location of discharge for Baker Springs. The location of the emergence of the spring appears to be associated with the Quaternary fault bounding the spring complex. The mixing of shallow and deep groundwater prior to discharge would be consistent with the fault influencing flow upward to the spring discharge point. It is likely that flow is diverted by the faults enough to cause some mixing, but the restrictions to flow are probably not significant enough to create a complete barrier to flow. There is substantial groundwater flow into the Valley from the west, but sufficient data do not exist to map the potentiometric surface across the fault. Based on chemistry and location, the spring complex appears to be the terminus of a shallow and local flow system exhibiting minor mixing with deeper-sourced water and minimal reaction with minerals in the aquifer matrix.

Summary

Provided herein is a summary of findings related to the key questions for this AOI.

- *Question No. 1 - What is the source for the spring water (recharge from nearby creeks, shallow groundwater, or upwelling from the deeper aquifer along faults)?*

Finding(s)

1. The Baker Springs Complex contains numerous seeps, springs, and an attendant wetland. The sample collected for this complex is from the down slope end and has significant flow emerging from the bedrock and alluvium contact, but no evidence of ponding, evaporation, or stagnation. The sample collected appears to be representative of the groundwater at this point and was used to represent the chemical composition of the complex.
2. Two shallow wells upgradient from Baker Spring were sampled. Mass transfer modeling and inspection of isotopic data indicate that the water emerging from the spring could be shallow groundwater modified by a very small extent of reaction with aquifer minerals. However, chloride and bromide do not fit the mass balance calculations well enough to state confidently that all of the water emerging from the spring is derived from shallow groundwater.
3. The modeling scenarios are not unique because other minerals could be used, and well W341 has a mixed water composition. Based on chemistry and location, the spring complex appears to be the terminus of a shallow and local flow system exhibiting minor mixing with deeper-sourced water and minimal reaction with minerals in the aquifer matrix.
4. The deeper aquifer was sampled from well W341. Unfortunately, the screened interval for this well is sufficiently shallow that the produced water is commingled shallow and deep groundwater as evidenced by the presence of tritium. If it is assumed that deeper water, upgradient from the spring has essentially the composition of well W341, then a mixture of 7% well W341 with 93% shallow well T844 with a small contribution from mineral reactions results in a composition essentially the same as the Baker Spring complex. The isotopic data support the modeling results. Because the fault is known to transect the area, and plausibly could be diverting deeper water upward, this scenario seems plausible for the data available.

- *Question No. 2 - Is there a difference in composition across the faulted area?*

Finding(s)

1. The only sampled well immediately downgradient and on the east side of the Quaternary fault bounding the spring complex was well V013N. This well is located on the Valley floor and is dissimilar to other groundwater samples in the Baker Springs area. It is assumed to be influenced by local recharge of dilute surface water or inflow from the north. As a result, the data collected in this study is not sufficient to answer this question.

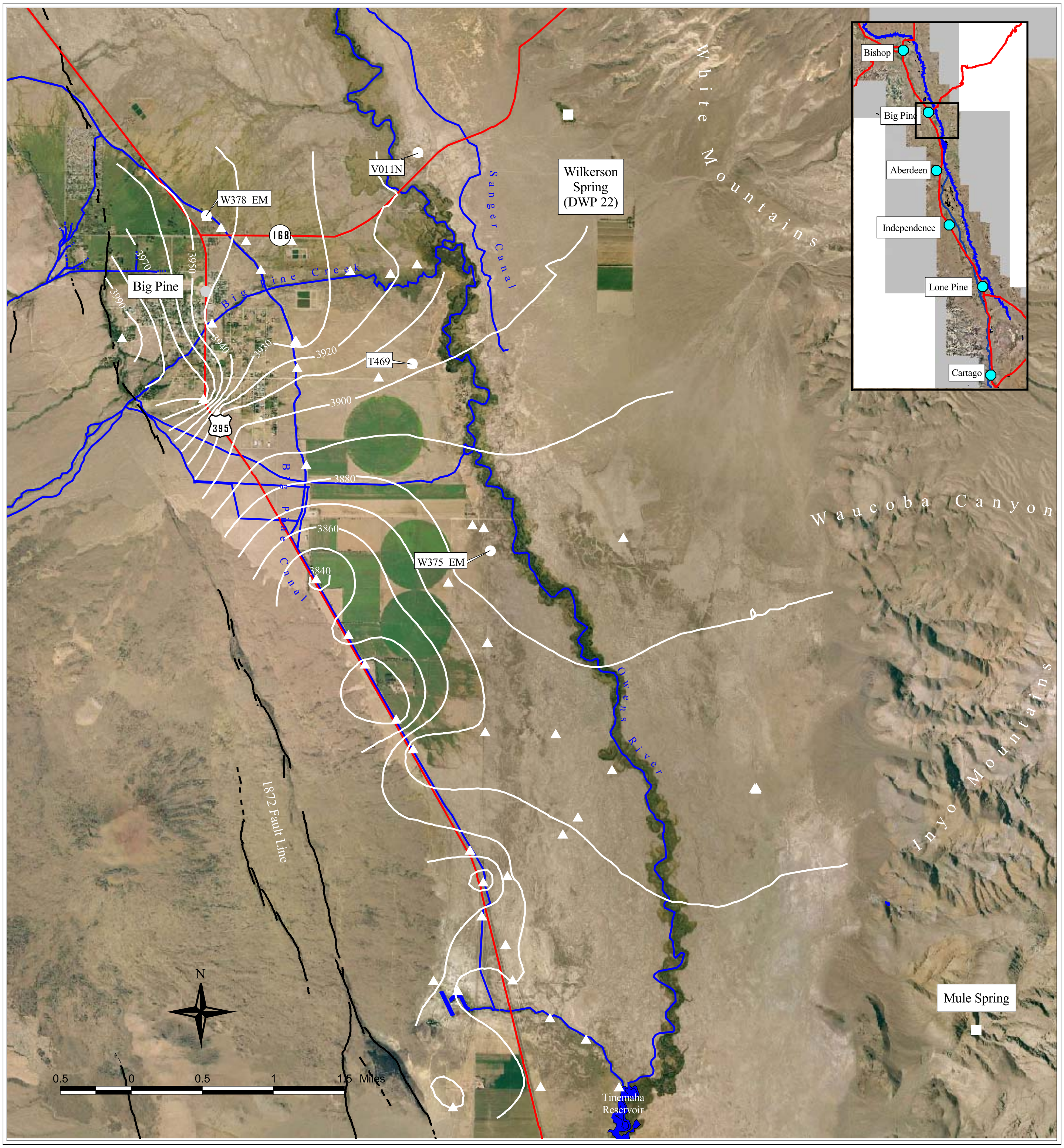
WILKERSON SPRINGS

The Wilkerson Springs (DWP 22) AOI and its associated features, including sampling locations (**Table 1-1**) are shown on **Figure 5-3**. In addition, the piezometric surface for April 2002 is shown on this map. At least three separate springs comprise the Wilkerson Springs area, and inspection suggests that faulting may affect the locations of spring discharge. Wilkerson Springs emerge on the east side of the Owens Valley approximately 2.7 miles northeast from Big Pine. Access to the springs is limited by ponding and a dense growth of cattails and rushes. The easternmost small spring was least affected by evaporation, vegetation, or structural improvements by water users, and was sampled at the orifice.

Four wells in the vicinity were sampled for comparison to the spring composition including two shallow wells (T469 and V011N) and two deep production wells (W375 and W378). All four wells are located on the Valley floor significantly downgradient from Wilkerson Springs. A water sample was also collected from Mule Spring, located approximately 6 miles southeast of Wilkerson Springs, for comparison purposes. Mule Spring is a mountain-front spring discharging from the Paleozoic rocks of the Inyo Mountains.

The objective of sampling at this AOI was to answer the following key questions:

- Question No. 1 - Is the composition of Wilkerson Springs distinctive because it is located in a different geologic regime on the east side of the Owens River?
- Question No. 2 - Is the chemical and isotopic composition of Wilkerson Springs correlative with the composition of downgradient wells?
- Question No. 3 - Can the shallow and deep aquifers be differentiated by the analytical data?



Legend

- □ Spring
- △ Shallow Aquifer Data Point Used to Construct Piezometric Surface
- ○ Sampled Well
- Fault
- River

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Figure 5-3
Piezometric Surface Map for
Wilkerson Spring Area of Interest
(DWP 22)(April 2002)

Analytical Data Discussion

The general water type for each sample is illustrated by means of a Stiff Diagram for visual comparison between sampled locations (**Appendix F**), and detailed chemical and isotopic compositions for samples from this location are reported in **Table 3-3**.

Wilkerson Springs and Mule Spring have a different water composition from that of the sampled wells, but are similar to one another by water type. Wilkerson Spring discharges from the Waucoba Canyon alluvial fan. The alluvial fan is composed of erosional sediments from the White Mountains and Pliocene lacustrine deposits associated with Owens Lake. Mule Spring emerges at the top of an alluvial fan closer to the bedrock outcrop of sedimentary sequences of the Inyo Mountains. The White and Inyo Mountain ranges are folded and faulted sedimentary rocks from the early to middle Paleozoic, composed of limestone, dolomite, sandstones, and marine shales, locally metamorphosed by the intrusion of granitic plutons (Hollett et al., 1991). Erosion of these rocks would be expected to yield a calcium-magnesium-bicarbonate type water. Furthermore, the marine shales are a source of pyrite that oxidizes, thereby creating sulfate acidity, accelerating the chemical weathering of the carbonate rocks, and enhancing the production of sulfate, calcium, magnesium, and bicarbonate. This oxidation scenario would yield a water composition consistent with that observed for these two springs.

Wilkerson Springs and especially Mule Spring have elevated TDS (250 mg/l and 530 mg/l, respectively) and sulfate (85 mg/l and 220 mg/l, respectively), and isotopic signatures that are distinctively different from the springs on the west side of the Valley (**Tables 3-2 through 3-8**). The $\delta^{34}S$ value for Mule Spring is 23.4 ‰, which is the most enriched $\delta^{34}S$ value of any spring sampled in the Owens Valley and is consistent with the source of the sulfate being marine rocks of early to middle Paleozoic age. Claypool at al. (1980) compiled and illustrated the historical record for the $\delta^{34}S$ signature of marine sulfate. One of the most notable features of the historical $\delta^{34}S$ record is the extremely enriched values observed for the early to middle Paleozoic, with values near 30 ‰. Weathering of the pyritic sulfur in Paleozoic marine shales of the White and Inyo Mountains should yield a sulfate $\delta^{34}S$ close to these values after accounting for small isotopic shifts from reduction of marine sulfate to pyrite in marine sediments, and subsequent small isotopic shift with oxidation of pyrite to sulfate with weathering. The $\delta^{34}S$ value observed for Mule Spring of 23.4 ‰ is reasonable for marine sulfur of Paleozoic age.

The differences in the $\delta^{34}S$ enriched values between Wilkerson Springs (9.4 ‰) and Mule Spring (23.4 ‰) may be related to hydrogeology. Wilkerson Springs derives its water by integrating a large flow field that may, in addition to the Paleozoic marine shales, include sulfate from the Mesozoic intrusive rocks and Quaternary sediments, which would be more depleted in $\delta^{34}S$ than marine sulfur from the early Paleozoic. Consequently the $\delta^{34}S$ for Wilkerson Springs is somewhat enriched, but not to the extent of Mule Spring, by a Paleozoic sulfate source.

The two deep wells, W375 and W378, are located more than two miles west and southwest, and W375 is clearly downgradient from Wilkerson Springs and on the opposite side of the Owens River. These wells produce from the deeper aquifer and should be hydraulically removed from any impact on the springs. The $\delta^{34}S$ values for wells W375 and W378 are 27.4 ‰ and 27.5 ‰, respectively. In contrast, the shallow wells (T469 and V011N) have more depleted $\delta^{34}S$ values (4.8 ‰ and non-detect, respectively). The enriched values, which are characteristic of the rocks in the White and Inyo Mountains to the east, indicate a different source for the deep and shallow wells. The isotopic data may imply that water in the center of the Valley, at least in the Big Pine area, is significantly influenced by recharge from the White and Inyo Mountains. In addition, this water may be remnant of a much earlier recharge (e.g. Pleistocene), and may be related to the large flux down the Waucoba Canyon. Alternatively, this water could represent water from the east side of the Valley that was backed up in the deeper aquifer against the Poverty Hills fault that cuts across the Valley (**Figure 5-3**). In summary, the sulfur isotopic data indicate that the sulfur detected in these wells is from the White or Inyo Mountains.

The boron isotopic signature ($\delta^{11}B$) is consistent with the sulfur isotopic data. The most enriched values of $\delta^{11}B$ are generally identified with marine sources (e.g., seawater has a $\delta^{11}B$ value of +39 ‰). The two pumping wells (W378 and W375), Wilkerson Springs, and Mule Spring all have enriched $\delta^{11}B$ (17.3, 7.4, 8.5, and 15.3 ‰, respectively) (**Table 3-3**). In contrast, the shallow wells (T469 and V011N) have more depleted $\delta^{11}B$ levels (-2.2 and –0.3 ‰, respectively), indicating a different and clearly non-marine source.

In all samples (Wilkerson and Mule Springs, W375, W378, and V011N) except the shallow well (T469), tritium is below detection limit, implying that the water has not been recently recharged.

Geochemical Modeling

Reaction State Modeling

The reaction state geochemical modeling of Wilkerson Springs, Mule Spring, and the downgradient wells of V011N, T469, W378, and W375 yielded variable results. Even though both Mule Spring and Wilkerson Springs have elevated sulfate concentrations (220 and 85 mg/l respectively), they are both substantially undersaturated with respect to gypsum and at equilibrium with the less soluble mineral barite. The source rocks are carbonates and shales; therefore, the sulfate source is oxidation of sulfide minerals in shale such as pyrite rather than marine evaporates.

The model indicates that the movement of groundwater near Wilkerson Springs may be sufficient to supply oxygen to oxidize pyrite. However, groundwater movement is too fast for the solution to become concentrated enough for gypsum to precipitate. On the other hand, if gypsum were the sulfate source, then the rapid dissolution would likely yield saturation states much closer to equilibrium. The source for sulfate in both springs is undoubtedly sulfide minerals, but the isotopic data discussed below indicate sulfides from different ages are involved. All wells have low sulfate and chloride concentrations (20 mg/l or less), and the spring water compositions are dominated by sodium, calcium, and bicarbonate

Mule Spring, well W375, and well V011N are the only three locations saturated with respect to the mineral calcite, whereas Wilkerson Springs is not. Wilkerson Springs, like Mule Spring, derives its water from the Paleozoic carbonates. The lack of saturation with calcite may indicate that the sediments of the Waucoba fan contain substantial percentages of non-carbonate detrital material.

No aluminum values are available for any of these sampled locations, but supersaturation with clay minerals is expected based on the evaluation done for well V258 as discussed in the Fault Scarp Spring (DWP 9) AOI section.

Trace metal content (Al, Cd, Cr, Cu, Fe, Se, Zn) is below detection limit in all samples except for one Chromium result near the detection limit for well V011N. One copper analysis was near the detection limit for well T469, and two zinc results were obtained for wells T469 (2,300 μg/l) and V011N (7.7 μg/l). Zinc is often introduced as a result of well or pump hardware corrosion, and owing to the absence of zinc in other samples and the elevated zinc in well T469, it is assumed to be related to well corrosion. Uranium and vanadium are present in about half of the samples because of their mobility as oxyanion or carbonate aqueous complexes in this environment.

Geochemical Mixing Calculations

No mixing simulations were performed owing to the hydraulic isolation of Wilkerson Spring from the wells in the Valley.

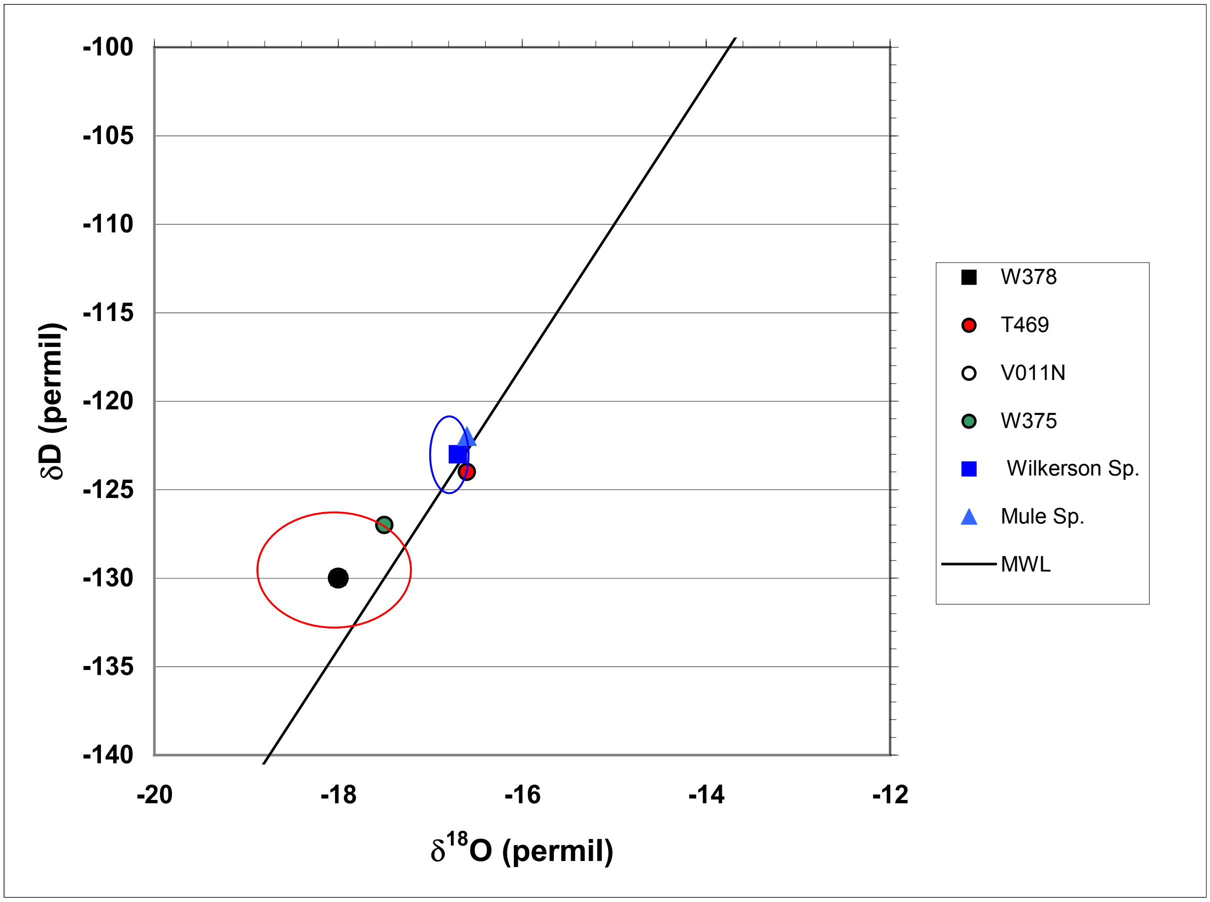
Shallow versus Deep Aquifer

The tri-linear diagram for Wilkerson Springs (**Appendix C**) indicates that, in terms of water type and chemical composition, the four wells sampled for this area are similar. The differences are seen in the isotopic contents. Tritium (5.2 TU) indicates that the shallow well T469 contains recent recharge, while the lack of tritium in the other three wells indicates that they have not been recently recharged. $\delta^{34}S$ levels indicate that the water source for the deep pumping wells, wells W375 (27.4 ‰) and W378 (27.5 ‰), is influenced by recharge from the east, and shallow wells T469 (4.8 ‰) and V011N (not detected) are not.

The environmental isotopes of δD and $\delta^{18}O$ are also informative. Note that the shallow well V011N and the pumping wells W375 and W378 are significantly removed from the spring data and more depleted as shown on **Figure 5-4**. These data are consistent with water recharged either from a colder source such as snowmelt from a higher elevation or from a cooler paleoclimate. The latter may further support the concept of Pleistocene water being present at depth in this part of the Valley. Conversely, the shallow well and the springs plot on the MWL indicating modern water with no significant evaporation.

Data indicates that the shallow water in well T469 is isotopically different from the deeper aquifer, and the difference is in part due to the different origins.

Figure 5-4
Isotope Data for the Wilkerson Springs Area



Summary

Provided herein is a summary of findings related to the key questions for this AOI.

- *Question No. 1 - Is the composition of Wilkerson Springs distinctive because it is located in a different geologic regime on the east side of the Owens River?*

Finding(s)

1. Chemical composition of both Wilkerson Springs and Mule Spring are derived from chemical weathering of Paleozoic carbonate rocks of the White and Inyo Mountains and is distinctive because of its location in a different geologic regime on the east side of the Owens River. The sulfur isotopes indicate that Wilkerson Springs derives some of the chemical and isotopic composition from non-carbonate erosional debris, perhaps of lacustrine or granitic origin.
2. The springs, located on the east side of the Valley, have significantly different composition from virtually all other wells or springs within the flow field of the alluvial fans draping the west side of Owens Valley. This circumstance derives from the difference in geology on either side of the Valley and could probably be used to determine the influence of eastern sources to wells on the Valley floor. Furthermore, these two springs are very different from one another.

- *Question No. 2 - Is the chemical and isotopic composition of Wilkerson Springs correlative with the composition of downgradient wells?*

Finding(s)

1. The pumping wells sampled (W378 and W375) have the same enriched δ^{34}S value as Mule Spring (23.4 – 27.5 ‰), and the implication is that water produced from these two deeper wells is at least influenced by recharge from the east side of the Valley. Comparatively, the δ^{34}S value for Wilkerson Springs (9.4 ‰) is significantly less than that for W378 and W375 (27.5 ‰ and 27.4 ‰, respectively), thereby indicating that it is neither correlative with these somewhat distant wells nor correlative with Mule Spring.

2. The boron isotopes support a source of solute derived from marine deposits in the deep wells, and δD and δ^{18}O suggest the water to be from a colder and wetter paleoclimate. It is not known if this deeper water is from much earlier recharge (e.g. Pleistocene) dammed up against the Poverty Hills fault, or simply represents rapid and significant groundwater movement down the Waucoba Canyon alluvial fan derived from snowmelt and rainfall.

- *Question No. 3 - Can the shallow and deep aquifers be differentiated by the analytical data?*

Finding(s)

1. The analytical data demonstrate that the shallow and deep aquifer chemistries can be differentiated. There is chemical similarity between the composition of shallow wells (T469 and V011N) and the deep wells, but the isotopes are different, indicating a different source for the water. Well T469 has modern tritium levels (V011N does not), and both shallow wells have expected levels for δD and δ^{18}O, and depleted levels of δ^{11}B and δ^{34}S, whereas the deep wells do not have tritium and have enriched levels of δ^{11}B and δ^{34}S. The isotopic data indicate that the source of shallow groundwater may be derived from upgradient flow or

flow from the west. The deeper wells have marine signatures of $\delta^{34}S$ and $\delta^{11}B$, no detectable tritium, and δD and $\delta^{18}O$ indicate that the source is from colder climate or snowmelt.

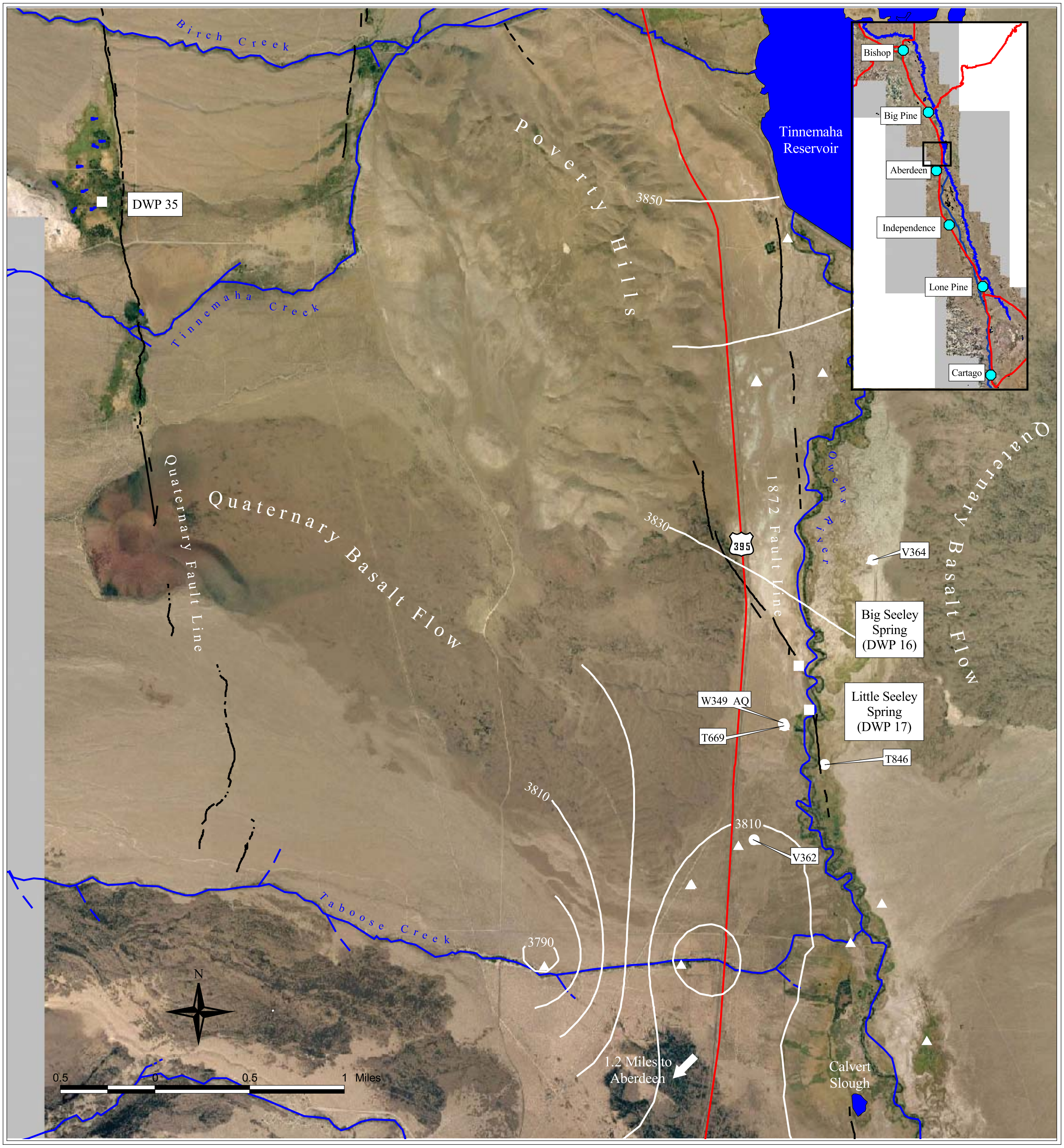
SEELEY SPRINGS

The Seeley Springs (DWP 16 & 17) AOI and its associated features, including sampling locations (**Table 1-1**) are shown on **Figure 5-5**. In addition, the piezometric surface for April 2002 is shown on this map. Big and Little Seeley Springs are valley-floor springs that were dry during the sampling trips of March 2002 and April 2003; therefore, no samples were collected from these springs. When Big Seeley Spring is flowing, it flows warm (Randy Jackson, personal communication, 2004).

Although Seeley Springs were not flowing, samples were collected from a fault-controlled mountain front spring approximately 4.5 miles to the northwest (DWP 35), a pumping well (W349), one deep well (V362), and three shallow wells (T669, T846, and V364).

The objective of sampling at this AOI was to answer the following key questions:

- Question No. 1 - What is the source for the water in production well W349?
- Question No. 2 - Is it possible to determine a mixing percentage between shallow and deep aquifer contribution to the production well?



Legend

□ Spring

△ Shallow Aquifer Data Point Used to Construct Piezometric Surface

○ Sampled Well

∧ Fault

∧ River

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Figure 5-5
Piezometric Surface Map for Seeley Springs Area of Interest (DWP 16 & 17)(April 2002)

Analytical Data Discussion

The general water type for each sample is illustrated by means of a Stiff Diagram for visual comparison between sampled locations (**Appendix F**), and detailed chemical and isotopic compositions for samples from this location are reported in **Table 3-4**.

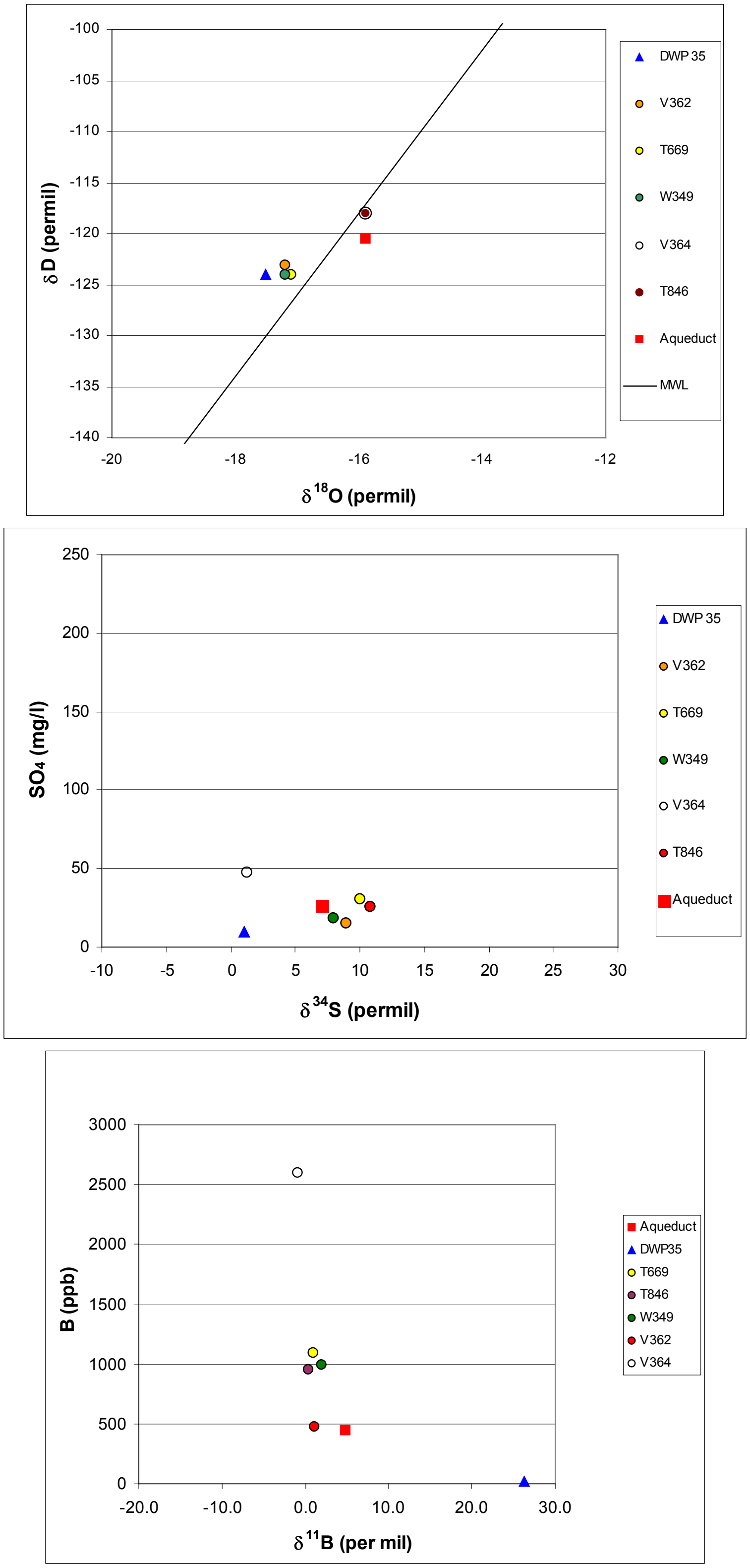
All of the wells sampled in the Seeley Springs AOI are located within one half mile of the Owens River and are less than three miles downgradient from the Tinemaha Reservoir. It would be reasonable to assume that both features influence the water composition observed in these wells. Data indicates that four of the five wells are of similar chemical composition and of the same general water type as the Owens River/Aqueduct samples. Well V364 is the obvious exception in terms of chemical composition, water type, and the stable isotopes of sulfur and boron. **Figure 5-6** presents isotopic data for this AOI.

Groundwater gradient in this region of the Valley is toward the south where the Valley narrows because of the Poverty Hills on the west and the Big Pine volcanic field on the east. All the wells in this region are relatively shallow, including the pumping well W349, which is only 231 feet total depth. Consequently, the shallow flow system influences all sampled wells in this area. In addition, tritium is present in all samples. In fact, the shallow well T669 (52 feet depth) has a virtually identical composition to the pumping well W349 (231 feet depth). As such, no distinction can be made between the shallow and deep aquifers in this region. The isotopic data for sulfur and boron also cluster among these wells, and the inclusion of the Aqueduct isotopic values that are also similar, further supports the argument that recharge from the Owens River is influencing the aquifer's groundwater composition.

The composition of well V364 is clearly different, and the location of the well suggests that the portion of the aquifer it samples may derive recharge from the Quaternary volcanic rocks to the east. The TDS levels are greater in this well (690 mg/l), especially the sodium bicarbonate (120 mg/l), but the δD and δ^{18}O levels, which are consistent with the other samples, do not indicate that evaporation is significant. These data suggest the solute source is from weathering of a rock type other than the Paleozoic carbonates of the White Mountains, and the volcanics would provide elevated sodium and bicarbonate through the weathering process of silicate hydrolysis, which yields bicarbonate from soil dissolved $CO2_{(aq)}$. Furthermore, the boron and the sulfur would be from different mineral phases than the source observed for the shallow aquifer in most the Valley, which can be observed by the separation in sulfur and boron isotopic data.

The mountain-front spring (DWP35) is dilute and of very different boron isotopic composition. The water source for this spring does not appear to be influential to the downgradient wells.

Figure 5-6
Isotopic Data for Seeley Springs AOI



Geochemical Modeling

Preliminary geochemical modeling was conducted for this AOI. However, there were no end members for analysis. Consequently, the results were unconstrained.

Summary

Provided herein is a summary of findings related to the key questions for this AOI.

- *Question No. 1 - What is the source for the water in production well W349?*

Finding(s)

1. Five wells and one mountain-front spring on the west side of the Owens River were sampled. The composition of the shallow wells (T669, T846), the pumping well (W349), and one deep well (V362) all have similar composition to each other and to the Owens River/Aqueduct samples. As such, the data demonstrates that the source of water for well W349 is similar to other sampled shallow and deep wells, with the exception of well V364. Well V364 is located on the east side of both the Owens River and 1872 fault line and has a different chemical and isotopic composition. The chemical composition for well V364 is consistent with what would be expected from weathering of volcanic rocks such as those adjacent to and east of the well.
2. The five wells of similar composition have sample depths that range from 41 to 231 feet, thereby indicating that the shallow aquifer system is well mixed in this area. Furthermore, the tritium content at all wells is detectable and indicates that the portion of the aquifer that is affected by recent recharge is a significant proportion of the produced water.

- *Question No. 2 - Is it possible to determine a mixing percentage between shallow and deep aquifer contribution to the production well?*

Finding(s)

1. It was not possible to determine mixing percentages between the shallow and deep aquifer contributions to the production well because there was not a clear picture of either end member.

Additional findings from investigation at this AOI include:

- The sampled mountain front spring DWP35 has a dilute solute, a distinct boron isotopic value, and the groundwater source for the spring does not appear to be influencing the composition of the sampled downgradient wells.
- The cluster of isotopic data for sulfur and boron coupled with the inclusion of the Aqueduct isotopic values that are also similar supports the argument that recharge from the Owens River is influencing the aquifer composition in this area.

THIBAUT SPRINGS

The Thibaut Springs (DWP 11) AOI and its associated features, including sampling locations (**Table 1-1**) are shown on **Figure 5-7**. In addition, the piezometric surface for April 2002 is shown on this map. The Thibaut Springs AOI is approximately 6 miles north of Independence. The discharge area for the sampled spring is 0.3 miles to the west and upgradient of the Aqueduct. Water samples were collected from Thibaut Springs, five wells (F053, T655, V055, W382, and T676), and Grover Anton Spring during the 2002 sampling trips. In April 2003, two additional shallow wells were sampled (T863 and T864).

The objective of sampling at this AOI was to answer the following key questions:

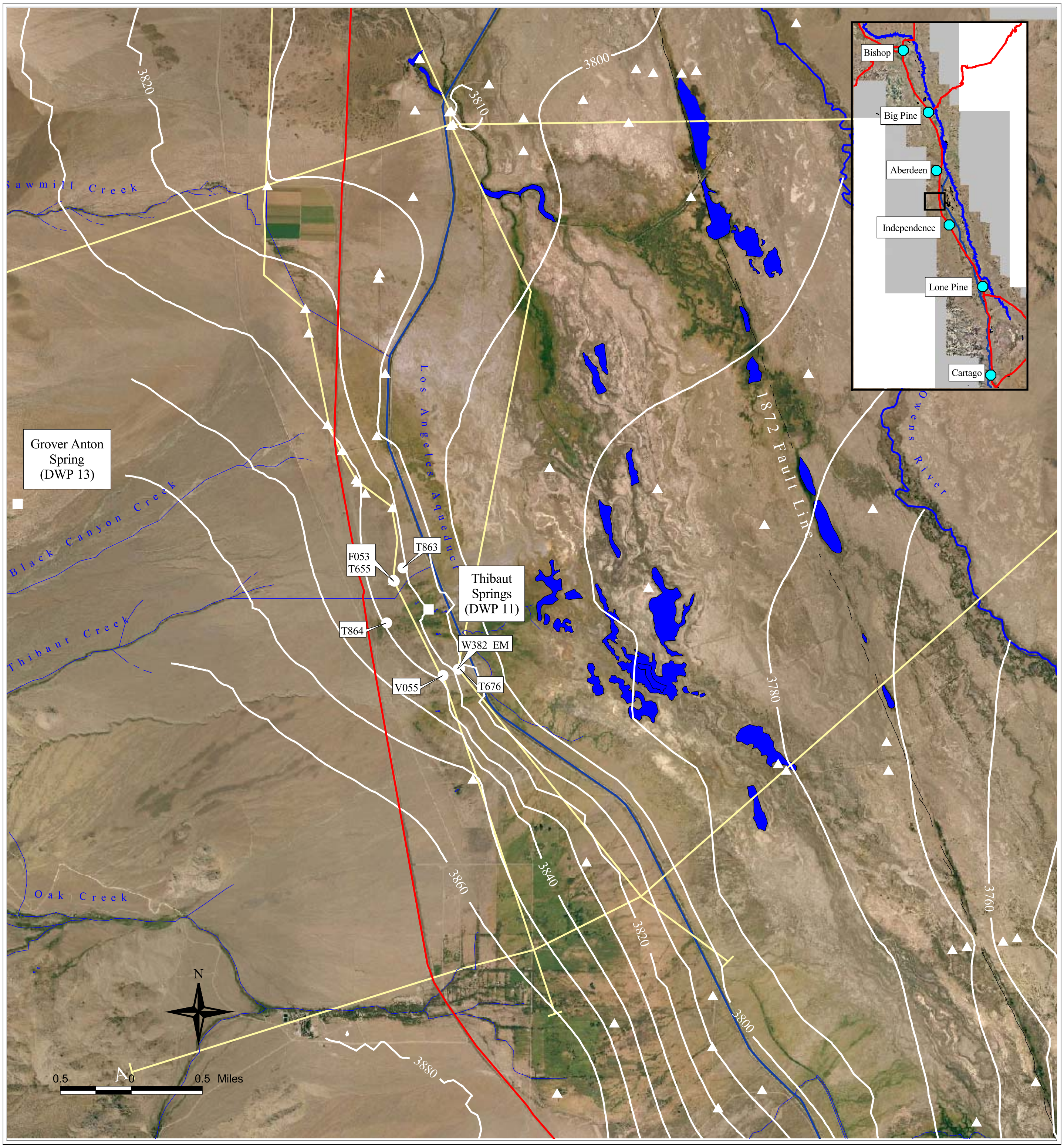
- Question No. 1 - Water emerges from Thibaut Springs even during seasonal pumping periods. Is the flow topographically controlled or is a component of this discharge from the deeper aquifer diverted to the surface by a facies change or fault?
- Question No. 2 - Is there an observable component of the spring water composition in the nearby production well W382 that would indicate a common groundwater source?
- Question No. 3 - Although the Aqueduct is downgradient, is there geochemical evidence that recharge from the Aqueduct is contributing to flow?

Analytical Data Discussion

The general water type for each sample is illustrated by means of a Stiff Diagram for visual comparison between sampled locations (**Appendix F**), and detailed chemical and isotopic compositions for samples from this location are reported in **Table 3-5**.

Interpretation of the spring water source was initially more difficult because there were no wells directly upgradient for sampling during the 2002 field season. Subsequently, three shallow wells were installed in the vicinity of Thibaut Springs. One of the wells, well T864, was located approximately 0.25 miles west directly upgradient from the spring. Because of the potential for useful chemical data, this well and a second well north of the spring, well T863, were sampled during a second field season in April 2003. The objective of the secondary sampling was to provide confirmation that the shallow groundwater composition seen elsewhere was representative of the groundwater upgradient to the spring.

The chemical composition and sulfur isotopic data for wells T863 and T864 and the spring are similar to well T676, but boron and tritium data are not. Cross-sections through this AOI, which are provided in **Appendix G** and whose locations are shown on **Figure 1-1**, clearly define the relationship between well depths, the aquifer continuity between wells, and the location of the aquitards that separate the zones vertically. By interpolating the spring location on the C-C’ north to south cross-section and the A-A’ west to east cross-section, it appears that there are significant aquitards in the immediate vicinity of the spring. These aquitards create a separation between the shallow flow system of less than 50 feet depth and a zone below the aquitard that may be as deep as 100 to 150 feet, before a second aquitard is encountered. However, to the west of the spring, the separation of these two aquifer zones appears much less prominent and mixing between shallow and deep could occur.



Legend

□ Spring

△ Shallow Aquifer Data Point Used to Construct Piezometric Surface

○ Sampled Well

Fault

River

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Figure 5-7
Piezometric Surface Map for
Thibaut Springs Area of Interest
(Area A) (April 2002)

Mixing between shallow and intermediate depths upgradient from Thiabut Spring is supported by the chemical data at all wells, with the exception of wells F053 and T655, indicating similar Ca-Na-HCO_3 water compositions with only minor variations. This water type is seen repeatedly on the western slopes of the Valley and is the consequence of weathering the igneous rocks of the Sierra Nevada. The δD and $\delta^{18}O$ values do not indicate any significant evaporation, but clearly show that Thibaut Springs water is similar to the deeper water sources (wells W382 and V055) and the shallow downgradient wells (T676 and T655), but is dissimilar to the shallow upgradient well T864, shallow well T863, Grover Anton Spring, and the Aqueduct. Tritium data are measurable and show a similar correlation in well T863, Grover Anton Spring, and the Aqueduct. On the other hand, Thibaut Springs, well T864, and deep wells show as tritium non-detects.

The $\delta^{11}B$ and the total boron concentration for wells F053 and T655 (-4.0 ‰ and –0.1 ‰, respectively and 2,600 µg/l and 2,700 µg/l, respectively) are remarkably similar to each other, but distinct from all other samples, with the exception of well T676. This distribution is consistent with the differences in chemical compositions and with the known hydrogeologic circumstance for these two wells. Well F053 is a flowing well and water discharging from this well is presumed to recharge into the shallow aquifer (ICWD personnel, personal communication). Consequently, it is assumed that the chemical and isotopic composition observed for well T655 is derived from well F053 and does not represent the local shallow groundwater. The isotopic data also indicate a connection between wells F053 and T655. Furthermore, the $\delta^{34}S$ for the balance of the samples cluster and can be interpreted as representing a sulfur source for the sulfate that is similar (e.g., the sulfide minerals in the granitic rocks of the Sierra Nevada).

The boron and sulfur stable isotopic data are quite unusual for Thibaut Springs. Both the $\delta^{11}B$ (11.8 ‰) and $\delta^{34}S$ (-1.2 ‰) levels at Thibaut Spring are distinctly different from all other samples, whereas the other samples are clustered in reasonable associations.

Thibaut Springs has a $\delta^{34}S$ value that is significantly depleted when compared to the other samples, but there is no obvious source for this depletion of sulfur. One plausible explanation for the depleted $\delta^{34}S$ is sulfur reduction in the sediments of Thibaut Springs, which would represent an isolated depletion effect on the spring water values relative to the nearby groundwater. The discharge from Thibaut Springs is from seeps, and is predominantly diffused, rather than emerging from a defined fracture or orifice. Consequently, it is suspected that the organic-rich sediments may be creating a microbial reducing environment and altering the chemical composition of the solute. However, the water emerging from the seeps shows no evidence of reducing in terms of dissolved oxygen measurements. These measurements indicate a near saturation of oxygen within the solute, but no pore water redox measurements were attempted. Nevertheless, the sulfur isotopes indicate that some sulfate reduction may have occurred prior to discharge.

Similarly, the $\delta^{11}B$ is unique from all other samples. Boron is often present in plant material and if there is significant organic decomposition then there may be a local source for boron. Additionally, fine-grained sediments may have a low pore water volume to surface area ratio, which could result in a fraction of the dissolved boron being absorbed. Boron absorption in fine-grained sediments can result in isotopic fractionation, thus yielding a water with enriched $\delta^{11}B$.

Therefore, it is plausible that the sulfur and boron isotopic data are indicating that some alteration in water composition may be occurring as water seeps to the surface at Thibaut Springs, and the observed values are representing local rather than regional conditions. It should be noted that the δD and $\delta^{18}O$ values will not be affected by these processes and are considered accurate indicators of water source, and are not unique from any other samples in this AOI.

Comparison of chemical composition alone does not support the shallow upgradient well T864 as representing groundwater that predominates in the Thibaut Springs discharge. **Table 5-2** clearly indicates that by comparing the temperature, conservative elements such as chloride and bromide, and assuming that the alkalinity is defined by the flow path, the evidence is substantial that the spring is composed of, if not dominated by, deeper water that has mixed with shallow groundwater. As discussed in the modeling section below, a mixture of well T864 at 10% and well V055 at 90% could result in the composition observed for Thibaut springs.

Table 5-2
Compositions for Water Sources for Thibaut Springs

	T864 Upgradient Shallow Well	W382 Downgradient Deeper Well	V055 Downgradient Intermediate Depth Well	DWP 11 Thibaut Springs
T (°C)	19.8	19	16.5	17.8
Br	50	14	17	16
Cl	13	3.7	2.3	3.1
HCO_3	163	89	71	89

Geochemical Modeling

Reaction State Modeling

The reaction state geochemical modeling for the Thibaut Springs area included Thibaut Springs, Grover Anton Spring, and all seven wells sampled in this AOI. All nine samples are undersaturated with respect to gypsum. All but well V055 and Thibaut Springs are near equilibrium with calcite, and all but wells V055 and W382 are at equilibrium with cristobalite. Clay minerals and minerals that would be affected by trace metal concentrations were not considered in this analysis, because trace metal concentrations are in most cases below detection limits. Uranium is present as a mobile oxyanion or carbonate aqueous complex.

Geochemical Mixing Calculations

Thibaut Springs discharges onto the alluvial slopes above the Aqueduct and is not affected by Aqueduct recharge. Wells within the immediate area that might plausibly produce from groundwater influencing the spring composition include pumping well W382, shallow well T864, and deep well V055. Flowing well F053 is not considered because the chemical composition and isotopic data are divergent. Neither Thibaut Springs nor these three nearby wells have any measurable tritium, supporting the spring source as being predominantly from the deeper aquifer. The chemical composition of the shallow well T864 is slightly different and a little more concentrated than the spring; however, the chemical compositions of the shallow well

T864 and the deeper well V055 bracket the composition of Thibaut Springs. The chemical compositions between the shallow and deep wells are generally similar, and the conservative elements illustrate the subtle differences between the three sites (**Table 5-2**). A mixture of water from wells T864 and V055 in the proportion of approximately 90% V055 and 10% T864, with some ion exchange and mineral reaction, would yield the sampled spring composition. The isotopic data for boron and sulfur at Thibaut Springs may not be reliable, due to the atypicality of the results; therefore, the mixing calculations exclude these isotopic entities.

Summary

Provided herein is a summary of findings related to the key questions for this AOI.

- *Question No. 1 - Water emerges from Thibaut Springs even during seasonal pumping periods. Is the flow topographically controlled or is a component of this discharge from the deeper aquifer diverted to the surface by a facies change or fault?*

Finding(s)

1. It could not be determined definitively what controls the flow at Thibaut Springs. West of Thibaut Springs, the separation between the shallow and deep aquifer is not pronounced and mixing could easily occur. In the vicinity of the spring the combination of a break in the slope of the land surface and the emergence of aquitards could divert the mixed water into shallower zones yielding the discharge at Thibaut Springs. However, it is probable that the spring is composed predominantly of deeper water such as that represented by wells V055 or W382.

- *Question No. 2 - Is there an observable component of the spring water composition in the nearby production well W382 that would indicate a common groundwater source?*

Finding(s)

1. Thibaut Springs has chemical characteristics similar to both shallow and deep wells in the vicinity of the spring (including well W382), with the exception of wells F053 and T655. The flowing well F053 is suspected of influencing the composition of the nearby shallow well T655. However, this water is clearly different from and unrelated to the discharge from Thibaut Springs.
2. A new shallow well, T864, was constructed upgradient to Thibaut Springs following the field sampling of 2002. Consequently, this well was sampled in 2003 for comparison to the spring composition. Computations indicate that the composition of the deeper wells more closely compare to the spring than do the shallow wells. A mixture of 90% V055 and 10% T864 with ion exchange and mineral dissolution, would yield the observed composition of Thibaut Springs.

- *Question No. 3 - Although the Aqueduct is downgradient, is there geochemical evidence that recharge from the Aqueduct is contributing to flow?*

Finding(s)

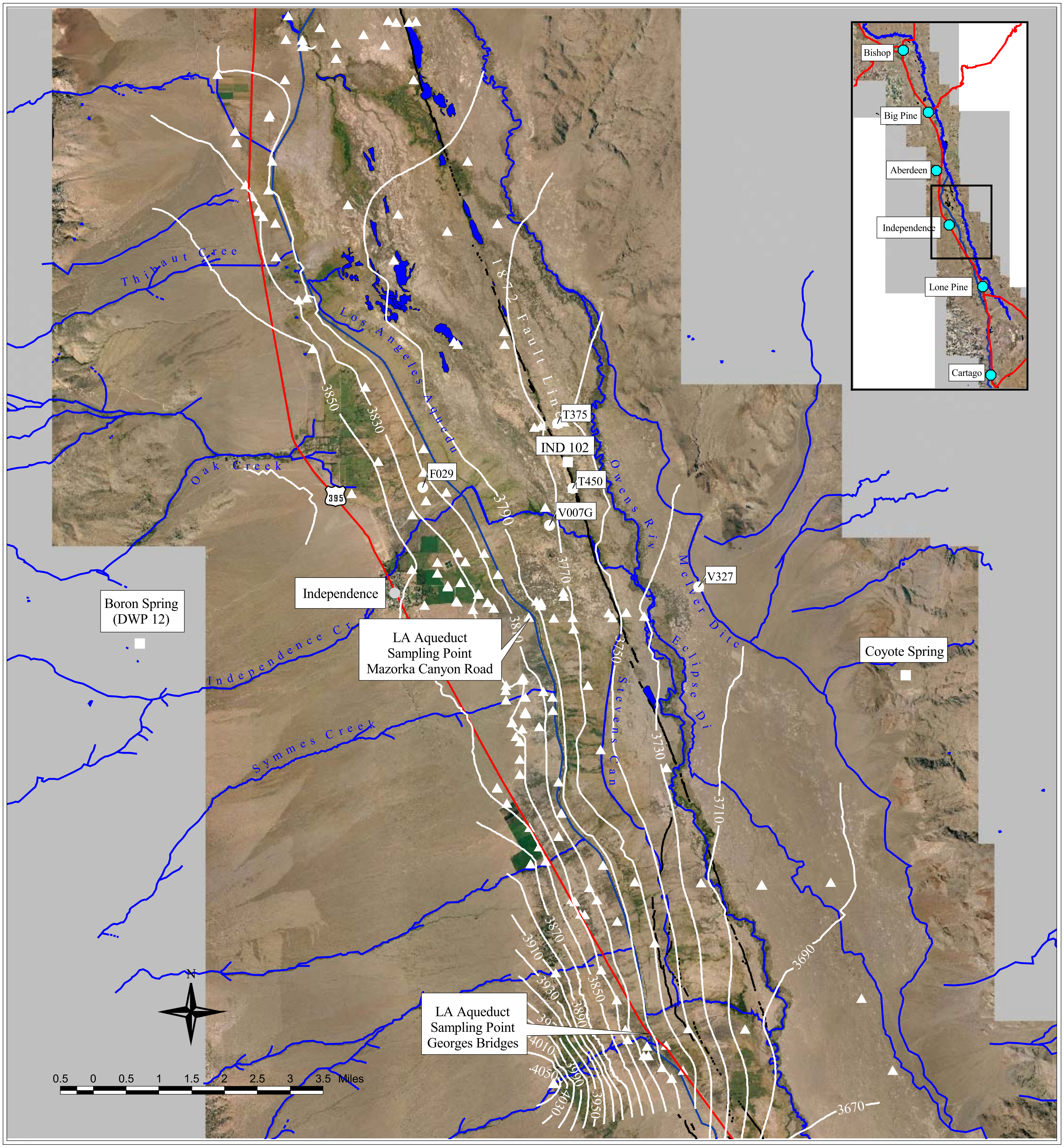
1. Thibaut Springs discharges onto the alluvial slopes above the Aqueduct and is not affected by Aqueduct recharge. Geochemical evidence shows that the spring water is compositionally different from the Aqueduct water and suggests a deep groundwater source for Thibaut Springs.

FAULT SCARP SPRINGS (IND 102)

The Fault Scarp Springs (IND 102) AOI and its associated features, including sampling locations (**Table 1-1**) are shown on **Figure 5-8**. In addition, the piezometric surface for April 2002 is shown on this map. The fault scarp spring complex, referred to as IND102, is located approximately 2.5 miles east of Independence and creates a marshy area with abundant phreatophytic plants along the trace of the 1872 earthquake fault. The marsh is between the Aqueduct, approximately 1 mile to the west, and the Owens River, approximately 0.5 miles to the east. Springs in the mountains to the west (Boron Spring) and to the east (Coyote Spring) were sampled, as were two deep wells (F029 and V327), and three shallow wells (V007G, T450, and T375).

The objective of sampling at this AOI was to answer the following key questions:

- Question No. 1 - What is the source of the spring water, and is there an Aqueduct component?
- Question No. 2 - Is there an observable difference in water composition across the fault?
- Question No. 3 - Does the spring or any of the downgradient wells have a correlative composition to the mountain front springs?



Legend

- □ Spring
- △ Shallow Aquifer Data Point Used to Construct Piezometric Surface
- ○ Sampled Well
- Fault
- River

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Figure 5-8
Piezometric Surface Map for
Fault Scarp Springs Area of Interest
(IND102)(April 2002)

Analytical Data Discussion

The general water type for each sample is illustrated by means of a Stiff Diagram for visual comparison between sampled locations (**Appendix F**), and detailed chemical and isotopic compositions for samples from this location are reported in **Table 3-6**. Sulfur and boron isotopic data are plotted on **Figure 5-9**.

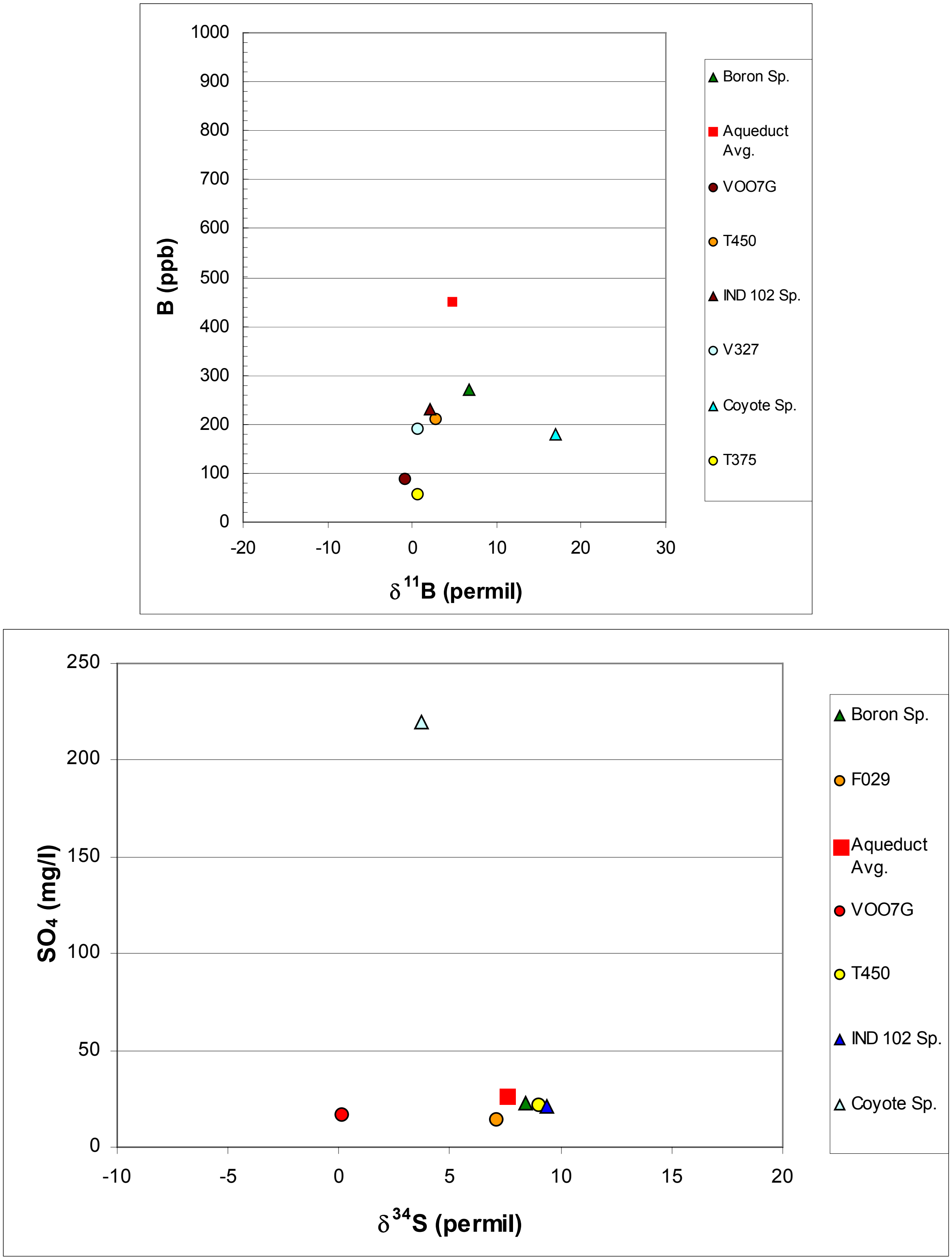
There are no pumping wells in the immediate vicinity of the IND102 complex. Consequently the potential impacts of pumping on spring discharge were not hypothesized.

Coyote Spring is a mountain-front spring on the east side of the Owens Valley within the Inyo Mountains. The water type for Coyote Springs is calcium sulfate, and has the highest TDS content among the samples in this AOI (540 mg/l). Coyote Springs chemical composition is similar to Mule Springs in the Wilkerson Springs AOI, which also originates in the Paleozoic sedimentary rocks of the Inyo Mountains, with obvious and subtle differences. For example, the stiff diagrams clearly indicate that magnesium and alkalinity levels are slightly higher in Mule Spring, possibly indicating more contribution of solute from the dissolution of dolomite. The sampled sulfate concentration at the two springs was identical (220 mg/l) and elevated when compared to the Valley samples. The elevated sulfate is most likely derived from the oxidation of pyrite in the marine shales of the Inyo Mountains and, as such, both springs should exhibit significantly enriched $\delta^{34}S$, as discussed in the Wilkerson Springs AOI section. However, Mule Spring exhibits enriched $\delta^{34}S$ levels of 23.4 ‰, while Coyote Springs is anomalous with levels of 3.7 ‰. No clear evidence supports an explanation for this anomaly. However, if the shales containing the sulfides formed in significantly reducing environments with significantly consumed reservoirs of sulfate, as in a lagoon or restricted region, then the pyrites could have had a large isotopic fractionation event during early sedimentary formation that would yield the sulfate values seen in Coyote Springs. The important conclusion for this AOI is that the chemical and isotopic composition of Coyote Springs is local and not observed in any of the wells or springs elsewhere in this AOI. It should also be noted that the $\delta^{11}B$ from both Boron (6.8 ‰) and Coyote springs (17.0 ‰) is enriched as would be expected in marine rocks. In addition, boron isotopic values would not be affected by the reducing conditions that fractionate sulfur.

The sample from IND102 was difficult to collect because of diffuse flow and shallow ponded water, but the sample appears to be representative of water in the immediate vicinity. Nearby well T450 has an almost identical composition to the IND102 spring.

An aerial photo survey of this region indicated that surface water and spring formations within this AOI followed the 1872 fault line. Groundwater potentiometric surface mapping and hydrographs indicate an effect due to faulting (see hydrographs in **Appendix H**). Two additional wells [V007G (a shallow well approximately 0.5 miles southwest and upgradient of IND102) and T375 (a shallow well approximately 0.25 miles east of the fault and 1.0 mile north of IND102)] were sampled. None of the chemical compositions of these wells were significantly different enough to indicate that the fault creates a barrier to groundwater flow.

Figure 5-9
Sulfur and Boron Isotopic Data for Fault Scarp Springs AOI



Well V327 is a deep well located on the east side of the Owens River and at the foot of the Inyo Mountains approximately 2.0 miles southeast and downgradient of IND102. This well exhibited an extremely low sulfate concentration (below the detection limit) that is not characteristic of flow values on the east side of the Valley. This site may be influenced by recharge from the Owens River or from groundwater draining the alluvial fan of Mazourka Canyon. Consequently, no interpretation should be made regarding the influence of the 1872 fault by comparison to well V327.

Shallow well V007G, located approximately 0.5 miles southwest and upgradient of IND102, has a chemical composition significantly different from the spring and the adjacent shallow wells T375 and T450. The solute of well V007G has diluted TDS values (150 mg/l), contains tritium (2.8 TU), and the $\delta^{11}B$ (-0.9 ‰) and $\delta^{34}S$ (0.1 ‰) values are substantially depleted relative to wells T375 and T450. The tritium values are particularly significant because neither of the shallow wells or the spring have any measurable tritium, yet the spatial separation is minimal. The difference in composition between well V007G and the shallow wells along the fault could be explained by recharge to the shallow groundwater near well V007G from Independence Creek.

No deep wells were sampled in the immediate vicinity of IND102, and therefore the composition of the deeper aquifer in this AOI is unknown. It could be presumed that the deeper water in this AOI would have little if any tritium, and the isotopic signature for $\delta^{34}S$ would be similar to other deep wells, which is enriched relative to well V007G and more like the fault wells. Well F029 is a deep well located 3 miles to the west of IND102 and upgradient of all other wells within the AOI. In addition to the distance from the site, well F029 has an anomalous tritium value. This value is the largest tritium measurement for any location sampled during the project (14.3 TU). Consequently, the unusual tritium reinforces the exclusion of this well from being representative of deeper groundwater in the immediate vicinity of the IND102 complex.

The potentiometric gradient between the Aqueduct and the spring complex is slight; therefore, recharge from the Aqueduct is not expected. However, recharge from Independence Creek should impact the shallow aquifer between the Aqueduct and the spring. Furthermore, the composition of the spring is not similar enough to the Aqueduct either chemically or isotopically to attribute any contribution from the Aqueduct to the spring.

Geochemical Modeling

Reaction State Modeling

The reaction state geochemical modeling for the IND102 AOI included Boron Spring, Coyote Spring, and the five sampled wells (F029, V007G, T450, T375, and V327). All eight samples are undersaturated with respect to gypsum and fluorite. All but well V007G are undersaturated with respect to barite. Conversely, all but wells F029 and T450 are at equilibrium with calcite are essentially at equilibrium with cristobalite. Clay minerals and minerals that would be affected by trace metal concentrations were not considered in this saturation analysis because almost all the trace metal concentrations including aluminum are below detection limits. Uranium is present as a mobile carbonate complex.

Geochemical Mixing Calculations

IND102 springs discharges along the fault scarp downgradient from the Aqueduct. The spring is probably primarily shallow water, even though the tritium content is below detection. The low tritium may reflect the long flow path that water has taken down the alluvial fans to the west. The potentiometric gradients in this area are still from west to east and are not yet reoriented down the Valley. The Owens River is east of the IND102 area and, consequently, the shallow water is probably minimally affected by surface recharge with its elevated tritium content except near creeks, as is demonstrated in well V007G near Independence Creek.

The nearest well to IND102 springs is shallow well T450 that, although only 20 feet in total depth, may also be along the fault. The composition of IND102 was simulated using inverse modeling. For the modeling, the initial well was T450 and by using the well's water composition as the source groundwater, adding dissolution of calcite ($CO_{2(g)}$), and considering ion exchange, the composition of IND102 can be easily simulated. This simulation indicates that both IND102 and well T450 are from the same source. Without more plausible deep-well compositions, the simulations using a deep well will not be useful. At present, the modeling indicates that the spring and shallow wells near the fault are representative of the composition of the shallow groundwater.

Summary

Provided herein is a summary of findings related to the key questions for this AOI.

- *Question No. 1 - What is the source of the spring water, and is there an Aqueduct component?*

Finding(s)

1. The Aqueduct composition is not considered contributory to the composition observed for the wells in the IND102 vicinity. The Aqueduct is almost two miles away, separated by a low potentiometric gradient, and the intermediate groundwater would be impacted by creek recharge.
2. The chemical and isotopic compositions of the spring and the nearby shallow wells are similar in water type, general composition, and for the most part, similar isotopic composition, suggesting a shallow groundwater source for the spring.

- *Question No. 2 - Is there an observable difference in water composition across the fault?*

Finding(s)

1. The IND102 spring complex appears related to the 1872 fault lineament and surface ponding, seeps, and springs are aligned with the fault trace. The potentiometric gradient across the fault in the vicinity of IND102 indicates that there is an impact on groundwater flow.
2. Shallow well V007G has a more dilute TDS value, detectable levels of tritium, and has a depleted $\delta^{34}S$ value than the wells along the fault. The most obvious and consistent explanation for these anomalous values is that this groundwater is affected by recharge from the nearby Independence Creek and does not represent a difference from the wells near the fault due to the presence of the fault.

3. Overall, there is not an observable difference in water composition across the fault.

- *Question No. 3 - Does the spring or any of the downgradient wells have a correlative composition to the mountain front springs?*

Finding(s)

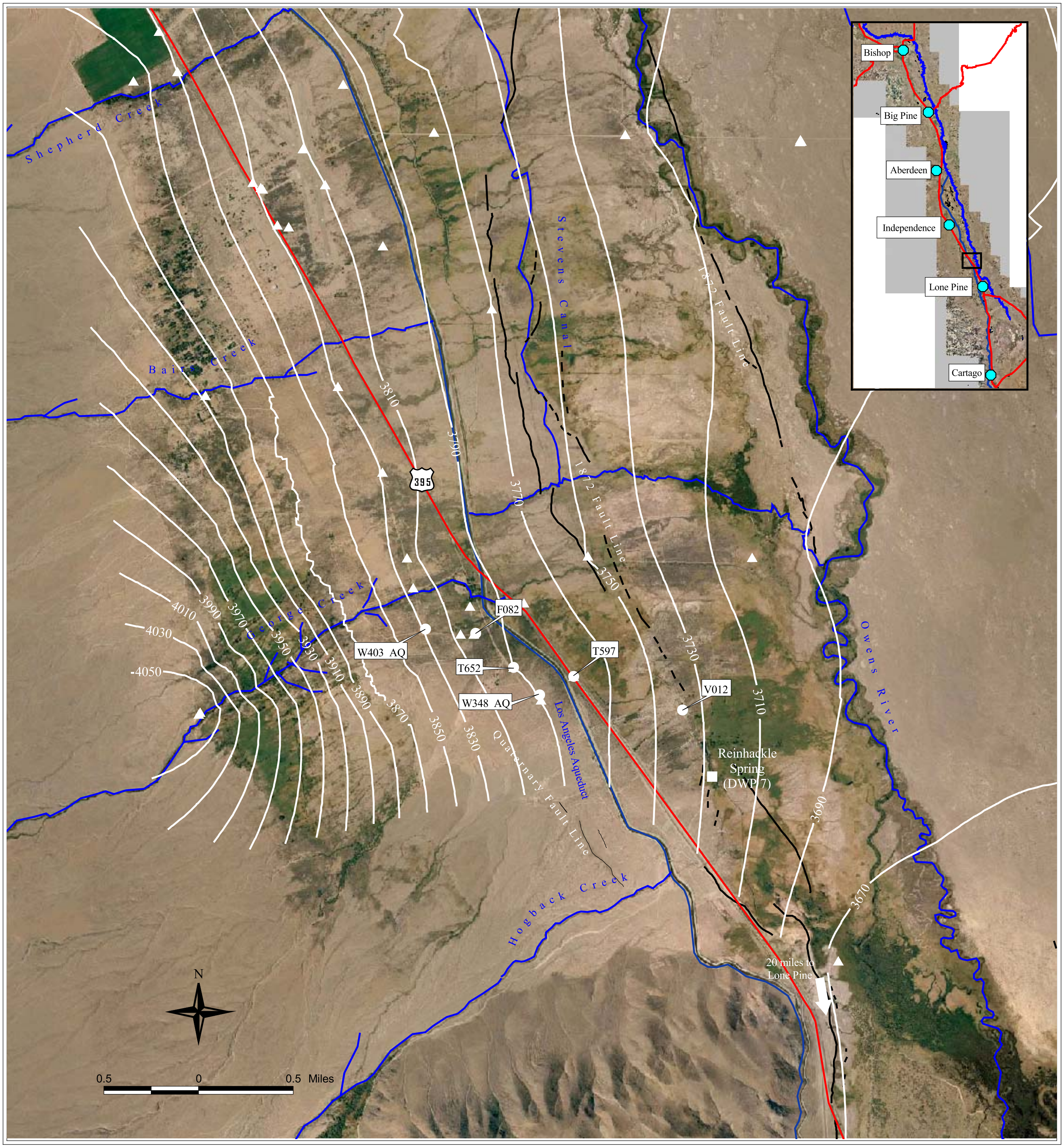
1. Coyote Springs has a chemical and isotopic composition, except for $\delta^{34}S$, that is typical of water derived from the Paleozoic carbonates of the Inyo Mountains. The $\delta^{34}S$ is depleted and may represent a sulfate source that was fractionated during marine deposition. There is no evidence that the groundwater source of Coyote Spring has any influence on the composition of IND102 or the wells in the vicinity of the IND102 complex. The important conclusion is that the chemical and isotopic composition of Coyote Springs is local and not observed in any of the wells or springs elsewhere in this AOI.

REINHACKLE SPRING

The Reinhackle Spring (DWP 7) AOI and its associated features, including sampling locations (**Table 1-1**) are shown on **Figure 5-10**. In addition, the piezometric surface for April 2002 is shown on this map. Reinhackle Spring discharges perennially into a large seepage area approximately 0.5 miles east and downgradient of the Aqueduct.

Reinhackle Spring, the Aqueduct, and four nearby wells were sampled in March of 2002 and additional samples were collected in April 2003 from two more wells in order to provide specific information about the deeper aquifer. The six wells sampled include two that are shallow [T652 (<40 ft deep and upgradient from the Aqueduct) and [T597 (<21 feet deep and adjacent to and downgradient from the Aqueduct)], two pumping wells [W348 (488 ft deep) and W403 (560 ft deep)], flowing well F082 (266 feet deep), and a deep well [V012 (485 ft deep)]. Cross-sections were developed for this AOI and are provided in **Appendix I** with their locations shown on **Figure 1-1**.

The rationale for the second sampling trip was to obtain a more specific assessment of the chemical and isotopic composition of the deeper aquifer to better assess distinction between shallow and deep aquifer contribution to flow at Reinhackle Spring. As can be seen from **Figure 5-10**, there are no deep wells directly upgradient along an interpolated flow vector from Reinhackle Spring. However, deep aquifer wells W403, W348, and F082 are upgradient, but the potentiometer flow lines of these wells pass nearly a mile north of the spring. Wells F082 and W403 were deemed critical because the tops of their screened intervals are in the deep aquifer and begin more deeply than the screens in well W348. Furthermore, it appears from examination of the cross sections created for the Reinhackle Spring AOI (**Appendix I**) that both wells F082 and W403 are screened below interpolated aquitards, increasing the probability of obtaining samples representative of the deeper aquifer.



Legend

□ Spring

△ Shallow Aquifer Data Point Used to Construct Piezometric Surface

○ Sampled Well

Fault

River

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Figure 5-10
Piezometric Surface Map for
Reinhackle Spring Area of Interest
(Area F) (April 2002)

MWH

The objective of sampling at this AOI was to answer the following key questions:

- Question No. 1 - Does the chemical or isotopic composition of the spring indicate that recharge from the Aqueduct is a component of spring flow?
- Question No. 2 - Can the composition of surrounding shallow or deep wells be correlated to the spring composition?

Analytical Data Discussion

The general water type for each sample is illustrated by means of a Stiff Diagram for visual comparison between sampled locations (**Appendix F**), and detailed chemical and isotopic compositions for samples from this location are reported in **Table 3-7**.

All seven sampling locations yield similar water compositions dominated by Na, Ca, and bicarbonate. Although all samples are related by "water type," there are significant differences in minor components and isotopic composition.

The three samples from the Aqueduct, the shallow well T597, and Reinhackle Spring all have similar chemical compositions. In all five samples, the respective concentrations are almost identical for the more chemically conservative elements such as chloride (15, 15, 15, 14, 15 mg/l), boron (470, 460, 440, 390, 550 μg/l), and bromide (38, 34, 36, 30, 38 μg/l). In contrast to these five samples, the concentrations of the same conservative elements for the three deep wells (F083, W348, and W403) ranged from two to ten times less. The Aqueduct, well T597, and Reinhackle Spring are all slightly more concentrated in total solute and have similar elevated values for pH, alkalinity, and fluoride.

The six sampled wells, Reinhackle Spring, and the Aqueduct sample site closest to Reinhackle Spring (George Creek Bridge) were tested for ^{3}H, δD, δ^{18}O, δ^{11}B, and δ^{34}S. All sample sites had detectable tritium values with the lowest value being 2.1 TU measured at well W403 and the highest values measured at Reinhackle Spring (5.8 TU), well T597 (4.5 TU), and the George Creek Bridge Aqueduct sample (5.1 TU). These tritium values of 5 TU or higher are consistent with what is generally observed for modern atmospheric tritium concentrations and is expected for surface water exposed to the atmosphere. The occurrence of near-identical values at Reinhackle Spring, the Aqueduct sites, and well T597 further supports the supposition that the Aqueduct is the major source for the spring. Unexpectedly, the deeper wells, and in particular well W403, which is screened from 250-550 feet below ground surface, were found also to have measurable tritium. If the water in well W403 is only sampling the deeper aquifer, then the presence of tritium is an enigma. Prior to the nuclear testing in the late 1950s and early 1960s, the atmospheric tritium levels were near 5 TU. During testing, tritium levels were recorded as high as 10,000 TU. Because the half life of tritium is 12.43 years, and because some dilution of recharge water with existing groundwater would be expected, then water older than 4 or 5 half lives should have measured tritium concentrations near or below the detection limit. Consequently, water sampled from 200 to 500 feet below ground surface in the deeper aquifer supposedly separated from the shallow aquifer by an aquitard would be expected to be much older than 50 years and devoid of tritium. Nevertheless, tritium is present in all three of the "deep" aquifer wells sampled in the Reinhackle Spring area; therefore, the assumption that these wells are in fact sampling only the deep aquifer may not be correct. There are at least three plausible arguments listed below for the anomalous tritium concentration in samples collected from wells in the deep aquifer.

- The tritium in deep aquifer samples represents contamination obtained from sampling procedures.

  Contribution of excess tritium to the deep aquifer samples as the result of errors in the sampling procedure is not likely. First, all samples were collected and preserved using the same standard and generally accepted protocol. No evidence of persistent excess tritium was observed; to the contrary, samples from 13 wells and 6 springs had tritium concentrations below the detection limit. Secondly, the presence of tritium in the samples from the three deep aquifer wells represents the only surprising and anomalous results for tritium. The balance of the tritium results is consistent with what would be expected at each sampled site. The explanation for the anomalous tritium values obtained for the deep aquifer samples cannot be attributed to sampling error.

- The tritium is representative of the deep aquifer and implies rapid travel time from the recharge area to the well.

  As described by Danskin (1998) most groundwater in the Owens Valley originates as mountain front recharge through the alluvial fans of the Sierra Nevada. As groundwater moves from recharge areas to the valley floor, the flow splits into shallow and deep aquifers. Danskin (1998) estimates the travel times are between 50 and 200 feet per year. Using these rates by Danskin, then the age of water in the deep wells sampled near Reinhackle Springs should be between 200 and 800 years before present. However, these rates do not account for factors such as faulting or the component of vertical flow. Since tritium is atmospherically derived, clearly the travel times are much too long for tritium still to be present at the levels measured.

- The tritium is indicating that water from the shallow zone is migrating to the deep zone, and the clay zones interpolated from the driller's logs do not actually represent an aquitard that defines a complete separation between the aquifers.

  Tritium is observed in most shallow wells sampled for this study, as would be expected for wells that contain water recharged in the past few decades. The source of the shallow groundwater is snowmelt and surface water exposed to the atmospheric sources of tritium, which includes recharge of runoff, recharge of nearby creeks or streams, or closer-in recharge in alluvial fans. The groundwater in the shallow aquifer is a convenient and available source of tritium, requiring only mixing in the upper portion of the screened intervals of the wells. However, the chemical compositions of the deep aquifer samples are dilute and do not indicate significant mixing with more concentrated groundwater compositions observed for nearby shallow aquifer wells such as T652 and T597. In particular, note that the elevated boron concentration of these shallow aquifer wells would contribute a significant concentration of boron to the deep aquifer wells with the mixing percentage required to elevate the tritium content of the deep aquifer samples. This scenario is not observed. It is more probable that the mixing that resulted in the observed composition of the deep aquifer samples is with shallow aquifer groundwater in regions where recharge of dilute creek or stream water is prevalent. Few analyses are available for surface runoff; however, stream and creek water for example in another AOI, the Baker Springs Area, is dilute, has elevated tritium, and low boron concentration; characteristics that fit will with the mixing scenario required to elevate the deep aquifer tritium, but not the dissolved solids and boron content.

In addition to the natural mixing of shallow and deep groundwater that may be occurring near the upper screened section of the deep aquifer wells, one could speculate that the pumping wells are creating a gradient for drawing shallow tritiated groundwater into the well. Although this pumping scenario may contribute to the mixing, it does not appear to be a required mechanism because similar elevated tritium values are also seen in the flowing well F082.

In summary, tritium observed in the samples from the three deep wells F082, W348, and W403 is probably the result of co-mingling of shallow dilute groundwater with the deep aquifer, and the actual tritium content of the deeper aquifer would be below detection limit. Flow in Reinhackle spring with its elevated tritium would therefore not be dominated by groundwater from the deep aquifer with its postulated negligible tritium content. This lack of a deep aquifer component is consistent with the spring flow being predominantly derived from the Aqueduct.

Well V012 is in the valley floor between the Aqueduct and the Owens River and is subject to the effects of infiltration from surface sources of water, which have elevated tritium.

Four stable isotopic signatures were determined for the Reinhackle Spring site: hydrogen, oxygen, boron, and sulfur. Using the conventional interpretation for the environmental isotopes of hydrogen and oxygen, the data collected from all locations were consistent with the MWL (**Figure 4-1**). **Figure 5-11** shows the Reinhackle area data at an expanded scale. The cross-plot of hydrogen and oxygen depicts two circumstances:

- The data are all reasonably close to the MWL, and therefore significant evaporation or reaction with the aquifer matrix has not occurred, and
- The data are distinctly different among the locations.

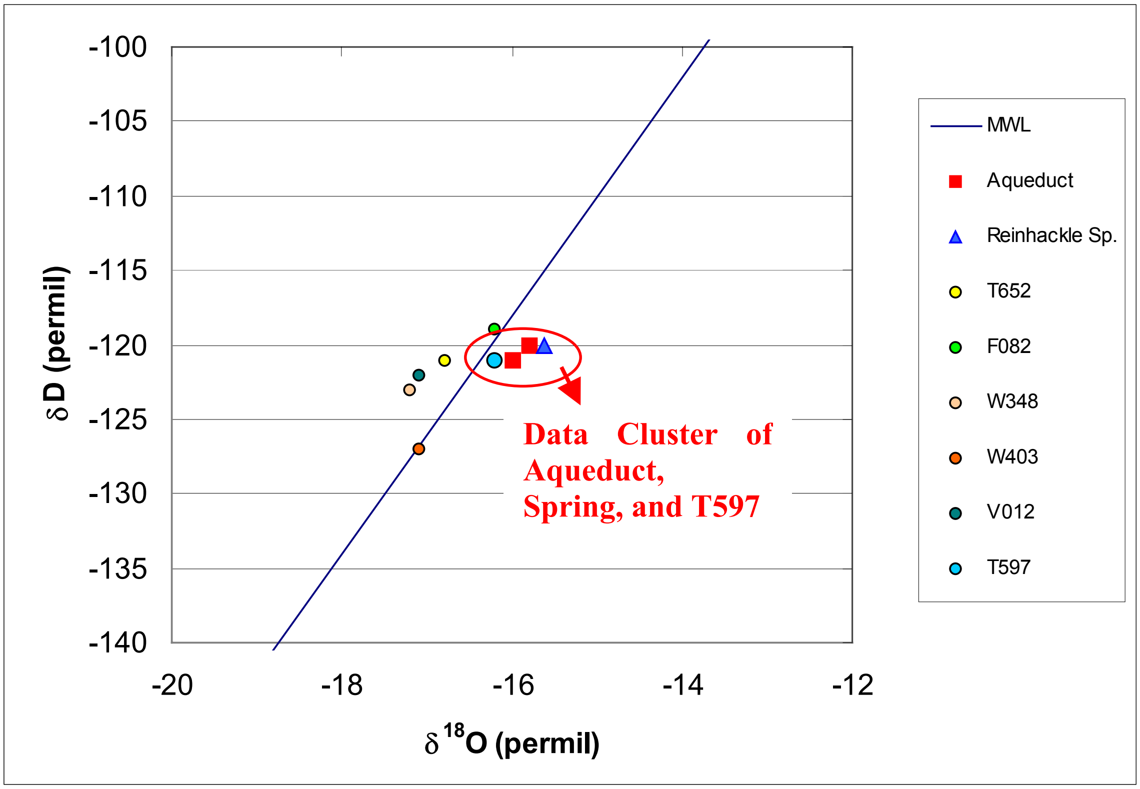
The cluster of data noted on this figure includes the Aqueduct, Reinhackle spring, and the shallow well T597. This plot is further evidence that all three are similar in origin, have experienced some evaporation as evidenced by the trend away from the MWL, and are dissimilar to the deep aquifer samples and the second shallow groundwater well T652 that is upgradient from the aqueduct.

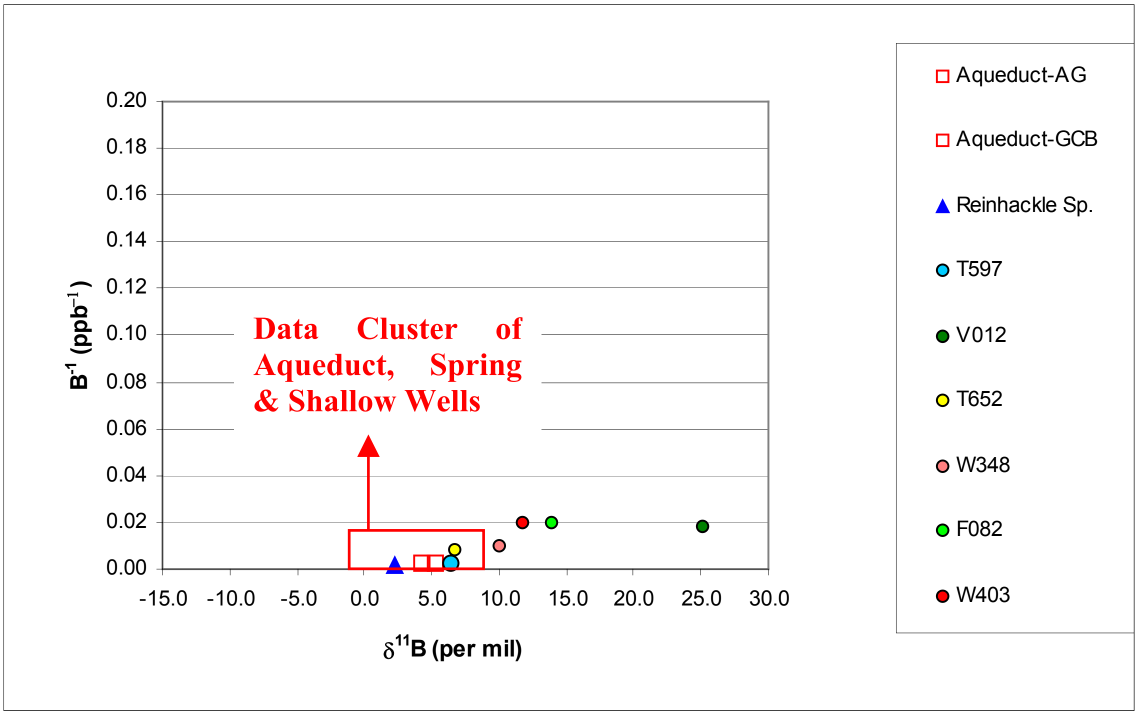
Similarly, the boron stable isotopic data yield a cluster of the same group (i.e. the Aqueduct, well T597, and Reinhackle Spring), implying that the boron was derived from the same source, whereas the other wells are clearly of different origins (**Figure 5-11**). In this plot, it appears that the shallow groundwater well T652 also plots within this cluster but with low boron concentration relative to the other locations. Plotting the boron isotopic value against the inverse of the boron concentration will yield a trend in the data if mixing between two waters is pronounced. There is a general linearity observed in the data, but the data do not show evidence of a typical mixing trend. Rather, it would be more reasonable to interpret the data as simply indicating that each well has developed its own isotopic signature based on the rocks it has encountered from recharge to the sampled location.

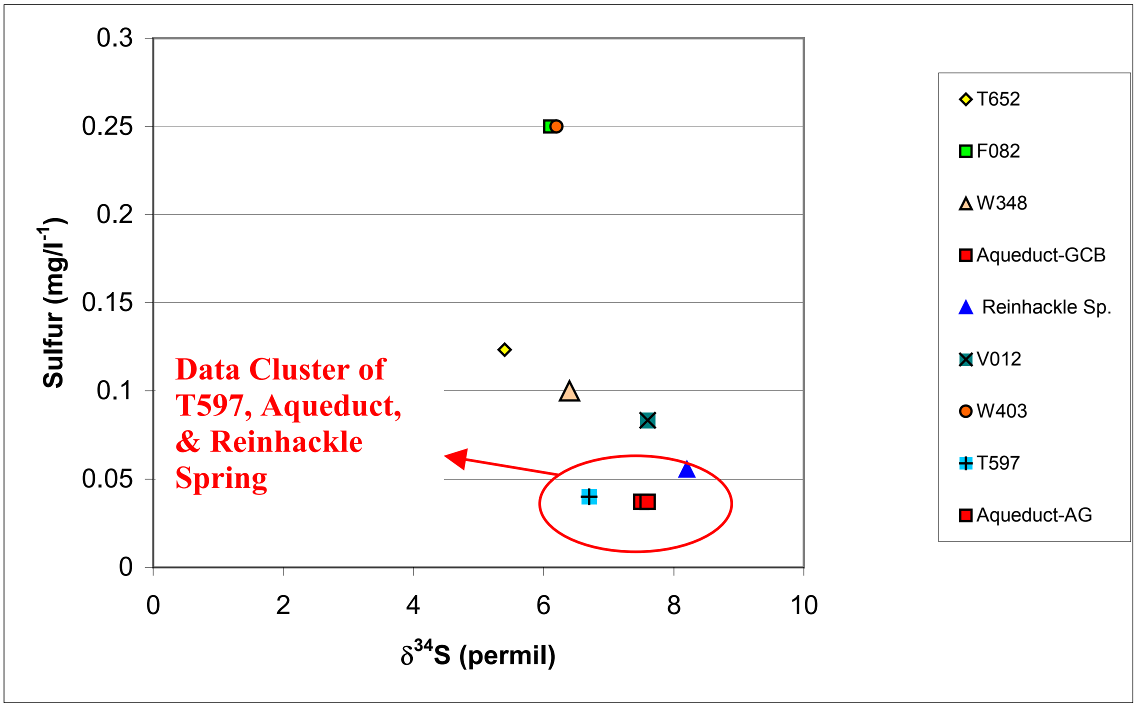
As noted above, shallow well, T652, has a similar boron isotopic signature to the cluster group that includes T597. Well T652 is located close to the Aqueduct but slightly upgradient and may suggest that some Aqueduct influence can be seen upgradient. This scenario would be possible if Aqueduct leakage has created a groundwater mound that provides a local gradient reversal on the west side of the mounded water.

The sulfur isotopic values ($\delta^{34}S$) imply signatures similar to the other isotopic data. The sulfate is derived from oxidation of sulfide minerals, gypsum, and atmospheric sources. Consequently, the sulfur provides a significant distinction among the wells. **Figure 5-11** clearly shows the separation that the deep wells provide, especially wells W403 and F082, by depicting the low sulfate content and slightly depleted isotopic signature. The isotopic sulfate data provide further confirmation of the connection between the Aqueduct and Reinhackle Spring.

Figure 5-11
Isotopic Data for Reinhackle Spring AOI







0.3
0.25
0.2
0.15
0.1
0.05
0
Sulfur (mg/l-1)
0
2
4
6
8
10
δ34S (permil)
Data Cluster of T597, Aqueduct, & Reinhackle Spring
T652
F082
W348
Aqueduct-GCB
Reinhackle Sp.
V012
W403
T597
Aqueduct-AG

Geochemical Modeling

Reaction State Modeling

The reaction state geochemical modeling for the Reinhackle Spring area included six wells in addition to the spring. All seven samples are undersaturated with respect to gypsum and fluorite. All but well T597 are undersaturated with respect to barite, and only the shallow well T597 and Reinhackle Spring is at equilibrium with calcite. The shallow well T597 and Reinhackle Spring have almost identical chemical composition to the Aqueduct samples, and the Aqueduct water is also at equilibrium with calcite. Clay minerals and minerals that would be affected by trace metal concentrations are not considered in this saturation analysis because almost all the trace metal concentrations including aluminum are below detection limits. Uranium is present as a mobile carbonate complex.

Geochemical Mixing Calculations

Reinhackle Spring and the shallow well T597 have identical chemical concentrations. Reinhackle Spring, the shallow well T597, and the Aqueduct are identical, within reasonable analytical error, for the major ions (except for sulfate in the spring) including boron and the isotopic composition. Therefore, no mixing or geochemical reaction calculations were necessary to define the composition of Reinhackle Spring.

Summary

Provided herein is a summary of findings related to the key questions for this AOI.

- *Question No. 1 - Does the chemical or isotopic composition of the spring indicate that recharge from the Aqueduct is a component of spring flow?*

Finding(s)

1. Reinhackle Spring is similar in both chemical and isotopic composition to the sampled Aqueduct water, thereby suggesting that recharge from the Aqueduct is a component of spring flow.
2. Although the composition of Reinhackle Spring is virtually identical to the Aqueduct, the conclusion that the spring exists because of the Aqueduct recharge cannot be made with chemical data alone. The Aqueduct is recharging water to the shallow groundwater and may not be elevating the potentiometric surface to any significant amount beyond a recharge mound below the Aqueduct. The assessment that the groundwater composition is the same as the Aqueduct does not imply that the elevation of the groundwater and thus the discharge rate of the spring are significantly altered because of the Aqueduct. Rather, this assessment primarily establishes a link in flow path between the Aqueduct and the spring.

- *Question No. 2 - Can the composition of surrounding shallow or deep wells be correlated to the spring composition?*

Finding(s)

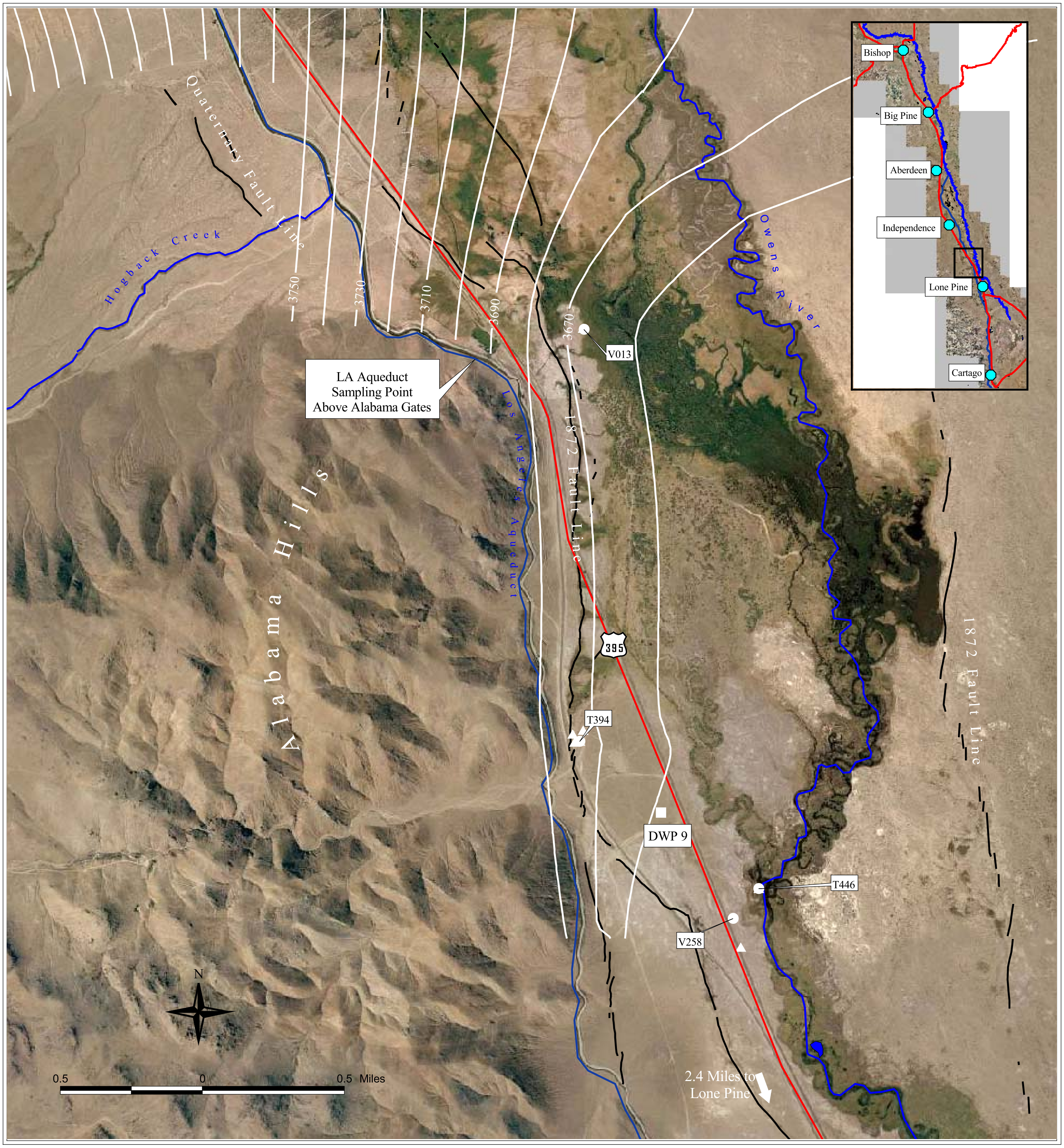
1. The compositions of the surrounding shallow wells and the Aqueduct samples are correlative with Reinhackle Spring's composition. The three samples from the Aqueduct, the shallow well T597, and Reinhackle Spring all have similar chemical compositions. In all five samples, the concentrations of the more chemically conservative elements such as chloride, boron, and bromide are almost identical. In contrast to these five samples, the concentrations of the same conservative elements for the deep wells ranged from two to ten times less.
2. The deep wells should not contain measurable tritium; therefore, the amounts of tritium detected in deep wells create a scientific dilemma. The presence of tritium is not likely a result of sampling error. Furthermore, travel times documented by Danskin (1998) indicate that rapid recharge and transport to the deep aquifer is probably not the cause of measurable tritium. Consideration of surface water recharge from nearby creeks, leakage from the shallow groundwater aquifer, and access to the upper-screened sections of wells does provide an explanation for elevated tritium in the sampled deep wells. The source for the tritium detected in three wells that sample the deeper aquifer is still unverified, but the probable origin is shallow groundwater.

FAULT SCARP SPRING (DWP 9)

The Fault Scarp Spring (DWP 9) AOI and its associated features, including sampling locations (**Table 1-1**) are shown on **Figure 5-12**. In addition, the piezometric surface for April 2002 is shown on this map. DWP 9 discharges from a fault scarp about 2.5 miles north of Lone Pine adjacent to Highway 395. This "spring" was a trench dug perpendicular across the fault scarp as part of a paleoseismology study coincident with the Highway 395 widening project. This location was chosen for sampling over several nearby springs on the fault because the springs had little or diffuse flow through thick vegetation. In contrast, the trench location was a distinct discharge point within the fault. There are no pumping wells in the vicinity; however, two shallow wells (T394 and T446) and two deep wells (V013 and V258) were sampled.

The objective of sampling at this AOI was to answer the following key questions:

- Question No. 1 - Is the spring water composition similar to other fault scarp springs?
- Question No. 2 - Does the composition indicate a source for the water?



Legend

□ Spring

△ Shallow Aquifer Data Point Used to Construct Piezometric Surface

○ Sampled Well

Fault

River

Inyo/LA Geochemical Cooperative Study Final Report

Figure 5-12
Piezometric Surface Map for
Fault Scarp Spring Area of Interest
(DWP 9)(April 2002)

Analytical Data Discussion

The general water type for each sample is illustrated by means of a Stiff Diagram for visual comparison between sampled locations (**Appendix F**), and detailed chemical and isotopic compositions for samples from this location are reported in **Table 3-8**.

The focus of investigation was to consider the geological setting of this spring and its associated hydrogeology and to determine if this spring is similar to other fault scarp springs.

This unusual spring composition is almost identical chemically and isotopically to that of the two nearby shallow wells T394 and T446. The composition is dominated by sodium chloride with high TDS (>500 mg/l). This spring represents groundwater whose origin is difficult to explain given the local geology. The AOI is bounded on the west by the Alabama Hills, which represents an erosional remnant of the granitic rocks of the Sierra Nevada, and on the east by a graben that forms the Owens Valley floor (Hollett et al., 1991). The spring and the closest shallow well (T394) are warm waters with measured temperatures of 23.2 and 27.5 °C, respectively. These temperatures are significantly higher than all other temperatures measured on samples for this project. Furthermore, the concentrations of boron, bromide, fluoride, sodium, and chloride are unusually elevated for the region. The composition is not consistent with the rock type unless it is a mixture of saline water, perhaps related to a hot spring, or water circulating more deeply than the more local mountain front springs allowing for heating and accelerated dissolution of the host rock. Although the shallow wells have lower tritium than the spring, the other isotopic signatures are essentially the same. Well V013, a deep well on the northern edge of the AOI, which is typical of the sodium-bicarbonate type water to the north in the Reinhackle area, is completely different from the spring and shallow well samples within the AOI. Well V258 is on the southern end of the AOI and is compositionally similar to the well V013 deep sample except that the isotope values (e.g., $\delta^{11}B$ of -12.7 ‰) indicate some contribution from another area.

The relationship of the spring and samples wells is shown on **Figure 5-12**. It is not clear exactly where the fault trace occurs in relation to the spring and shallow wells, but the fault spring sample is clearly very different from the more regional samples obtained from the wells V258 and V013, which are probably deriving water from both deep- and shallow-aquifer sources. The most probably scenario is that the water emerging from the fault scarp is from a source deeper than the local groundwater and different from the more regional groundwater upgradient to the north. The shallow wells downgradient are being influenced by the fault scarp discharge, and in the absence of this source, the shallow groundwater would have the commonly observed sodium-calcium-bicarbonate characteristics.

Geochemical Modeling

Reaction State Modeling

The reaction state geochemical modeling for the DWP 9 fault scarp spring AOI includes DWP 9 and four wells (T394, V013, T446, and V258). All five samples were undersaturated with respect to gypsum. The two shallow wells and the spring were in equilibrium with fluorite and calcite, and all are essentially at equilibrium with cristobalite. Clay minerals and minerals that would be affected by trace metal concentrations are not considered in this saturation analysis because almost all the trace metal concentrations including aluminum are below detection limits. Uranium is present as a mobile carbonate complex.

Geochemical Mixing Calculations

There are no pumping wells or upgradient wells that could be used as mixing water compositions to simulate potential source water for the fault spring.

Summary

Provided herein is a summary of findings related to the key questions for this AOI.

- *Question No. 1 - Is the spring water composition similar to other fault scarp springs and does the composition indicate a source for the water?*

Finding(s)

1. The fault scarp spring composition is unique and easily differentiated from the deeper aquifer. The composition is not consistent with a granitoid host rock and is dissimilar from any other spring on the west side of the Valley. The water emerging from the fault scarp is from a source deeper than the local groundwater and different from the more regional groundwater upgradient to the north. The shallow wells downgradient are being influenced by the fault scarp discharge, and in the absence of this source, the shallow groundwater would have the more commonly observed sodium-calcium –bicarbonate characteristics.
2. This spring is an example of a fault-controlled spring in that the flow may actually be emerging at the surface because of the fault. Other springs emerge at the surface in areas where faults exist as partial barriers to flow diverting local groundwater to the surface, and in such cases (e.g., Baker Springs) the nearby groundwater is similar to and the origin of the spring water. In this spring circumstance, the water composition is enigmatic. The fault may be a conduit, and the groundwater similarity is only with downgradient groundwater that is a mixture of the spring water and local upgradient groundwater.
3. The spring temperature and solute load is elevated anomalously. Interpretations would seem to require that the spring is related to the fault, and may in fact represent some upwelling of water derived from hot springs, or perhaps more deeply circulating groundwater that is heated slightly and allowed to react more vigorously with the host rock.

Section 6

Broader Conclusions for the Study

Section 6
Broader Conclusions for the Study

To conclude, the purpose of this study was to examine the geochemical signatures of selected springs and seeps and to compare these signatures to shallow and deep groundwater samples to identify the source of spring/seep water. As such, the Inyo/Los Angeles Technical Group and extended Geochemical Cooperative Study Team were successful in meeting the objective of the study.

A summary of findings for each AOI is presented in Section 5 within the subsection devoted to each individual AOI. However, there are several broader conclusions for the overall Geochemical Cooperative Study that are presented herein.

- The analytes and isotopes selected for the study are appropriate for a study of this scope. The field effort to obtain the required samples was significant, but it was sufficiently well planned such that useful and informative results were obtained.
- Future investigations of this scope should have budget and schedule options that allow for re-sampling of key springs that are dry and key wells that have malfunctioned or may have had water levels too low to sample during the initial field season. It may also be instructive to sample in a winter season to assess base flow compositions for springs that flow all year. Similarly, consideration should be given to sampling the Aqueduct for several key isotopic signatures $\delta^{11}B$, $\delta^{34}S$, δD and $\delta^{18}O$ in addition to the standard selection of analytes currently reported because the isotopic data used here have no historical basis in the Valley.
- Field measurements for dissolved oxygen and oxidation/reduction potential were less reliable than anticipated, in part because of malfunctioning equipment. There were no detrimental consequences because it is now believed that these parameters would not serve as discriminators for the needed spring and seep-source interpretations.
- The stable isotopic values of boron, sulfur, hydrogen, and oxygen are definitive and vary over a large range of values. In the final analysis, it appears that these values were most useful in defining mixing and continuity between aquifers.
- Owens Valley is bounded by batholithic granitic rocks of the Sierra Nevada on the west and Paleozoic sedimentary deposits of the White and Inyo ranges on the east. The chemical and isotopic composition of groundwater and springs is generally what would be expected from these geologic provenances. Nevertheless, on a smaller scale, the chemical and isotopic data are most useful in interpreting local water sources and defining mixing scenarios between shallow and deep aquifers. However, the local-scale compositions should not necessarily be assumed to be unique values for regional scale interpretation. For example, local-scale compositional changes can indicate deeper water influx such as is the case in the Fault Scarp AOI, or in the case where mixing of shallow and deep aquifers occurs because of large screened intervals. This independent chemical data source supplements the hydrogeolgic information routinely collected throughout the Valley.
- The only radioactive isotope collected was tritium, and this isotope proved useful for identifying Los Angeles Aqueduct influence and defining shallow versus deep aquifer samples, with certain exceptions.

- Defining the distinction between shallow and deep aquifers was difficult because the wells that have deep penetration are often screened across both aquifers. It appears from examination of the chemical data and from available well data related to screened intervals that most of the deep wells yield commingled production from the deep and shallow aquifers. By defining the shallow water compositions, it may be possible with additional modeling to employ an inverse approach to describe the deep-aquifer chemical and isotopic characteristics.
- The chemical and isotopic data indicate that several of the wells produce water with unusual characteristics that were contrary to pre-conceived notions about the aquifer. Examples are listed below:
    - A deep flowing well with significantly elevated tritium (F029) in the Fault Scarp Spring (IND102) AOI,
    - Wells with high dissolved solids and water types that are different from surrounding wells. These differences are potentially related to anthropogenic sources or local geological changes as seen in wells F053 and T655 in the Thibaut Springs AOI.
    - Fault spring and nearby shallow wells with compositions that are dissimilar to any other well in the valley as seen in DWP9 and wells T394 and T446 in the Fault Scarp Spring (DWP 9) AOI.
- Future work should include the use of radiogenic isotopes such as ^{36}Cl, especially for complicated circumstances such as the seeps at Thibaut Springs, Wilkerson Springs, AOI deep wells, and anomalous sites. These data would provide a signature of chloride source and also provide an indication of the age of the chloride based on the historical cosmogenic source of ^{36}Cl.

Section 7

References

Section 7
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