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# Groundwater-Surface Water Interactions: Effects of Geothermal Spring Inputs to Jemez River Water Quality

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**Groundwater-Surface Water Interactions:  
Effects of Geothermal Spring Inputs to Jemez River Water Quality**

**by**

**James R. Dyer**



Committee

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A Professional Project Submitted in Partial Fulfillment of the Requirements for the  
Degree of

Masters of Water Resources

Water Resources Program

The University of New Mexico

Albuquerque, New Mexico

March 2007

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The Jemez River, lies within the Valles Caldera and Jemez Mountains, which is located in North Central New Mexico. In the study area, numerous geothermal springs discharge into the Jemez River. A base line water quality study was conducted to determine salt and metal loading effects of spring inputs. Ten sites along a 25-km reach of the river through San Diego Canyon were sampled for major and selected trace element concentrations to evaluate water quality. The Jemez River and geothermal springs were sampled under summer and baseflow conditions in 2006. Hydrothermal water chemistry data collected in the study are consistent with earlier reports of Trainer, 1984, Goff, 1994; Goff and Shevenell, 1987. Hydrothermal inputs examined include Soda Dam, Jemez Springs, and Indian Springs. Jemez River water displays a consistent increase in total dissolved solids (TDS) and metals reflecting significant geothermal inputs between San Antonio Creek and the confluence with the Guadalupe River, and reflecting mixing of a low TDS calcium, magnesium-bicarbonate water with a high TDS sodium chloride water. The Guadalupe River dilutes these contributions; however, concentrations again increase along the Jemez River between the Guadalupe and San Ysidro. Loading calculations for TDS and arsenic under a variety of flow regimes typical of the Jemez River indicate that the allowable limits are exceeded for these parameters between Soda Dam and the Guadalupe River beginning at discharges below 27.5 ft<sup>3</sup>/sec as measured at the USGS gauging station near Jemez Springs. In 2006, flows were below this threshold value for many days.

Note: This report is the Professional Project of James Dyer, submitted in partial fulfillment of the requirements for the Master of Water Resources degree at the University of New Mexico. This project was supervised and approved by the following committee: Dr. Laura Crossey, Department of Earth and Planetary Sciences, UNM (Chair); Dr. Abdul-Mehdi Ali, Department of Earth and Planet Sciences, UNM; and Dr. Bruce Thomson, Department of Civil Engineering and Water Resources Program, UNM.

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## Acknowledgments

I would like to thank...

Dr. Laura Crossey for her direction and interest in this project, Dr. Abdul-Mehdi Ali for his patience and sharing laboratory knowledge, and Dr. Bruce Thomson's willingness to collaborate with me and my project.

My parents, Vivian and David Dyer, for all the support in my academic pursuits.

Everyday, walking to UNM, I think to myself how blessed I am to have parents like you who play such an important role in my life.

Allison and Jeff Stevens for always being there whenever I needed a true friend to talk to.

Eileen Embid for all her help with GIS mapping for my project. Johanna Blake, Kim Gugliotta, and Matt Kirk for all the help and direction in the E&PS laboratory.

All my friends in the Water Resources Program for their friendship while in the WR program.

## 1. Introduction

The Jemez River, lies within the Valles Caldera and Jemez Mountains which is located in North Central New Mexico. The Valles Caldera lies at the intersection of two major geologic features, the Rio Grande Rift and the Jemez lineament and is a Quaternary silicic volcanic complex containing a well-studied liquid-dominated geothermal resource (Goff, 2002). The study area consists of volcanic rocks of basaltic to rhyolitic composition that overlie Tertiary to Paleozoic sediments on the western margin of the Rio Grande rift (Shevenell et al, 1987). The Jemez River head-waters originate near Redondo Peak, flow through Battle Ship Rock, Soda Dam, Jemez Springs, and Jemez Pueblo eventually reaching the Rio Grande about 10 miles north of Bernalillo, New Mexico.

In the study area, geothermal fluids percolate through the faults towards the surface and form numerous springs. These springs are located throughout the Jemez River watershed, and upon reaching the surface, the springs form travertine deposits. Soda Dam is a calcium carbonate travertine deposit built by presently active hot springs originating from the geothermal system outside the Valles Caldera (Goff and Shevenell, 1987). The Jemez Springs consist of approximately 10 springs flowing through fractures associated with the Jemez Fault (Purtymun, 1974). Due to the salt and metal loading from these springs, a base line water quality study was conducted to determine salt and metal loadings along the Jemez River. The objectives of the study were to investigate the hydrothermal impacts on water chemistry/quality and estimate the metal and salt load input into the Jemez River.

## **2. Hydrologic Setting**

The Jemez River watershed area is approximately 560 square miles. At Battleship Rock, the Rio San Antonio and East Fork-Jemez meet to form the Jemez River. Below Jemez Springs, the Rio Guadalupe flows into the Jemez River (figure 1) and increases the discharge by about forty percent. In 2006 the average mean flow for the Jemez River was  $37.9 \text{ ft}^3/\text{sec}$  (USGS, 2006). Typically, the Jemez River has high peak flows in the monsoon months (July-August) and low peak flows during the winter months (USGS, 2006). Designated usages of the Jemez River are divided up into three reaches. Above Soda Dam, Jemez River water is used to support domestic water supply, high quality coldwater aquatic life, fish culture, irrigation, and live stock watering. Between Jemez Pueblo and Soda Dam, river water is used to support coldwater aquatic life, irrigation, livestock watering, and wildlife habitat. Below the Jemez Pueblo, Jemez River water usage includes irrigation, livestock watering, and wildlife habitat.

## **3. Materials and Methods**

### **3.1 Field Methods**

A total of ten sites were sampled (map 1), and GPS readings were recorded for each site. Sites were chosen above and below Soda Dam and Jemez Springs to determine salt and metal loading effects along the Jemez River. Water sampling and preservation were performed according to standard USGS procedures (USGS, 2002). Field measurements of temperature, turbidity, hydraulic conductivity, and pH were determined using a multi-electrode meter (table 1). There were a total of three sampling dates 8/15/06, 9/12/06, and 10/25/06. On each of these dates, two samples were collected at



each site, a raw sample along with a second sample that was filtered through a .045 µm filter and acidified with nitric acid. Both filtration and acidification were performed in the field.

### **3.2 Laboratory Methods**

Alkalinity was determined by acid titration (Standard Methods for the Examination of Water and Wastewater, 1976). A .020N sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) solution was used to determine the alkalinity for river samples, and a 0.200N sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) solution was used to determine alkalinity for spring samples. The alkalinity was determined for each sampling date at each site (table 2).

Ion chromatography (IC) was used to determine common anions (table 2) and Inductive Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES) was used to determine cations and metals in samples (table 3). Due to expected high concentration of analytes in spring samples, these samples were diluted by a factor of ten before analysis. The ICP-AES was used to determine arsenic concentration for spring water samples because they were within detection limits of the instrument. The hydride generation system (FIAS-400) was used to determine arsenic concentrations for Jemez River water samples because their concentration were below the detection limits of ICP-AES. These samples were diluted one to six before analysis.

Data were validated by implementing quality control (QC) measures to assure accurate and precise results. A blank and three calibration standards were used to calibrate each instrument. Initial Calibration Blank Verification (ICBV) and Initial Calibration Verification (ICV) solutions were used to verify calibration accuracy. Continuing Calibration Verification (CCV) solution at different concentration from ICV

and calibration standards were used to verify instrument stability and calibration drift. Matrix spikes were used to verify matrix interferences during analysis. The above are accuracy measurements where as sample(s) and matrix spike duplicates were used to determine precision during analysis. Based on these QC measures the data were determined to be verified and validated for reporting.

### **3.3 Data Interpolation**

A Piper diagram was used to provide visual composition of major ion chemistry (Drever, 1997). The piper diagram was constructed by plotting the equivalents of major cations [Ca, Mg, (Na+K)] on one triangular diagram, and plotting the equivalents of major anions (alkalinity, chloride, and sulfate) on the other triangular diagram.

The geochemical, modeling program PHREEQE was run for each of the sampling sites to determine any relationships between spring and river waters. The PHREEQE program was used to determine the saturation index (SI) for calcite, CO<sub>2</sub>, and quartz (Parkhurst et al., 1980). If the SI is equal to zero, then equilibrium is reached. If SI is less than zero, the solution is under-saturated, and if SI is greater than zero, the solution is saturated with respect to calcite, CO<sub>2</sub>, and quartz.

## **4. Results**

### **4.1 Cations**

Cation concentrations used were measured during the sampling session conducted on 10/25/06. Anions and cations water balance was calculated for each sampling date to ensure data accuracy and reliability (table 2). Data suggests a general trend of lower concentrations of cations above Soda Dam and higher concentrations downstream. This

was due to the spring water input of Soda Dam, Jemez Springs, and Indian Spring (Figures 1, 2, 3, 4). Calcium, potassium, magnesium, and sodium all displayed similar concentration trends in the Jemez River. There were reasonable low concentrations of cations (<25 mg/L) in the Rio San Antonio and the East Fork (table 2). Due to the input of spring water from Soda Dam, there was a noticeable increase in the cation concentrations in the Jemez River (Figures 1,2,3,4, 15). From spring water inputs, calcium and sodium concentrations in the Jemez River below Soda Dam increased approximately 3 times, potassium 7 times, and magnesium 2 times (table 2). Due to spring water inputs from Jemez Springs, there was a slight increase of cation concentrations in the Jemez River (Figures 1, 2, 3, 4, 15). Just below the confluence of the Jemez River and the Rio Guadalupe, the calcium and magnesium increased. On other hand, potassium and sodium concentrations were lower below the confluence. As a result of these inputs from Indian Springs, the concentrations of calcium, potassium, magnesium, and sodium in the Jemez River increased (Figures 1, 2, 3, 4).

## **4.2 Anions**

The chloride and bromide concentration increased in the Jemez River downstream from Battleship Rock. Chloride and bromide displayed similar concentration trends in the Jemez River. The Rio San Antonio and East Fork had reasonably low concentrations (< 7 mg/L) of chloride and (< 0.03 mg/L) of bromide (table 2). Due to the input of Soda Dam spring water, there was a noticeable increase of anions chloride and bromide in the Jemez River (figure 6, 15 & 7, 16). Downstream from Soda Dam, chloride concentrations increased by approximately 15 times and bromide by 10 times (table 2). The

concentrations of chloride and bromide decreased slightly below Jemez Spring and continued to decrease below the Rio Guadalupe and Jemez River confluence. On the other hand, the concentration of chloride and bromide increased below Indian Springs (table 2).

The concentration for fluoride in the Jemez River stayed reasonably constant (Figure 8, 16). The concentration of fluoride in the Rio San Antonio was 1.3 mg/L and .97 mg/L in the Jemez River at San Ysidro. Soda Dam and Jemez Springs waters had almost 3 times the concentration of fluoride than the Jemez River (table 2). There was an increase of fluoride concentration from the input at Indian Springs. The concentration of fluoride at Indian Springs was nearly 6 times greater in the spring water than in the Jemez River.

The concentration of sulfate in the Jemez River increased slightly downstream from Battleship Rock (graph 9, 15). The concentration of sulfate in the Rio San Antonio was 16 ppm and 2 ppm in the East Fork. The concentration decreased by 5 ppm from above Soda Dam to below the springs. Sulfate concentration in the Soda Dam Spring is nearly 4 times greater than that within the Jemez River water sampled (table 2).

Compared to sulfate concentration above Soda Dam, the concentration increased slightly to 12 ppm below Jemez Springs (table 2). The concentration also decreased at the confluence of the Rio Guadalupe and Jemez River and then increased below Indian Springs (graph 6). Nitrate concentrations in the Jemez River were not affected by spring inputs (graph 10) (table 2).

### **4.3 Bicarbonate**

Downstream from Battleship Rock, the concentration of bicarbonate ( $\text{HCO}_3$ ) increased in the Jemez River (figure 12, 15). The concentration of bicarbonate in the Rio San Antonio was 75 ppm and 59 ppm in the East Fork (table 2). The concentration increased approximately by 100 ppm from above Soda Dam to below Soda Dam (table 2). The concentration of bicarbonate in the Soda Dam spring was nearly 6 times greater than that within the Jemez River water (table 2). Compared to bicarbonate concentration above Soda Dam, the bicarbonate concentration decreased slightly from 194 mg/L to 188 mg/L below Jemez Springs (table 2). Once below Jemez Springs the concentration of bicarbonate began to increase downstream. Indian Spring's bicarbonate concentration of 1,269 mg/l increased the Jemez River's bicarbonate concentration by 50 mg/L at San Ysidro.

#### **4.4 Arsenic**

Arsenic (As) concentrations in the Jemez River increased downstream due to spring input (Figure 13). Rio San Antonio and East Fork had arsenic concentrations of 4.6  $\mu\text{g/L}$  and 4.1  $\mu\text{g/L}$  respectively (table 6). Soda Dam spring water concentration of arsenic was around 1300  $\mu\text{g/L}$ , and this arsenic concentration input increased the Jemez River arsenic concentration to 102  $\mu\text{g/L}$  below Soda Dam (table 6). Even though the arsenic concentration in Jemez Spring waters was 813  $\mu\text{g/L}$ , the Jemez River arsenic concentration decreased from below Soda Dam to below Jemez Springs. This decreasing arsenic concentration trend continued downstream to San Ysidro.

## **5. Discussion**

### **5.1 Metal and Salt Load Calculations**

The discharge of the Jemez River is monitored by a USGS gauging station below the confluence of the Rio Guadalupe. There is no present gauging station for the Rio Guadalupe or the Jemez River above Jemez Springs. This presents a problem when determining the metal or salt load input upstream. The average discharge ( $\text{ft}^3/\text{sec}$ ) for the Jemez River and Rio Guadalupe was obtained by using the daily mean discharge data for 10/25/1993, 10/25/1994, and 10/25/1995 (USGS, 2006). These hydrographs were chosen because after 1995, the gauging station on the Rio Guadalupe was shut down. From this data, it was determined that the Rio Guadalupe results in about 39 percent of the flow into the Jemez River at the above specified confluence. This percentage was used to estimate the discharge of the Rio Guadalupe, the Jemez River upstream from the gauging station, the Rio San Antonio, and the East Fork. Jemez River discharge values were converted from  $\text{ft}^3/\text{sec}$  to liter/sec (table 4).

Spring discharge values collected by Trainer from 1973-1974 were used for Soda Dam and Jemez Springs (Trainer, 1984). Spring discharge values from January 1999 for Indian Springs and test well were also used (Witcher, 2004). These spring and river discharge values were used in the equation to determine salt and metal loading concentrations at each site (table 4 and 5).

$$[(\text{discharge liter/sec} * \text{Conc. mg/liter}) = \text{Total load in mg/sec}]$$

A mass balance was performed to determine if all inputs from springs to the Jemez River were accounted for. Results from the mass balance suggest that there are other inputs besides Soda Dam, Jemez Springs, and Indian Springs. These other inputs would influence the estimated discharge values to where the cation, anion, arsenic, and bicarbonate loading in the Jemez River would be over or underestimated (table 4 & 5).

## 5.1 Estimated Cation Loading

Due to all spring inputs, the cation loading (mg/sec) downstream in the Jemez River increased (table 5). Calcium, potassium, magnesium, and sodium displayed similar loading trends in the Jemez River (graph 5). The calcium load input at Soda Dam was 5,923 mg/sec and 2,615 mg/sec at Jemez Springs (table 5). Calcium concentrations at Soda Dam were approximately 7 times higher than the Jemez River concentration (table 4). Above Soda Dam, calcium loading concentrations of 5,759 mg/sec were estimated. This estimated calcium load increased to 19,323 mg/sec below Soda Dam. There was an 11 percent increase in the estimated loading of calcium between Soda Dam and below Jemez Springs. Due to spring water input at Indian Springs, the calcium loading concentration continued to increase by 53 percent at San Ysidro.

The potassium loading in the Jemez River increased from 1,220 mg/sec above Soda Dam to 8,087 mg/sec below Soda Dam. Estimated potassium loading at Soda Dam spring water was 4,785 mg/sec and 1,719 mg/sec at Jemez Springs (table 5). In the Jemez River the estimated potassium loading increased by 33 percent from below Jemez Springs to San Ysidro (table 5).

The concentration of magnesium at Soda Dam was nearly five times greater than Jemez River samples (table 5). The magnesium load input at Soda Dam was 533.3 mg/sec and 98.9 mg/sec at Jemez Springs (table 5). The Jemez River magnesium load increased from 1,284 mg/sec above Soda Dam to 2,310 mg/sec below Soda Dam. There was an additional magnesium loading increase from 2,310 mg/sec below Soda Dam to 2,406 mg/sec below Jemez Springs. The loading concentration of magnesium continued to increase by 58 percent from below Jemez Springs to San Ysidro (table 5).

The sodium load input at Soda Dam was 1143 mg/sec and 735 mg/sec at Jemez Springs (table 5). The sodium loading in the river increased from 11,511 mg/sec above Soda Dam to 49,657 below Soda Dam. From below Soda Dam to below Jemez Springs, the sodium loading increased by approximately 5,048 mg/sec (table 5). From below Jemez Springs to San Ysidro, sodium loading increased by 50 percent (table 5).

## **5.2 Estimated Anion Loading**

Chloride, bromide, fluoride, and sulfate exhibited similar anion loading rates into the Jemez River (graph 11). There was a higher load of chloride, bromide, fluoride, and sulfate in the Rio San Antonio compared to the E. Fork (graph 11). Soda Dam anion loading into the Jemez River was 52,608 mg/sec for chloride, 226 mg/sec for bromide, 83 mg/sec for fluoride, and 989 mg/sec for sulfate. This load rate increased the over all load in the Jemez River. Chloride loading increased from 2,851 mg/sec above Soda Dam to 84,177 mg/sec below Soda Dam (table 4). Bromide loading increased from 5.7 mg/sec above Soda Dam to 217 mg/sec below Soda Dam (table 4). Fluoride loading increased from 472 mg/sec above Soda Dam to 542 mg/sec below Soda Dam (table 4). Sulfate loading increased from 5,113 mg/sec above Soda Dam to 6,509 mg/sec below Soda Dam Spring (table 4). The loading from Jemez Springs was estimated at 22,221 mg/sec for chloride, 67 mg/sec for bromide, and 813 mg/sec for sulfate. The Jemez Springs and Indian Springs load contribution of chloride, bromide, fluoride, and sulfate into the Jemez River increased the loading of all four anions below Jemez Springs to San Ysidro.

The Jemez River nitrate ( $\text{NO}_3$ ) loading values at the Rio San Antonio and E. Fork were greater than Soda Dam Spring and Jemez Springs. Soda Dam input was nearly 40 times greater than Jemez Springs loading. The nitrate load increased from 66 mg/sec



above Soda Dam to 206 mg/sec below Soda Dam. This load increase is slightly misleading because the increase is mostly due to the large discharge value below Soda Dam. Due to Jemez Springs minor input of nitrate, the loading decreased by 180 mg/sec below Jemez Springs. The Jemez River load of nitrate increased from 20 mg/sec below Jemez Springs to 183 mg/sec in San Ysidro.

### **5.3 Estimated Bicarbonate Loading**

Downstream from Battleship Rock, there was a general increasing trend of the bicarbonate loading in the Jemez River (graph 11). The bicarbonate load increased from 36,341 mg/sec above Soda Dam to 109,845 mg/sec below Soda Dam. The estimated loading from Soda Dam was 29,593 mg/sec and 16,139 from Jemez Springs. The over all load of bicarbonate in the Jemez River increased by 894 mg/sec due to Jemez Springs. The Indian Spring contributed 21,055 mg/sec to increase the bicarbonate loading by 20 percent above Indian Spring to San Ysidro.

### **5.4 Estimated Arsenic Loading**

Arsenic loading was minimal in the Rio San Antonio and East Fork (table 6) (graph 14). Input from Soda Dam spring water increased the arsenic loading rate in the Jemez River by 44.6 m/sec (table 6). The loading below Soda Dam was 57.9 mg/sec and 57.4 mg/sec below Jemez Springs. Just below the confluence of the Rio Guadalupe and Jemez River, the loading of arsenic was highest at 71 mg/sec. Even with aresnic loading input from Indian Spring, the loading in the Jemez River decreased to 58.3 mg/sec at San Ysidro.

### **5.5 Piper Diagram and Modeling**

The spring waters were primarily sodium type and chloride type (piper diagram 1) (Drever, 1997). The Jemez River waters above Soda Dam had no dominant type for the cations but were primarily bicarbonate type for anions (piper diagram 1). The Jemez River downstream from Soda Dam was mostly sodium type for cations and bicarbonate type for anions (piper diagram 1). Due to the springs input, the Jemez River waters downstream became less bicarbonate dominate and more chloride driven.

Results from PHREEQE were run for the third round of sampling only. Soda Dam and Jemez Springs were saturated with respect to calcite (table 2). The Jemez River was only saturated with respect to calcite at site JR SpQ and JR B Guad (table 2). All Jemez River water samples were saturated with respect to quartz. Soda Dam and Jemez Springs were under-saturated with respect to quartz. Samples collected above Soda Dam had similar  $p\text{CO}_2$  of that of the atmosphere  $10\text{e-}3.35$ . Sampling sites below Soda Dam and Jemez Springs had higher  $p\text{CO}_2$  values (table 2). The higher value of dissolved  $\text{CO}_2$  in the Jemez River was the result from the inputs from Soda Dam and Jemez Springs.

Data obtained from water sample analysis implied that cation, anion, and trace elements concentrations in the Jemez River were elevated due to the inputs from Soda Dam, Jemez Springs, and Indian Springs. The lower the flow in the Jemez River the greater the water chemistry would be influenced by the springs. During drought conditions, the flow in the Jemez River can go as low as  $5.4 \text{ ft}^3/\text{sec}$  (USGS, 2006). At this discharge, Soda Dam and Jemez Springs play a major role in determining the over all water chemistry of the Jemez River.

For a  $5.4 \text{ ft}^3/\text{sec}$  discharge in the Jemez River at the USGS gauging station, a concentration of  $777 \text{ mg/l}$  of chloride in the Jemez River below Soda Dam was estimated.

Impacts of Soda Dam on the Jemez River water quality were greater than Jemez Springs because Soda Dam is nearly twice as mineralized as Jemez Springs (Trainer, 1984). This concentration would exceed the recommended EPA secondary drinking water regulations of 250 mg/l. Below Jemez Springs, a concentration of 828 mg/l of chloride was estimated, which would also exceed the standard. Any discharge below 17 ft<sup>3</sup>/sec in the Jemez River would induce a concentration of chloride that would exceed the drinking water standard. In the past 25 years, the discharge of the Jemez River has reached this discharge 566 times. So, based on these calculations, the Jemez River during these low discharge values would not meet the recommended chloride EPA secondary drinking water standard.

Even though sulfate concentrations do not exceed the secondary drinking standards; sulfate is a contributor to the overall total dissolved solids concentration. During drought conditions (5.4 ft<sup>3</sup>/sec) in the Jemez River, there would be a 12.4 mg/L sulfate concentration below Soda Dam and a 14.2 mg/l below Jemez Springs. The estimated sodium concentration during low flow would be 433 mg/L below Soda Dam and 511 mg/L below Jemez Springs. By combining the chloride, sulfate, and sodium concentration, the TDS can be estimated. The TDS estimated below Soda Dam during drought conditions was estimated at 1230 mg/L and 1363 mg/L below Jemez Springs. This TDS estimated exceeds the recommended EPA drinking water standard of 500 mg/L. In the Jemez River system, chloride contributes the most and sulfates the least to the TDS.

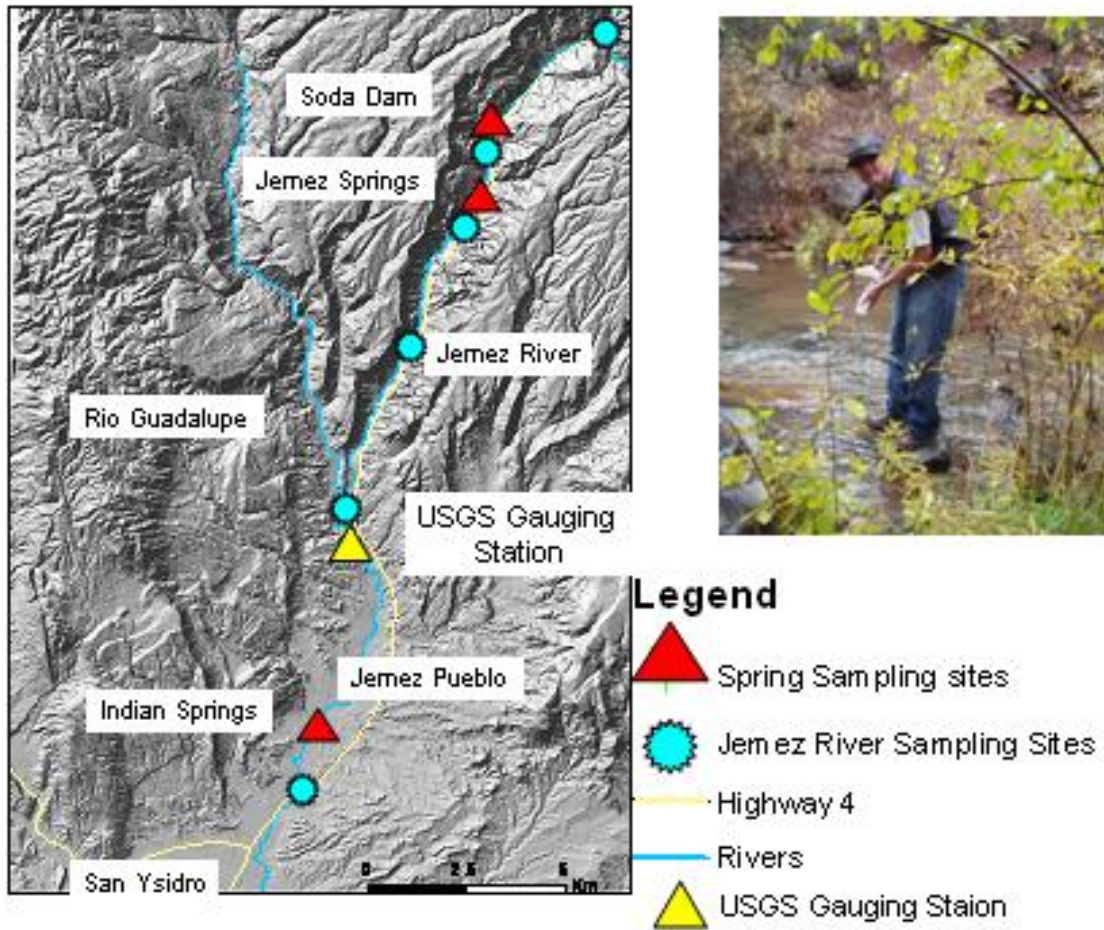
Continuing with a low flow of 5.4ft<sup>3</sup>/sec, an arsenic concentration of 250 µg/L was estimated below Soda Dam. This concentration would exceed the new EPA standard

of 10 µg/L. Below Jemez Springs, the concentration of arsenic estimated at this discharge would be 0.154 mg/L or 154 µg/L which also exceeds the EPA drinking water standard. A discharge of 360 ft<sup>3</sup>/sec in the Jemez River would have an estimated concentration just below the .01 mg/L EPA drinking water standard. Even though this is estimated number, water with arsenic levels such as these, if used for drinking water, could cause skin damage and problems with the circulatory systems. Most of the arsenic contributed into the Jemez River is from geothermal processes and erosion from natural deposits. One plausible explanation for arsenic in solution decreasing downstream from the springs is from absorption to iron-oxides. More detailed information can be found in Ferguson and Gavis's review on the arsenic cycle in natural waters (Ferguson and Gavis, 1972).

## **5. Conclusions**

The Jemez River is an important resource for residents, fishermen, and the people of the Jemez Pueblo. The effects of spring water inputs on water quality of the Jemez River are an important issue to be explored. All data collected and analysis performed suggest that geothermal springs do in fact affect the water chemistry of the Jemez River. Further monitoring of Soda Dam and Jemez Springs inputs could lead to determining the effects of the seasonal changes, on the Jemez River. More data needs to be collected during high flow months to compare to already existing data for implications of a seasonal correlation.

## 6. Maps and Tables



**Table 1 Locations and Field Parameters**

Site Code	Sites 8/15/06	Sampling Round	SPL ID	Latitude	Longitude	Temp_C	pH	Cond_µS	TDS_ppm
JR SA	Rio San Antonio at Battleship Rock	1	JD-06-JR-10	351524	3965959	20	8.3	124.5	62.3
JR EF	East Fork Jemez at Battleship Rock	1	JD-06-JR-09	351547	3965883	17.6	7.93	76.7	38.9
I SD a	Spring #1 across from Soda Dam	1	JD-06-JR-06	347565	3962028	37.7	6.25	6570	3260
I SD b	Soda Dam Spring inside cave	1	JD-06-JR-07	347692	3961960	33.8	7.22	7470	3720
JR BSD	South of Soda Dam	1	JD-06-JR-08	347562	3961883	18.5	6.95	379	188
I JS	The Bath House Spring	1	JD-06-JR-04	347182	3959793	70.5	6.65	4520	2260
JR BUS	Jemez Springs Bridge South of Bath House	1	JD-06-JR-05	347080	3959708	18.6	7.25	436	209
JR SpQ	Jemez River at Spanish Queen	1	JD-06-JR-03	344782	3954566	18	8.21	406	234
JR B Guad	Bridge where the Guadalupe and Jemez River	1	JD-06-JR-02	342190	3948390	19.2	8.17	504	249
JR SY	Jemez River in San Ysidro	1	JD-06-JR-01	340697	3937833	23.5	7.87	514	256

Site Code	Sites 9/12/06	Sampling Round	SPL ID	Latitude	Longitude	Temp_C	pH	Cond_µS	TDS_ppm
JR SA	Rio San Antonio at Battleship Rock	2	JD-06-JR-10	351524	3965959	14.8	8.22	140.5	70.1
JR EF	East Fork Jemez at Battleship Rock	2	JD-06-JR-09	351547	3965883	15	8.22	90.6	45.2
I SD a	Spring #1 across from Soda Dam	2	JD-06-JR-06	347565	3962028	31.4	6.89	6630	3290
I SD b	Soda Dam Spring inside cave	2	JD-06-JR-07	347692	3961960	32.8	7.34	6900	3480
JR BSD	South of Soda Dam	2	JD-06-JR-08	347562	3961883	16.5	7.11	660	332
I JS	The Bath House Spring	2	JD-06-JR-04	347182	3959793	69.3	6.5	4400	2200
JR BUS	Jemez Springs Bridge South of Bath House	2	JD-06-JR-05	347080	3959708	16.7	7.51	679	342
JR SpQ	Jemez River at Spanish Queen	2	JD-06-JR-03	344782	3954566	15.9	8.4	665	333
JR B Guad	Bridge where the Guadalupe and Jemez River	2	JD-06-JR-02	342190	3948390	15.6	8.4	634	322
JR SY	Jemez River in San Ysidro	2	JD-06-JR-01	340697	3937833	18.3	7.91	944	483

Site Code	Sites 10/25/06	Sampling Round	SPL ID	Latitude	Longitude	Temp_C	pH	Cond_µS	TDS_ppm
JR SA	Rio San Antonio at Battleship Rock	3	JD-06-JR-10	351524	3965959	7	8.02	128	64.6
JR EF	East Fork Jemez at Battleship Rock	3	JD-06-JR-09	351547	3965883	7	8.03	56.4	28.5
I SD a	Spring #1 across from Soda Dam	3	JD-06-JR-06	347565	3962028	29	7.08	5120	2520
I SD b	Soda Dam Spring inside cave	3	JD-06-JR-07	347692	3961960	32	7.34	5050	2540
JR BSD	South of Soda Dam	3	JD-06-JR-08	347562	3961883	8	6.76	626	310
I JS	The Bath House Spring	3	JD-06-JR-04	347182	3959793	69	6.75	2160	1070
JR BUS	Jemez Springs Bridge South of Bath House	3	JD-06-JR-05	347080	3959708	9	7.41	590	297
JR SpQ	Jemez River at Spanish Queen	3	JD-06-JR-03	344782	3954566	9	8.29	546	274
JR B Guad	Bridge where the Guadalupe and Jemez River	3	JD-06-JR-02	342190	3948390	8	8.19	350	172
JR SY	Jemez River in San Ysidro	3	JD-06-JR-01	340697	3937833	8.0	7.61	418	236

Table 2 Major Ions, Charge Balance and Saturation Index

Site Code	Sample Round	mg/L														Charge Balance	
		F	Cl	NO2	Br	NO3	PO4	SO4	CO3	HCO3	Ca	K	Mg	Na	%		
JR SA	1	0.902	7.07	0.03	0.031	5.54	<0.1	21.7	0.00	76.3	16.4	3.18	2.89	19.5	-1.28		
JR EF	1	0.978	10.7	0.04	<0.05	5.45	0.19	8.44	0.00	50.0	10.7	3.10	2.45	9.83	-7.47		
1 SD a	1	2.64	1298	<0.02	5.49	0.18	<0.1	33.8	0.00	1488	120	131	25.1	766	-16.1		
1 SD b	1	2.67	1717	<0.02	7.07	1.18	<0.1	33.9	0.00	1232	231	181	24.2	1036	-4.76		
JR BSD	1	0.908	40.8	0.09	0.114	7.75	<0.1	16.2	0.00	108	21.7	7.94	3.23	40.2	-2.03		
1 JS	1	5.02	980	<0.02	2.79	0.038	<0.1	37.0	0.00	695	108	73.6	4.52	633	-6.5		
JR BJS	1	1.11	34.6	0.08	0.092	7.44	0.13	14.2	0.00	117	23.9	8.19	3.27	47.0	4.72		
JR SpQ	1	1.12	40.1	<0.02	0.093	5.21	<0.1	15.5	0.00	132	26.7	8.44	3.68	47.1	1.63		
JR B Guad	1	1.05	44.3	<0.02	0.097	6.23	<0.1	13.3	0.00	147	30.8	7.86	3.98	47.3	0.37		
JR SY	1	0.841	42.40	<0.02	0.110	5.98	<0.1	13.1	0.00	172	32.4	6.74	4.99	47.6	-1.83		

Site Code	Sample Round	mg/L														Charge Balance	
		F	Cl	NO2	Br	NO3	PO4	SO4	CO3	HCO3	Ca	K	Mg	Na	%		
JR SA	2	0.719	4.02	<0.02	<0.05	0.072	<0.1	10.2	0.00	81.1	15.0	2.68	2.78	25.7	12.1		
JR EF	2	0.361	4.4	<0.02	<0.05	0.058	<0.1	2.2	0.00	59.8	9.54	2.11	2.41	16.7	10.8		
1 SD a	2	2.28	1576.02	<0.02	5.18	0.031	<0.1	51.6	0.00	1080	252	168	23.2	1121	3.18		
1 SD b	2	3.01	1803.99	<0.02	7.65	0.719	<0.1	32.8	0.00	1281	268	170	21.6	1037	-5.95		
JR BSD	2	0.867	108	<0.02	0.276	0.027	<0.1	9.32	0.00	172	33.7	13.9	4.12	84.7	-0.54		
1 JS	2	4.95	990	<0.02	2.97	<0.02	<0.1	35.2	0.00	701	114	73.6	4.23	755	0.4		
JR BJS	2	0.882	111	<0.02	0.259	<0.02	<0.1	9.98	0.00	176	36.3	13.2	4.11	88.3	0.3		
JR SpQ	2	0.863	115	<0.02	0.265	0.313	<0.1	10.2	0.00	188	37.7	13.2	4.5	91.5	-0.28		
JR B Guad	2	0.83	97.9	<0.02	0.23	0.103	<0.1	9.71	0.00	189	39.1	11.3	4.75	80.2	0.06		
JR SY	2	0.095	122	<0.02	0.289	0.093	<0.1	17.7	0.00	247	46.2	63.5	5.99	108	7.34		

Site Code	Sample Round	mg/L														Charge Balance	
		F	Cl	NO2	Br	NO3	PO4	SO4	CO3	HCO3	Ca	K	Mg	Na	%		
JR SA	3	1.30	7.07	<0.02	0.021	0.196	<0.1	16.2	0.00	75.7	13.2	2.54	2.53	24.5	3.91		
JR EF	3	0.455	3.51	<0.02	<0.05	0.052	<0.1	2.74	0.00	59.2	8.15	1.99	2.25	18.2	10.9		
1 SD a	3	2.79	1382	<0.02	5.58	0.143	<0.1	55.5	0.00	1452	266	154	23.3	954	-2.85		
1 SD b	3	3.34	2104	<0.02	9.05	1.57	<0.1	39.6	0.00	1184	237	191	21.3	1143	-7.89		
JR BSD	3	0.961	149	<0.02	0.385	0.366	<0.1	11.5	0.00	195	34.2	14.3	4.09	86.0	-10.4		
1 JS	3	5.07	966	<0.02	2.9	0.059	<0.1	35.4	0.00	702	114	74.8	4.21	735	0.12		
JR BJS	3	0.986	128	<0.02	0.316	0.034	<0.1	12.0	0.00	189	37.0	14.1	4.10	93.1	-2.94		
JR SpQ	3	1.06	137	<0.02	0.311	0.091	<0.1	11.8	0.00	204	41.1	14.9	4.70	102	-1.8		
JR B Guad	3	0.889	106	<0.02	0.239	0.105	<0.1	10.2	0.00	202	42.6	11.8	4.97	82.8	-0.99		
JR SY	3	0.978	124	<0.02	0.287	0.189	<0.1	17.6	0.00	253	46.9	12.7	5.90	111	-0.64		

\* Saturation Index Calculated for Third Round of Sampling Only

**Table 3**  
**Metals and Trace Metals**

Conc. mg/L	Ag	Al	As	B	Ba	Be	Ca	Cd	Co	Cr	Cu	Fe	K	Li	Mg	Mn	Na	Ni	Pb	Se	Si	Sr	V	Zn	SiO <sub>2</sub>
<b>Sampling Sites</b>																									
JR SY	<.05	0.014	<.05	0.257	0.182	<.01	37.6	<.01	<.05	<.025	0.003	<.01	63.6	0.953	5.99	<.03	108	<.10	<.05	<.10	20.5	0.286	<.10	<.50	43.9
JR B Guard	<.05	0.605	<.05	0.493	0.137	<.01	35.7	<.01	<.05	<.025	0.002	0.016	11.4	0.872	4.75	<.03	80.3	<.10	<.05	<.10	22.2	0.168	<.10	<.50	47.4
JR SpQ	<.05	0.133	<.05	0.448	0.114	<.01	30.0	<.01	<.05	<.025	0.214	0.375	8.8	0.904	3.73	<.03	51.6	<.10	<.05	<.10	23.7	0.12	<.10	<.50	50.7
I.S	<.05	0.043	0.828	8.00	0.274	<.01	119	<.01	<.05	<.025	<.05	0.046	75.9	11.3	4.58	0.109	674	<.10	<.05	<.10	45.1	0.484	<.10	<.50	96.4
JR BJS	<.05	0.192	<.05	0.484	0.111	<.01	26.9	<.01	<.05	<.025	<.05	0.148	8.77	0.511	3.32	<.03	51.08	<.10	<.05	<.10	23.5	0.111	<.10	<.50	50.2
I.SD b	<.05	<.010	1.18	11.5	0.301	<.01	296	<.01	<.05	<.025	<.05	0.378	150	13.7	24.9	0.319	880	<.10	<.05	<.10	17.3	1.07	<.10	<.50	36.9
I.SD a	<.05	<.010	1.754	15	0.386	<.01	234	<.01	<.05	<.025	<.05	<.01	190	18.4	22.1	0.163	1060	<.10	<.05	<.10	22.4	1.10	<.10	<.50	47.9
JR BSD	<.05	0.165	<.05	0.496	0.11	<.01	24.0	<.01	<.05	<.025	<.05	0.121	8.59	0.43	3.25	<.03	44.2	<.10	<.05	<.10	22.2	0.107	<.10	<.50	47.4
JR EF	<.05	0.228	<.05	0.018	0.094	<.01	12.2	<.01	<.05	<.025	<.05	0.188	3.66	0.044	2.53	<.03	15	<.10	<.05	<.10	20.4	0.071	<.10	<.50	43.5
JR SA	<.05	0.28	<.05	0.017	0.092	<.01	18.6	<.01	<.05	<.025	<.05	0.057	3.66	0.089	2.94	<.03	24.2	<.10	<.05	<.10	27.5	0.071	<.10	<.50	58.8

Conc. mg/L	Ag	Al	As	B	Ba	Be	Ca	Cd	Co	Cr	Cu	Fe	K	Li	Mg	Mn	Na	Ni	Pb	Se	Si	Sr	V	Zn	SiO <sub>2</sub>
<b>Sampling Sites</b>																									
JR SY	<.05	<.010	<.05	0.919	0.186	<.01	46.2	<.01	<.05	<.025	0.003	<.01	63.6	0.953	5.99	<.03	108	<.10	<.05	<.10	20.5	0.286	<.10	<.50	43.9
JR B Guard	<.05	0.005	<.05	0.804	0.186	<.01	39.1	<.01	<.05	<.025	<.05	0.007	11.4	0.872	4.75	<.03	80.3	<.10	<.05	<.10	22.2	0.168	<.10	<.50	47.4
JR SpQ	<.05	0.037	<.05	0.985	0.09	<.01	37.7	<.01	<.05	<.025	<.05	0.058	13.2	1.04	4.5	<.03	91.5	<.10	<.05	<.10	24.3	0.164	<.10	<.50	52.0
I.S	<.05	<.010	0.818	7.9	0.232	<.01	114	<.01	<.05	<.025	<.05	<.01	73.6	10.9	4.23	0.086	755	<.10	<.05	<.10	42.5	0.478	<.10	<.50	90.8
JR BJS	<.05	0.046	<.05	0.949	0.088	<.01	36.4	<.01	<.05	<.025	<.05	0.064	13.3	1.01	4.11	<.03	86.4	<.10	<.05	<.10	23.8	0.155	<.10	<.50	50.8
I.SD b	<.05	<.010	1.12	12.8	0.325	<.01	252	<.01	<.05	<.025	<.05	0.027	168	15.8	23.2	0.227	1121	<.10	<.05	<.10	18.9	1.35	<.10	<.50	40.4
I.SD a	<.05	<.010	1.79	15.03	0.395	<.01	268	<.01	<.05	<.025	0.054	<.01	170.3	18.0	21.6	0.189	1037	<.10	<.05	<.10	21.7	1.31	<.10	<.50	46.4
JR BSD	<.05	0.048	<.05	1.003	0.082	<.01	33.7	<.01	<.05	<.025	<.05	0.091	14.0	0.944	4.12	<.03	84.7	<.10	<.05	<.10	23.2	0.154	<.10	<.50	49.7
JR EF	<.05	0.029	<.05	0.02	0.061	<.01	9.5	<.01	<.05	<.025	<.05	0.076	2.11	0.007	2.41	<.03	16.7	<.10	<.05	<.10	20.8	0.064	<.10	<.50	44.5
JR SA	<.05	0.078	<.05	0.02	0.065	<.01	15.0	<.01	<.05	<.025	<.05	0.076	2.68	0.093	2.78	<.03	25.7	<.10	<.05	<.10	27.5	0.072	<.10	<.50	58.7

Conc. mg/L	Ag	Al	As	B	Ba	Be	Ca	Cd	Co	Cr	Cu	Fe	K	Li	Mg	Mn	Na	Ni	Pb	Se	Si	Sr	V	Zn	SiO <sub>2</sub>
<b>Sampling Sites</b>																									
JR SY	<.05	<.010	0.060	0.951	0.164	<.01	46.9	<.01	<.05	<.025	0.003	<.01	12.6	0.959	5.9	<.03	110	<.10	<.05	<.10	20.4	0.284	<.10	<.50	43.7
JR B Guard	<.05	0.011	0.074	0.853	0.105	<.01	42.6	<.01	<.05	<.025	0.002	0.016	11.7	0.909	4.97	<.03	82.8	<.10	<.05	<.10	22.0	0.175	<.10	<.50	47.1
JR SpQ	<.05	0.028	0.100	1.11	0.237	<.01	41.1	<.01	<.05	<.025	<.05	0.021	14.9	1.2	4.69	<.03	101	<.10	<.05	<.10	25.7	0.171	<.10	<.50	55.0
I.S	<.05	<.010	0.813	7.83	0.237	<.01	113	<.01	<.05	<.025	<.05	<.01	74.7	10.8	4.21	0.083	734	<.10	<.05	<.10	41.9	0.476	<.10	<.50	89.6
JR BJS	<.05	0.033	0.098	1.03	0.091	<.01	36.9	<.01	<.05	<.025	<.05	0.035	14.0	1.08	4.09	<.03	93.1	<.10	<.05	<.10	24.7	0.155	<.10	<.50	52.8
I.SD b	<.05	<.010	0.95	11.6	0.322	<.01	286	<.01	<.05	<.025	<.05	<.01	153	14.2	23.2	0.24	953	<.10	<.05	<.10	17.3	1.25	<.10	<.50	37.0
I.SD a	<.05	<.010	1.78	14.6	0.404	<.01	236	<.01	<.05	<.025	<.05	<.01	191	17.4	21.3	0.155	1143	<.10	<.05	<.10	21.0	1.35	<.10	<.50	44.9
JR BSD	<.05	0.037	0.103	1.07	0.06	<.01	34.2	<.01	<.05	<.025	<.05	0.046	14.3	1.01	4.09	<.03	87.9	<.10	<.05	<.10	24.0	0.153	<.10	<.50	51.4
JR EF	<.05	0.079	0.004	0.036	0.05	<.01	8.14	<.01	<.05	<.025	<.05	0.017	1.98	0.084	2.24	<.03	18.2	<.10	<.05	<.10	22.5	0.053	<.10	<.50	48.0
JR SA	<.05	0.074	0.005	0.029	0.051	<.01	13.2	<.01	<.05	<.025	<.05	0.021	2.54	0.096	2.52	<.03	24.5	<.10	<.05	<.10	27.7	0.064	<.10	<.50	59.2

\*arsenic levels from round three from a hydride system with lower detection limit



**Table 4 Loading Concentrations for Anions**

Sampling Sites	Actual Discharge													
	ft3/sec	l/sec	Cl mg/l	Cl mg/sec	Br mg/l	Br mg/sec	NO3 mg/l	NO3 mg/sec	SO4 mg/l	SO4 mg/sec	HCO3 mg/l	HCO3 mg/sec	F mg/l	F mg/sec
JR SA	9.5	270	7.1	1904	0.021	5.7	0.2	52.8	16.2	4375	75.7	20390	1.3	350
JR EF	9.5	270	3.5	947			0.1	14.0	2.7	740	59.2	15952	0.455	123
I SD a	0.9	25.0	1382	34557	5.6	139	0.1	3.6	55.5	1388	1452	36305	2.79	69.8
I SD b	0.9	25.0	2104	52609	9.1	226	1.6	39.3	39.6	989	1184	29593	3.34	83.5
JR BSD	19.9	564	149	84178	0.4	217	0.4	207	11.5	6510	195	109845	0.961	542
I JS	0.8	23.0	966	22221	2.9	67.0	0.1	1.4	35.4	814	702	16139	5.07	117
JR BJS	20.7	587	128	74923	0.3	186	0.0	20.0	12.0	7056	189	110739	0.986	579
JR SpQ	20.7	587	137	80350	0.3	183	0.1	53.4	11.8	6923	204	119702	1.06	621
JR B Guad	34.0	963	106	102272	0.2	230	0.1	101	10.2	9846	202	194473	0.889	856
I Indian	0.3	9.5	1141	10840	4.7	44.4			213	2024	1269	12056	6.9	65.6
JR SY	34.3	972	124	120624	0.3	279	0.2	184	17.6	17120	253	246226	0.978	951

Sampling Sites	Low Discharge													
	ft3/sec	l/sec	Cl mg/l	Cl mg/sec	Br mg/l	Br mg/sec	NO3 mg/l	NO3 mg/sec	SO4 mg/l	SO4 mg/sec	HCO3 mg/l	HCO3 mg/sec	F mg/l	F mg/sec
JR SA	1.5	42.5	7.1	300	0.021	6.30	0.2	8.33	16.2	690	75.7	3214	1.3	55.2
JR EF	1.5	42.5	3.5	149			0.1	2.21	2.7	117	59.2	2514	0.455	19.3
I SD a	0.9	25	1382	34557	5.6	192726	0.1	3.58	55.5	1388	1452	36305	2.79	69.8
I SD b	0.9	25	2104	52609	9.1	476215	1.6	39.3	39.6	989	1184	29593	3.34	83.5
JR BSD	2.4	68.0	149	10138	0.4	3903	0.4	24.9	11.5	784	195	13229	0.961	65.3
I JS	0.812	23	966	22221	2.9	64775	0.1	1.357	35.4	814	702	16139	5.07	117
JR BJS	3.2	90.6	128	11560	0.3	3653	0.0	3.08	12.0	1089	189	17086	0.986	89.4
JR SpQ	3.2	90.6	137	12397	0.3	3856	0.1	8.25	11.8	1068	204	18469	1.06	95.8
JR B Guad	5.4	153	106	16243	0.2	3882	0.1	16.1	10.2	1564	202	30887	0.889	136
I Indian	0.3	9.5	1141	10840	4.7	50620			213	2024	1269	12056	6.9	65.6
JR SY	5.7	161.4	124.1	20025	0.3	5747	0.2	30.5	17.6	2842	253	40876	0.978	158

**Table 5 Loading Concentrations for Cations**

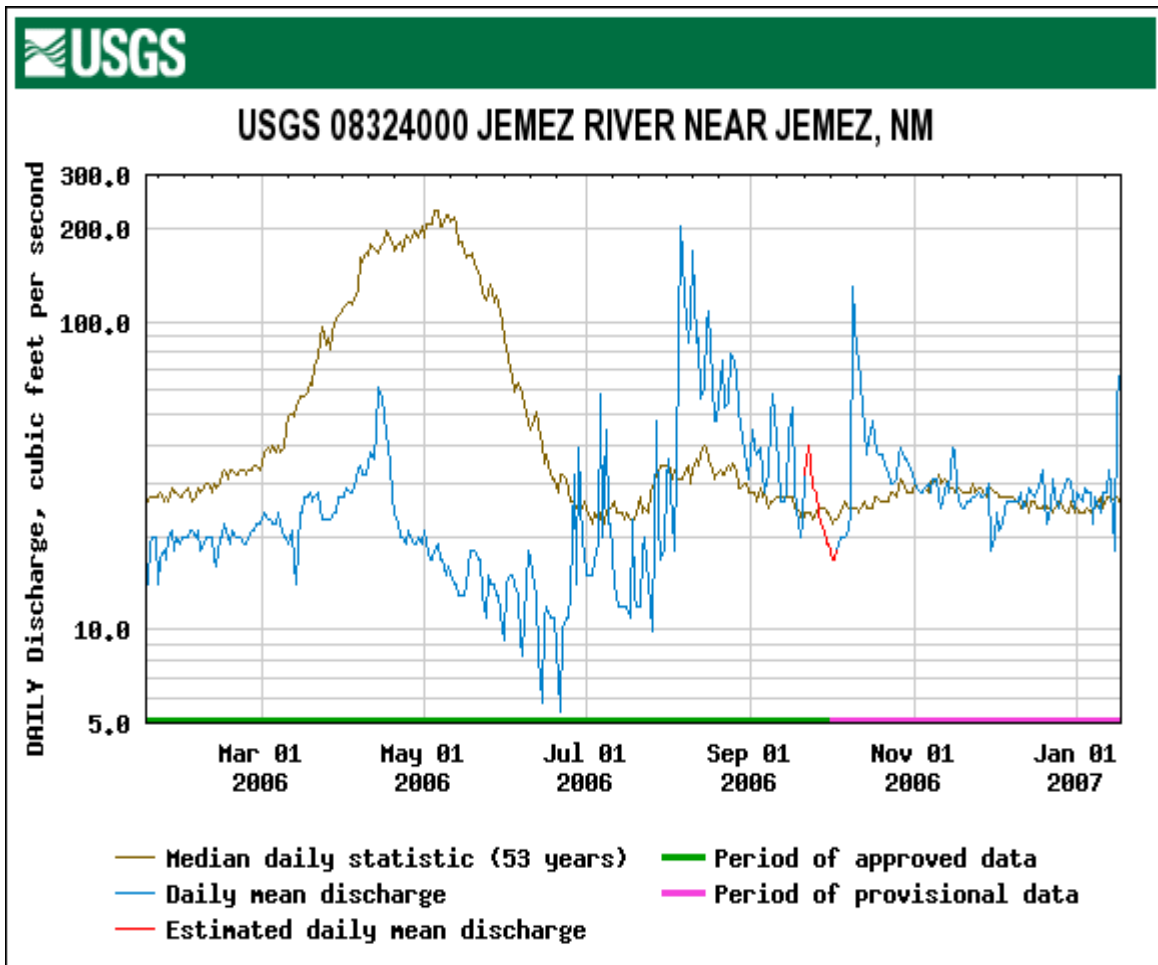
Sampling Sites	Actual Discharge										
	ft3/sec	l/sec	Ca mg/l	Ca mg/sec	K mg/l	K mg/sec	Mg mg/l	Mg mg/sec	Na mg/l	Na mg/sec	
JR SA		9.51	270	13.2	3563	2.5	685	2.5	682	24.5	6603
JR EF		9.51	270	8.1	2196	2.0	536	2.2	605	18.2	4908
I SD a		0.88	25.0	266	6653	153.5	3838	23.3	581	954	23838
I SD b		0.88	25.0	237	5923	191.4	4785	21.3	533	1143	28575
JR BSD		19.9	564	34.2	19323	14.3	8087	4.1	2310	88.0	49657
I JS		0.81	23.0	114	2615	74.8	1719	4.2	96.9	735	16894
JR BJS		20.7	587	37.0	21714	14.1	8252	4.1	2407	93.1	54706
JR SpQ		20.7	587	41.1	24164	14.9	8757	4.7	2760	102	59616
JR B Guad		34.0	963	42.6	41038	11.8	11323	5.0	4786	82.8	79726
I Indian		0.34	9.5	63.3	601.4	64.5	613	10.7	102	1140	10830
JR SY		34.3	972	46.9	45644	12.7	12330	5.9	5737	111	107642

Sampling Sites	Low Discharge										
	ft3/sec	l/sec	Ca mg/l	Ca mg/sec	K mg/l	K mg/sec	Mg mg/l	Mg mg/sec	Na mg/l	Na mg/sec	
JR SA		1.5	42.5	13.2	562	2.5	108	2.5	107	24.5	1041
JR EF		1.5	42.5	8.1	346	2.0	84	2.2	95.4	18.2	774
I SD a		0.9	25	266	6782	154	3912	23.3	593	954	24303
I SD b		0.9	25	237	6038	191	4878	21.3	543	1143	29133
JR BSD		2.4	68.0	34.2	2327	14.3	974	4.1	278	88.0	5981
I JS		0.813	23.0	114	2618	74.8	1721	4.2	97	735	16911
JR BJS		3.2	90.6	37.0	3350	14.1	1273	4.1	371	93.1	8441
JR SpQ		3.2	90.6	41.1	3728	14.9	1351	4.7	426	102	9198
JR B Guad		5.4	153	42.6	6518	11.8	1798	5.0	760	82.8	12662
I Indian		0.3	8.50	63.3	538	64.5	548	10.7	90.9	1140	9685
JR SY		5.7	161	46.9	7577	12.7	2047	5.9	952	111	17870

Table 6 Arsenic Loading

Site	As ppb	mg/l	ft3/sec	l/sec	mg/sec
JR SA	4.6	0.005	9.5	270	1.25
JR EF	4.1	0.004	9.5	270	1.12
I SD a	1782	1.78	0.9	25.0	44.6
I SD b	950	0.95	0.9	25.0	23.8
JR BSD	103	0.103	19.9	564	57.9
I JS	813	0.813	0.8	23.0	18.7
JR BJS	97.8	0.098	20.7	587	57.4
JR SpQ	101	0.100	20.7	587	58.7
JR B Guad	73.8	0.074	34.0	963	71.1
I Indian	312	0.312	0.34	9.5	2.96
JR SY	60.0	0.060	34	972	58.3

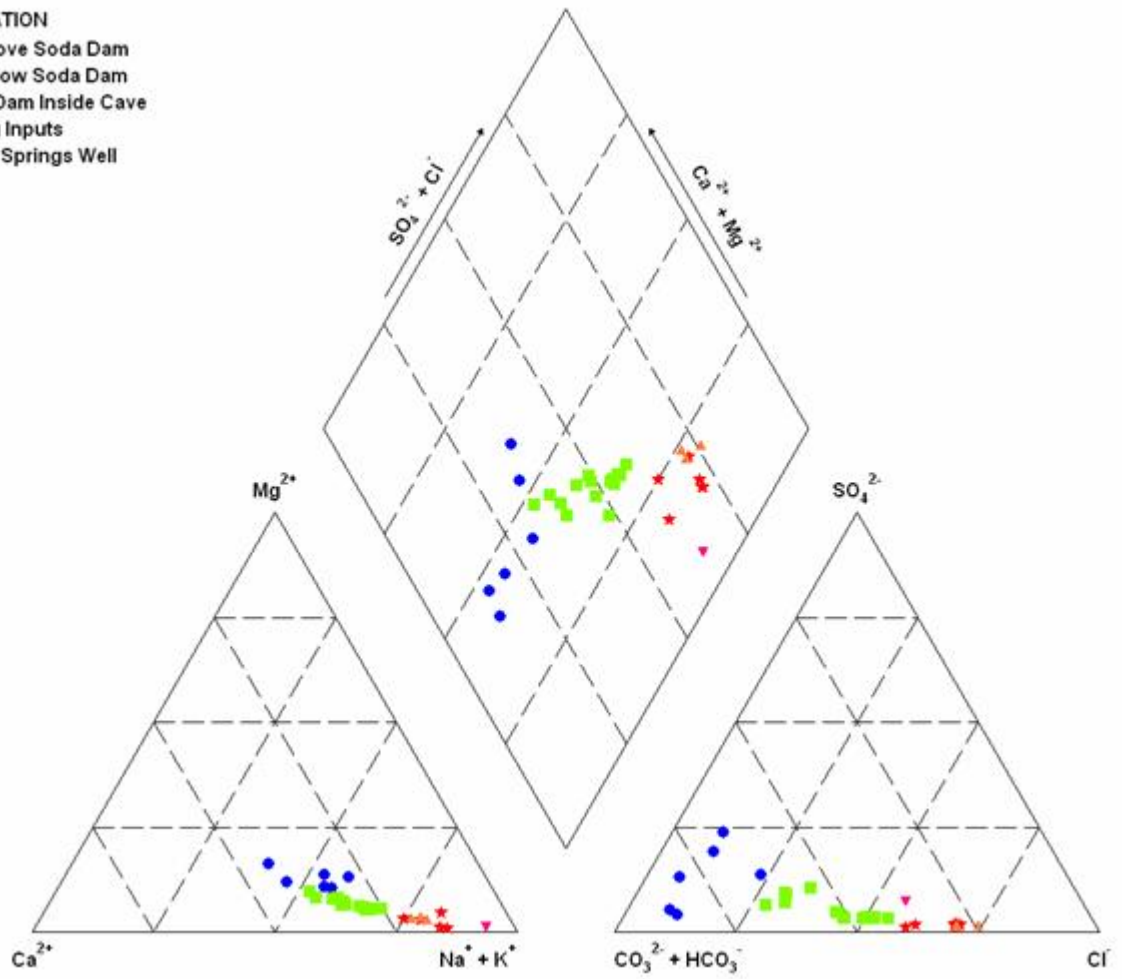
# Hydrograph of the Jemez River



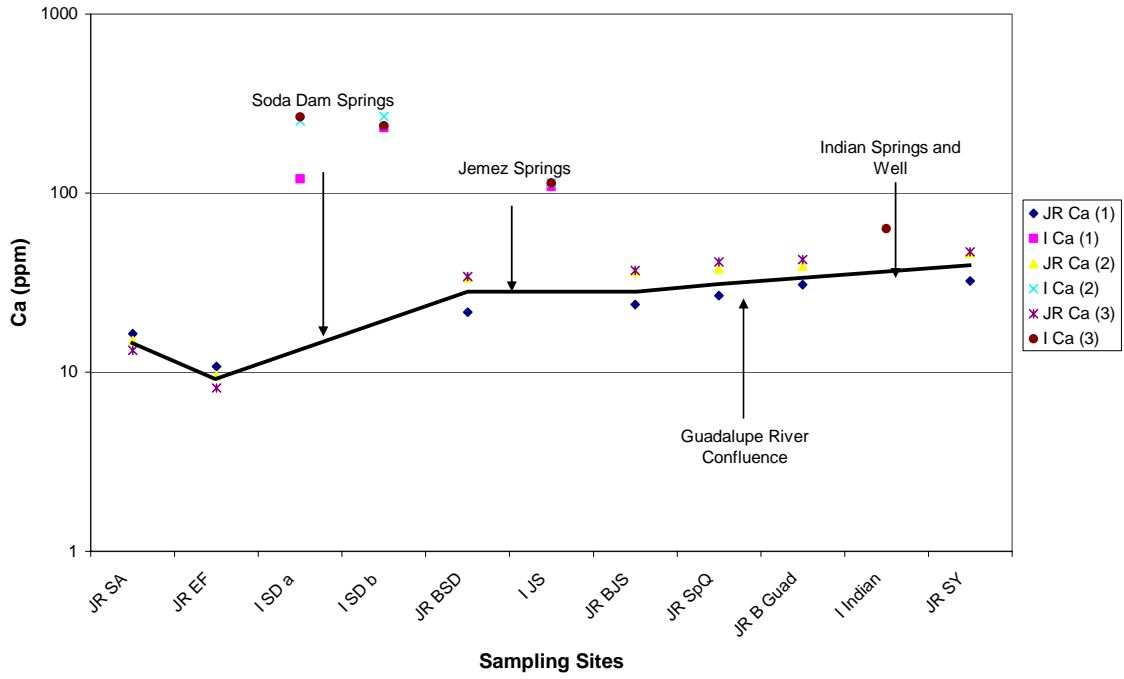
## 7. Piper Diagram and Graphs

### EXPLANATION

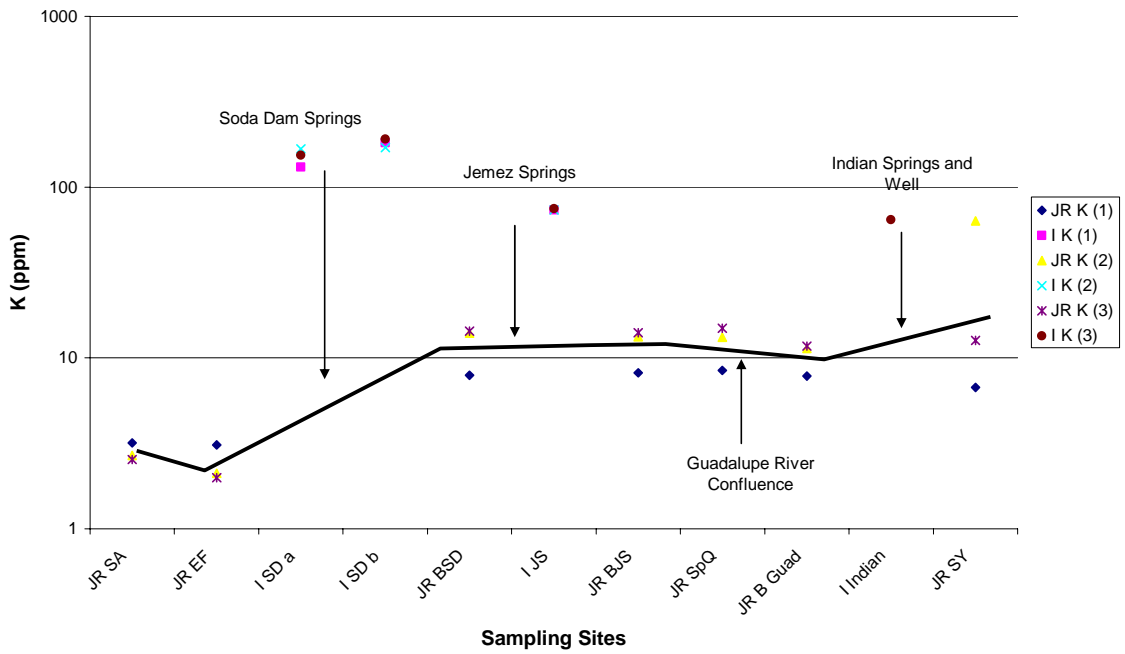
- JR Above Soda Dam
- JR Below Soda Dam
- ▲ Soda Dam Inside Cave
- ★ Spring Inputs
- ▼ Indian Springs Well



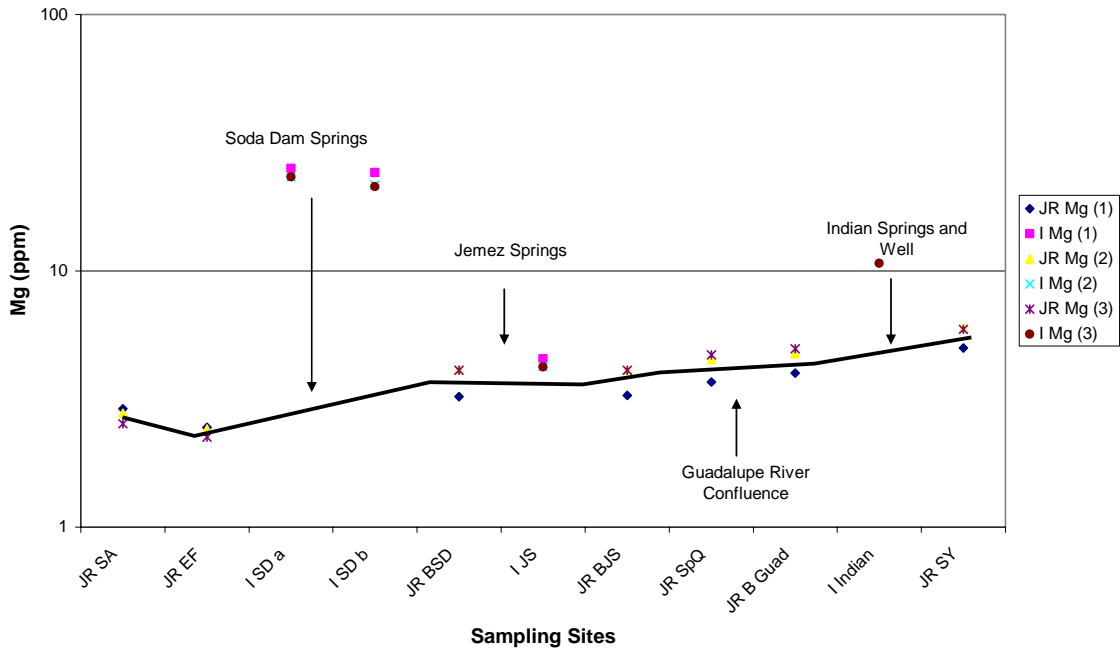
**Figure 1**  
**[Ca] Downstream from Battleship Rock**



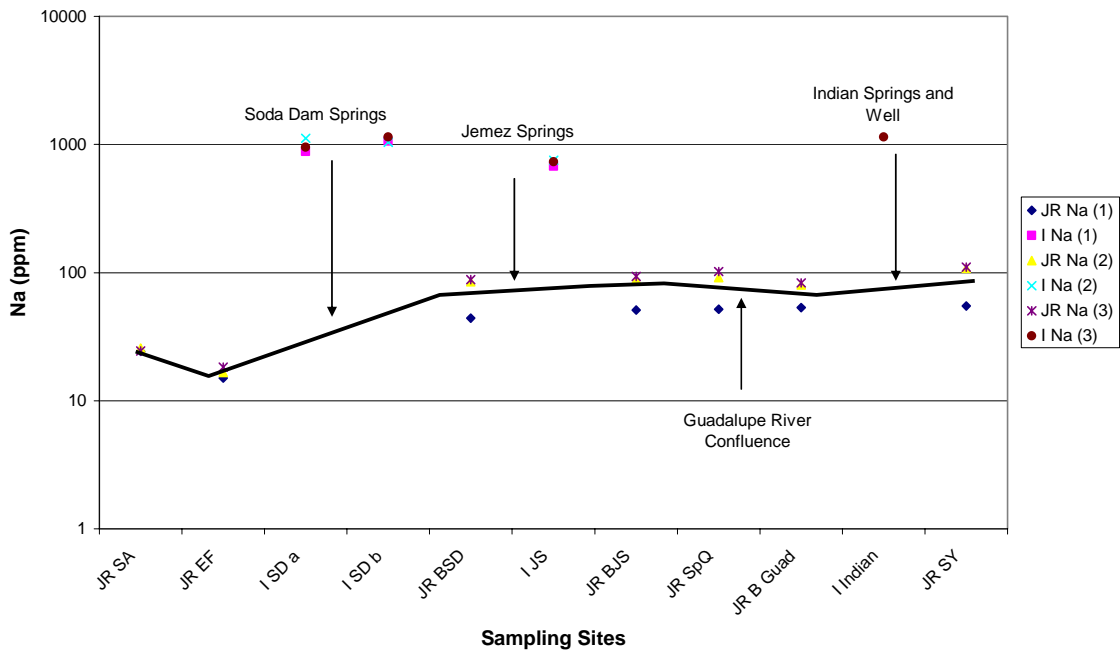
**Figure 2**  
**[K] Downstream from Battleship Rock**



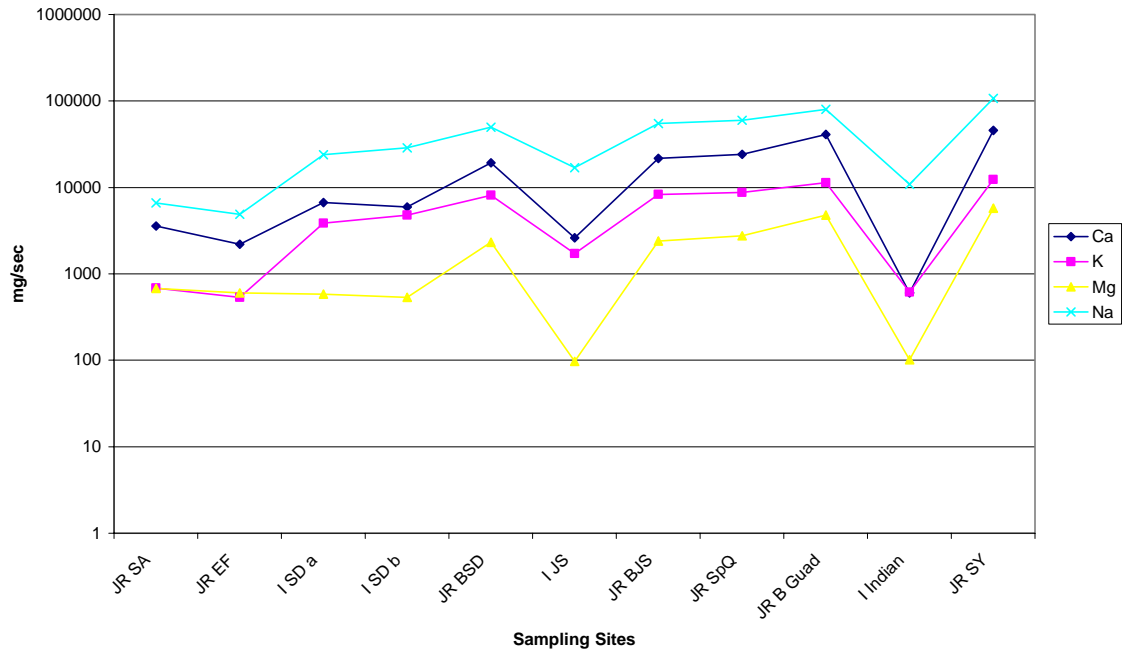
**Figure 3**  
**[Mg] Downstream from Battleship Rock**



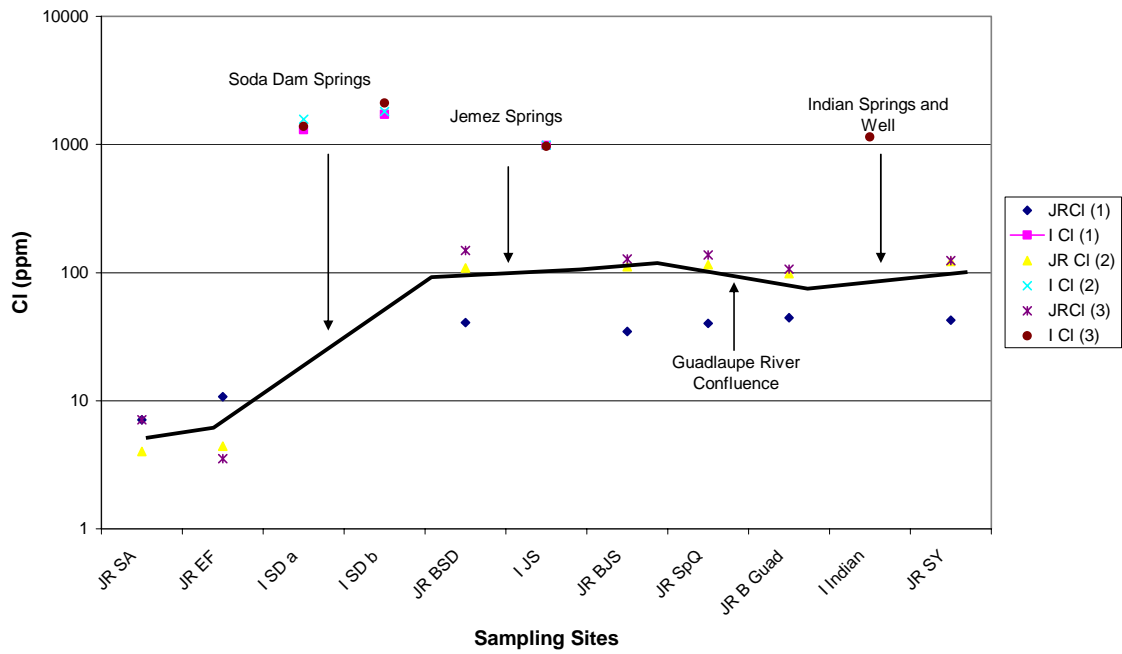
**Figure 4**  
**[Na] Downstream from Battleship Rock**



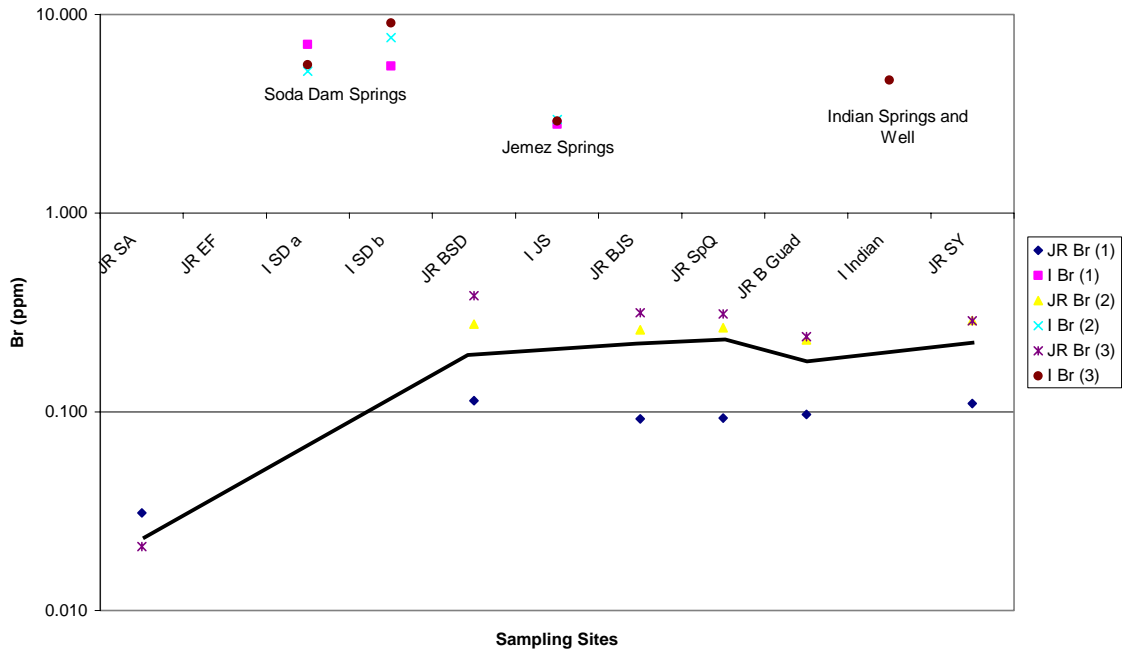
**Figure 5**  
Cation Loading Along Jemez River



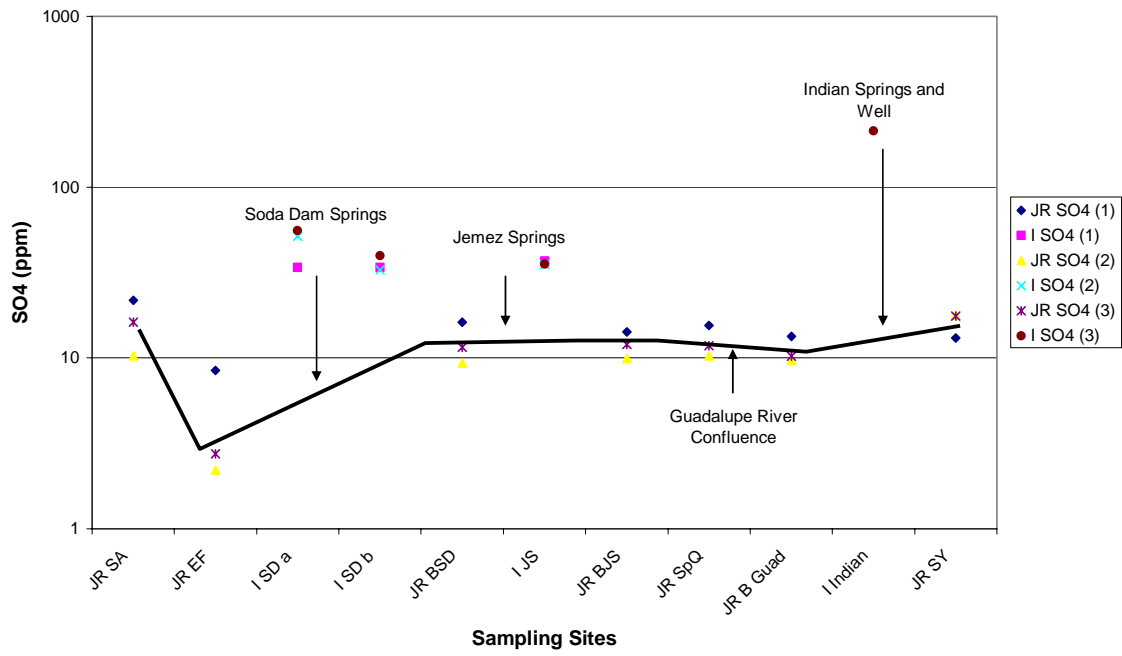
**Figure 6**  
[Cl] Downstream from Battleship Rock



**Figure 7**  
**[Br] Downstream from Battleship Rock**

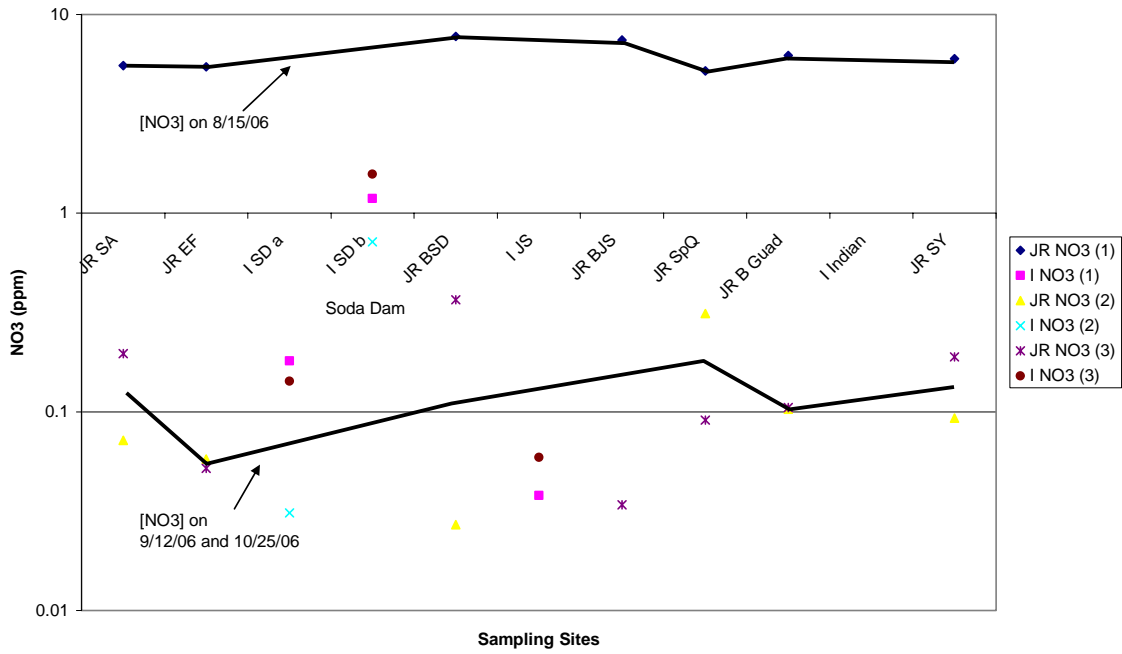


**Figure 9**  
**[SO4] Downstream from Battleship Rock**

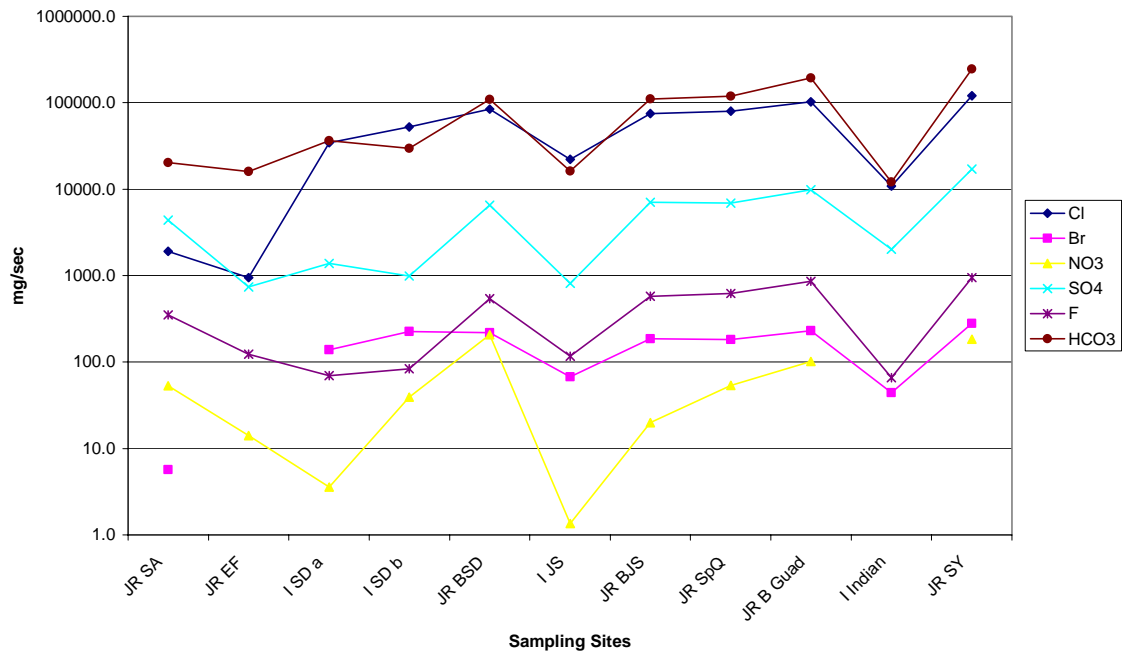




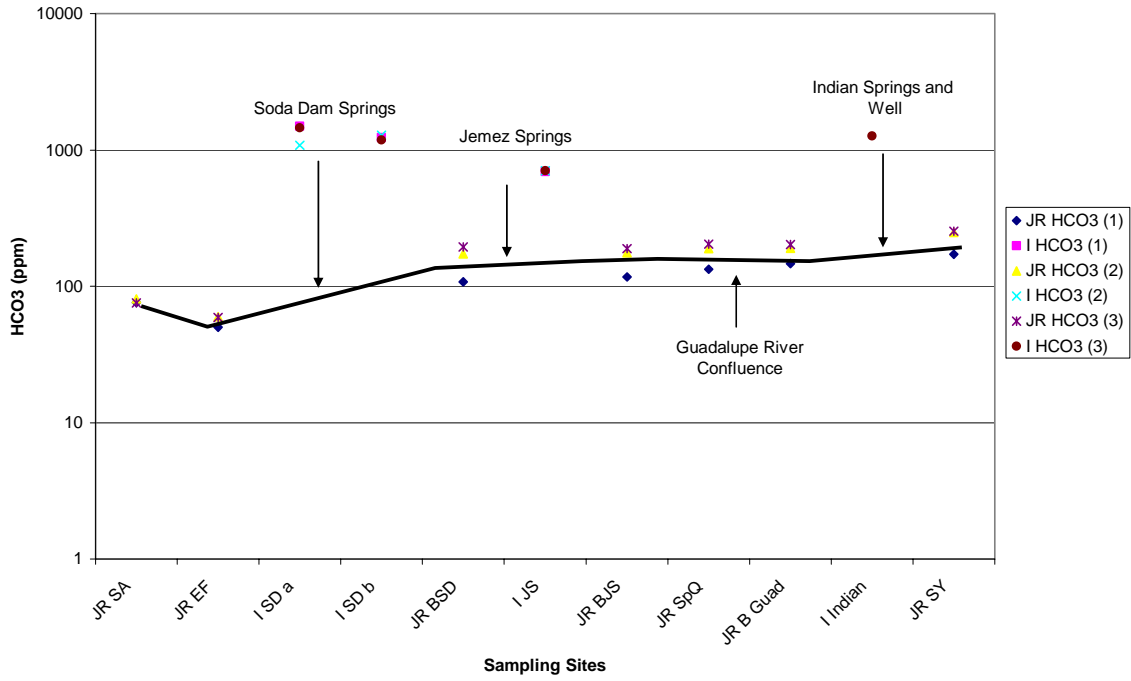
**Figure 10**  
**[NO3] Downstream from Battleship Rock**



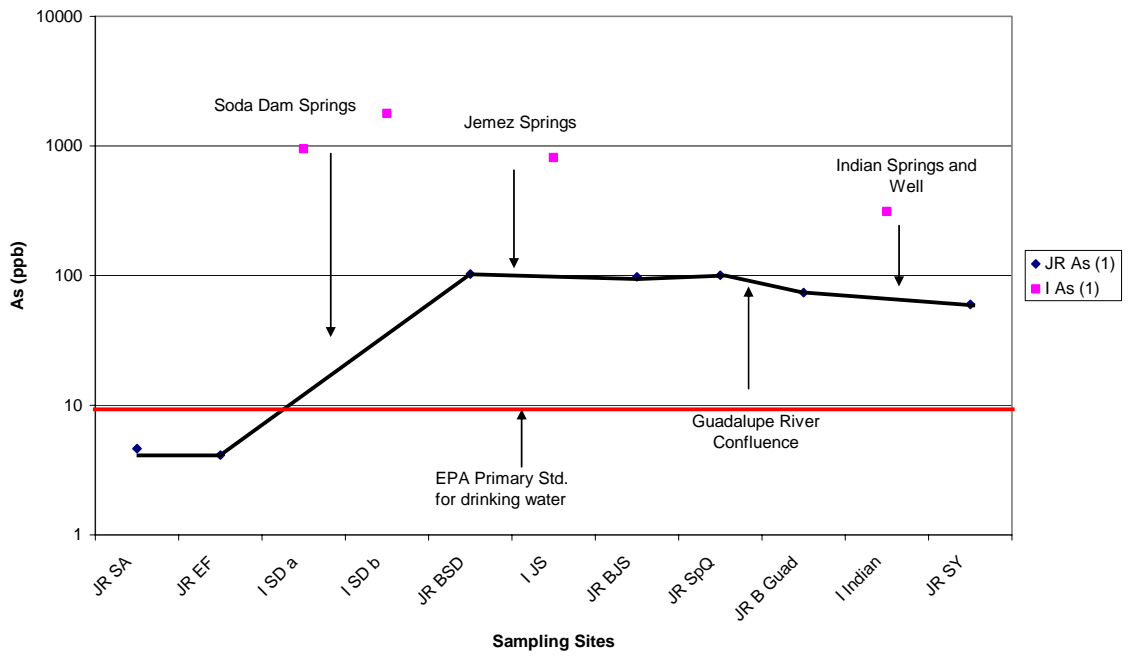
**Figure 11**  
**Anion Loading Along Jemez River**



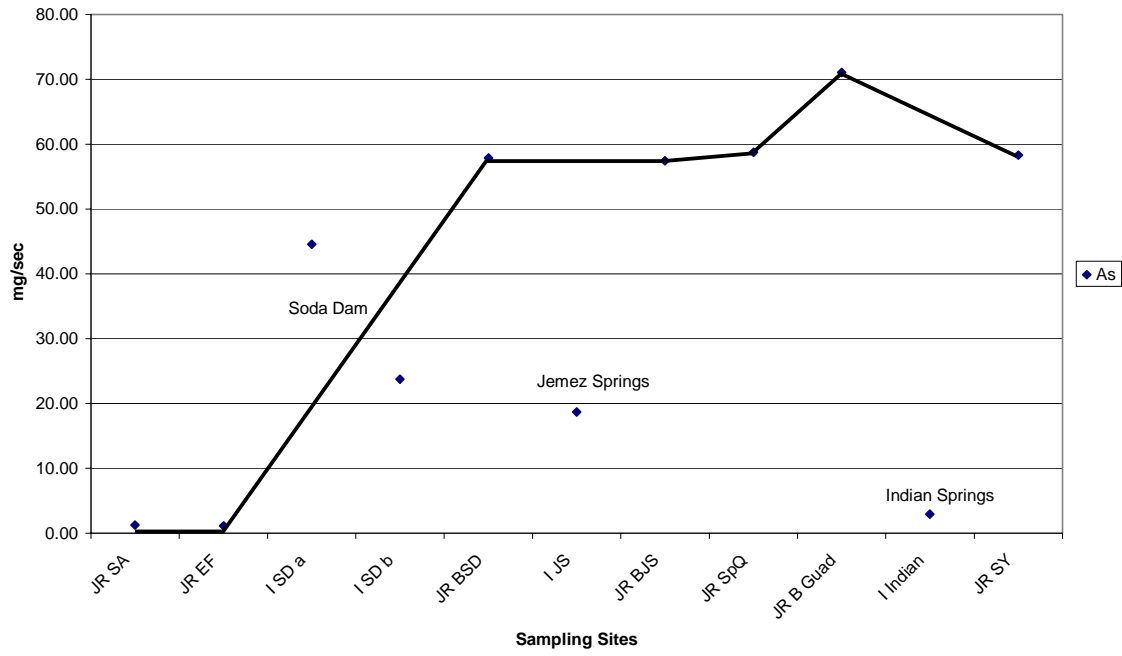
**Figure 12**  
**[HCO<sub>3</sub>] Downstream from Battleship Rock**



**Figure 13**  
**[As] Downstream from Battleship Rock**



**Figure 14**  
As Loading Along Jemez River



**Figure 15**

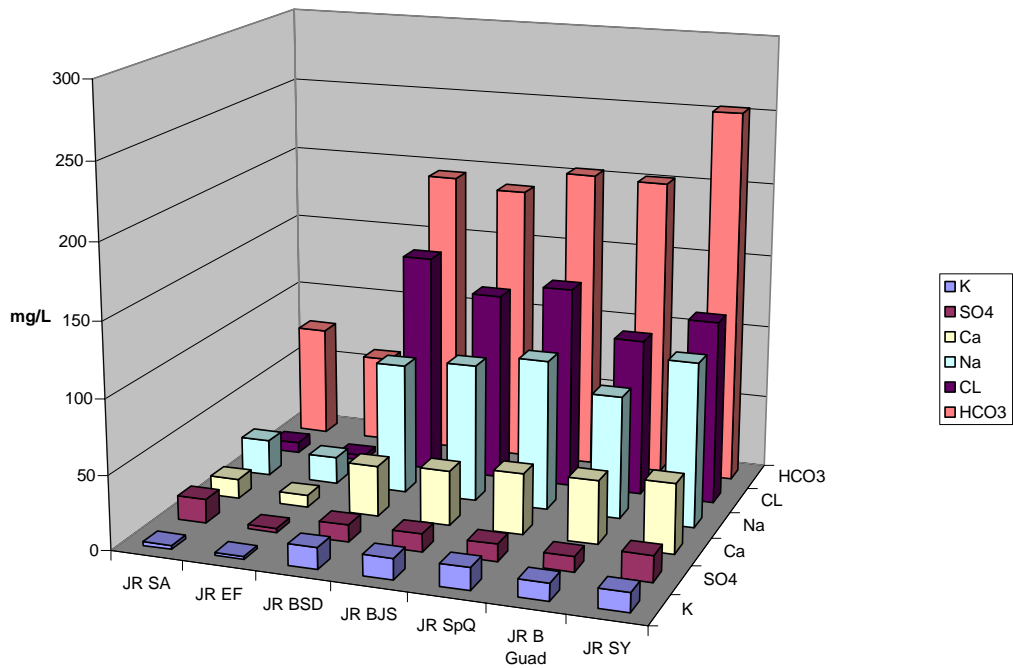
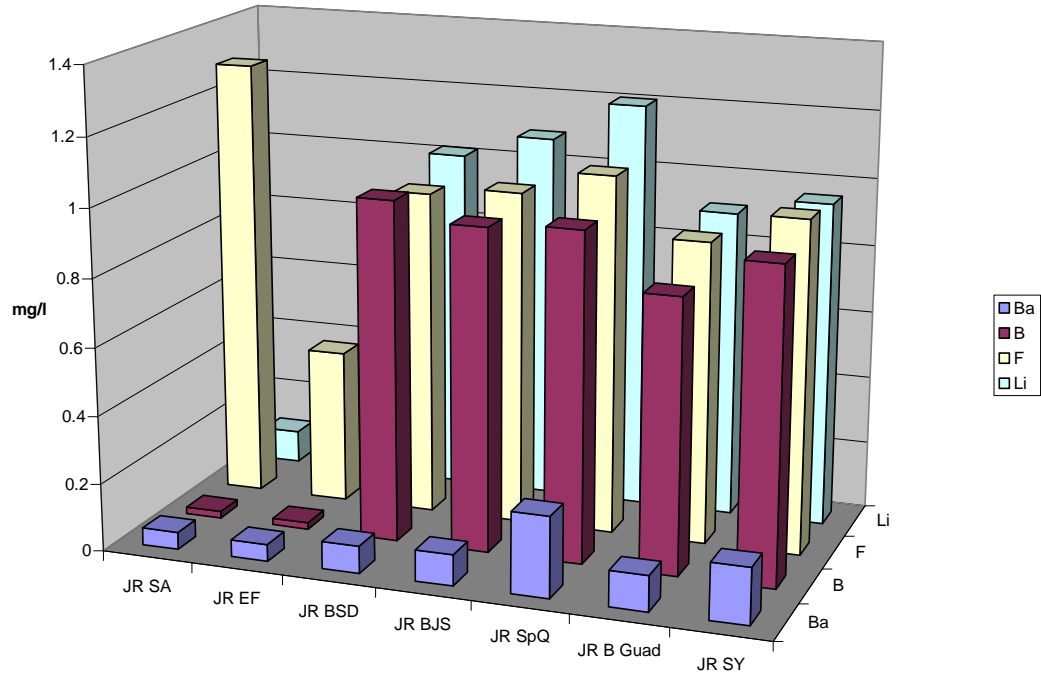


Figure 16



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